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Cow behaviour and milk yield during different categories temperature-humidity indices

Comportamiento de las vacas y producción de leche durante diferentes categorías de índices de temperatura-humedad

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ABSTRACT

The goal of this investigation was to study the influence of different values of Temperature-Humidity index (THI) on the duration of lying down and feed consumption, productivity, and heat production by dairy cows in two variants of feedlots (with and without shelters). The study was conducted from February 2007 to early August 2021 in the central part of Ukraine (Kyiv region) in different periods of THI. This index was divided into three categories: 1) 66–71: normal (14 days); 2) 72–79: alert (11 days); 3) $\geq$80: dangerous (9 days). Two variants of feedlots were selected: Open feedlot with shelters and open feedlot without shelters. The largest increase in values of THI affecting the cows was observed in open feedlots without shelters. There, in alert and danger periods duration of feed consumption decreased by 8.0 and 23.1 min, lying down by 17 and 38 min, productivity by 2.3 kg (or 8.77%) and 3.6 kg (or 13.74%), energy consumption by 4.7 and 9.6 MJ, respectively, in comparison to normal period.

Key words: dairy cows, feedlots, heat stress, productivity, cows' welfare

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RESUMEN

El objetivo del estudio fue evaluar la influencia de diferentes valores de Índice temperatura-humedad (IHT) sobre el tiempo de reposo y el consumo de alimento, la productividad y la producción de calor de las vacas lecheras en dos variantes de *feedlots* (con y sin refugio). El estudio se llevó a cabo desde febrero de 2007 hasta principios de agosto de 2021 en la parte central de Ucrania (región de Kiev) en diferentes períodos de IHT. El índice se dividió en tres categorías: 1) 66–71: normal (14 días); 2) 72–79: alerta (11 días); 3) >80: peligroso (9 días). Se seleccionaron dos variantes de *feedlots*: abierto con sombra y abierto sin sombra. El mayor aumento en los valores de IHT que afectaron a las vacas se observó en los corrales de engorda abiertos sin sombras. Allí, en periodos de alerta y peligro, la duración del consumo de alimento disminuyó en 8.0 y 23.1 min, acostado en 17 y 38 min, la productividad en 2.3 kg (o 8.77%) y 3.6 kg (o 13.74%), el consumo de energía en 4.7 y 9.6 MJ, respectivamente, en comparación con el periodo normal.

Palabras clave: vacas lecheras, corrales de engorde, estrés por calor, productividad, bienestar de las vacas

INTRODUCTION

During global warming period and climate change, which are accompanied by an increase livestock numbers and intensification of agriculture (Polsky and Keyserlingk, 2017; Hempel *et a*l., 2019; Borshch *et al*., 2022b), issues related to overcoming the consequences of heat stress becomes increasingly relevant (De Palo *et al*., 2006; Brügemann *et al*., 2011; Nguyen *et al*., 2017).

One of the major challenges in milk production during warm seasons is the increased thermal stress experienced by dairy cows. This is a result of specific environmental conditions, where high temperatures and humidity make it difficult for cows to regulate their body temperature effectively (Segnalini *et al*., 2013; Bertocchi *et al*., 2014; Schüller *et al*., 2014). Dikmen and Hansen (2009) have suggested that the threshold temperature and humidity at which dairy cows begin to show signs of heat stress is 28 °C and 50%, respectively.

During the heat load period the dairy cows increase respiration rate to reduce their own body temperature, while the duration of feed consumption and productivity are decreased (Brown-Brandl *et al*., 2005; Curtis *et al*., 2017; Tousova *et al*., 2017). Animals create a large amount of metabolic heat and accumulate additional heat from radiant energy, which leads to an increase heat load on the body and, as a result, a decrease dry matter intake and productivity loss (Kadzere *et al*., 2002; Ruban *et al*., 2020; Lutsenko *et al*., 2021; Demir and Yazgan, 2023).

