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The impact of high temperatures on respiration rate, breathing condition and productivity of dairy cows in different production systems

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The aim of our research was to estimate the effect of high temperatures on respiration rate, breathing condition and productivity of Holstein cows in different production systems. The best values of air temperature (Tair), breathing frequency, Environmental Stress Index (ESI) and Heat Load Index (HLI) among the investigated production systems were recorded on a farms with misting and ventilation systems. In the period of the highest thermal stress (12.00–16.00 pm), T_{air} did not exceed 29ºC , breathing rate – 77 breaths/min, ESI – 39.07ºC and HLI – 76.29. Least optimal for cow comfort values were found in the low cost housing: T_{air} – 33ºC, breathing rate – 82 breaths/min, ESI – 41.88ºC and HLI – 79.80. Intermediate values were observed at the open feedlots with

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shelters: T_{air} – 33ºC, breathing rate – 79 breaths/min, ESI – 41.18ºC and HLI – 77.98. For all types of production systems the average daily temperature rise to +27.7°C became a significant stress factor for cows, which considerably influenced the dynamics of breathing rate, breathing severity, ESI and HLI values. It was established that keeping cows in facilities with misting and ventilation systems and on open feedlots, the Temperature-Humidity Index (THI), breathing rate and severity during the period of maximum temperature load (12.00-16.00 pm) were lower than that for low cost housing. The use of misting and ventilation systems allowed to minimise productivity losses during the period of thermal stress, which decreased by 2.67%, while for maintenance at feedlots the losses amounted to 9.22%, while in the low cost housing – 11.88%.

KEYWORDS: breathing severity / dairy cows / production systems / productivity / temperature / thermal stress

One of the main problems in dairy cow milk production, along with the duration of animals productive life, reproduction, quantitative and qualitative composition of milk fat and protein is temperature stress [DeShazer *et al.* 2009, Fournel *et al.* 2017, Borshch *et al.* 2019]. The thermoneutral state that does not affect negatively comfort, welfare and productivity of dairy cattle ranges from -5 to 25 °C [Kadzere *et al.* 2002; Bernabucci *et al.* 2014]. Under conditions of thermoneutral temperature, the body utilizes the minimum amount of energy needed to support life or balance with the environment [Borshch *et al.* 2017a, Borshch *et al.* 2017b]. The temperature influence on a cow's body should be considered in conjunction with such factors as atmospheric pressure, relative humidity, solar insolation, wind velocity, amount of precipitation, which increase or decrease its effect [Nabenishi *et al.* 2011, Gaughan *et al.* 2012, Das *et al.* 2016]. One of the biggest problems in milk production is posed by thermal stress. Dikmen and Hansen [2009], were of an opinion that the threshold of thermoneutral temperature and humidity for dairy cows, after which the thermal stress symptoms begin to show, are 28°C and 50% respectively. Thermal stress is a certain ambient temperature and humidity conditions, when dairy cows are unable to dissipate their own heat to maintain normal body temperature [Segnalini *et al.* 2013; Bertocchi *et al.* 2014, Schüller *et al.* 2014]. It has a serious economic impact on the production of milk [Adamczyk *et al.* 2015, Chen *et al.* 2015, Chen *et al.* 2016]. Thus, according to Fournel *et al.* [2017], due to heat stress American milk producers lose 900-1500 million $ annually because of productivity decrease, deterioration of milk quality composition and reproductive problems. At the same time, the high-temperature load reduces feed consumption and worsens the physiological performance of the animal (increase of body temperature and respiratory rate). Dairy cows are more susceptible to thermal stress than other mammals due to higher metabolic heat production because of fermentation processes in the rumen [Bernabucci *et al.* 2014]. Lactation creates a large amount of metabolic heat while additional heat from radiation is acumulated [Brown-Brandl *et al.* 2005]. Production of heat and its accumulation lead to an increase of the heat load on the cow to such an extent that the body temperature rises, while the consumption of fodder dry matter decreases which ultimately leads to loss of productivity. A variety of planning, construction and engineering solutions are being used to reduce the thermal stress effect [Calegari *et al*. 2014, Menconi and Grohman

