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Analysis of environmental conditions in two different Compost Bedded Pack Barn systems for dairy cattle

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Abstract. The objective of this study was to analyse and compare the thermal environment of dairy cattle facilities in an open compost bedded pack barn (CBP) with natural ventilation and closed CBP (without thermal insulation) and climate control system. The research was conducted in a property located in Zona da Mata, Minas Gerais, Brazil. During the summer and for different periods of the day, the following average environmental variables observed inside the facilities were measured: dry bulb temperature, relative humidity and Temperature and Humidity Index (THI). The results were submitted to an analysis of variance to determine the significance of the variables in the different treatments. It was found that the closed and climate control system CBP promoted greater control of the facility's internal microclimate, registering smaller thermal amplitudes and a greater reduction in the animals' exposure time to stressful thermal conditions, compared to the CBP with natural ventilation. However, during summer afternoons, comfort indices indicated moderate stress. It is concluded that the closed CBP, regarding the analysed variables, indicated potential use, provided that a careful study of the climate of the region is carried out before implementation, the factors related to the ambient conditioning and better insulation of the construction are adjusted. The climatic variables inside the open CBP indicated a high stress condition for the animals, suggesting the placement of positive pressure fans and sprinklers properly distributed in the feed alley, to guarantee benefits to the entire area of the animal housing.

Key words: animal welfare, housing systems, livestock farming, mechanical ventilation, thermal environment.

INTRODUCTION

Milk production is increasingly technological, with more sensors embedded in processes, as well as more ways to achieve sustainability, particularly associated with soil health, water quality and reduction of ammonia and greenhouse gas emissions (Britt et al., 2018). Thus, the new technologies of agricultural activities and processes have been gaining significant attention among milk producers in different regions of the world (Beber et al., 2021; Damasceno et al., 2022; Oliveira et al., 2023).

In Brazil, the dairy industry has undergone major transformations, with high levels of production and consumption. Cow's milk is among the most important products in the Brazilian agricultural sector (Embrapa, 2022). In the main producing regions of the country, intensive breeding systems are widespread, in which the animals are confined during the productive period, receiving all kinds of adequate treatment, mainly with regard to food (bulky, hay and feed) in feeders (Souza et al., 2021). The microclimate inside the facilities influences the comfort, well-being and performance of production animals.

For this reason, it must be ensured that dairy cattle are housed in properly designed facilities to mitigate the effects of climatic elements and provide animal welfare (Cook & Nordlund, 2009; Fagundes et al., 2020). As mentioned by Biasato et al. (2019), housing systems and management practices have a strong influence on the welfare of dairy cattle and, consequently, on milk quality, making the choice of breeding environment extremely important (Vilela et al., 2019).

In this sense, the facilities for the confinement of dairy cattle must be well designed, to promote maximum comfort for the animals and mitigate the effects of climatic factors that may negatively interfere with the quality of production. Among the options that indicate to be economically accessible and technically efficient for dairy farming, which can improve the thermal problems faced in the field, the compost bedded pack barn (CBP) system is promising for the climatic conditions of Brazil (Damasceno, 2020). The confinement of dairy cattle in CBP facilities is one of the main alternatives adopted by Brazilian producers in order to achieve higher productivity rates (Oliveira et al., 2022). CBP facilities, when well-managed, have provided greater longevity for confined animals, better hoof and mammary gland health, and increased milk production, while still allowing animals to express their natural behaviours (Black et al., 2013; Yameogo et al., 2021).

In Brazil, most CBP facilities are open on the sides, and can be ventilated naturally or using mechanical ventilation (artificial) by positive pressure. However, recently, as a way of mitigating variations in the thermal environment between the different seasons of the year and facilitating the management of facilities, Brazilian producers have been observed adhering to the closed and climate control CBP system (Valente et al., 2020; Andrade et al., 2022a; Obando et al., 2022).

The pioneering project of the closed and climate controlled CBP was conceived in negative pressure ventilation in tunnel mode, associated with the evaporative cooling system, and was built in the state of Minas Gerais, Brazil, in 2015, and since then it has been spreading in different regions of the country (Damasceno, 2020; Yameogo et al., 2021; Andrade et al., 2022b).

However, as the increase in this closed and climate controlled CBP technology in milk production systems in Brazil is observed, the questions on the part of producers have also been intensifying. Mainly regarding the applicability of fully closed facilities for the constructive typology and climatic conditions present in the country.

