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Effects of Different Cooling Systems on Cows' Behaviour and Comfort during the Hot Period

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Keywords: *dairy cows, barns, heat stress, fans, irrigation, behavior, comfort.*

Abstract. *The purpose of this study was to compare the effects of high temperatures on the behavior, comfort and thermoregulation energy consumption of cows at free-stall keeping in two barns. The first barn had the system of forced ventilation and air irrigation, and the second one had only fans. Barn parameters were (Length × Width × Height) 94 × 32.1 × 10.5 m. The research was conducted in central Ukraine (Kyiv region) during July 2021. The average daily ambient temperature during the study period was +26.4°C. In each of the barns, the groups of similar of non-pregnant and lactating animals (107 ± 14 days in milking) of Holstein breed were formed. Cows were fed the total mixed ration twice a day in both barns. Hours of air cooling elements operation in the barns were from 10.00 to 18.00. The use of fans in combination with irrigation systems during hot periods had a positive effect on the heat transfer of cows compared with the heat transfer of cows that were in the barn with fans. With this combination, the temperature of the skin and the resting place under the lying cow and energy consumption for heat production were 0.5°C and 0.8°C and 3.1 MJ lower. In addition, this combination of air cooling systems had a positive effect on the duration of lying down and eating food (32 and 16 minutes longer, respectively), and the indicators of standing time, physical activity and drinking were lower by 16, 21 and 6 minutes, respectively. Accordingly, the best values were the cow comfort index (CCI), stall use index (SUI) and cow feeding index (CFI) (4.78, 4.87 and 0.08). In terms of stall standing index (SSI), stall perching index (SPI) and cow drinking index (CDI), slightly higher rates were observed in the barn using fans only (3.72, 1.06 and 0.013).*

Introduction

Dairy cow breeds are the most vulnerable animals to heat stress, and highly productive lactating cows stress at temperatures above +25°C or even +20°C. Heat stress is a global phenomenon and is studied even in countries with moderate temperate climates (Dunn et al., 2014; Angrecka and Herbut, 2016). The world is experiencing global warming, which has manifested itself in the form of rising average annual temperatures, prolonging of the year hot period, increasing of the number and duration of heat waves (Collier et al., 2017; Borshch et al., 2021b). Each degree of global temperature increase leads to a multiple increase in the frequency of heat waves and increased heat stress in dairy cattle (Polsky and von Keyserlingk, 2017).

Temperature stress is the condition of the body when it is unable to dissipate metabolic heat effectively, which leads to an increase of internal body temperature and reduction of living organism's physical activity (Kadzere et al., 2002; Borshch et al., 2019; Ruban et al., 2020; Borshch et al., 2021a). Heat dissipation is carried out by conduction, convection, radiation, and evaporation (Kadzere et al., 2002). Heat stress is observed when the sum of heat produced by the body and received from outside exceeds the total heat loss (Kadzere et al., 2002). The amount of produced and absorbed heat depends on the physiological state, level of productivity, age in calving, lactation stage, color of an animal, as well as genetic factors (Kim et al., 2017; Laporta et al., 2017). Heat stress affects the productive and reproductive qualities of animals, as well as leads to other changes. Changes in productive properties include reduction of milk productivity, reduction of protein, fat, and dry skim milk residue level, slowdown in growth, reduction of feed consumption (West, 2003). Changes in reproductive properties include reduction of fertilization rate, less intense manifestation of sexual desire, deterioration of sperm production (Allen et al., 2015).

Behavioral changes manifest in reducing of lying down duration to 30%, reducing of the duration of cud chewing, increased water consumption, increasing of the motor activity of the animal (Herbut et al., 2020).

Genetic changes are represented by the release of heat shock proteins, in particular *HSP70*, which are synthesized by the genes *HSF-1* and *HSPA6* (Baena et

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al., 2018). Physiological changes include an increase in body temperature, faster heart and respiration rate, lowering of the pH level in the rumen. Increased soreness is manifested by mastitis, acidosis and scar ketosis, weakening of the immune system, increasing of the number of heat strokes and even increasing mortality (Kadzere et al., 2002).

Deterioration in the welfare of cows depends on discomfort, increased soreness, skin contamination due to frequent lying in the manure alley, lameness (due to prolonged standing and increased activity), malnutrition, increased thirst, frustration and manifestation of aggression (Herbut and Angrecka, 2017). In order to effectively cope with heat stress, it is necessary to take measures related to the use of forced ventilation and cooling of animals (fans and irrigation systems), the use of mattresses for rest with pumping chilled water, the use of feedlot with canopies for rest and feeding, as well as their combinations (Gebremedhin et al., 2016; D'Emilio et al., 2018).