Dairy cows are particularly vulnerable to heat stress compared to other mammals, as they generate more metabolic heat due to the fermentation processes that occur in their rumen (Bernabucci *et al*., 2014). Additionally, milk production in cows result in an increase in internal heat loads (Chebel *et al*., 2004; Aharoni *et al*., 2005), further exacerbating the impact of heat stress on these animals.

The measurement of animal welfare and comfort is of utmost importance (Mattachini *et al*., 2011), as it directly influences various aspects of dairy cow health and productivity, including their resting behavior, hormonal status (Skliarov *et al*., 2022), metabolic changes, and milk production (Veèeøa *et al*., 2016). Thus, indicators of animal welfare and comfort serve as essential tools for evaluating and optimizing the overall management and well-being of dairy cows (Angrecka and Herbut, 2017).

According to different variants animal housing to the main phenotypic traits of animal comfort include behavioral indicators (Angrecka and Herbut, 2016; Borshch *et al*., 2021, 2022a). Dairy cattle behavior varies substantially depending on ambient temperature and temperature-humidity index (THI) (De Palo *et al*., 2005; Segnalini *et al*., 2013; Galan *et al*., 2018). To address the challenges of heat stress in dairy cows, it is necessary to implement various planning, structural, and technical solutions for cattle housing facilities, including modifications to buildings, cooling systems, and management practices (Yi *et al*., 2018; Borshch *et al.*, 2019). The implementation of various measures such as light curtains, ridge vents for ventilation, open feedlots equipped with shelters, irrigation and ventilation systems, and dual-chamber waterbeds to facilitate cow rest can effectively mitigate heat stress (Vasseur *et al*., 2012; Mondaca *et al*., 2013; Menconi and Grohmann, 2014).

The goal of this investigation was to study the influence of different values of THI on the duration of lying down and feed consumption, productivity, and heat production by dairy cows in two variants of feedlots (with and without shelters).

Materials and Methods

The research was conducted from February 2007 to early August 2021 in the central part of Ukraine (Kyiv region) in different periods of temperature-humidity index (THI). This index was divided into three categories: 1) 66–71 is normal (14 days), 2) 72–79 is alert (11 days) and 3) 80 or more is dangerous (9 days).

Table 1 summarizes the key environmental factors that were measured across different phases of the study. Farm with two variants feedlots was selected for analysis.

- The first variant – open feedlot with shelters (72×25 m. An exercise area of 20 m^2 per individual, including shelter area of 5 m^2 per individual). The surface of the exercise area is made of soil and has an even relief. There are four group drinking bowls along the perimeter of feedlot.

Table 1. Environmental indicators under different Temperature-humidity index (THI) in two variants of feedlots

Indicators		THI		
		Normal	Alert	Danger
Temperature (°C):	Feedlot with shelters	20.6	25.8	29.4
	Feedlot without shelters	21.1	26.6	31.6
Relative humidity (%)	Feedlot with shelters	65.7	55.1	63.1
	Feedlot without shelters	65.4	55.7	57.8
Wind speed (m/s)	Feedlot with shelters	2.2	2.6	2.8
	Feedlot without shelters	2.3	2.6	2.8

- The second variant – open feedlots without shelters (100×120 m. An exercise area of 59.5 m^2 per individual). The surface of the exercise area is unpaved and has sloping sections (tilt angle up to 2°). Two group drinking bowls are in the center of the feedlot and in the feeding area.

At the farm, cows are fed with a total mixed ration throughout the year. Each cow intake between 21.4 to 21.8 kg of dry matter per day. The consumed fodder had an energy value of 211 to 220 MJ, and the energy concentration in each kilogram of dry matter is between 10.3 to 10.4 MJ.

Second lactating Holstein cows during the period of maximum productivity (2–3 months of lactation) were selected. The first feedlot variant had 34 cows and the second feedlot variant: 32 cows. The THI was calculated according to Dikmen and Hansen, 2009: THI = $(1.8 \times T_{air} + 32) - (0.55 – 0.0055 \times RH) \times (1.8 \times T_{air} - 26.8)$, where T_{air} – air temperature, °C; RH – relative humidity, %.

