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ORIGINAL ARTICLE

Thermal environment in growing and finishing pig facilities of different building typologies

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Abstract The objective of this study was to evaluate the thermal comfort of growing and finishing pigs affected by the different constructive typologies of the installations regarding the floor and lateral partitions. Were evaluated the following pen types: pen with water pit, pen with partially slotted floor on the sides, and pen with partially slotted floor on the sides and in the center of the facilities. The following thermal variables were measured: dry bulb temperature, black globe temperature, relative humidity, and air velocity. Based on these data, the temperature and humidity index, the temperature index of the globe and humidity, and the specific enthalpy were calculated. The pen with a water pit showed higher average relative air humidity and lower black globe temperature compared to the other pens. In the hottest period of the day, the temperature index of the globe and humidity presented mean values above that recommended for adult pigs, although there were no differences between pens. This indicates that animals, irrespective of the type of pen used, have suffered from thermal stress, which most likely affected their performance.

Keywords: rural buildings, swine, house design, thermal comfort

Introduction

Among many other challenges faced in animal production, the conditions regarding management and the thermal environment are of extreme importance (Barbosa Filho et al 2009, Menegali et al 2010). In intensive breeding systems, the environment has a direct influence on the welfare and well-being of the pigs, which are of vital importance for the economic viability of a pig farm (Viera et al 2010).

Thermo-environmental variables (temperature, relative humidity, and air velocity) influence animal production (Silva et al 2013) and significantly impact animal performance (Lima et al 2011), making it a limiting factor of productivity in the growth and finishing stages of pigs due to their low tolerance to heat. An inadequate environment is also considered a potential source of respiratory diseases, causing discomfort and behavioral and physiological changes and reducing food consumption and, consequently, weight gain (Kiefer et al 2010). At high ambient temperatures, pig performance is considerably affected (Kiefer et al 2009, Rocha et al 2012). According to Luz et al (2016), in situations of thermal stress, the animals resort to thermolysis via evaporation. In the case of pigs, this regulation is indicated by increasing the respiratory rate (Manno et al 2006).

Given the impacts of housing conditions and typology, factors which determine which pathways of thermolysis are used by the animal, on the performance and well-being of the animals, the objective of this study was to evaluate the thermal comfort of growing and finishing pigs and to which extent it is affected by the different constructive typologies of the installations, esp. in regard to the floor and lateral partitions.

Materials and Methods

The study was carried out in a commercial swine farm (Granja Niteroi) (21º 11’ 37” S; 45º 02’ 49’’ W; 918 m) in the municipality of Lavras-MG, Brazil, from June to September 2014, representing the winter season.

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The climate of the region, according to Köppen's classification, is Cwa, i.e., rainy temperate (mesothermal) with dry winters and rainy summers, subtropical. The temperature of the coldest month is below 18°C, while temperatures exceed 22°C in the hottest month. Average annual precipitation is 1,276 mm (Baruqui et al 2006, Dantas et al 2007). The animals were reared in total confinement. Were evaluated 216 hybrid pigs in the growth and finishing phases.

The animals were housed in pens as follows, according to their body weight: mean weight of 28.69 kg (pen with water pit, WPP); 28.75 kg (pens with partially slotted floors on the sides, SLS), and 28.5 kg (pens with partially slotted floor on sides and in the center, SLC). The animals remained in the pens during the growing and finishing stages, reaching final mean weights of 83.47 kg (WPP pen), 85.47 kg (SLS pen), and 87.67 kg (SLC pen).

The animals were housed in masonry barns covered with fiber-cement roofing, supporting structures in reinforced concrete, concrete floor, and East-West orientation. Each pen was equipped with two automatic feeders and four nipple drinkers and had a total area of 72 m² (8 x 9 m), ceiling height of 3 m, containing 72 animals each. The WPP pen had, on one of its sides, a lowering on the concrete floor (1 m wide and 10 cm deep), filled with water, and was fenced by masonry dividers with ceramic bricks covered with a layer of concrete render and painted in white. The SLC pen had dividers made of steel wire ropes, a ceiling height of 3 m, and a concrete floor, with sides made of slotted precast concrete plates. The SLS pen had masonry dividers with a layer of cement render painted in white, a concrete floor, with sides and the center made of slotted concrete plates.