2014]. The use of light curtains, light-aeration ridge, exercise areas with shelters, misting and ventilation systems, two-chamber water mattresses in the cubicles reduce thermal stress, stabilize cows' productivity and increase the duration of rest [Mondaca *et al.* 2013, Perano *et al.* 2015; Gebremedhim *et al.* 2016; Smith *et al.* 2016]. Italian studies indicated the production system and housing conditions, including the climatic zone, microclimate indicators along with the genetic features may influence thermal sensitivity [Menconi and Grohman 2014].

The aim of our study was to evaluate the impact of high temperatures on respiration rate, breathing condition and productivity of Holstein cows in different production systems.

Material and methods

Climate. The research was conducted from 02.07 to 12.07.2018 (183–194 days of the year) in the central part of Ukraine (49°52'28'' North latitude, 30°5'12'' East longitude; 49°39'8''North latitude, 30°46'54'' East longitude; 49°45'29'' North latitude, 30°4'10'' East longitude) during the high-temperature load. The average daily temperature in thet period was +27.7°C. The Ukraine territory is located in a moderate climatic belt. The climate is continental with four distinct year seasons. The summer weather is variable with an average daily temperature from +17 to +25°C. The dry and hot tropical air masses, coming from the desert areas of Africa and Southwest Asia bring hot weather in summer and cyclones emerging from the North Atlantic and the Mediterranean form unstable cloudy and windy weather with much rainfall.

Cows. In this study Holstein cows in the maximum period of the second lactation were investigated (days in milk 90±8 days; milk yield = 31.77±3.82 kg/d). Daily cow productivity during the high-temperature period compared with the average milk yield during the thermoneutral period. In each farm there were groups of 20 cows.

Barns. Three farms with the loose housing system of cows and various animal comfort levels were selected for analysis. The first variant (T-1) – loose housing in a low cost housing facility (150x40x10 m). The second variant (T-2) – loose housing in a low cost housing facility and a misting system (100x32x8 m). Ventilation and misting systems operate at 0.5 and 1 hour intervals between 12.00 and 16.00 p.m. The third variant (T-3) – open feedlots with shelters (72x25 m; the exercise area of 20 m^2 per individual, including shelter area of 5 m^2 per individual).

Measurement methodology. The air temperature and relative humidity in the barns were determined by a combined digital environment meter model DVM401 (Velleman, Belgium). The wind speed inside the barn was determined by handheld pocket digital anemometer AZ, model AZ-8919 (Taiwan). Solar radiation was measured using a RAT-2P-F radiometer (Ukraine).

Calculation of Temperature-Humidity Index (THI), Environmental Stress Index (ESI), Heat Load Index (HLI) and breathing condition associated respiration rate panting score. The Temperature-Humidity Index was calculated according to Dikmen and Hansen [2009]:

$$THI = (1.8 \times T_{air} + 32) - (0.55 - 0.0055 \times RH) \times (1.8 \times T_{air} - 26.8), \quad (1)$$

where:

THI – Temperature-Humidity Index;

T_{air} – air temperature (°C);

RH – Relative Humidity (%).

THI was divided into 3 categories: 1) 66-71 – normal; 2) 72-79 – alert; 3) 80 and more – danger.

The Environmental Stress Index (ESI) was calculated according to Moran *et al.* [2001], as follows:

$$ESI = 0.63T_{air} - 0.03RH + 0.002SR + 0.0054(T_{air} \cdot RH) - 0.073(0.1 + SR)^{-1}, \quad (2)$$

where:

ESI – Environmental Stress Index (°C);

SR – Solar Radiation ($W/m^2/h$).

