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Analysis of environmental conditions and management in a compost-bedded pack barn with tunnel ventilation

B. Yameogo[1], R.R. Andrade[2], C.G.S. Teles Júnior[3], G.S. Laud[4], V. Becciolini[1], L. Leso[1], G. Rossi[1] and M. Barbari[1,*]

[1]University of Florence, Department of Agriculture, Food, Environment and Forestry, Via San Bonaventura, 13, IT50145 Firenze, Italy
[2]Federal University of Viçosa, Department of Agricultural Engineering, Av. Peter Henry Rolfs, s/n Campus University of Viçosa, BR 36570-900 Viçosa, Minas Gerais, Brazil
[3]Federal Rural University of the Amazon, Institute of Agricultural Sciences, Av. Perimetral, Terra Firme, BR 66077830 Belém, Pará, Brazil
[4]Federal University of Viçosa, Department of Animal Science, Av. Peter Henry Rolfs, s/n Campus University of Viçosa, BR 36570-900 Viçosa, Minas Gerais, Brazil
[*]Correspondence: matteo.barbari@unifi.it

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Abstract. The housing system based on compost-bedded pack for dairy cows is spreading rapidly in Brazil. Completely open buildings without curtains and simple roofs are usually provided. However, in the last years some new completely closed barns have been realized. This study aims to analyse one of these closed barns, located in the State of Minas Gerais. The two main sides of the facility are provided with polyethylene curtains of blue colour and five deflectors. The barn is equipped with an evaporative adiabatic cooling system, associated with the tunnel-style ventilation, realized with exhaust fans, continuously operating 24 hours a day. 85 lactating Holstein cows were housed in the barn during the trials carried out in the winter season 2019. Microclimatic data were collected continuously. Air speed, illuminance and bedding temperature were measured during the farm visits. Pack moisture was calculated. The results state the importance of bedding management and climatic conditions inside the barn. It emerges that the cows housed in this kind of closed barn, with forced ventilation, are in good thermal conditions, which are fairly constant. The average illumination of the barn can be considered acceptable (55.06 lx), even if some areas of the barn present values below the minimum ones reported in literature. The bedding temperature varies between a maximum of 36.33 °C and a minimum of 25.44 °C with an average of 31.26 °C. The values of bedding moisture are between a maximum of 64.36% and a minimum of 60.81% with an average of 62.48%.

Key words: compost bedded-pack barns, dairy housing, tunnel ventilation, ventilation systems.

INTRODUCTION

Housing conditions and facility design play a fundamental role on cow's health and performance (von Keyserlingk et al., 2009; Gaworski et al., 2018). In recent decades, the standard housing solution for dairy cows worldwide has been represented by free stall barns. Such system allowed reaching considerable improvements in labour requirement and cow cleanliness (Bewley et al., 2017). Anyway, recent research underlined that free stall system can have several failings, with specific respect to animal welfare (EFSA, 2009). Free stall system may also favour a large production of liquid manure, which is known to contribute to emission of greenhouse gases (Petersen, 2018).

In recent years the compost bedded pack-barn (CBP) system for dairy cows has found a sudden development worldwide (Leso et al., 2020). In Brazil after the first realization in 2011 of a compost barn (CBP), this alternative loose housing solution has found an increasing development. To date, some thousands of compost barns can be counted in the Country. The success of compost barns around the world is mainly related to improvement of animal welfare of dairy cows (Black et al., 2013; Bewley et al., 2017; Leso et al., 2020). Anyway, only a good design allows this innovative system to achieve its goals.

