APPEALS FOR TESTING THE ENVIRONMENT PARAMETERS IN DAIRY FARMING

**Jana LENDELOVÁ[1], Miroslav ŽITŇÁK[1], Peter HERBUT[2], Sabina ANGRECKA[2]
Vladimír MADOLA[3], Peter KUCHAR[1]**

[1]Institute of Agricultural Engineering, Transport and Bioenergetics, Faculty of Engineering, Slovak University of Agriculture in Nitra
[2]Department of Rural Construction, Faculty of Environmental Engineering and Land Surveying, University of Agriculture in Krakow
[3]Information and Coordination Centre of Research, Faculty of Engineering, Slovak University of Agriculture in Nitra

Abstract
The research work addresses the issue of the impact of the precision of placement and method of use of cooling technologies, as well as the impact of the precision of climate factor measurements on the determined level of heat load. Two identical barns with the same number of animals and cooling capacity but different fan installations were tested using two evaluation methods. The central method of data collection and computational evaluation did not detect a significant difference in the level of thermal load between buildings A and B (p>0.05), where the average index THI-A=76.24±1.03 and THI-B=76.60±0.304 during extreme hot weather with a selection of at least 5 following days. However, the ambulatory mesh method detected differences in the trend and location of the most risky levels of heat stress between barns. In barn B, the greatest cooling effect was demonstrated outside the animal zone, in the feeding corridor area. Conversely, in the animal zone, the levels of selected THI and ETIC indices were above the limit. The results of the research showed the possibilities of more accurate detection of the effectiveness of cooling technologies.

Key words: *cow dairy; heat stress; measurement method.*

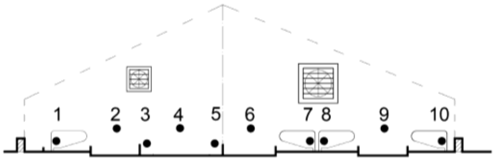
INTRODUCTION

Environmental factors such as air temperature, relative humidity, air flow velocity, and solar radiation affect the productivity and health of dairy cows, with negative consequences unfortunately increasing, especially among the most productive groups (*Berman, 2019; Sejian et al., 2018*). According to experts, the occurrence and intensity of heat waves in Europe will increase with climate change (*Stegehuis et al., 2013; Ceglar, et al., 2019*). Many studies have shown that long-term exposure to high ambient temperatures has a negative impact on the physiological balance of dairy cows through a reduction in feed intake and rumination time, increasing nutritional requirements, and reducing productive and reproductive efficiency (*Kadzere et al. 2002; Abeni et al. 2007; Calamari et al. 2007; Bernabucci et al. 2010).*
Heat stress in dairy cows and its identification in the context of environmental changes require an understanding of physiological indicators such as increased heart rate, respiratory rate, and rectal temperature, which reflect the animal's heat state in its environment. In professional practice, environmental climate indices are commonly used to estimate heat stress. Machine learning models that use both environmental and physiological indicators have also been developed for more accurate stress detection. Originally, the Temperature-Humidity Index (THI) was used to determine the level of heat stress, which assessed the environment based on air temperature and relative humidity. Currently, extended indices are also used, which take into account not only air temperature and humidity, but also air flow velocity and solar radiation, for example THI_{adj} (*Mader et al., 2006*), HLI (Baeta et al., 1987), CCI (*Mader et al., 2010*), ITSC (*Da Silva et al., 2015*), ETIC (*Wang et al., 2018*), and others. Heat stress indices are usually the main determining factor for farmers' decisions on heat stress management and can serve as a rough indicator of the impact of heat stress on production parameters (*Herbut et al., 2018*). Since information about the quality of the rearing environment helps with heat stress management and breeder decision-making, it is important that this information is not only correct but also accurate.

The aim of this study was to highlight the impact of the precision of the location and method of use of cooling technologies, as well as the impact of the precision of climate factor measurements and subsequent climate index calculations, the reliability of which may be important for farmers.