Heat Load Index was calculated according to Gaughan *et al.*, [2002] as follows:

$$HLI = 33.2 + 0.2 \times RH + 1.2 \times BGT - (0.82 \times WS)^{0.1} - \log(0.4 \times WS^2 + 0.0001), \quad (3)$$

where:

HLI – Heat Load Index;

BGT – Black Globe Temperature (°C);

WS – Wind Speed.

HLI was divided into 4 categories: 1) thermoneutral conditions, when the HLI is <70.0; 2) warm conditions, when the HLI is 70.1 to 77.0; 3) hot conditions, when the HLI is 77.1 to 86.0; and 4) very hot conditions, when HLI is >86.0.

Breathing condition and the associated respiration rate were defined according the scale from 0 to 4.5 panting score, Gaughan *et al.*, [2008], where: 0 – no panting; 1 – slight panting, mouth closed, no drool, easy to see chest movement; 2 – fast panting, drool present, no open mouth; 2.5 – as for 2, but occasional open mouth panting, tongue not extended; 3 – open mouth and excessive drooling, neck extended, head held up; 3.5 – as for 3, but with the tongue out slightly and occasionally fully extended for short periods; 4 – open mouth with tongue fully extended for prolonged periods with excessive drooling, neck extended and head up; 4.5 – as for 4, but head held down, drooling may cease.

Statistical analysis. All data are presented as the means±standard error of the mean. Student's *t*-test was used to estimate statistical significance of the obtained values. Data were considered significant at $P<0.05$, $P<0.01$, $P<0.001$. Student's *t*-test was performed to compare of average milk yield during the thermo-neutral period and average daily milk yield during the period of thermal stress. These computations were performed using the STATISTICA software (Version 11.0, 2012).

Results and discussion

Under low cost housing (T-1) dairy cow production system we observed higher average daily air temperature indices (T_{air}) by 2.66°C as compared to low cost housing with ventilation and misting systems (T-2) on 2.66 °C and open feedlots with shelters (T-3) by 1.58°C (Fig. 1). Thus, in the period from 12.00 till 16.00 p.m., the temperature was in the range 29-33°C, with the lowest value – 23°C noted only at 04.00 a.m. In the facilities with misting and ventilation systems (T-2), the temperature during the periods of the highest thermal stress did not exceed 29 °C and at night time from 00.00 to 04.00 it was 21°C. In the variant with the open feedlots with shelters (T-3) we observed the highest average daily air temperature variation at 13°C. In the period from 02.00 to 04.00 a.m. the temperature was 20°C and from 12.00 to 16.00 p.m. – 28-33°C.