In this sense, the objective of this research study was to analyse and compare the thermal environment of dairy cattle facilities in an open CBP with natural ventilation and closed CBP (without thermal insulation) and climate control system.

MATERIALS AND METHODS

General considerations

The study was carried out in a dairy production unit that uses CBP facilities for the confinement of dairy cattle. Two different CBP facilities were analyzed: a) compost bedded pack barn closed (CBPC) and provided with negative pressure ventilation in tunnel mode, associated with the evaporative cooling system (EC), with porous plates use.; b) compost bedded pack barn open (CBPO) with natural ventilation system.

The milk production property was located in the Zona da Mata region, Minas Gerais, Brazil (670 m altitude, coordinates 20° 46' 41" S, and 42° 48' 57" W). The local climate, according to the Köppen classification, is of the Cwa-type, with cold, dry winter and hot and humid summer (Alvares et al., 2013).

The facility CBPO has a northwest-southeast orientation, total dimensions of 25.0 m long × 18.4 m wide, a gable roof, corrugated metal roof tiles, a height of 5 m, and eaves of 1.5 m. The internal spatial distribution of the CBPO is composed of: a) drive-through alley with a concrete floor with an area of 100 m² (containing a single trough 25 m long), being the region where the tractor circulates for food distribution; b) feeding alley with concrete floor with an area of 100 m², with four drinking fountains in this region; c) 350 m² bedding area. During the trials 25 cows were housed inside with a density in resting area of 14.0 m² $head^{-1}$.

The CBPC has a northwest-southeast orientation, 55.0 m length × 26.4 m width, gable roof, corrugated metal roof tiles, 5.0 m height, and 0.8 m eaves. The internal spatial distribution of the CBPC is composed of (a) a 220 m^2 drive-through alley with a concrete floor (containing a single 55 m long trough), being the region where the tractor circulates for food distribution; (b) a 220 m^2 feeding alley with a concrete floor (separated from the pack area by a 1.2 m high concrete wall), with four drinking points in this region; (c) an 880 m^2 bed area (on compacted soil); and (d) a 132 m^2 service corridor with a concrete floor. During the trials 83 lactating cows were housed inside with a density in resting area of 11.0 m² $head^{-1}$.

On the southeast side of the CBPC, a series of five porous cellulose was used in the EC composition. A sensor positioned inside the CBP, monitored environmental conditions and was programmed to be activated when the air temperature was equal to or higher than 21 °C and relative humidity below 75%. Thus, the plates were moistened by dripping to allow the adiabatic cooling of the external air that passed through the same suction path (negative pressure). At the opposite end (northwest side) of the facility were five large exhaust fans (BigFan®, HVLS, 3.5 m in diameter, six propellers, an air volume of 150,000 m³ h^{-1}, and power of 1491.4 W). The five exhaust fans remained on continuously (24 hours day^{-1}).

The CBPC had a bed composed of a mixture of wood shavings and coffee husks, with a thickness of approximately 0.60 m. The CBPO had a bed composed of wood shavings, with a thickness of approximately 0.30 m.

The bed stirring was mechanized and occurred periodically, twice a day, usually at 6:30 a.m. and 12:00 p.m., at depth of 0.20 m. The stirring was carried out through the hybrid implement (chisel with roller) coupled to with a tractor (JOHN DEERE® 5078E, 78 hp) to incorporate animal waste into the bedding material, promote higher aeration for the composting process, and decompress the bedding. The superficial washing of the feeding aisle floor was performed by the known flushing system and occurred once daily, in the morning.

Animals in both facilities had ad libitum access to fresh water provided from a self-filling trough located in the feeding alley.

Evaluation of the thermal environment

The microclimatic data collection occurred uninterruptedly, 24 hours day^{-1}, at 5-minute intervals, in summer. The air dry-bulb temperature (t_{db-min} and t_{db-max}, °C) and air relative humidity (RH_{min} and RH_{max}, %) data were recorded using 10 sensors (DHT22, model AM2302) distributed over the region of the bed and the feeding alley. The sensors were installed at a height of 2.0 m.

Subsequently, in possession of the collected microclimate data and to assess possible conditions of heat stress and the spatial variability of the attributes, the average of Temperature-Humidity Index (THI_{min} and THI_{max}) was calculated for the four periods of the day investigated, using Equation 1corrected and modified by Mader et al. (2006).

$$THI = 0.8.t_{db} + \text{RH.}\left(\frac{t_{db} - 14.4}{100}\right) + 46.4$$

where t_{db} = air dry-bulb temperature (°C); RH = air relative humidity (%).

