Effects of Different Cooling Systems on Heat Stress and Behaviour of Dairy Cows

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Abstract: This paper shows the results of a research study aimed at investigating the effects of a sprinkler system coupled with forced ventilation on the heat stress and the behaviour of dairy cows reared in a free stall barn without paddock. To this aim, an experiment was carried out inside a free-stall dairy house equipped with two different cooling systems: a fogging system associated with forced ventilation in the resting area and a sprinkler system associated with forced ventilation in the feeding alley. The trial regarded two adjacent pens and the experimental protocol required that the treatment group was housed in one pen where the two cooling systems were always activated following an established timetable, whereas the control group was housed in the adjacent pen, where the sprinkler system associated with forced ventilation was deactivated. Climatic parameters were measured inside each pen of the barn and outside. Then, thermal humidity index (THI) was calculated. Rectal temperature and respiration rate of a sample of dairy cows were monitored each day of the trial. Cow behaviour was monitored by means of a multi-camera video-recording system equipped with 6 cameras in one pen and 4 cameras in the other pen. During the trial, the cows reared in each pen were subjected to mild or moderate heat stress with average daily THI values of about 74. However, during daytime, THI reached values very close to 80, corresponding to a severe heat stress. The physiological parameters values of the treatment group were always significantly lower than the corresponding ones of the control group. Specifically, the sprinkler system especially influenced the respiration rate (56.4 vs 70.1 breaths/min), while it had more limited effects on rectal temperature (38.8 vs 39.4°C). Furthermore, it was observed that the sprinklers influenced the behaviour of the cows. The cows of the treatment group tended to feed more than those of the control one especially when the sprinklers were active. Furthermore, when the sprinkler system was on, cows were encouraged to stand in the feeding alley also without feeding. The results also suggest that the sprinkler system had a positive influence on the behaviour of the cows during night, as the cows of the treatment group tended to lay in cubicles almost for all the nighttime, whereas the control group tended to interrupt the lying activity to go to the rack.

Keywords: Animal welfare, animal behaviour, breeding environment, microclimate control.

1. Introduction

1.1 Effects of heat stress on milk production

In intensive farming of dairy cows, the continuous and uninterrupted occurrence of high ambient temperatures, combined with high values of air relative humidity, results in a worsening of productive and reproductive performance, that is specifically evident in high-producing animals.

Climatic factors such as air temperature and relative humidity, solar radiation, air speed, together with their interactions can affect the productivity of dairy cows (Sharma et al., 1983). The direct quantification of the effects of the climate on milk production is difficult, as it is also closely related to other factors such as, for example, the management of food ration (Fuquay, 1981). However, some authors (Johnson, 1976; Thatcher, 1974) reported a decrease in milk production and a reduction in the adipose fat layer of the cows as a direct consequence of high ambient temperatures. This could have been caused by heat stress that has negative consequences on the secretion functions of the mammary glands (Silanikove, 1992). Bianca (1965) found a 35% reduction in the milk production of different breeds of cows and continuously exposed to air temperatures of 35°C. McDowell et al. (1976) found a 15% reduction in milk production accompanied by a 35% reduction in the energy efficiency used for reproductive purposes when Frisone cows were transferred from an ambient with air temperature of about 18°C to another with air temperature of 30°C.

Heat stress affects the productivity of cows in a different way in relation to their production phase. Specifically, during the early lactation stages, cows are less able to counteract the adverse effects of heat stress, so that a decline in milk production is determined. In this regard, Sharma et al., (1983) found that climatic conditions exert the greatest adverse influence over the first 60 days of lactation. Indeed, during this first period energy balance of high-producing cows is negative, so that they compensate through the mobilization of body reserves. Barash et al., (1996) also showed that under Mediterranean climate, that cows which start lactation in summer produce less milk than those which start lactation in winter.

1.2 Effects of heat stress on fertility

Heat stress is responsible of important losses of livestock production. When air temperature is within the thermoneutrality zone, cows can maintain homeostasis without excessive use of energy for thermoregulation; therefore, energy is available to maintain good health and productivity conditions (Yuosef, 1985).

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When the climate becomes warmer, the animals spends their energy to dissipate the excess of heat in order to keep the internal heat balance, causing stress conditions (Bernabucci et al., 2014; Mader et al., 2006; Segnalini et al., 2013) that negatively affect production (West, 2003) and behaviour (Allen et al., 2015; Cook et al., 2007).