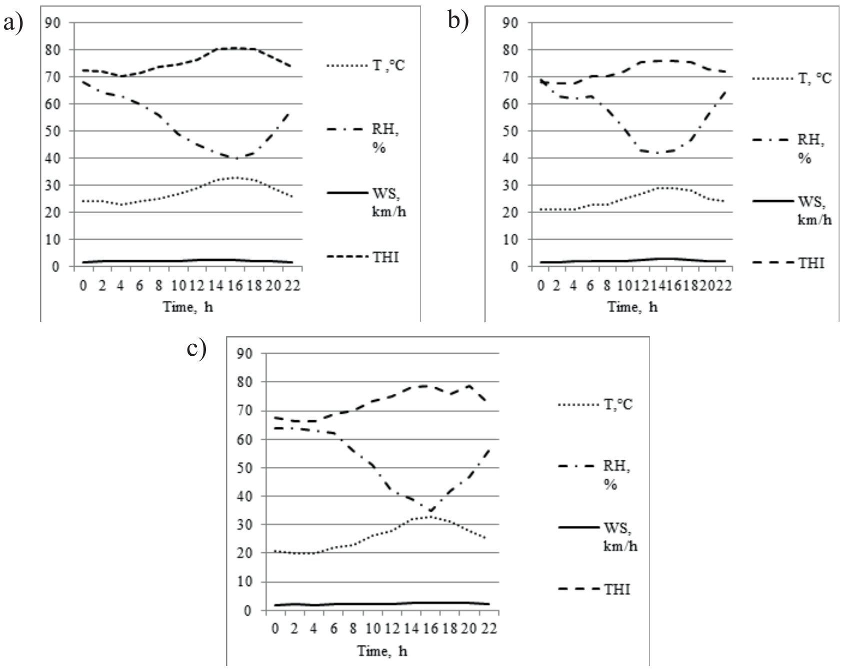

Fig. 1. Average hourly Air Temperature (Tair), Relative Humidity (RH), Wind Speed (WS) and Temperature-Humidity Index in different loose housing variants: a) T-1, b) T-2, c) T-3.

As for relative air humidity, in all the production systems we observed a gradual decrease after 12.00 p.m. with a further slight increase at 20.00 p.m. The highest average daily relative humidity was observed in the technology with misting and ventilation systems (T-2) – 55.08%, which is by 1.88 and 3.33% higher than that for animal keeping in a low cost housing and the open feedlots with shelters, respectively.

According to Webster [2005], the optimum value of wind speed for keeping dairy cattle should not exceed 0.7 m/s (or 2.52 km/h). The results of our research showed the lowest average daily wind speed for cows in alow cost housing (T-1) – 0.57 m/s (or 2.08 km/h). The housing variant with misting and ventilation systems (T-2) showed a slightly higher average wind speed of 0.61 m/s (or 2.18 km/h). The largest value of wind speed was observed when keeping cows in the open feedlots (T-3) – 0.64 m/s (or 2.30 km/h). This is due to the fact that the site is in an open space and there are no buildings other than shelters.

The temperature-humidity index value (THI) indicated how the combination of air temperature and relative humidity can affect the heat stress of animals [Bernabucci*et al.* 2014, Herbut and Angrecka 2018]. It was established that keeping of cows in a low cost housing (T-1) showed that THI varied significantly during the day. During the period from 00.00 to 06.00 a.m. there was no thermal stress, during the period from 08.00 to 12.00 a.m.,moderate thermal stress was observed and from 14.00 till 18.00 p.m. there was a severe thermal stress. The research results for the technology using misting and ventilation systems (T-2) and the open feedlots with shelters (T-3) were identical. For both production systems between 00.00 and 08.00 a.m., there was no thermal stress, while from 10.00 to 22.00 this figure was moderate.

Our data is consistent with the data reported by Shiao *et al.* [2011], who investigated the effect of using indoor fans on comfort and respiration rate of cows in Taiwan. They found that the use of fans in hot weather gave an additional 4.2 hours/day of thermoneutral temperature (+26°C).

High values of air temperature and relative humidity, along with loss of productivity and deterioration of animal welfare, also affected respiratory rate [Brown-Brandl *et al.* 2005, Eigenberg *et al.* 2005]. Moreover the respiratory rate influences bio-energetic and hematological parameters of dairy cattle, as well as transport of oxygen to vital organs and tissues. The results of the studies showed that the number of respiratory movements per minute for all production systems increased gradually from 10.00 a.m., while a decrease was observed after 16.00 p.m. (Fig. 2). The highest respiratory rate was observed between 12.00 and 16.00 p.m. Under housing in open feedlots with shelters (T-3) the frequency of respiratory movements in that period was 76-77 breaths/min with a peak of 79 breaths/min at 14.00 p.m. In the facility with misting and ventilation systems (T-2) in the hottest period of the day the following parameters of the respiration rate were recorded: 12.00-14.00 p.m. – 77 breaths/min; 16.00 p.m. – 75 breaths/min. Somewhat higher indicators of breathing intensity, both during the day and in the period of the highest temperature load, were observed for keeping in a low cost housing (T-1). Thus, at 12.00 p.m. the number of respiratory movements was 78 breaths/min, and at 14.00 p.m. and 16.00 p.m., 82 breaths/min and 77 breaths/min, respectively. Our studies are consistent in part with the results of American scientists [Brown-Brandl*et al.* 2005], who compared the effects of shelters on feedlots on respiration rates of cows under various values of the temperature-humidity index. They found that the presence of shelters somewhat reduces the frequency of respiration as compared with housing in outdoor areas (without shelters). A study by Ortiz *et al.* [2015], who compared two different air cooling systems in a Saudi Arabia dairy farm,