The building design, equipment and materials employed can influence the microclimatic conditions inside the barns (Kic, 2017). Climate may influence CBP design because the pack drying rate is strictly related to air conditions (Eckelkamp et al., 2016). In Brazil, due to climatic conditions, completely open buildings without curtains and simple roofs are usually provided. The main advantage of this building technique is the low investment cost. In addition, during hot periods, maximizing sidewall open area gives an important contribution to removal of heat and moisture given by the cows as well as the additional heat and moisture created by the composting process (Smits & Aarnink, 2009). However, in the last years some new completely closed barns have been realized with the main objective to allow a better microclimatic control inside the facility. The first dairy barn designed to use negative pressure ventilation in tunnel mode in closed facility was built in the State of Minas Gerais in 2015. Since that time, this solution has found various applications throughout several Brazilian regions (Andrade, 2020).

In the CBP, a proper ventilation system is necessary for several reasons: maintaining a comfortable environment for the animals, removing gases and heat, drying of bedding material (Janni et al., 2007; Lobeck et al., 2011). Fully enclosed facilities rely on mechanical ventilation (negative pressure) and generally use evaporative cooling pads to reduce inside temperature during the hottest period of the year (Lobeck et al., 2012).

In a closed building the environmental control is particularly important to reduce thermal stress of the cows, especially during hot season. Furthermore a good internal environment allows to create suitable conditions of bedding temperature and moisture. During cold season, an excessive air velocity can lead to excessive heat loss from the pack, which limits the pack drying rate and results in wetter bedding (Smits & Aarnink, 2009).

The moisture content is the most important feature of the pack. Moisture content should be between 40 and 60% (Bewley et al., 2012). In the range from 40 to 60% of moisture content, the composting process operates optimally, whereas if moisture content is below 30–35%, it may inhibit microbial activity, ceasing the composting process (Black et al., 2013). Furthermore, studies have shown that the moisture level of the pack can affect cow cleanliness, udder health, and ease of movement of the animals (Eckelkamp et al., 2016; Leso et al., 2020).

The bedding temperature is another fundamental parameter to take under control. Ventilation can cool the CBP surface, bringing the level of bedding temperature near the ambient temperature (Black et al., 2013). Studies have shown that compost temperatures above 55 °C promote sanitization and that temperatures between 45 and 55 °C maximize degradation of materials. While, when temperatures drop to 35 to 40 °C, the microbial population is less effective at degrading the bedding material (Stentiford, 1996; Black et al., 2013).

Another important aspect to take into consideration in a closed building is related to the level of illuminance. In a totally closed CBP, the artificial lighting system has to be distributed throughout the entire building, in order to guarantee brightness within the recommended range for lactating cows (Andrade et al., 2020). An efficient production response from lactating cows can be obtained assuring the recommended light intensity of 160 lux, with lamps placed between 3 and 4 m (Dahl et al., 2001).

Air-conditioned by a negative pressure ventilation system in tunnel mode requires to put special attention on some factors, such as greater difficulty in handling the bedding, availability of adequate space for installation of the barn, higher energy cost and maintenance, sufficient amount of bedding for more frequent replacement, need for rescue energy (generators) (Andrade, 2020).

This study aims at investigating the performance of a closed barn with tunnel ventilation in winter season, in order to give a contribution in the proper design and management of this kind of housing solution.

MATERIALS AND METHODS

The study was conducted for a month in 2019 (July 7th to August 6th), in a farm located in the State of Minas Gerais (Brazil), latitude 20°46'41"S, longitude 42°48'57"W and 670 m of altitude. The climate in this area, according to the Köppen classification, is tropical, characterized by a cold and dry winter and a hot and humid summer, with an average annual temperature of 19 °C.

In the compost barn, 80 to 88 lactating Holstein cows are generally housed. During the study 85 cows were present in the barn. The cows were fed and milked twice daily.

The CBP is oriented in north-west / south-east direction (Fig. 1). It is 55 m long and 26.8 m wide. The available area (1,100 m^2) is distributed between a bedding area of 880 m^2 (55 m × 16 m) and feeding alley area of 220 m^2 (55 m × 4 m). The available surface per cow is totally 12.94 m^2, considering an average number of 85 cows.