Various authors studied the effects of heat stress on reproduction (Wolfenson, 2000). Significant decrease in conception rate was observed in cows with body temperature above normal at inoculation, as the vitality and quality of oocyte and sperm is significantly reduced (Fallon, 1962; Ferreira et al., 2011; Fuquay, 1981; Stott and Williams, 1969) and could causes pregnancy losses (Garcia-Ispierto et al., 2006; López-Gatius et al., 2009). In addition, it was observed that heat stress could also prevent or delay ovulation (Her et al., 1988; Roth et al., 2000; Wilson et al., 1998).

1.3 Thermal stress indices

With air temperatures higher than 26°C dairy cows are no longer able to regulate their internal heat generation and come in heat stress (Bligh, 1973). Thermal stress can be assessed by measuring body temperature (Fuquay et al., 1979) that is highly susceptible to warm weather conditions (Akari et al., 1984) and therefore it is considered a stress-sensitive indicator.

McDowell et al., (1976) found that a good indicator of the thermal stress of animals is the Temperature Humidity Index (THI). The THI considers the combined effects of air temperature and relative humidity and its values are associated with the thermal stress level. Different animal species have different sensitivity to ambient temperature and humidity in the air. For example, dairy cows can tolerate high relative humidity values better than pigs (Bohmanova et al., 2006).

Other authors (Buffington et al., 1981, Oliveira and Esmay, 1982) suggested to modify the THI index and proposed the Black Globe-Humidity Index (BGHI), obtained by replacing the value of the dry bulb temperature with the value of the black-globe temperature. As black-globe temperature takes into account the effects of net radiation and air speed, the BGHI could be a heat stress index more accurate than THI when cows are exposed to high ventilation and/or heat radiation.

In literature, THI values are classified into several categories, indicating the level of heat stress experienced by animals. The definition of these levels varies among different authors. Armstrong (1994) identified THI values below 72 as characterizing the comfort zone, values between 72 and 78 as peculiarities of the mild stress zone, values between 79 and 89 as boundaries of the moderate stress zone and values above 90 as representative of severe stress conditions. Huhnke et al. (2001) divided the scale of values of THI into two parts: the range between 79 and 83 was defined as a dangerous situation and the range with THI greater than 84 was defined as emergency situation. Thom (1959) classified the values of THI in 4 intervals: normal ≤ 74, alert 75-78, danger 79-83, emergency ≥84.

The close relationship between the increase of THI and the decrease of milk production is well established. The American Society of Agricultural and Biological Engineers standards for the design of ventilation systems in dairy houses (ASABE, 2003) reports that milk production decreases when THI exceeds 72. In addition, this reduction is different depending on the animal production level, as the most productive cows are also the most sensitive to heat.

Also, the cow behaviour was found to be correlated with an increase of THI. In this regard, it is interesting to note that the behavioural changes can occur for THI values considered as not critical (Brown-Brandl et al., 2005; Mader et al., 2004).

Indeed, some authors (Armstrong, 2004; Igono, 1992) pointed out that lying, standing and feeding behaviours modifies starting from THI values above 60.

Many studies were carried out on the efficacy of different cooling systems in reducing heat stress of dairy cows. Some papers studied the effects of systems made by sprinklers and fans for the direct wetting of the animals coupled with forced ventilation on both cow physiology and lactation performances (Avendaño-Reyes et al., 2010; Berman, 2008, 2010; Avendaño-Reyes et al., 2012). However, in these studies the cooling systems were installed in the holding pen, so that they did not affect the microclimate of the barn.

In other cases, the cooling is carried out in the feeding alley and in the resting area. In this situation, if animals have free access to a paddock (Frazzi et al., 2000; Calegari et al., 2012), heat stress due to high levels of relative humidity could also be reduced by leaving the barn when microclimate becomes uncomfortable.

Porto et al. (2017) investigated the effects of the alternate use of two different cooling systems on the behaviour of dairy cows inside a free-stall barn without paddock. The results suggest that the use of a fogging system in the resting area during the central hours of the daytime could encourage the decubitus of dairy cows in the cubicles and that the activation of a sprinkler system in the feeding alley could not be able to influence the standing behaviour and had only a moderate positive influence on the feeding activity.