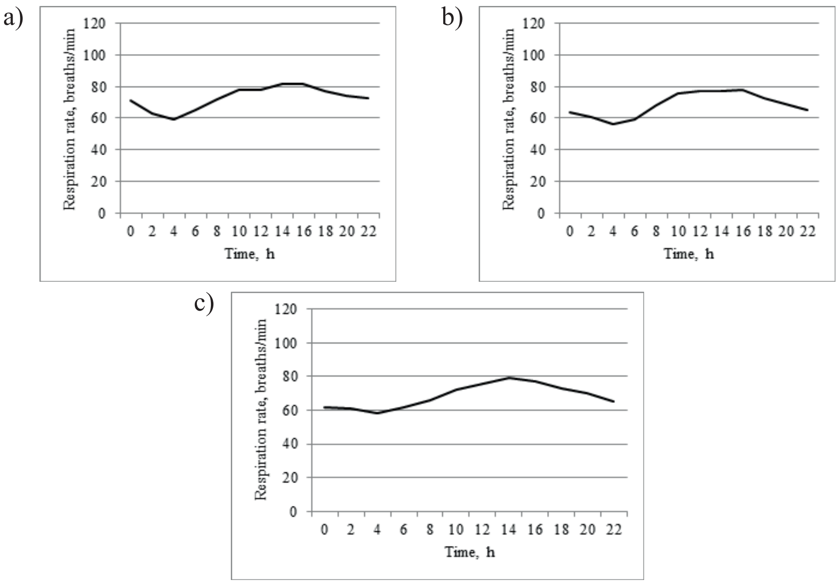

Fig. 2. Average hourly respiration rate in different loose housing systems:
a) T-1, b) T-2, c) T-3.

showed that air cooling systems mitigate negative effects of thermal stress on cows and thus reduce respiration rates.

One of the most important indicators that characterises the comfort of dairy cattle during periods of high-temperature load is connected with breathing difficulty [Mader *et al.* 2006, Shiao *et al.* 2011]. The observations showed that for all housing types during the day there were no critical breathing difficulty indices (Fig. 3). The overall values for each of the groups even at the temperature load peak (12.00-16.00 pm) did not exceed 3 points. The optimal breathing difficulty curve was observed for keeping in open feedlots with shelters (T-3) and in a facility with the artificial climate control (T-2). Under such housing variants the highest score of breathing difficulty was recorded in the period from 14.00 to 16.00 p.m. (T-3) and from 12.00 to 16.00 p.m. (T-2). For the variant of keeping cows in a low cost housing facility (T-1) slightly higher average breathing difficulty indexes were recorded and the average score in the group between 12.00 and 16.00 p.m. was 3.0 points. The average significant reduction in breathing difficulty to 2.0 points was observed only after 18.00 p.m. The results of our studies are consistent in part with the data of Gaughan *et al.* [2008], who conducted research on beef cows of different genotypes kept in the feedlot system. They found that the index of breathing difficulty is affected not only by air temperature, but also relative humidity and the level of solar radiation.