The aim of the study was to compare the effect of high temperatures on the behavior and comfort of cows kept in similar barns with the use of forced ventilation and air irrigation systems and only fans.

Material and methods

The research was conducted at a commercial dairy farm in Kyiv region, Ukraine (49°51-27-N, 30°6-36-E) during July 2021. The average weather indicators for the study period are shown in Table 1. Parameters of placements (Length × Width × Height): 94 × 32.1 × 10.5 m.

The farm uses free-stall keeping of cows with rest in boxes. The animals are kept in three easy-to-assemble barns. Two barns were used for the study. In the first barn, fans (located above the manure and feed aisles) were used during the summer, and in the second one, fans (located above the feed and manure alleys) and irrigation systems (located above the feed alleys) were used (Figure 1).

Technical characteristics and the timetable of cooling systems are given in Table 2.

Table 1. The main weather indicators during the research period (Mean ± SD)

Indicators	Ambient	Barns with:	
		fans	fans+sprinklers
Air temperature, °C	26.4 ± 0.9	23.0 ± 0.4	21.8 ± 0.2
Min–Max	21.7–34.3	20.4–25.6	19.8–23.2
Relative humidity, %	42.5 ± 0.3	58.1 ± 0.5	73.6 ± 1.7
Min–Max	36.2–51.0	53.7–66.1	62.0–78.4
Wind speed, m s^{-1}	6.1 ± 0.2	1.7 ± 0.02	1.7 ± 0.03
Min–Max	2.5–8.6	0.7–2.1	0.8–2.3

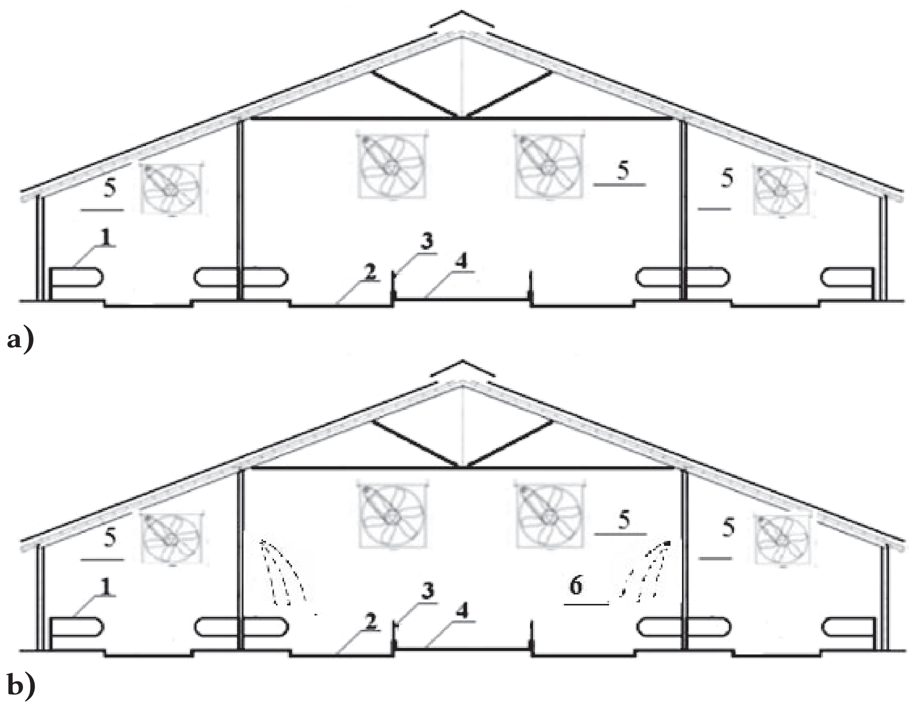

Figure 1. Easy-to-assemble barns with fans (a); with fans and irrigation (b).
1 – boxes for cows rest; 2 – feed and manure alley; 3 – feed passage fences; 4 – feed passage; 5 – fans; 6 – irrigation.