MATERIALS AND METHODS

The research focused on evaluating the level of heat stress in two identical dairy cow housing facilities with differently located cooling devices with two measurement methods. Each facility was renovated to house 144 Holstein-Friesian dairy cows. The barns had an asymmetrically located feeding corridor 4.5 m wide, which divided the space into a group with one row of cubicles and a group with three rows of cubicles, with corresponding movement corridors for dairy cows (Fig. 1 and Fig. 2). Barn A and barn B had a mirror layout and were connected to another barn by a passageway leading to the milking parlor. Both buildings had straw-bedded cubicles 1250 mm wide and 2650 mm long, and walkways 3200-3500 mm wide with rubber mats installed. Both buildings had the same feeding corridors with automatic feed distribution, the same drinkers, and rotating brushes. The difference was in the ventilation technology installed – type and location. In barn A, two louvered circulation fans (each with a capacity of 80,000 m^3h^{-1}) and two panel circulation fans (each with a capacity of 36,000 m^3h^{-1}) were used in the three-row zone. In the single-row section, 8 louvered circulation fans (each with a capacity of 30,000 m^3h^{-1}) were installed, for a total of 472,000 m^3h^{-1} in barn A. In barn B, 12 panel fans (5 fans with a capacity of 44,000 $m^3h^{-1}$and 7 panel fans with a capacity of 36,000 m^3h^{-1}) in an alternating right-left arrangement, with a total capacity in barn B the same as in barn A, 472,000 m^3h^{-1}.



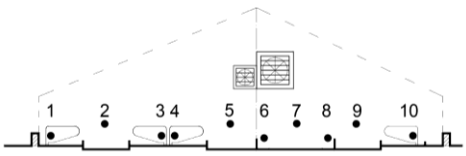


Fig. 1 (left) Orientation cross-section of barn A, where 1-10 are measurement points using the ambulatory mesh method. To the right of the column are louvered circulation fans (each with a capacity of 80,000 m^3h^{-1}), to the left are small louvered circulation fans (each with a capacity of 30,000 m^3h^{-1})
Fig. 2 (right) Orientation cross-section of barn B with mirrored layout, where 1-10 are measurement points. To the right of the column are large panel fans (each with a capacity of 44,000 m^3h^{-1}); to the left are small panel fans (each with a capacity of 36,000 m^3h^{-1})

Measurements of microclimatic parameters were focused on obtaining data for calculating climate indices using two methods: central and mesh. The central method processed data with a recording frequency of 10 minutes, and microclimatic parameter sensors were always located in the center of the building at a height of 3000 mm. The ambulatory mesh method took into account the expected level of predominant animal and staff activity and included measurements at 10 points in each building with a recording frequency of 5 seconds, as well as in each of the three cross-sectional profiles "AA", "BB," "CC" – a total of 30 measurement points (Figs. 1 and 2). Using the ambulatory mesh method, measurements were taken at a height of 700 mm in the rest zone and at a height of 1500 mm in the movement zone.
Data loggers COM S3121were installed in both buildings in the central zone for continuous measurement of climatic conditions. Measurements using the ambulatory mesh method were performed using ALMEMO 2490-1L devices with thermoanemometric and omnidirectional probes, FHAD 46-2 temperature and humidity probes with the appropriate range, and FL A623-GS global solar radiation probes.
Tepmetature-Humidity Index THI calculations were processed according to the *National Research Council (*1971) using the following equation:

$$THI = (1{,}8 \cdot T_{db} + 32) - (0{,}55 – 0{,}0055 \cdot RH) \cdot (1{,}8 \cdot T_{db} - 26) \quad (1)$$

Where T_{db} is the dry bulb temperature, °C and RH is relative humidity, %.
The value THI = 72 was considered a threshold of thermal neutral zone. Higher THI values can be classified into further heat stress levels: mild stress 72 < THI < 79, moderate stress 79 < THI < 89, and severe stress THI > 89 (*Akyuz et al., 2010*).
Equivalent Temperature Index for Cow Dairy ETIC was calculated from the equation according *Wang et al. (2018 a)*:

$ETIC = T_{db}-0,0038\cdot T_{db}\cdot(100-RH)-0,1173\cdot WS^{0,707}\cdot(39,2-T_{db})+1,86\cdot 10^{-4}\cdot T_{db}\cdot SR$ (2)

where T_{db} is temperature, °C, RH is relative humidity, %, WS is air flow velocity, $m.s^{-1}$, SR is solar radiation, $W.m^{-2}$.

Based on the resulting ETIC index value, the following heat load levels can be determined: mild 18 ≤ ETIC < 20, moderate 20 ≤ ETIC < 25, severe 25 ≤ ETIC < 31, emergency 31 ≤ ETIC *(Wang, et al., 2018b)*.