For a more detailed analysis of the effect of high temperatures on the welfare of cows under different production systems the Environmental Stress Index (ESI) and the Heat Load Index (HLI) were used (Fig. 4). The daily dynamics of the ESI changes for

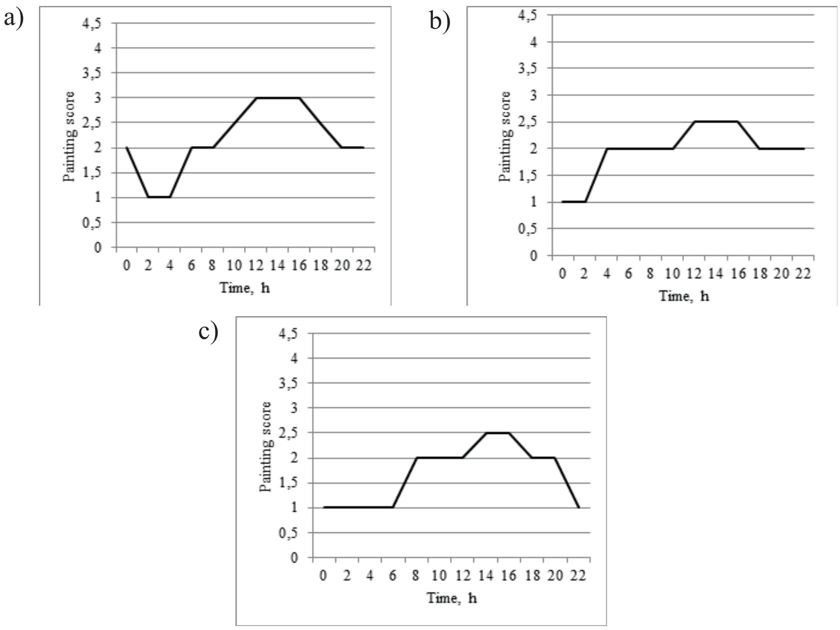

Fig. 3. Average hourly breathing condition in different loose housing systems: a) T1, b) T2, c) T3.

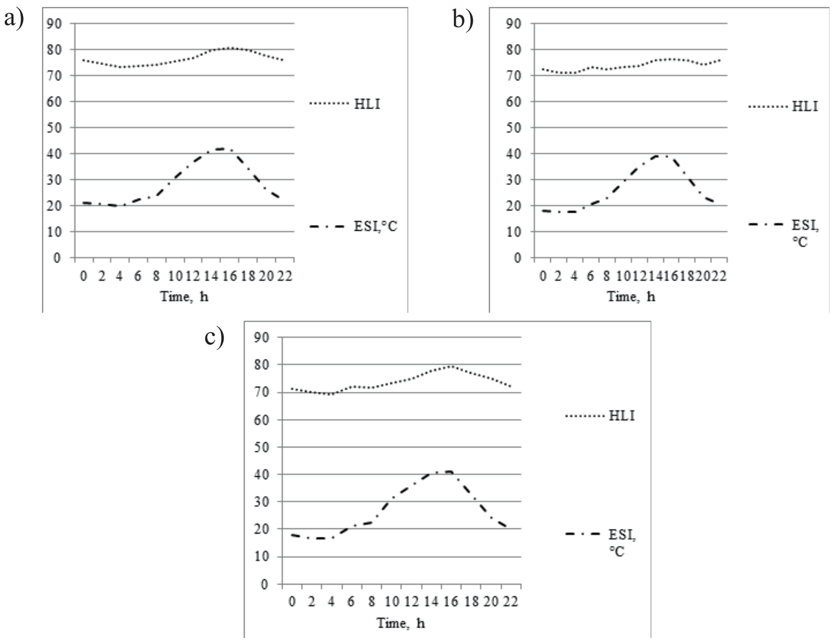

Fig. 4. Average hourly ESI and HLI in different loose housing systems: a) T-1, b) T-2, c) T-3.

all the production systems were comparable. Under keeping variants in a low cost housing facility (T-1) and open feedlots with shelters (T-3) for cows during the period from 14.00 to 16.00 p.m., the ESI value exceeded 40°C and amounted to 41.62-41.88°C and 40.79-41.18°C, respectively. At the same time, under the keeping technology with misting and ventilation systems for the same period these indicators did not exceed 39.07°C.