The Equivalent Temperature Index for Cattle (ETIC, °C) was calculated according to Wang *et al.,* 2018: ETIC = T - 0.0038 × T × (100 - RH) - 0.1173 × |v|0.707 × (39 × 20 - T) + 1.86 × 10-4 × T × Q, where v – air velocity, m/s^{-1}; Q – solar radiation, Wm^{-2}. ETIC was divided into four categories: 1) mild stress (18<–<20); 2) moderate stress (20≤–<25); 3) severe stress (25≤–<32); 4) emergency (e≥32).

The Equivalent Thermal Index (ETI, °C) was calculated according to Baeta *et al.,* 1987 as follows: ETI = $27.88 - 0.456 \times T_{air} + 0.010754 \times T_{air}^2 - 0.49505 \times RH + 0.00088 \times RH^2 + 1.1507 \times WS - 0.126447 \times WS^2 + 0.019876 \times T_{air} \times RH - 0.046313 \times T_{air} \times WS$, where WS – average wind speed (m/s).

ETI values are considered as representing a damaging risk to animals: no problem: 18 °C to <27 °C; caution: 27 °C to <32 °C; extreme caution: 32 °C to <38 °C; danger: 38 °C to <44 °C; extreme danger: ≥44 °C (Gosling *et al*., 2014).

The behavior of cattle was monitored using indoor security cameras. A total of eight Full HD Hikvision cameras were strategically placed around the perimeter of the feedlot with shelters, while 12 cameras were deployed around the feedlot without shelters. The cameras were set to record continuously for 24 hours, capturing footage of the sheds, rest areas, and manger spaces. Daily observations of the manger space were conducted during each period of THI from 10:00 to 19:00 hours (peak temperature load). At regular 10-minute intervals, the number of cows eating, lying down, and standing was recorded in the experimental groups.

Temperature and relative humidity levels were monitored by a Voltcraft DL-141 sensor (Germany) capable of measuring temperatures ranging from -40 to +70 °C and relative humidity levels between 0 to 100%. Sensors were placed 0.5 m above the floor and readings were automatically recorded every 10 minutes. Wind speed inside the barn was determined by a handheld pocket digital anemometer AZ-8919 model from AZ (Taiwan). Solar radiation levels were measured by radiometer RÀÒ-2P-F (Ukraine). The cows' skin surface temperature was measured in two locations: on the rumen and in the region of the last intercostal space, using a remote infrared thermometer (Thermo SpotPlus from Germany).

Indicators of wind speed inside the barns, solar radiation and temperature of the surface of the skin of cows were daily determined from 10.00 to 19.00 in different periods of the THI. Costs of energy for heat production in different periods of THI were calculated according to the methods of Kadzere *et al.* (2002).

Data are reported as means ± standard error of the mean. To assess the statistical significance of the obtained values, Student's *t*-test was employed, and data were consi-

Table 2. Average feed intake of dairy cattle and rest in a lying position by different values of Temperature-humidity index (THI)

Behavior indicators		THI		
		Normal	Alert	Danger
Duration of feed consumption (min)	Feedlot with shelters	187.3±6.3	177.1±5.8	170.5±4.4
	Feedlot without shelters	182.6±5.3	174.6±4.9	159.5±3.2[a]
Lying time (min)	Feedlot with shelters	312.7±6.0	301.3±5.1	286.8±4.4
	Feedlot without shelters	304.1±6.4	287.2±4.7[a]	266.5±4.1[b]

[a]P<0.05; [b]P<0.01 as compared with feedlot with shelters

dered significant at [a]P<0.05, [b]P<0.01, [c]P<0.001. A Student's *t*-test was performed to compare the average between the feedlot without shelters and the feedlot with shelters. All statistical analyses were conducted by the Statistica software (v. 11.0, 2012).

RESULTS AND DISCUSSION

The indicators that not only form the level of daily milk productivity, but also indicate the structural and space-planning features of cows housing option and their comfort are indicators of the duration of feed consumption, number of approaches to the manger and average duration of one feed consumption.