The height in eaves is 5 m while the height in ridge is 7 m. The gabled roof is made by galvanized steel sheets. The floor of the feeding aisle is covered with full concrete, as well as that of the alley for the passage of machineries. The two main sides of the facility (north-east and south-west sides) are provided with polyethylene curtains of blue colour and five deflectors are arranged inside the building. Inside the barn, led lamps (100 W) are distributed along the bedding area and the alley.

The barn is equipped with an evaporative adiabatic cooling system, composed of five panels of porous cellulose material (3.6 m × 3.6 m each), located on the south-eastern side of the building (Fig. 2). This cooling system is activated, with the humidification of the panels, when the internal air temperature reaches values above 21 °C and the relative humidity is below 75%. During the winter season the cooling system is generally non active. The evaporative cooling system is associated with the tunnel-style ventilation (negative pressure). Five exhaust fans (BigFan®, 3.5 m diameter, 150,000 m^3 h^{-1} air volume and 2.0 hp) are installed in the north-west side of the facility for tunnel-type ventilation, continuously operating 24 hours a day.

Figure 1. The compost barn with tunnel ventilation: deflectors (left) and large fans (right) are shown.

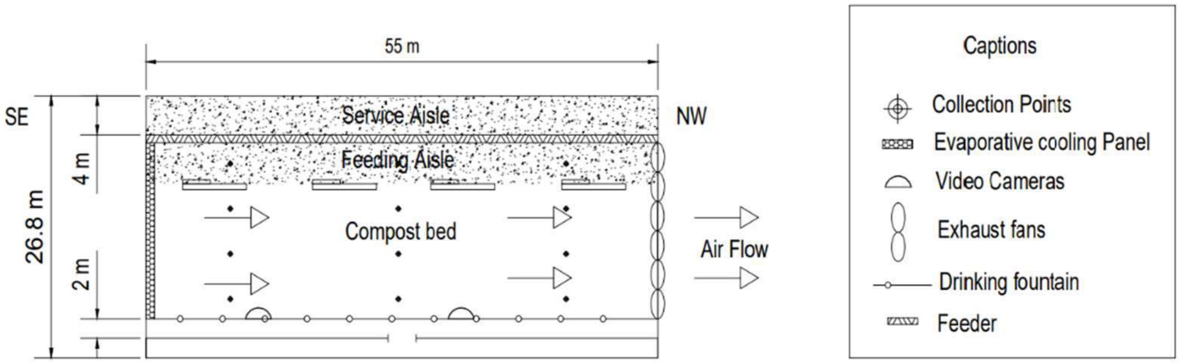

Figure 2. Scheme of the CBP with tunnel ventilation.

In the compost barn, in the resting area, a mixture of dry sawdust and coffee husk is used as bedding material, about 0.60 m thick. The bedding is stirred twice daily, for 9 minutes each time and therefore this operation requires 18 min day^{-1}. A chisel with roller is used, attached to a tractor with a power of 78 hp. A fresh and dry layer of bedding, 5 cm thick over an area of 880 m^2, either an amount of 44 m^3 (880 m^2 × 0.05 m), is added every 10 days approximately. The total monthly amount of bedding consumption is therefore 132 m^3, the equivalent of 1.55 m^3 per cow month^{-1}. This is the amount mainly necessary to maintain the moisture content of the pack under control. While the bedded pack is completely renewed twice a year. The amount of bedding removed annually is 528 m^3 (880 m^2 × 0.6 m).

Different sensors were used for continuous and discontinuous measures. For continuous measurements of air temperature and relative humidity inside the barn, two data loggers were installed, in the middle of the building, at a height around 2.5 m, and outside the shed (HOBO® Data Logger Ux100-003 - Onset - United States. Precision of the sensors: Temp: ± 0.21 °C; RH: ± 3.5%; Resolution: Temp: 0.024 °C; RH: 0.07%). All devices were programmed to measure and store at intervals of 5 minutes, 24 hours a day, throughout the data collection period.