The HLI value for keeping cows inlow cost housing (T-1) was different at different times of the day. In the period from 00.00 to 12.00 a.m. it was in the range of 75.79-76.80, which belongs to the category of warm keeping conditions; from 14.00 to 20.00 p.m. it amounted to 77.88-79.80 equivalent to hot keeping conditions. During the day when the misting and ventilation systems were used (T-2), the HLI value indicated the category of warm conditions and amounted to 71.13-76.29. As for cow keeping on the open feedlots with shelters (T-3), here the HLI value varied overnight. Between 02.00 and 04.00 a.m. it was 68.98-69.99, i.e. the thermoneutral category; from 06.00 to 12.00 a.m. – 71.92-75.00 (warm conditions); from 14.00 to 18.00 p.m. – 77.02-77.98 (hot conditions).

Thermal stress has a negative effect on the secretory function of the cows' udders accompanied with a loss of productivity of up to 20% and a decrease of efficiency of feed energy use. It was established that at the use of T-2 housing variant during the thermal load period productivity decreased by 1.3 kg (or 2.67%) (Tab. 1). In the feedlot management system T-3 productivity decreased by 2.8 kg (or 9.22%). The greatest loss of productivity was observed for the low cost housing system (T-1) – 3.7 kg (or 11.88%).

Table 1. Dynamics of average daily milk yields (standard deviations in parentheses) at different thermal periods (kg)

Variants of loose housing[1]	Average milk yield during thermo-neutral period (kg)	Average milk yield during the period of thermal stress (kg)									
		days									
		1	2	3	4	5	6	7	8	9	10
T-1	31.1 (0.48)	29.8 (0.36)	28.4 (0.39^{**})	28.5 (0.40^{**})	28.1 (0.32^{***})	27.6 (0.34^{***})	27.4 (0.40^{***})	27.8 (0.35^{***})	27.5 (0.32^{***})	28.1 (0.38^{***})	28.4 (0.33^{***})
T-2	33.8 (0.36)	32.6 (0.27)	33.2 (0.34)	33.3 (0.35)	32.9 (0.29)	32.5 (0.30)	33.1 (0.33)	33.3 (0.37)	33.1 (0.34)	33.3 (0.35)	33.4 (0.33)
T-3	30.4 (0.43)	29.3 (0.40)	28.6 (0.38^{*})	28.7 (0.39^{*})	28.2 (0.36^{**})	27.6 (0.34^{***})	28.0 (0.37^{***})	28.3 (0.31^{**})	28.3 (0.33^{**})	28.5 (0.36^{**})	28.9 (0.34^{*})

[1]T-1 – low cost housing facility; T-2 – low cost housing facility and a misting system; T-3 – open feedlots with shelters.
As compared with average milk yield in thermoneutral period *P<0.05; **P<0.01; ***P<0.001.

The results of our studies are consistent with the data reported by Chen *et al.* [2016], which indicated that the use of air humidification systems during high-thermal loads prevents arapid decrease of cows' productivity.

Conclusions

For all the cow housing variants the temperature rise to the average daily +27.7°C became a significant heat stress factor influencing the respiration dynamics, the respiration severity assessment, the ESI and HLI values. It was established that for the cows kept in housing facilities equipped with misting and ventilation systems and on feedlots, the THI indices, breathing frequency and severity during the period of maximum temperature load (12.00-16.00 pm) were lower than those for thelow cost housing variant. The use of microclimate control systems allowed T_{air} to be reduced from 12:00 to 16:00 by 2-4°C, as compared with keeping in a low cost housing facility and by 1-4°C compared with the feedlot system. The duration of the thermoneutral period for such keeping system increased by 2.3 and 1.7 hours in comparison to keeping in a low cost housing facility and in a feedlot. Under the use of microclimate control systems, productivity during the period of thermal stress decreased by 2.67%, for maintenance at the feedlots by 9.22% and the low cost housing by 11.88%, respectively.

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