Data relative to the ambient thermal comfort in the pens and outside were automatically collected using data loggers (Hobo, model U12-013) with an accuracy of ± 0.5oC. These devices recorded dry bulb temperature, relative air humidity, and black globe temperature in intervals of five minutes. To obtain the black globe temperatures (Tbg), the external sensors of the data loggers, inserted in black balloons, were used. Air velocity (Vair) was recorded at 9:00 a.m., 12:00 p.m., and 3:00 p.m. during the evaluation days, using a digital propeller anemometer of the ICEL Manaus® brand, model AN-3090, with a precision of ± 3.0%. The data loggers were positioned inside the facilities at a height of 1.20 m from the floor, as described in Sampaio et al (2004).

Based on the Tbs, RH, Vair, and Tbg values, the dew point temperature (Tdp), the temperature and humidity index (THI), the specific enthalpy (h), and the black globe temperature and humidity index were determined (BGHI). The BGHI, THI, and h were used to evaluate the thermal environment. Based on the BGHI, the effects of air velocity and radiation can be quantified indirectly.

The THI index was calculated using the equation proposed by Thom (1958):

$$\text{THI} = \text{Tdb} + 0.36\ \text{Tdp} + 41.2,$$

where: Tdb = dry bulb temperature (°C) and Tdp = dew point temperature (°C).

The BGHI index was calculated using the equation proposed by Buffington et al. (1981):

$$\text{BGHI} = \text{tbg} + 0.36\ \text{tdp} - 330.08,$$

where: Tbg = black globe temperature (K) and Tdp = dew point temperature (K).

The enthalpy (h) of the environment was calculated according to the equation below, proposed by Albright (1990):

$$h = 1.006 * \text{Tdb} + W\ (2{,}501 + 1.805 * \text{Tdb}),$$

where: h = enthalpy (kJ kg of dry air^{-1}); Tdb = dry bulb temperature (°C); W = mixing ratio (kg water vapor kg dry air^{-1}).

$$W = (0.622 * ea)\ /(Patm\text{-}ea),$$

where: ea = current water vapor pressure (kPa); Patm = atmospheric pressure (kPa).

The temperature and humidity index (THI), developed by Thom (1958), is one of the most widely used thermal comfort indices. This index associates the dry bulb temperature (Tdb) and the wet bulb temperature (Twb). The black globe temperature and humidity index (BGHI), developed by Buffington et al. (1981), considers in a single value the effects of Tbs, air humidity (RH), radiation level, and air movement. Buffington et al. (1981) stated that the BGHI is, under ambient conditions where solar radiation or air movement is high, a more accurate indicator of thermal comfort in animal production than the THI.

The thermal environment data were submitted to analysis of variance using the "F" test; subsequently, the means were compared by Tukey´s test at a significance level of 5%. For this, the analysis was conducted by adopting a randomized block design with arrangement in subdivided plots, in which the types of floor constituted the plots, the evaluation schedule, the subplots, and the days of collection the blocks. All analyses were performed using the statistical software Sisvar 5.3 (Ferreira 2008).

Results and Discussion

In terms of relative humidity, there were significant differences between the treatments for ($P < 0.05$). The WPP pen had a higher average value (68.5%), which was already expected due to the microclimate inside the pen created by water evaporation present on the blade. The Tdp in the WPP pens presented the highest mean values, differing from those in the other pens (Table 1).

For the variable Tdb, a significant difference was observed between pens, and the SLC pen presented a mean value higher (20.6 °C) than the others (P < 0.05, Tukey´s test). We observed the same type of differences for THI due to the direct influence of Tdb on THI.

Table 1 Mean values of environmental variables observed throughout the day in sheds for swine growing and finishing with different types of pens.

Variables	Pens		
	WPP	SLS	SLC
RH (%)	69.0^{A}	64.0^{C}	66.0^{B}
Tbg (ºC)	19.9^{C}	20.5^{B}	21.2^{A}
Tdb (ºC)	19.8^{B}	19.9^{B}	20.6^{A}
Tdp (ºC)	13.3^{A}	12.8^{B}	12.8^{B}
THI	65.8^{B}	65.8^{B}	66.4^{A}
BGHI	66.2^{B}	66.7^{B}	67.3^{A}
h	46.8^{A}	46.1^{B}	$46,8^{A}$

Pens: Water pit (WPP), Partially slotted floors on the sides (SLS), Partially slotted floor on sides and in the center (SLC). Relative air humidity (RH); Black globe temperature (Tbg); Dry bulb temperature (Tdb); Dew point temperature (Tdp); Globe temperature and humidity index (BGHI); Enthalpy of air (h); Temperature and humidity index (THI). Means followed by the same letter within one line do not differ significantly by Tukey's test (P<0.05).