The duration of feed consumption increased in both type of feedlots when the indicators of THI decreased (Table 2). On this, the greatest difference was between THI normal and alert and between normal and danger (8.0 and 23.1 min, respectively) was observed in cows in open feedlots without shelters. On the other hand, the duration of feed consumption decreased by 10.2 minutes during alert period and by 16.8 minutes during dangerous period of feedlot with shelters as compared to the normal period.

The indicator of duration cows rest in a lying position is one of the main ethological indicators, which indicates on comfort of housing conditions and has a direct connection with milk yield in 24 hours. At the normal value of THI, the longer cows rest lying down was 312 min by feedlot with shelters and slightly less time (304 min) in feedlot without shelters. The reduction time in lying position during alert categories of THI was 11.4 and 16.9 min on feedlot with shelters and without shelters respectively. A more significant reduction of lying position period occurred at a dangerous value THI in feedlot with shelters (25.9 min) and feedlot without shelters (37.6 min).

The shorter duration of feed consumption during heat stress periods correspond to results published by West (2003). The results of this study overlap with the results shown by Brown-Brandl *et al.* (2005), which established dependence between heat stress category and duration of feed consumption and number of meals consumed by animals housing on open feedlots with and without shelters. Moreover, the results correspond with data by Kanjanapruthipong *et al.* (2015) and Herbut and Angrecka (2018) indicating a decrease in total time to cows rest in lying position during heat stress periods.

Heat load (heat stress) on the body of dairy cattle is one of the factors that has a significant economic impact on milk production. The greatest productivity losses were 2.3 kg (8.77%) and 3.6 kg (13.74%) in cows on feedlot without shelters during alert and dangerous periods of THI (Table 3). When keeping cows in feedlot with shelters

Table 3. Milk yield and energy consumption in cows by different values of Temperature-humidity index (THI)

Indicators		THI		
		Normal	Alert	Danger
Milk yield (kg)	Feedlot with shelters	26.6±0.24	24.9±0.37	23.9±0.26
	Feedlot without shelters	26.2±0.18	23.9±0.25[a]	22.6±0.37[b]
Energy consumption of heat production, (MJ)	Feedlot with shelters	65.1±0.59	67.8±0.33	72.0±0.53
	Feedlot without shelters	64.6±0.78	69.3±0.41[b]	74.2±0.48[b]

[a]P<0.05; [b]P<0.01 as compared with feedlot with shelters

Table 4. Average of the Equivalent Thermal Index (ETI) and the Equivalent Temperature Index for Cattle (ETIC) indicators by different values of Temperature-humidity index (THI)

Behavior indicators		THI		
		Normal	Alert	Danger
ETI (°C)	Feedlot with shelters	21.04±0.16	25.95±0.24	38.03±0.47
	Feedlot without shelters	21.59±0.22[a]	26.89±0.29[a]	39.74±0.44[b]
ETIC (°C)	Feedlot with shelters	14.14±0.19	18.36±0.24	23.06±0.31
	Feedlot without shelters	14.52±0.29	19.25±0.33[a]	25.05±0.37[c]

[a]P<0.05; [b]P<0.01 as compared with feedlot with shelters

productivity losses in alert and dangerous categories of THI were 1.7 kg (6.39%) and 2.7 kg (10.15%) respectively. Similar results were obtained by Smith *et al*. (2013) in Mississippi State (USA), which indicate a decrease in the dynamics of daily milk yield of Holstein cows during heat stress period.

The results confirmed that increasing ambient temperature and, consequently, THI have affected to increase by energy consumption to heat transfer. In feedlots with shelters, energy consumption increased by 2.7 MJ during the THI alarm period and during the THI danger period by 6.9 MJ compared to the normal THI value. During the heat load period, higher energy consumption was observed in feedlots without shelters during the alert period, as THI value increased by 4.7 MJ, while the THI increased by 9.6 MJ during the dangerous period. These results agreed with Kadzere *et al*. (2002) which indicated that during temperature loads periods (heat or cold stress) energy consumption increasing in lactating cows.