Specific environmental parameters such as air speed (m s^{-1}), air temperature (°C), relative humidity (%) and illuminance (lx) were also measured during farm visits. Various portable devices were used for this purpose. For discontinuous measurements of ambient temperature (°C) and relative humidity (%) of the air inside and outside a data-logger was used (HOBO® U14-001 - Onset - United States. Precision of the sensor: Temp: ± 0.21 °C; RH: ± 2.5%; Resolution: Temp: 0.02 °C; RH: 0.05%). For the discontinuous measurement of the bedding temperature, a thermocouple-based thermometer was used. For the illuminance measurements, a portable digital lux meter was used (MINIPA® model MLM-1011, São Paulo, Brazil. Measuring range from 0 to 100,000 lx, 4% accuracy). A digital thermo-anemometer was used to measure air velocity (m s^{-1}) (Instrutherm; Model: TARF 180; Serie: Q594832).

To obtain representative information, all measures were taken in a number of spots inside and outside the barns, as shown in Fig. 3. Environmental parameters were measured in the resting area, in the eating alley and outside. The bedding zone was virtually divided into 9 equal areas, while the eating alley was divided into 3 areas. In the centre of all the measuring spots, environmental measures were taken at cow level (1.3 m height) and at pack level (0.1 m), except for the illuminance.

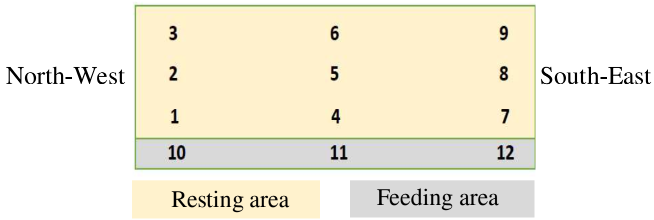

Figure 3. Different points of data collection in the CBP with tunnel ventilation.

Bedding measures concerned pack temperature and pack moisture. The temperature of the bedding was collected at a depth of 20 cm, at the same location points described in Fig. 3, that is in the 9 points of the resting area.

The samples collected were analysed in the laboratory of the Department of Agricultural Engineering (DEA) of the Federal University of Viçosa to determine pack moisture content, during all of the experimental period. Each sample was composed of materials obtained at different depths (from the surface to 20 cm deep).

RESULTS AND DISCUSSION

The bedding temperature in the compost barn varies between a maximum of 36.33 °C and a minimum of 25.44 °C for an average of 31.26 °C. As for bedding moisture, the values are between a maximum of 64.36% and a minimum of 60.81%, with an average of 62.48%, as shown in Fig. 4.

The analysis of data collected in the compost barn during the study concerning the bedding temperature and moisture makes it possible to compare the results obtained with what is encountered in literature.

The results obtained allow us to confirm that the bedding moisture in the barn, between 60 and 65% is fairly close to the range recommended by authors such as Bewley et al. (2012), which suggest values between 40–60%. However, bedding temperature is problematic, because it remains below what is proposed for maximizing the degradation of the material. Indeed, previous studies suggest temperatures between 45 and 55 °C while in the examined compost barn the temperatures is between 25 and 37 °C. According to Stentiford (1996) and Black et al. (2013), temperatures of 35 to 40 °C are a brake on the degradation of bedding material due to microbial activity.

Regarding the other discontinuous measures made during the trials, Table 1 presents the average and the standard deviations of the tested parameters, for each point in the barn. Table 2 highlights the average of all points for the entire period with maximum and minimum values. The different measurements were taken at the cow level (1.30 m height) and at the pack level (0.10 m above the bedding) for the different parameters except for those external and those of the illumination which were taken only at 1.30 m height.