Enthalpy (h) values were different between the pens; the WPP and SLC pens had the same average value, differing from the SLS pen, which presented a lower enthalpy value (P < 0.05, Tukey´s test).

A significant difference (P < 0.05) was observed for Tbg between the pens, with the SLC pen presenting the highest value (21.2 °C), followed by the SLS pen with the mean value of 20.5 °C and the pen WPP with the lowest value (19.9 °C). The wet environment, promoted by the water slide, may have aided in the reduction of Tdb through evaporation.

In this context, Moreira et al (2003) state that the RH in the installations directly influences atmospheric environmental conditions. In the present study, the RH differed between the pens in the hours of 9:00 a.m., 12:00 p.m., and 3:00 p.m. (Table 2); at 9:00 a.m., the WPP pen presented the highest RH value (76.5%). The SLS pen presented a greater value than the SLC pen. However, at 12:00 p.m. and 03:00 p.m, the WPP pen differed from the SLC, but not from the SLS. At these times, the air is warmer and has a greater capacity to withstand water vapor; thus, it does not affect RH values.

The variation of relative humidity, along with the thermal conditions, may have affected heat loss by the animals, since it is a condition of the use of the evaporative route, which pigs often resort to when subjected to high temperatures. Nienaber et al (1987) comment that raising the relative air humidity from 45 to 90% at an ambient temperature of 21 °C reduces pig heat losses by 8%. Huynh and Aarnink (2005) argue that RH is the factor of lower physiological influence, but can has a significant direct influence on the performance of the animal when combined with high temperatures, since pigs have difficulties in dissipating heat at high temperatures and humidity, mainly because excess humidity restricts evaporative losses through respiration and contributes to a decrease in appetite (Renaudeau et al 2003).

Table 2 Values of environmental variables observed throughout the day in sheds for swine growing and finishing with different types of pens.

Variables	Pen	Time					
		06 a.m	09 a.m	12 p.m	15 p.m	18 p.m	21 p.m
RH (%)	WPP	84.3^{aA}	76.5^{bA}	55.2^{dA}	49.5^{eA}	67.5^{cA}	78.5^{bA}
	SLS	85.0^{aA}	69.3^{cB}	52.3^{dAB}	47.0^{eAB}	66.0^{cA}	77.7^{bA}
	SLC	86.2^{aA}	63.2^{cC}	49.4^{dB}	44.3^{eB}	64.1^{cA}	77.3^{bA}
Tdp (°C)	WPP	10.6^{dA}	14.6^{aA}	14.6^{aA}	13.9^{abA}	13.8^{bA}	12.4^{cA}
	SLS	10.6^{dA}	14.3^{aA}	13.5^{bB}	13.0^{bcB}	13.3^{bA}	12.3^{cA}
	SLC	10.5^{eA}	14.4^{aA}	13.9^{abB}	12.6^{cdB}	13.3^{bcA}	12.3^{dA}

Pens: Water pit (WPP), Partially slotted floors on the sides (SLS), Partially slotted floor on sides and in the center (SLC). Relative air humidity (RH); Dew point temperature (Tdp). Averages followed by the same letter, lower case within one line and upper case within one column, do not differ significantly by Tukey´s test (P < 0.05).

Muller (1989) report that for pigs weighing over 30 kg and in thermal comfort, the optimal RH is between 50 and 70%. In our study, during the day, the average RH was within this range, except in the WPP at 09 a.m., when a slightly higher value was recorded, possibly due to the presence of the water pit.

Regarding black globe temperature (Tbg), there was an interaction ($P < 0.05$) between the pens and schedules (Table 3). Between the pens, there were differences in the schedules of 09:00 and 12:00 hours. At both times, the WPP pen presented lower temperature values than the SLC pen. Possibly, because the pen presented a closure by means of a rope, it allowed a greater incidence of solar radiation, with a consequent elevation of the internal temperature. However, in the SLS pen, there was no difference in Tbg values compared to the other pens. Values of Tbg were higher at 12:00 and 3:00 p.m. in all pens, reflecting the increase in Tdb (Table 3) recorded at the same time.

The minimum temperatures recorded in each pen were 10.2, 10.1, 9.7, and 8.0 ºC for WPP, SLS, SLC, and EXT (external), respectively; absolute maximum temperatures were 30.53, 30.73, 31.34, and 31.90 °C for WPP, SLS, SLC, and EXT, respectively, all registered on the same day at 14:00 h. The mean ambient temperature observed for the whole experimental phase was 18.5, 18.7, 19.1, and 17.7 °C for WPP, SLS, SLC, and EXT, respectively.