D'Emilio et al. (2017) found that a sprinkler system coupled with forced ventilation installed in the feeding lane of a free-stall barn without paddock could be able to mitigate heat stress in dairy cows. On this basis, this paper investigates if a such cooling system could also influence the behaviour of the cows.

2. Materials and methods

2.1 The barn under study

The experiment was carried out inside a free-stall dairy house located in Pettineo/Pozzilli (37°01'N, 14°32'E) in the province of Ragusa (Sicily, Italy), at the altitude of 234 m above the sea level. The barn was closed on the SW side, facing the feeding alley, and open on the other three sides. The experiment was carried out in two adjacent pens separated by transverse passages: one with a resting area consisting of 26 cubicles housing 19 Italian Fresian cows (pen 1) and the other one with a resting area consisting of 16 cubicles housing 15 Fresian cows (pen 2). The cubicles were bedded with sand and arranged in two rows head to head.

The barn was equipped with two different cooling systems: a fogging system associated with forced ventilation installed in the resting area and a sprinkler system associated with forced ventilation installed in the feeding alley.

2.2 The experimental protocol

The technical specification and the activation rules of the two systems in relation to both time and air temperature are reported in Table 1. The fans were automatically switched off during wetting to avoid the scattering of water. Both the systems were manually switched off during the two milking sessions and the cleaning of the feeding alley.

Cows were fed ad libitum and feed was delivered at 8:00. The feeding area was cleaned once a day between 8:30-9:30 using a scraper driven by tractor. Cow milking occurred twice daily between 5:00-6:00 and 17:30-18:30.

The experiment was performed from 27th June to 7th July 2016. The experimental protocol required that in pen 1 (treatment group) the two cooling systems were always activated as specified in Table 1, whereas in pen 2 (control group) the sprinkler system associated with forced ventilation was deactivated.

Air temperature and relative humidity were measured outdoor at the ridge line of the roof. Inside the barn, air temperature and relative humidity were measured by using four probes in pen 1 and two probes in pen 2 at the height of 2.00 m above the floor. All the sensors were connected to a data-logger that read the measurements every 5 seconds and recorded the corresponding average values every 5 minutes. The THI index was calculated by the following equation (Yousef, 1985):

$$THI = T_{db} + 0.36\ T_{dp} + 41.2 \qquad (1)$$

where T_{db} [°C] is the dry-bulb temperature and T_{dp} [°C] is the dew-point temperature.

Rectal temperature and respiration rate of 6 cows in pen 1, and 5 cows in pen 2 were monitored at about 15:00 of each day of the experiment. The measurements were carried out with cows blocked in the feeding rack. The respiration rate was measured by counting the breaths per minute with the aid of a digital timer, the rectal temperature was recorded by using a digital thermometer.

Table 1. Activation timetable of the cooling systems.

	Resting Area		**Feeding Area**	
	Fans	Sprinklers	Fans	Sprinklers
Technical specifications	Ventilation rate: 34,600 m^3/h	Pressure: 200 kPa Rate: 1.01 l/min	Ventilation rate: 22,250 m^3/h	Pressure: 200 kPa Rate: 2.57 l/min
Activation Time	8:00 – 9:00 10:00 – 15:00 20:30 – 21:30	11:00 - 14:30 17:00 - 17:30 20:00 - 05:30	9:00 – 10:00 15:00 – 17:00	9:00 – 10:00 15:00 – 17:15
Operating conditions	Always on with T>22°C Operative for 5 min every 25 min with T<22°C	Operative for 20 s every 5 min with T>27°C Off with T<27°C	Always on with T>20.9°C Operative for 4 min every 9 min with T<20.9°C	Operative for 18 s every 13 min and 38 s with T>27°C Off with T<27°C

2.3 Analysis of the cow behaviour

Dairy cow behaviour was studied by visual examination of time-lapse video-recordings provided by a multi-camera system composed of 6 cameras positioned in the pen housing treatment group and 4 cameras positioned in the pen housing the control group. Cameras had a maximum resolution of 1280 × 960 pixels and the ability to capture up to 25 fps. Moreover, this camera model was equipped with HTTP interface and IR sensors for night vision. The cameras were mounted on steel beams by means of special brackets.

The analysis of dairy cow behaviour was carried out by visual recognition of the obtained video sequence at ten-minute scan sampling interval.