The equivalent temperature index (ETI) and the equivalent temperature index for cattle (ETIC) were used to study the effect of THI on the comfort of cows according to variants of housing (Table 4). ETI indicators increased in both type of feedlots during alert and dangerous periods of THI values. However, during alert period of THI are observed no problem values of ETI. During alarm period of THI the values of ETIC were in range of mild stress by all feedlots variants. At the ETIC indicators in dangerous period of THI in feedlot with shelters values was refer in range of moderate stress (23.06), whereas in feedlot without shelters the values was refer in range of severe stress (25.05).

Conclusions

- An increase of THI indicator became a significant stress factor, which significantly affected the duration of feed consumption and lying down, productivity, energy consumption, and the values of Equivalent Thermal Index (ETI) and the Equivalent Temperature Index for Cattle (ETIC) in both type of cow housing.
- The best indicators of productivity and energy consumption, and values of ETI and ETIC during alert and dangerous periods of THI were marked due to a longer stay of cows in comfort zone (shadow) when housing cows on open feedlots with shelters in compared to open feedlots without shelters.

References

1. ***Angrecka S, Herbut P. 2016.*** Impact of barn orientation on insolation and temperature of stalls surface. Ann Anim Sci 16: 887-896. doi: 10.1515/aoas-2015-0096
2. ***Angrecka S, Herbut P. 2017.*** Eligibility of lying boxes at different THI levels in a freestall barn. Ann Anim Sci 17: 257-269. doi: 10.1515/aoas-2015-0074
3. ***Aharoni Y, Brosh A, Harari A. 2005.*** Night feeding for high-yielding dairy cows in hot weather: effects on intake, milk yield and energy expenditure. Livest Prod Sci 92: 207-219. doi: 10.1016/j.livprodsci.2004.08.013
4. ***Baeta FC, Meador NF, Shanklin MD, Johnson HD. 1987.*** Equivalent temperature index at temperatures above the thermoneutral for lactating cows. Am Soc Agric Engineers 87-4015: 21.
5. ***Bernabucci U, Biffani S, Buggiotti L, Vitali A, Lacetera N, Nardone A. 2014.*** The effects of heat stress in Italian Holstein dairy cattle. J Dairy Sci 97: 471-486. doi: 10.3168/jds.2013-6611
6. ***Bertocchi L, Vitali A, Lacetera N, Nardone A, Varisco G, Bernabucci U. 2014.*** Seasonal variations in the composition of Holstein cow's milk and temperature–humidity index relationship. Animal 8: 667-674. doi: 10.1017/S1751731114000032
7. ***Borshch AA, Ruban S, Borshch AV, Babenko O. 2019.*** Effect of three bedding materials on the microclimate conditions, cows behavior and milk yield. Pol J Nat Sci 34: 19-31.
8. ***Borshch OO, Ruban S, Borshch OV. 2021.*** The influence of genotypic and phenotypic factors on the comfort and welfare rates of cows during the period of global climate changes. Agraarteadus 32: 25-34. doi: 10.15159/jas.21.12
9. ***Borshch OO, Borshch OV. 2022a.*** The influence of changing conditions for keeping and cows' milking on their behavior, productivity and condition. Res Rural Dev 37: 7-12. doi: 10.22616/rrd.28.2022.001
10. ***Borshch OV, Ruban S, Kostenko V, Borshch OO, Cherniavskyi O, Korol-Bezpala L, Fedorchenko M, et al. 2022b.*** Effects of different cooling systems on cows' behaviour and comfort during the hot period. Vet Zootec 80: 10-15.
11. ***Brown-Brandl TM, Eigenberg RA, Nienaber JA, Hahn JL. 2005.*** Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, part 1: analysis of indicators. Biosyst Eng 91: 451-462. doi: 10.1016/j.biosystemseng.2004.12.006
12. ***Brügemann K, Gernand E, von Borstel U.U, König S. 2011.*** Genetic analyses of protein yield in dairy cows applying random regression models with time-dependent and temperature x humidity-dependent covariates. J Dairy Sci 94: 4129-4139. doi: 10.3168/jds.2010-4063
13. ***Chebel RC, Santos JEP, Reynolds JP, Cerri RLA, Juchem SO, Overton M. 2004.*** Factors affecting conception rate after artificial insemination and preg-

nancy loss in lactating dairy cows. Anim Reprod Sci 84: 239-255. doi: 10.1016/j.anireprosci.2003.12.012