Table 3 Means of environmental variables observed throughout the day in sheds for swine growing and finishing with different types of pens.

Variables	Pen	Time					
		06 a.m	09 a.m	12 p.m	15 p.m	18 p.m	21 p.m
Tbg (°C)	WPP	12.6 ^{dA}	20.1 ^{bB}	25.4 ^{aB}	26.1 ^{aA}	19.4 ^{bA}	15.8 ^{cA}
	SLS	13.4 ^{dA}	21.3 ^{bAB}	25.9 ^{aAB}	26.3 ^{aA}	20.0 ^{bA}	16.3 ^{cA}
	SLC	13.8^{dA}	22.0 ^{bA}	27.0 ^{aA}	27.1 ^{aA}	20.6 ^{bA}	16.9 ^{cA}
Tdb (°C)	WPP	13.2 ^{dA}	18.9 ^{bC}	24.6 ^{aB}	25.7 ^{aA}	20.1 ^{bA}	16.2 ^{cA}
	SLS	13.1 ^{dA}	20.1 ^{bB}	24.5 ^{aB}	25.6 ^{aA}	20.1 ^{bA}	16.3 ^{cA}
	SLC	12.7 ^{eA}	22.0 ^{bA}	28.8 ^{aA}	26.4 ^{aA}	20.4 ^{cA}	16.3 ^{dA}

Pens: Water pit (WPP), Partially slotted floors on the sides (SLS), Partially slotted floor on sides and in the center (SLC). Black globe temperature (Tbg); Dry point temperature (Tdb). Averages followed by the same letter, lower case within one line and upper case within one column, do not differ significantly by Tukey´s test ($P < 0.05$).

The ambient temperature outside the facilities ranged from 8.0 to 31.9 °C throughout the data collection phase. These temperatures are always higher than those registered inside the pens, demonstrating the positive effect of the installations in the attenuation of extreme external temperature conditions.

Based on the recommendations of Ferreira (2005), the ideal temperature for pig growth and finishing phase ranges between 15 and 28 ºC. At certain periods of the day, the temperature exceeded the 28°C reported by Furtado et al (2012) as the beginning of the zone of thermal discomfort for pigs in the growth and finishing phase. Thus, pigs exposed to high temperatures are affected in their performance (Kiefer et al 2010), mainly due to reduced food intake and energy expenditure associated with thermoregulation processes (Manno et al 2006). The efficiency of using these processes differs according to the type of pen used. As shown in Tables 4 and 5, the values of parameters that influence thermoregulation processes (air velocity, BGHI, enthalpy, and THI) largely vary, according to the time of day, with the type of pen used.

For the WPP pen, were recorded in all periods an average air velocity lower than that recorded in the other two pens. However, this difference was only significant ($P < 0.05$) at 12 p.m. (Table 4). This can be explained by the fact that at this time, ambient temperatures, water evaporation and, as such, temperature differentials increase, causing a decrease in air velocity.

Table 4 Average values of air velocity (Vair, m s^{-1}) in sheds for swine growing and finishing with different types of pens.

Treatments (Pens)	Time		
	09 a.m	12 p.m	15 p.m
WPP	0.26^{a}	0.30^{b}	0.20^{a}
SLS	0.40^{a}	0.69^{a}	0.43^{a}
SLC	0.50^{a}	0.87^{a}	0.48^{a}

Pens: Water pit (WPP), Partially slotted floors on the sides (SLS), Partially slotted floor on sides and in the center (SLC). Air velocity (Vair). Means followed by the same letter within one column do not differ significantly by Tukey´s test.

There were no differences in the other schedules. Although BGHI is affected indirectly by radiation and air velocity, ventilation was not sufficient to cause significant differences (Table 5).

Generally, values recorded in the WPP pen were lower than those in the other two pens, particularly in relation to the SLC pen. This difference was significant at 9 a.m., exactly as the temperature inside the pens began to rise. In fact, the evaluated parameters depend on air temperature, its moisture content, and the energy it contains. Thus, the increase in

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temperature increases water evaporation, which consumes energy and decreases air temperature. This phenomenon was more effective in the WPP pen, since there was a greater amount of water for evaporation.

In all treatments, the observed BGHI values were high at 12:00 and 3:00 p.m., following the parameters ambient temperature and globe temperature (Table 5). The same trend was observed by Sampaio et al (2004), who evaluated the thermal environment in facilities for growth and finishing of pigs in tropical conditions (winter and summer) and found the highest THI and BGHI values between 12 and 04 p.m.