Visual analysis of selected images allowed five different behaviours to be analysed among those most frequently studied (Bava et al., 2012; DeVries et al., 2003; Fregonesi et al., 2007; Overton et al., 2002; Provolo and Riva, 2009) for their high relation to the comfort of dairy cows:

- *lying*, which refers to all the possible decubitus positions inside the cubicle;
- *feeding*, which refers to the position standing still in the feeding alley with the head through the rack;
- *standing*, which refers to the standing still in the alleys or to the deambulation;
- *perching*, which refers to the position standing with only front feet inside the stall;
- *drinking*, which refers to the position with the head over the drinking trough.

For each day of trial, an operator filled a specifically designed form in a database, reporting the number of animals involved in the various activities in each pen. Subsequently, the following behavioural indices were calculated (Bava et al., 2012; Mattachini et al., 2011; Overton et al., 2002; Provolo and Riva, 2009):

- CLI (*cow lying index)* defined as the ratio between the number of cows resting in the cubicles and the total number of cows in the pen:

$$\text{CLI} = \text{cows lying in cubicles/total cows} \quad (2)$$

- CSI *(cow standing index),* defined as the ratio between the number of standing cows and the total number of cows in the pen:

$$\text{CSI} = \text{standing cows/total cows} \quad (3)$$

- CFI *(cow feeding index),* defined as the ratio between the number of feeding cows and the total number of cows in the pen:

$$\text{CFI} = \text{feeding cows/total cows} \quad (4)$$

- CPI *(cow perching index),* defined as the ratio between the number of perching cows and the total number of cows in the pen:

$$\text{CPI} = \text{perching cows/total cows} \quad (5)$$

- CDI *(cow drinking index),* defined as the ratio between the number of drinking cows and the total number of cows in the pen:

$$\text{CDI} = \text{drinking cows/total cows} \quad (6)$$

3. Results and discussion

Figure 1 reports the mean daily values of air temperature and relative humidity outside the dairy house and inside the two pens together with the respective calculated THI indices.

The mean outside air temperature and relative humidity were 25.8°C and 46.8%, respectively. However, during the trial the outside air temperature reached the maximum value of 34.4°C during daytime, whereas the outside relative humidity reached the maximum value of 84.7%, during night-time.

Inside the barn, air temperature in the two pens was almost the same, with a mean value of 26.5°C in the pen housing treatment group and 26.6°C in the pen housing control group. This result is mainly related to the almost open layout of the building. Air relative humidity was always higher in control pen, with a mean value of 59.3% in comparison to a value of 52.6% of the treatment pen. This result is mainly due to the position of the control pen in the middle area of the barn where the natural ventilation rate is lower than along the sides of the building. It also can be observed that, due to the presence of the animals, values of inside air temperature and relative humidity were higher than the corresponding outside ones.

As a consequence of the above mentioned microclimatic conditions, THI values occurred in control pen were slightly higher than the corresponding ones in treatment group, with a mean value of 74.0 in comparison to a value of 73.1 in the treatment pen.

Summarizing the previous results, during the trial the cows of both groups were subjected to mean climatic conditions corresponding to mild or moderate heat stress. However, during daytime, air temperature and relative humidity reached values corresponding to a severe heat stress, as it is shown by the maximum THI values that were higher than or very close to 80 (figure 1).

The results of the measurements of the physiological parameters in the monitored cows show that the mean values obtained in the treatment group were lower than the corresponding ones of the control group. Specifically, the sprinkler system especially influenced the respiration rate that in the treatment group was 56.4 breath/min on average, a little higher than the upper limit of the ideal range of 26-50 breath/min (Merck Veterinary Manual, 2012a). This result is in according with Calegari et al. (2012) and indicated a more favourable condition for heat dissipation in the pen with the sprinkler system. On the contrary, in the control group, the mean value of the respiration rate was 70.1 breath/min on average, that is considerably higher than the ideal range.

The sprinkler system had more limited effects on rectal temperature (38.8°C vs 39.4°C where an ideal range is 38-39.3°C) Indeed, in the treatment group, despite the heat stress conditions, the mean value of rectal temperature was 38.8°C and, therefore, within the ideal range of 38-39.3°C (Merck Veterinary Manual, 2012b). In the control group, the mean value of rectal temperature was 39.4°C, that is slightly higher than the upper limit of the ideal range, indicating mild heat stress. As reported by other studies (Khongdee et al., 2006; Calegari et al., 2012) rectal temperature values might have benefited by the mitigating effect of the cooling system installed in the cubicle area.