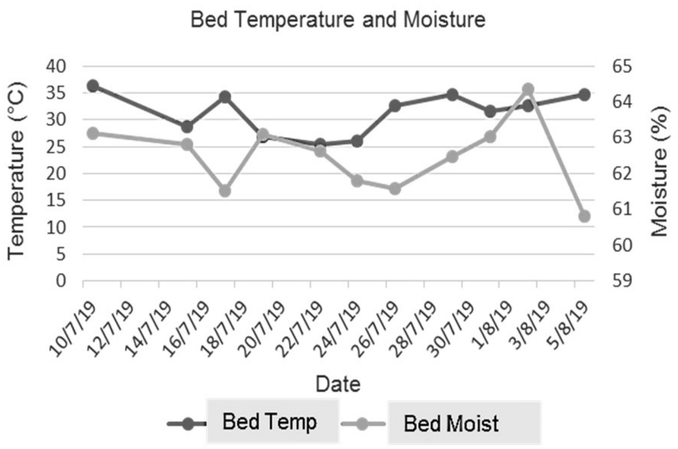

Figure 4. Bedding temperature and moisture in the closed compost barn.

Table 1. Averages and Standard deviations of RH, temperature, air velocity and illuminance, from July 10 to August 06, 2019 in each point.

Point	Height (m)	Rel. Humidity (%) Aver.	St.Dev	Temperature (°C) Aver.	St.Dev	Air velocity (m s^{-1}) Aver	St.Dev	Illuminance (lx) Aver	St.Dev
1	1.30	75.95	8.63	16.07	3.46	1.44	0.31	81.48	57.19
2	1.30	77.19	7.36	16.10	3.38	1.56	0.32	101.48	72.86
3	1.30	77.24	7.33	16.11	3.36	1.46	0.27	200.95	131.63
4	1.30	77.57	7.47	15.83	3.36	1.53	0.29	25.00	34.09
5	1.30	78.14	7.42	15.88	3.28	1.50	0.24	14.86	9.40
6	1.30	78.52	6.35	15.89	3.24	1.37	0.28	48.00	51.73
7	1.30	77.57	6.85	15.76	3.12	2.71	4.21	3.29	4.43
8	1.30	77.90	7.00	15.70	2.90	1.81	0.29	9.95	7.04
9	1.30	78.19	7.47	15.90	2.87	1.55	0.37	67.00	19.62
10	1.30	79.00	6.73	16.10	3.03	0.83	0.44	91.20	86.63
11	1.30	77.81	7.63	16.13	3.05	1.67	2.39	16.25	12.71
12	1.30	77.76	7.80	16.11	3.00	1.44	0.47	3.95	11.03
1	0.10	78.05	7.51	16.16	3.36	1.14	0.30	-	-
2	0.10	79.57	5.53	16.13	3.41	1.09	0.24	-	-
3	0.10	80.14	5.63	16.19	3.31	1.18	0.28	-	-
4	0.10	80.10	5.74	15.92	3.34	1.30	0.29	-	-
5	0.10	80.95	5.78	15.93	3.29	1.20	0.22	-	-
6	0.10	80.90	4.74	15.89	3.22	1.18	0.22	-	-
7	0.10	79.48	5.90	15.73	3.07	1.53	0.43	-	-
8	0.10	79.86	6.13	15.79	2.95	1.42	0.35	-	-
9	0.10	80.62	6.05	16.00	2.78	1.10	0.42	-	-

Fig. 5 shows the values of illuminance (lx) taken at the height of 1.3 m in the compost barn, as average of all the points for the entire study period. Inside the closed barn the average illuminance is 55.06 lx, while outside the illuminance is 21,005.08 lx on average. The maximum and minimum values are respectively 200.95 lx and 1.30 lx inside and 36,249.52 and 1,424.14 lx outside.