The values of THI followed the same trend as the BGHI values, recorded at 3:00 p.m. With higher temperatures, between 12:00 and 03:00 p.m, there evaporation increased, thus increasing the value of humidity relative. As both THI and BGHI values increase with higher temperature and humidity, their high values at 12:00 and 03:00 p.m. are justified.

Table 5 Environmental variables observed throughout the day in sheds for swine growing and finishing with different types of pens.

Variables	Pen	Time					
		06 a.m	09 a.m	12 p.m	15 p.m	18 p.m	21 p.m
BGHI	WPP	57.9^{dA}	66.9^{bB}	72.2^{aA}	72.6^{aA}	65.9^{bA}	61.7^{cA}
	SLS	58.7^{dA}	67.9^{bAB}	72.3^{aA}	72.5^{aA}	66.3^{bA}	62.2^{cA}
	SLC	59.1^{dA}	68.6^{bA}	73.5^{aA}	73.1^{aA}	66.8^{bA}	62.9^{cA}
h	WPP	35.7^{dA}	48.0^{bB}	53.9^{aA}	53.8^{aA}	47.8^{bA}	41.5^{cA}
	SLS	35.6^{dA}	48.7^{bB}	51.8^{aB}	52.1^{aA}	47.0^{bA}	41.4^{cA}
	SLC	35.1^{eA}	50.8^{bA}	53.8^{aA}	52.3^{abA}	47.3^{cA}	41.5^{dA}
THI	WPP	58.2^{dA}	65.3^{bB}	71.0^{aAB}	71.9^{aA}	66.2^{bA}	61.9^{cA}
	SLS	58.1^{dA}	66.5^{bB}	70.5^{aB}	71.5^{aA}	66.1^{bA}	61.9^{cA}
	SLC	57.7^{eA}	68.3^{bA}	72.0^{aA}	72.1^{aA}	66.4^{cA}	62.0^{cA}

Pens: Water pit (WPP), Partially slotted floors on the sides (SLS), Partially slotted floor on sides and in the center (SLC). Black Globe Temperature and Humidity Index (BGHI); Enthalpy of air (h) in (kJ kg-1); Temperature and humidity index (THI). Means followed by the same letter, lower case within one line and upper case within one column, do not differ significantly by Tukey´s test ($P < 0.05$).

In the present study, the THI values were below the values stipulated by PIC (2015), which consider a THI below 74 normal for pigs, 75 to 79 alert situation, 80 to 85 hazardous, and above 85 critical (emergency situation).

In relation to the enthalpy, differences between the pens and the schedules were observed. The pens presented a difference at 09:00 and 12:00 (Table 5), with the SLC pen having the highest enthalpy value (50.8 kJ kg of dry air^{-1}) at 09:00 a.m. At 12:00, both WPP and SLC pens had higher values (53.9 and 53.8 kJ kg of dry air^{-1}, respectively). At other times, there was no significant difference between the pens.

The enthalpy values express the amount of energy contained in a mixture of dry air and water vapor, thus influencing the thermal changes between the animal and the environment (Nazareno et al 2012). According to Moura (1999), the desired enthalpy value for the pig growth phase is 60.44 to 68.62 kJ kg dry air^{-1}. In this way, all the treatments, in all the evaluated schedules, presented enthalpy values below the recommended threshold value. The results found in this study agree with those observed by Nazareno et al (2012), who, although working with matrices (animals that use the same mechanisms of thermoregulation as pigs in the growth and finishing phase) in different breeding systems (confinement and not confinement), found enthalpy values of 49.84 and 47.87 kJ kg^{-1}, respectively.

Conclusions

The main objective of the present study was to evaluate the effects of different constructive typologies of pig raising facilities on the thermal comfort of growing and finishing pigs. The environmental data presented, in general, not high average values, with similar values between stalls.

In all pens, the BGHI inside the pens presented average values in the hottest period of the day, slightly above is the maximum value recommended for adult pigs, indicating that the animals were subjected to periods of thermal stress.

The WPP pen during the day promotes a better environment for the animals presenting a slightly higher average relative humidity, but with lower ambient temperature and lower black globe temperature than the other pens, which resulted in lower THI values and BGHI when compared to the SLC pen.

Since data collection was performed in the winter season, where temperatures are milder compared to the summer, it is recommended that further studies are conducted in the summer season to more accurately assess the conditions of the facilities.

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