Milk production in the two groups was different. Specifically, the mean value in the treatment group over the whole period was 36.3 kg/day against a value of 34.4 kg/day in the control group.

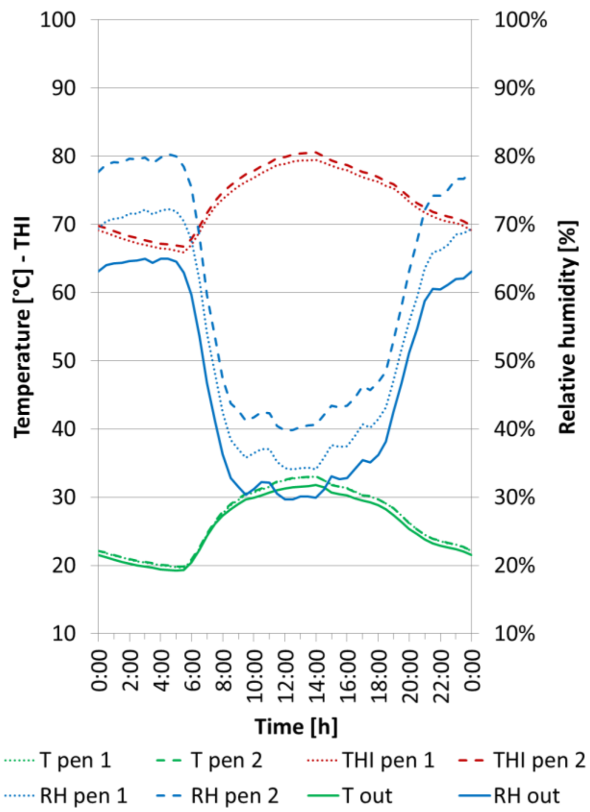

Figure 1. Mean daily values of air temperature and relative humidity measured outside the dairy house and in the two pens inside the dairy house together with the respective THI indices.

Figures 2-6 show the mean values of the behavioural indices obtained for both groups by averaging daily data at 10 minutes intervals for each day of the trial. The analysis of the graphs reveals some differences of behaviour between treatment group and control group.

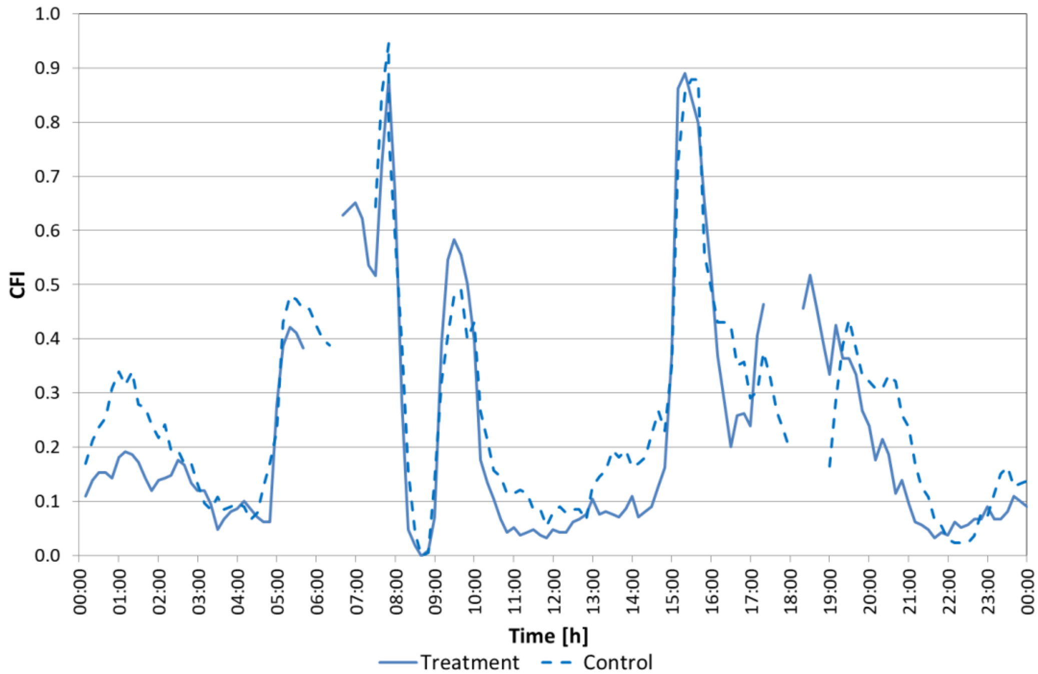

Figure 2. Mean values of CFI index obtained averaging daily data at 10 minutes intervals for each day of the trial