Table 2. Average, maximum and minimum values of all points for the entire period

	RH (%)	T (°C)	Air vel (m s^{-1})	Illumin (lx)
	Inside CBP 1.3 m			
Average	77.74	15.97	1.57	55.06
Max	79.00	16.13	2.71	200.95
Min	75.95	15.70	0.83	1.30
	Inside CBP 0.1 m			
Average	79.96	15.97	1.24	-
Max	80.95	16.19	1.53	-
Min	78.05	15.73	1.09	
	Outside CBP 1.3 m			
Average	71.89	18.64	0.59	21,005.08
Max	75.05	18.83	0.97	36,249.52
Min	70.14	18.55	0.24	14,24.14

From the data in Table 2, it can be noted that the interior of the facility is not uniformly illuminated. Indeed, there is a maximum of lighting in the area of point 3 (200.95 lx) while the areas identified by points 7 and 12 are very dimly illuminated with a light intensity of 3.29 and 3.95 lx. The comparison of these values with the ones found in literature allows us to state that the average illumination of the barn is acceptable (55.06 lx). The optimal illumination to allow the locomotion of animals is indicated between 39 and 119 lx (Phillips et al., 2000, Andrade et al., 2020), Therefore, the average value found inside the barn is included in this range. However, the illuminance is not uniform, because half of the points give values below what is required as a minimum: 6 places out of the 12 examined have values between 3.29 and 25 lx. In a previous study, carried out in compost barns with similar tunnel ventilation, Damasceno et al. (2019) found that the passage of light can be hindered by the presence of air deflecting curtains throughout the facility, causing lower levels of illuminance in some areas of the building. For animals in production, as in the case of dairy cows in the closed barn, the value of illuminance should be revised upwards through an improvement of the lighting system in the facility at its different places. According to Dahl et al. (2000), to stimulate milk production, 150 lx of illumination are required throughout the barn and 16 to 18 hours of continuous lighting have to be provided.

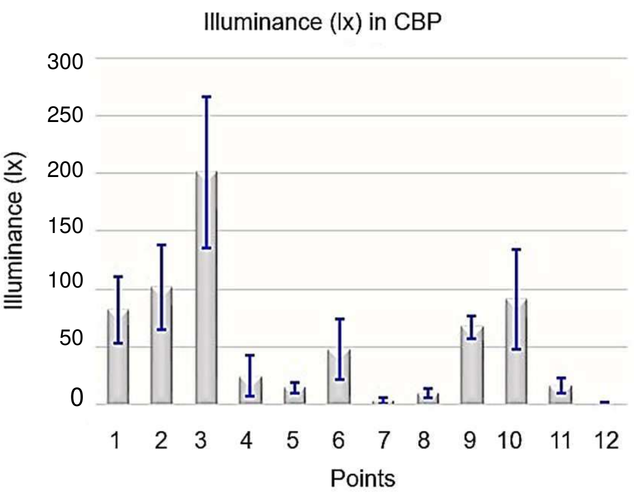

Figure 5. Illuminance inside and outside CBP at a height of 1.3 m.

Measurements of temperature, relative humidity and velocity of the air in the barn were also taken at height of 1.3 m and 0.1 m inside and outside the barn, during the visits in the morning time (9–12 a.m.). The values are reported in Table 2 and Table 3. The values of temperature and relative humidity remain more or less constant during all the experimental period, with little variations between the maximum and minimum. The average air temperature is 15.97 °C at height 1.3 m inside the barn and 18.64 °C outside the barn. The average relative humidity is 77.74% inside the barn and 71.89% outside the barn.

Fig. 6 shows the average and the standard deviations, for each point throughout the study period, of the air velocity (m s^{-1}) inside the barn. At 1.3 m height the average speed is 1.57 m s^{-1}, the maximum speed 2.71 m $s^{-1}$and the minimum speed 0.83 m s^{-1}. At 0.1 m height, there is an average speed of 1.24 m s^{-1}, a maximum of 1.53 m $s^{-1}$and a minimum of 1.09 m s^{-1}. Outside the barn, on the other hand, the values are: 0.59 m s^{-1}average speed, 0.97 m s^{-1}maximum and 0.24 m s^{-1}minimum.