Statistical Analysis

The results were submitted to an analysis of variance to determine the significance of the variables in the different treatments, using the Minitab® software.

RESULTS AND DISCUSSION

According to the statistical analysis carried out, the values of tdb max, THI_{max} were statistically different for the two treatments (CBPO and CBPC), at the level of $\alpha = 0.05$.

Table 1. Mean values of the variables used in the characterization of the thermal environment of compost bedded pack barn, open and with natural ventilation (CBPO) and closed and acclimatized (CBPC), during the summer

FACILITY	t_{db-min}(°C)	t_{db-max} (°C)	HR_{min} (%)	HR_{max} (%)	THI_{min}	THI_{max}
CBPO	19.9a	31.1a	46a	95a	68a	79a
CBPC	20.3a	27.5b	69b	93a	69a	78a

The profile of hourly average values of air temperature, relative humidity and temperature and humidity index inside the CBPO and CBPC facilities is shown in Fig. 1.

The hourly average values of t_{db} inside the CBPC, behaved similarly to the values observed inside the CBPO, until the moment when the t_{db} reached 21.0 °C, from which point, in the CBPC facility, the automatic spraying on the porous material, with a view to promoting evaporative cooling of the incoming air.

Before EC activation, that is, under air temperatures below 21.0 °C, although following parallel behavior curves, it was verified that the air temperature values inside the CBPO facility were slightly higher than those observed for the CBPC. The increase in temperature inside the CBPC can be attributed to the inefficiency of the material used in the side and roof closures, added to the heat produced by the cows and equipment, by the heat generated in the litter composting process.

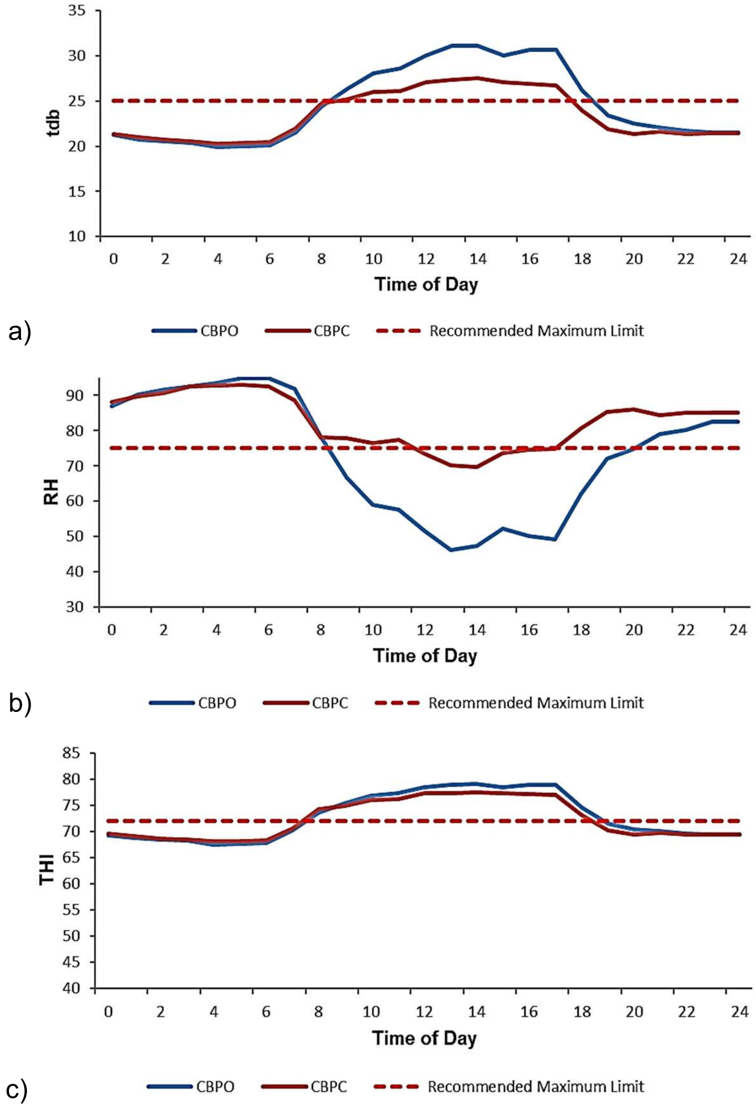

Figure 1. Average variation of hourly values of (a) dry bulb temperature (tbs), in °C, (b) relative humidity (RH), in % and Temperature-Humidity Index (THI) inside the CBPO and CBPC, throughout the summer period.