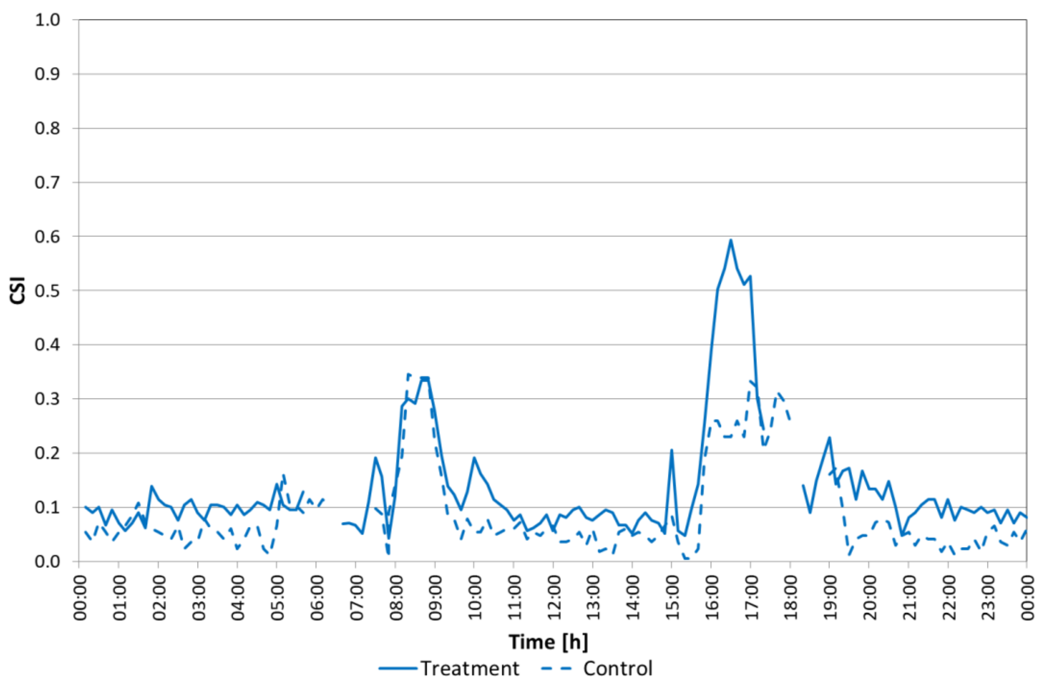

Figure 3. Mean values of CSI index obtained averaging daily data at 10 minutes intervals for each day of the trial