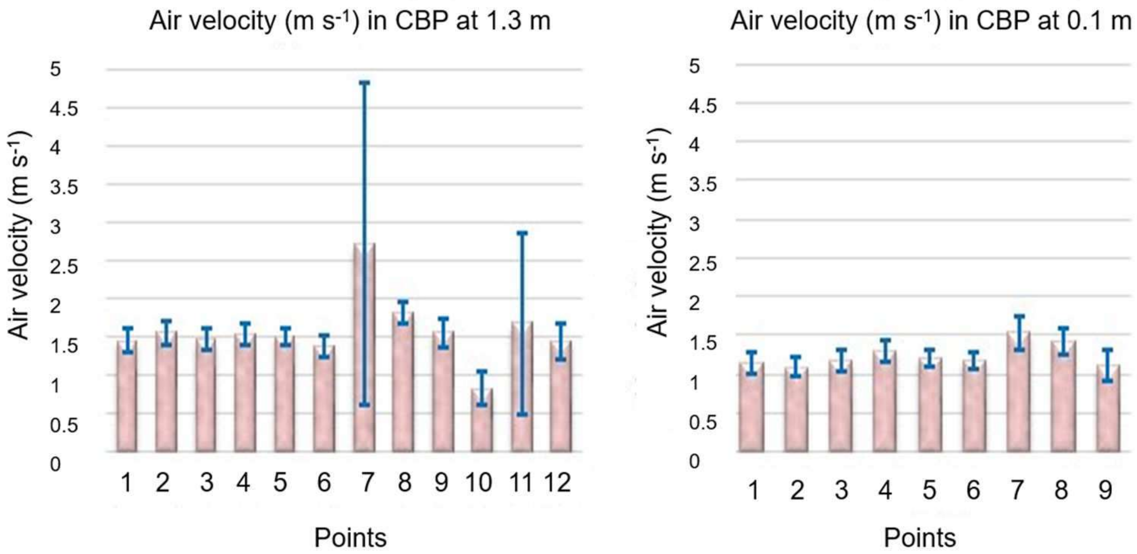

Figure 6. Air velocity inside the compost barn at a height of 1.3 and 0.1 m.

The values found inside the barn can be considered acceptable on average, but the huge differences between the different points of the barn state that the air is not well distributed in the building. The ventilation system, based on the extraction of the air by five big fans and on the movement of the air in the building by means of the five deflectors installed, needs to be designed in a more proper way to give a uniform distribution of air in whole the barn. As general statement, artificial ventilation with fans can be used in CBP to promote pack drying as well as to control cows' heat stress during hot periods. However, during the cold season, the tunnel ventilation in a totally closed barn requires particular attention to avoid the cooling of the pack, which is detrimental for the working of the bedding. Furthermore, designing ventilation in CBP, particular attention should be paid to obtaining uniform airflow within the barn.

Pad cooling systems can be activated during the summer season, but these systems could not be appropriate for CBP, especially over the bedded area, because an increase in relative humidity reduces the evaporation rates. As this study dealt with the analysis of tunnel ventilation system only during the winter season, a specific deep study has to be carried out during the summer season to analyse the functioning of the evaporative cooling system in the barn.

CONCLUSIONS

A good layout can allow the innovative compost-bedded pack system to achieve its objectives. It is fundamental to guarantee a minimum area per cow that can be considered between 12 and 15 m^2. A good control of humidity of the bedding by cultivating it regularly (twice a day), with the continual supply of new litter material in sufficient quality and quantity, is required. The ventilation system is crucial for a proper management of the bedding.

A completely closed barn with tunnel ventilation can guarantee good environmental conditions inside the barn, but a proper design is necessary. The study shows that during the winter season some problems can occur related to the high values of bedding moisture. The movement of the air inside the barn has to be well distributed avoiding areas scarcely or excessively ventilated. The illuminance is another important item to take into account to guarantee a uniform light distribution.

The study conducted here was not exhaustive on the subject addressed. In particular the summer season would be to monitor with the same procedure in order to obtain useful information during hot season when also the evaporative cooling system is working.

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