14. ***Curtis A, Scharf B, Eichen P, Spiers D. 2017.*** Relationships between ambient conditions, thermal status, and feed intake of cattle during summer heat stress with access to shade. J Therm Biol 63: 104-111. doi: 10.1016/j.jtherbio.2016.-11.015
15. ***Demir O, Yazgan K. 2023.*** Effects of air temperature and relative humidity on milk yield of Holstein dairy cattle raised in hot-dry southeastern Anatolia region of Türkiye. J Agr Sci 29: 710-720. doi: 10.15832/ankutbd.1159540
16. ***De Palo P, Tateo A, Padalino B, Zezza F, Centoducati P. 2005.*** Influence of temperature-humidity index on the preference of primiparous Holstein Friesians for different kinds of cubicle flooring. Ital J Anim Sci 4: 194-196. doi: 10.4081/ijas.2005.2s.194
17. ***De Palo P, Tateo A, Zezza F, Corrente M, Centoducati P. 2006.*** Influence of free-stall flooring on comfort and hygiene of dairy cows during warm climatic conditions. J Dairy Sci 89: 4583-4595. doi: 10.3168/jds.S0022-0302(06)72508-5
18. ***Dikmen SJ, Hansen S. 2009.*** Is the temperature-humidity index the best indicator of heat stress in lactating dairy cows in a subtropical environment? J Dairy Sci 92: 109-116. doi: 10.3168/jds.-2008-1370
19. ***Galan E, Llonch P, Villagra A, Levit H, Pinto S, Del Prado A. 2018.*** A systematic review of non-productivity related animal-based indicators of heat stress resilience in dairy cattle. Plos One 13: e0206520. doi: 10.1371/journal.pone.-0206520
20. ***Gosling SN, Bryce EK, Dixon PG, Gabriel KMA, Gosling EY, Hanes JM, Hondula DM, et al. 2014.*** A glossary for biometeorology. Int J Biometeorol 58: 277-308. doi: 10.1007/s00484-013-0729-9
21. ***Hempel S, Menz C, Pinto S, Galán E, Janke D, Estellés F, Müschner-Siemens T, et al. 2019.*** Heat stress risk in European dairy cattle husbandry under different climate change scenarios – uncertainties and potential impacts. Earth Syst Dynam 10: 859-884. doi: 10.5194/esd-10-859-2019
22. ***Herbut P, Angrecka S. 2018.*** Relationship between THI level and dairy cows' behaviour during summer period. Italian J Anim Sci 17: 226-233. doi: 10.1080/1828051X.2017.1333892
23. ***Kadzere CT, Murphy MR, Silanikove N, Maltz E. 2002.*** Heat stress in lactating dairy cows: a review. Livest Prod Sci 77: 59-91. doi: 10.1016/S0301-6226-(01)00330-X
24. ***Kanjanapruthipong J, Junlapho W, Karnjanasirm K. 2015.*** Feeding and lying behavior of heat-stressed early lactation cows fed low fiber diets containing roughage and nonforage fiber sources. J Dairy Sci 98: 1110-1118. doi: 10.3168/jds.2014-8154
25. ***Lutsenko M, Halai O, Legkoduh, V Lastovska I, Borshch O, Nadtochii V. 2021.*** Milk production process, quality and technological properties of milk for the use of various types of milking machines. Acta Sci 43: e51336. doi: 10.4025/actascianimsci.v43i1.51336
26. ***Mattachini G, Riva E, Provolo G. 2011.*** The lying and standing activity indices of dairy cows in free-stall housing. Appl Anim Behav Sci 129: 18-27. doi: 10.1016/j.applanim.2010.10.003
27. ***Menconi ME, Grohmann D. 2014***. Model integrated of life-cycle costing and dynamic thermal simulation (mild) to evaluate roof insulation materials for existing livestock buildings. Energ Buildings 81: 48-58. doi: 10.1016/j.enbuild.2014.06.005
28. ***Mondaca M, Rojano F, Choi CY, Gebremedhin KG. 2013.*** A conjugate heat and mass transfer model to evaluate the efficiency of conductive cooling for dairy cattle. T ASABE 56: 1471-1482. doi: 10.13031/trans.56.10178