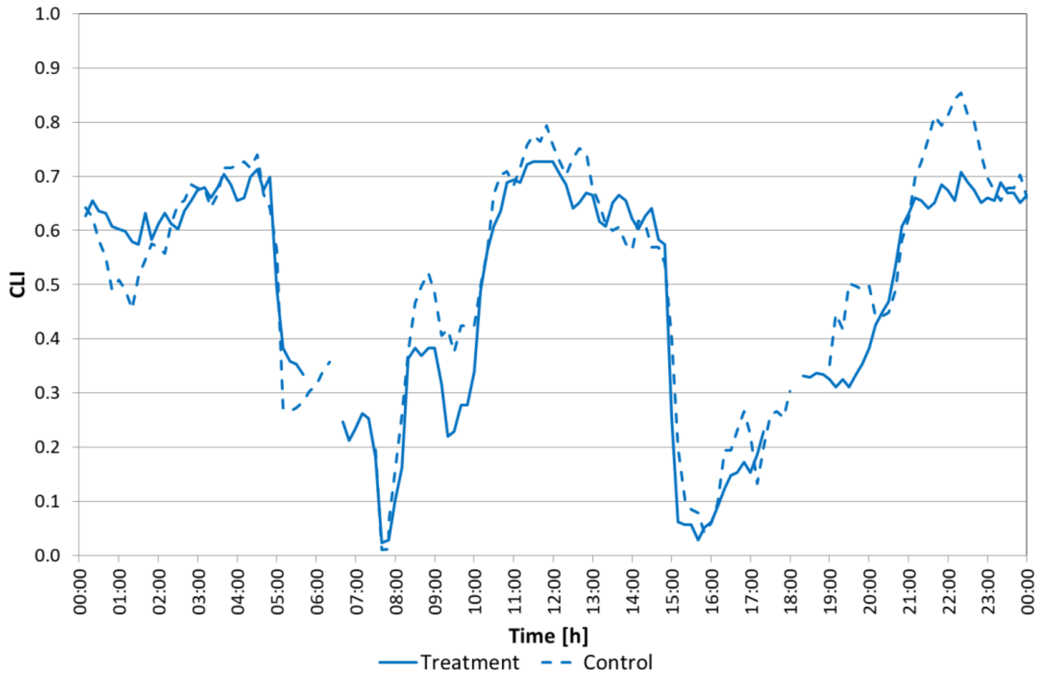

Figure 4. Mean values of CLI index obtained averaging daily data at 10 minutes intervals for each day of the trial

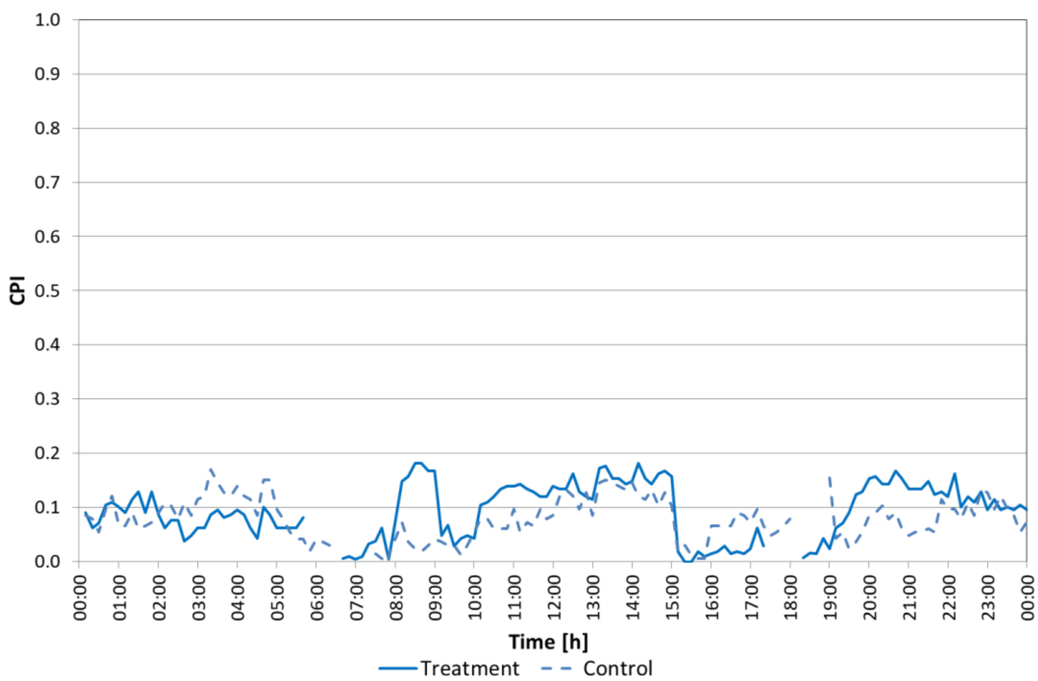

Figure 5. Mean values of CPI index obtained averaging daily data at 10 minutes intervals for each day of the trial