Table 2. Activation timetable and technical specification of the cooling systems

Technical specifications	Barn with:	Barn with:	
	fans	fans	irrigation
Manufacturer	Multifan, Vostermans Ventilation, (Netherlands)	Multifan, Vostermans Ventilation, (Netherlands)	Vdykh-Nova, (Ukraine)
Production capacity	to 48000 m^3/h	to 48000 m^3/h	pressure: 200 kPa
Activation time and operating conditions	Always on with when ambient T > 23°C	Always on with ambient T > 23°C	Operative for 30 s every 10 min with ambient T > 25°C

In each of the barns, groups of similar (n = 36) non-pregnant, lactating animals (107 ± 14 days in milking) of Holstein breed were formed. The average productivity of experimental cows is 25.32–25.63 kg/day. The cows were fed the total mixed ration twice a day in both barns. The cows were milked three times per day at the Parallel installation (DeLaval 2×16, Sweden) in the farm. Milking of the cows took place at 06.00, 12.00 and 18.00 hours.

Weather indicators of the environment during the study period were recorded according to the meteorological station of Bila Tserkva (Kyiv region, Ukraine).

The temperature, relative humidity and wind speed were measured by MISOL WN-5300CA (PRC). The sensors were placed in the zone occupied by cows 0.5 m above the floor. All the measurement results were recorded automatically every 10 min. The cows skin surface temperature was determined in two places: on rumen and in the region of the last inter costal space by using a remote infrared thermometer Thermo Spot Plus (Germany). The temperature at the resting place as well as under the lying cow was determined by the thermometer A36PF-D43 (USA). Costs of energy for heat production were calculated according to the methods of Kadzere et al. (2002).

The cows' behavior during the hot period was determined using internal surveillance cameras. In each barn, 16 Hikvision cameras (Full HD) were installed. Filming in both barns took place around the clock. Placing cameras in the barns allows you to record a recreation area, feeding passage and drinking bowl area and also cows moving. Every 10 minutes, in experimental groups, the number of cows, which during the observation consumed food, were resting by lying, standed, were moving and drinking water and also contact with the stall was recorded. The effect of free-stall housing on stall comfort, welfare, and natural behavior of cows following behavioural indices were calculated: cow comfort index (CCI): number of cows lying in stalls per number of cows in contact with stalls: (Nelson, 1996); stall standing index (SSI): number of cows standing in stalls per number of cows in contact with stalls (Cook et al., 2007); stall perching index (SPI): number of cows standing with 2 front feet in the stall and the rear feet in the alley per number of cows in contact with stalls (Tucker et al, 2005); stall use index (SUI): number of cows lying in stalls per number of cows not actively feeding (Overton et al., 2002); cow feeding index (CFI): defined as the ratio between the number of feeding cows and the total number of cows in the pen (DeVries et al., 2003); cow drinking index (CDI): defined as the ratio between the number of drinking cows and the total number of cows in the pen (Fregonesi et al., 2007).

The obtained data were statistically processed using STATISTICA (Version 11.0, 2012) software. The Student *t* test was used to estimate the statistical significance of the obtained values. The data were considered significant at $P < 0.05$, $P < 0.01$, $P < 0.001$.

Results

It was found that in the barn with the use of fans and irrigation systems the value of the skin temperature during the period of high temperature load was 0.5°C lower compared with the barn in which only fans were used (Table 3). Also, with such a combination of air cooling elements, lower indicators of resting place temperature (by 3.3°C) and resting place under a lying cow (by 0.8°C) were observed. In a room with fans and cooling sprinklers, the energy consumption for heat exchange was 3.1 MJ lower compared with a barn where only fans were used to cool the air.

When keeping cows indoors using fans and sprinklers, the indicators of the main daily behavioral reactions during the period of high temperature load, which characterizes comfort, were slightly better compared with keeping cows in the barn using only fans (Table 3). Thus, the durations of lying down and eating food were 32 and 16 minutes longer, respectively. At the same time, the duration of standing, motor activity and watering was dominated by animals kept in the barn with the use of only fans as elements of air cooling by 16, 21 and 6 minutes, respectively.

To more fully study the impact of using different options for cooling barns during hot periods, we studied the values of six comfort indices for free-stall keeping of cows, which depend on the indicators of daily behavior (Table 5).

The values of the cow comfort index (CCI) and the stall use index (SUI), which depend on the daily duration of lying down, were higher (by 4.78 and 4.87) than those of cows kept in a barn that used fans and sprinklers. The value of the cow feeding index (CFI),

Table 3. Temperature indices of rest places and energy expenditure for heat production during hot period (Mean ± SD)

Indicators	Barns with:	
	fans	fans + sprinklers
Skin temperature, °C	34.9 ± 0.2	34.4 ± 0.1*
Rest place temperature, °C	28.1 ± 0.3	24.8 ± 0.6***
Rest place temperature under lying cow, °C	28.9 ± 0.3	28.1 ± 0.2*
Σ energy for heat production, MJ	64.4 ± 1.6	61.3 ± 1.4

Note: as compared with the barn with only fans $^{*}P < 0.05$; $^{***}P < 0.001$.