However, from the activation of the EC, there was an inversion of the tbs curves, with a reduction in the internal temperatures of the housing, compared to the external environment. These variations in the average indoor and outdoor t_{db} therefore show that the use of the evaporative adiabatic cooling system was able to reduce the t_{db} of indoor air to the CBPC during the most critical periods of the day (max-t_{db} values of 31.1 °C for CBPO and 27.5 °C for CBPC).

It was verified that, during the afternoon period, in the summer, the t_{db} averages (for both facilities) remained above the thermoneutrality zone, that is, above the interval between 5 and 25 °C cited by Yousef (1985) and Roenfeldt (1998) as being of comfort. It was also above the limit recommended by Nääs (1989), who mentions the air temperature range characterized as a comfort situation for lactating cows between 4.0 and 24.0 °C, and can be ideally restricted to the limits of 7, 0 to 21.0 °C, depending on the relative humidity.

With regard to the RH variable (Fig. 1, b), similar behaviour was observed in the average hourly RH values of the CBPC over time, when compared to the values measured in the CBPO. However, in the case of periods with higher temperatures, in the CBPC facility it was necessary to use the EC in the hottest hours of the day (temperatures above 21 °C), demanding the activation of the dripping on the porous plate, generating an increase in the value of RH inside the CBPC facility. The mean RH values observed were high inside the CBPC facility, during the two analysed seasons (UR > 70%). The average ambient temperature condition found during the hottest time of the afternoon in summer, associated with the average relative humidity recorded in the same period, constitutes a situation of thermal stress, which may be harmful to the productive performance of the cows (Armstrong, 1994).

It should be mentioned that several studies have reported that the efficiency of the evaporative cooling system depends on the HR of the ambient air in the region, and the drier the air, the greater the cooling potential of the system (Jacobson et al., 2009). Thus, it is observed that when analysing the values obtained for t_{db} and RH in the summer, for the CBPC, the system did not reach the maximum cooling potential during the most critical periods of the day. Possibly because the installation is located in a region with a hot and humid climate.

In Fig. 1, c are presented the hourly average values of the Temperature and Humidity Index (THI), referring to the CBPO and CBPC, during the experimental summer period.

It appears that the average hourly THI variation, for both facilities at times of higher air temperature, was the one that was above the maximum limit recommended in the literature of 74 (Mader et al., 2006) for dairy cattle. Demonstrating that at the hottest times of the day, the architectural characteristics of the CBPC facility and the adopted ventilation system, as well as for the facility without a ventilation system, were not enough to reduce the THI values.

Herbut & Angrecka (2018) analyzed the relationship between the THI value during the summer months and the behavior of dairy cows. It has been observed that cows change their behavior during the summer depending on the prevailing environmental conditions.

Heat stress can reduce the daily rumination time of cows and, consequently, reduce the productive performance of animals (Grinter et al., 2023). Souza et al. (2004) analyzed the physical environment of dairy cattle facilities in a freestall system with and without air conditioning. According to the same authors, the use of acclimatization equipment (ventilation and nebulization) brought positive changes in the physical environment of the freestall studied, as well as increased the milk production of the animals.

In view of this, in order to reduce these high THI values, it would be important to carry out some internal improvements in the CBPC facility, such as using covering materials and side closures with thermal insulation. You can also use other building and ventilation devices that can contribute to better thermal comfort for the animals. For the CBPO facility, fans should be added uniformly distributed in the area of the bed and the feeding alley.

CONCLUSIONS

This study found significant differences in the thermal environment between the use of negative pressure ventilation and natural ventilation facilities. The use of the negative pressure ventilation system brought about positive changes in the physical environment of CBP facilities. However, the climatic variables inside the open CBP indicated a high stress condition for the animals, suggesting the placement of positive pressure fans and properly distributed sprinklers, in order to guarantee benefits to the entire area of the animal housing. It is possible, based on the obtained results, to trace strategies for the improvement in the constructive typology of the building, in the used ventilation system. However, attention should be paid to other variables (study of the local climate, litter management, litter area per animal, among others) when deciding on the best ventilation system.

To improve this study, additional research is needed to address the cost of milk production in closed intensive CBP systems, including the analysis of the profitability of this type of installation. It is also necessary to cover aspects of energy consumption and alternative bedding materials, as well as behavioural studies that correlate the variability of microclimatic conditions measured inside the facilities.

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