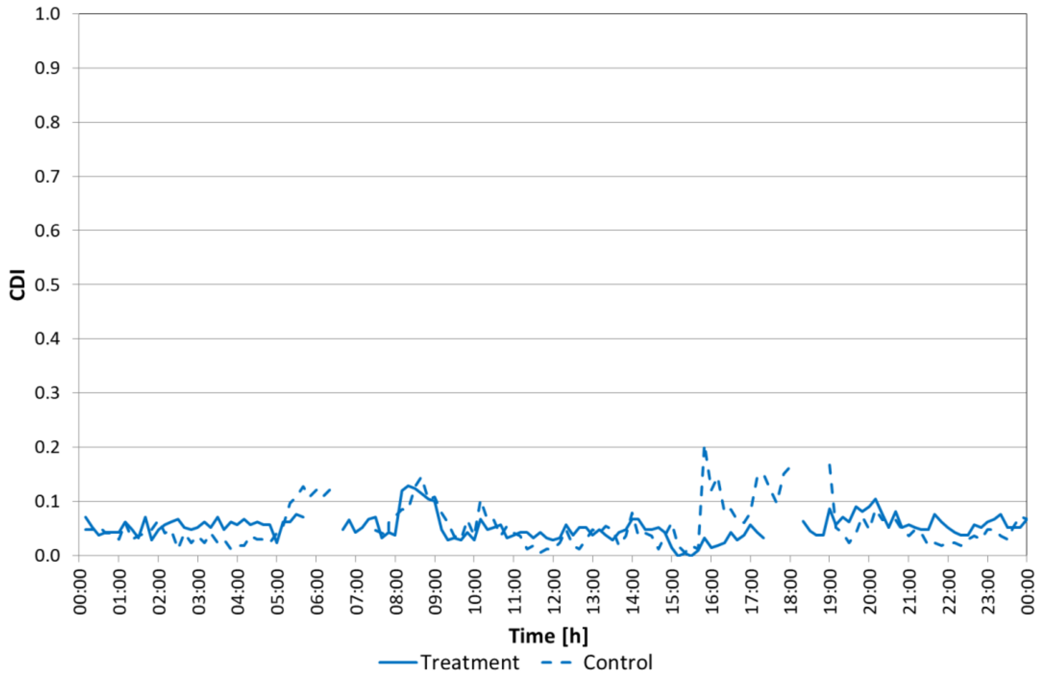

Figure 6. Mean values of CDI index obtained averaging daily data at 10 minutes intervals for each day of the trial

Specifically, figure 2 shows that when the sprinkler system in the feeding lane was activated in the morning (9:00-10:00) the cows of the treatment group tended to stay in feeding more than the control group (CFI=0.50 vs 0.42).Subsequently (10:00-15:00) the cows of the treatment group limited almost entirely this activity (CFI=0.09) whereas some cows of the control group continued to stay in feeding and, after a short pause, tended to go in feeding again, up to reach CFI=0.35 at 15:00.

Figure 3 shows that when the sprinkler system in the feeding lane was activated in the afternoon (15:00-17:00), the cows of the treatment group tended to stand (CSI=0.54) much more than the cows of the control one (CSI=0.30). This result suggests that the sprinkler system in the feed lane encouraged the animals to stay in the feeding alley also without the need of feeding.

During night-time, the cows of the treatment group had a steadier behaviour than those ones of the control group. Indeed (figure 4), the CLI of the treatment group was inside the range 0.6 – 0.7 almost for all the night-time, whereas the CLI of the control group varied in a wider range between 0.45 and 0.85. Specifically, the cows of the control group tended to go to the rack from 0:30 and 2:30, as attested by the maximum value of CFI, equal to 0.35, during this time interval.

The CPI index was always less than 0.2 for both groups. Specifically, figure 5 shows that in the treatment group perching activity was almost absent during the activation of the sprinkler system in the feed lane and it was very low during nighttime when, on the contrary, it was present in the control group.

Finally, the CDI index (figure 6) assumed very low values at all times without meaningful differences between the two groups. Specifically, the mean value of CDI was 0.05 for treatment group and 0.06 for control group.

4. Conclusions

Although the sprinkler system installed in the feed lane did not influence the microclimatic conditions, it contributed to relieve heat stress. Specifically, the system especially influenced the respiration rate that, in the treatment group, kept itself inside or very close to the ideal values, while in the control group was up to 20 breath/min higher than the maximum suggested value. The sprinkler system had more limited effects on animal rectal temperature.

Furthermore, it was observed that the sprinkler system in the feed lane influenced the behaviour of the cows. Indeed, the cows of the treatment group tended to stay in feeding especially when the sprinklers were activated and they were encouraged to stand in the feeding alley also without feeding. The results also suggest that the system had a positive influence during night, as the treatment group tended to lay in cubicles almost for all the night-time, whereas the control group tended to interrupt the lying activity to go to the rack or to stay in perching.

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