Table 4. Duration of main daily behavior reactions‡ during the hot period (Mean ± SD)

Behavior reactions, min	Barns with:	
	fans	fans + sprinklers
Lying	706 ± 9.2	738 ± 8.8*
Feeding	253 ± 4.6	269 ± 4.3*
Moving	66 ± 1.8	51 ± 1.4***
Standing	189 ± 8.3	168 ± 5.7*
Drinking	49 ± 0.4	43 ± 0.9***

Note: as compared with the barn with only fans; $^{*}P < 0.05$; $^{***}P < 0.001$; ‡ – excluding milking time.

Table 5. Values of indices that characterize cow comfort during the hot period (Mean ± SD)

Comfort indices	Barns with:	
	fans	fans + sprinklers
CCI	83.64 ± 3.18	88.42 ± 2.76
SSI	8.75 ± 0.42	5.03 ± 0.28***
SPI	7.61 ± 0.21	6.55 ± 0.23**
SUI	72.16 ± 2.03	77.03 ± 1.27*
CFI	0.39 ± 0.02	0.47 ± 0.03*
CDI	0.064 ± 0.0003	0.051 ± 0.0004***

Note: as compared with the barn with only fans; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$; CCI – cow comfort index; SSI – stall standing index; SPI – stall perching index; SUI – stall use index; CFI – cow feeding index; CDI – cow drinking index.

which depends on the value of the daily foraging activity of the animals, was also higher than under the keeping of cows in the barn that used fans and sprinklers (by 0.08). The stall standing index (SSI) and stall perching index (SPI), which depend on the daily standing time of cows, were slightly higher in the barn that used fans only (3.72 and 1.06). The cow drinking index (CDI), the value of which depends on the duration of daily watering of animals, was higher (by 0.013) under keeping in a barn that used only fans as cooling elements.

Discussion

The negative effects of high temperatures on dairy cattle during global climate change are a significant problem for the industry (Collier et al., 2017). According to Johnson (2018), to reduce the impact of heat stress is possible through the breeding of heat-resistant breed, the use of microclimate control and modernization of feeding management methods. However, the most effective in the short term is the use of microclimate control tools that can reduce the temperature in barns during hot periods (Gebremedhin et al., 2016; Polsky and von Keyserlingk, 2017).

The results of our studies partially coincide with the studies of Her et al. (1988) and Wolfenson et al. (1988), conducted at commercial farms in Israel where automated irrigation systems (30 s) were used, followed by ventilation (4.5 min) during 30-minute periods. The results showed that this combination of cooling was effective and helped to reduce heat stress in cows, as well as to improve their heat balance and lower body temperature, and met the recommended duration of behavioral responses. Frazzi et al. (2000) reports that, during the hot period, whose cows are kept in pens with only fans less time lying down (from 15.00 to 20.00 hours) and more time standing (from 15.00 to 17.00 hours) in comparison with cows that kept in pens with fans plus misting. These data partially coincide with our results. Barbari et al. (2010) indicate that under the option of keeping cows when fans and irrigation systems are located above the feed passage, the animals spend less time per day for lying down, which does not coincide with our data. Somewhat different from our data, Matarazzo et al. (2007) reported that the standing time of a group of cows housed in a section using fans and irrigation systems was longer than in the section without air cooling elements.

Tao Ding et al. (2019) in their studies conducted in China reported about lower values of skin temperature in cows during periods of high temperature load using irrigation systems that also coincide to some extent with our data. Gaughan et al. (2004) have also reported similar research results.

Our studies do not coincide with the data obtained by Lovarelli et al. (2020) in northern Italy, which indicate that in barns with fans in the rest area and irrigation systems in the feeding area, the duration of animals' resting lying down was lower than in barns with only fans in the rest area.

It has been found that the use of fans in combination with irrigation systems during hot periods had a positive effect on the heat transfer of cows compared with the keeping of cows in the barn with fans. With this combination, the skin temperature and the resting place under the lying cow were 0.5°C and 0.8°C lower. The duration of cows' lying down and eating fodder with this combination was 32 and 16 minutes longer, respectively. At the same time, the duration of standing, motor activity and watering was dominated in animals kept in the barn with the use of only fans as elements of air cooling by 16, 21 and 6 minutes, respectively. In addition, the combination of fans and irrigation systems contributed to better comfort indices for dairy cows under free-stall keeping.

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