29. ***Nguyen TT, Bowman PJ, Haile-Mariam M, Pryce JE, Hayes BJ. 2016.*** Genomic selection for tolerance to heat stress in Australian dairy cattle. J Dairy Sci 99: 2849-2862. doi: 10.3168/jds.2015-9685
30. ***Polsky L, von Keyserlingk MAG. 2017.*** Invited review: effects of heat stress on dairy cattle welfare. J Dairy Sci 100: 8645-8657. doi: 10.3168/jds.2017-12651
31. ***Ruban S, Borshch OO, Borshch OV, Orischuk O, Balatskiy Y, Fedorchenko M, Kachan A, et al. 2020.*** Respiration rate, breathing condition and productivity of dairy cows. Anim Sci P 38: 61-72.
32. ***Schüller LK, Burfeind O, Heuwieser W. 2014.*** Impact of heat stress on conception rate of dairy cows in the moderate climate considering different temperature-humidity index thresholds, periods relative to breeding, and heat load indices. Theriogenology 81: 1050-1057. doi: 10.1016/j.theriogenology.2014.-01.029
33. ***Segnalini M, Bernabucci U, Vitali A, Nardone A, Lacetera N. 2013.*** Temperature humidity index scenarios in the Mediterranean basin. Int J Biometeorol 57: 451-458. doi: 10.1007/s00484-012-0571-5
34. ***Skliarov P, Kornienko V, Midyk S, Mylostyvyi R. 2022.*** Impaired reproductive performance of dairy cows under heat stress. Agric Conspec Sci 87: 85-92.
35. ***Smith DL, Smith T, Rude BJ, Ward SH. 2013.*** Short communication: comparison of the effects of heat stress on milk and component yields and somatic cell score in Holstein and Jersey cows. J Dairy Sci 96: 3028-3033. doi: 10.3168/jds.2012-5737
36. ***Tousova R, Duchacek J, Stadnik L, Ptacek M, Pokorna S. 2017.*** Influence of temperature-humidity relations during years on milk production and quality. Acta Univ Agric Silvic Mendelianae Brun 65: 211-218. doi: 10.11118/actaun201765010211
37. ***Vasseur E, Rushen J, Haley DB, De Passille AM. 2012.*** Sampling cows to assess lying time for on-farm animal welfare assessment. J Dairy Sci 95: 4968-4977. doi: 10.3168/jds.2011-5176
38. ***Vecera M, Falta D, Filipèík R, Chládek G, Lategan F. 2016.*** The effect of low and high cowshed temperatures on the behaviour and milk performance of Czech Fleckvieh cows. Ann Anim Sci 16: 1153-1162. doi: 10.1515/aoas-2016-0021
39. ***Wang X, Gao H, Gebremedhin KG, Bjerg BS, Van Os J, Tucker CB, Zhang G. 2018.*** A predictive model of equivalent temperature index for dairy cattle (ETIC). J Therm Biol 76: 165-170. doi: 10.1016/j.jtherbio.2018.07.013
40. ***West JW. 2003.*** Effects of heat-stress on production in dairy cattle. J Dairy Sci 86: 2131-2144. doi: 10.3168/jds.S0022-0302(03)73803-X
41. ***Yi Q, König M, Janke D, Hempel S, Zhang G, Amon B, Amon T. 2018.*** Wind tunnel investigations of sidewall opening effects on indoor airflows of a cross-ventilated dairy building. Energ Buildings 175: 163-172. doi: 10.1016/j.enbuild.-2018.07.026