RESULTS AND DISCUSSION

Using the central method and calculating THI from 10-minute records of climatic factors in the center of the barns, no significant differences were found between the calculated heat load levels in barns A and B (p>0.05). Table 1 shows an example of the results of selecting climate parameters from the hottest part of the day (always from 11:00 a.m. to 5:00 p.m.) using values from 5 consecutive days with temperatures above 30°C (always 360 records). Similarly, according to Table 2, no differences were found between the values of the monitored THI indices when the 24-hour data were processed, always together for 5 days (1440 records).

Tab. 1 Results of selected heat waves (5 hottest days) between 11:00 a.m. and 5:00 p.m. with a recording frequency of 10 minutes (marked with *) evaluated at an average outdoor index value $THI_{ext}^{(11-17)}$ = 79,16; Results of the selected heat wave (5 hottest days) from measurements taken over 24 hours with a recording frequency of 10 minutes (marked **) evaluated at an average outdoor index level of $THI_{ext}^{(24)}$ = 77,83.

	*Barn $A^{(11-17)}$	*Barn $B^{(11-17)}$	**Barn $A^{(24)}$	**Barn $B^{(24)}$
THI_{avg}	76.24	76.60	74.34	74.93
THI_{min}	75.61	76.15	64.09	64.62
THI_{max}	78.55	77.51	81.38	81.61
STDEV	1.03	0.304	4.09	2.02

The results of the heat stress assessment using the ambulatory mesh method in building A are shown in Tab.2. The results indicate that the ventilation technology in the animal zone (especially in locations A2, A7, and A8) reduces the level of heat stress according to both the THI and ETIC indices. However, given the outdoor climate conditions ($THI_{avg,\ ext}$>78), all values were in the area of increased risk of heat load. The greatest improvement was found in areas with increased air flow rates in the direct reach of fans, which remove the excessive heat and ensure a faster supply of fresh air (marked in italics in Tab. 2).

Tab. 2 Results of ambulatory mesh measurements in barn A, where THI and ETIC are indices for determining the level of heat stress in animals

Place	THI-A avg	THI-A min	THI-A max	ETIC-A avg	ETIC-A min	ETIC-A max
A1	77.50	76.48	78.73	23.33	22.75	23.98
A2	***75.53***	***74.79***	***76.90***	***21.17***	***20.97***	***21.52***
A3	76.21	75.40	76.81	22.29	21.89	22.29
A4	76.22	75.54	77.14	22.05	21.92	22.33
A5	76.11	75.20	76.96	22.02	21.80	22.17
A6	77.20	76.15	78.10	23.06	22.48	23.43
A7	***75.49***	***74.99***	***77.13***	***21.51***	***21.34***	***21.66***
A8	***74.51***	***74.39***	***74.84***	***20.43***	***19.89***	***21.10***
A9	75.79	74.60	77.07	21.79	21.35	21.77
A10	76.28	75.62	76.97	22.30	22.05	22.36

The results of the heat stress assessment for animals in building B are shown in Table 3. The greatest reduction in heat stress according to the THI index and, more significantly, according to the ETIC index was in the area outside the animal zone (locations B6, B7, and B8 – marked in bold in Table 3), where

the feeding corridor is located. The central location of the fans in this building had the greatest effect on the zone not available to animals.
The results obtained by calculating THI and ETIC in building B show that, despite the ventilation technology used, the index levels were also in the excessive zone (THI>72), where a decline in milk production can be observed (*Galik et al., 2021*). According to recent research on the negative effects of heat stress on dairy cows, even stricter THI values (starting at THI=68) have been defined to indicate the occurrence of negative changes in the behavior, health, and production of dairy cows (*Nordlund et al., 2019*).
In our research, the most risky values detected by the ambulatory network method in barn B are found in the animal zone, although they were lower than the outdoor values (Δ THI_{min} = 2.52). The highest benefit of the installed cooling technology and the best THI and ETIC values detected in the 30-point mesh are found in the feeding corridor, i.e., outside the animal zone, in the area where service personnel and machines move.

Tab. 3
Results of ambulatory mesh measurements in barn B, where THI and ETIC are indices for determining the level of heat stress in animals

Place	THI-B avg	THI-B min	THI-B max	ETIC-B avg	ETIC-B min	ETIC-B max
B1	75.78	74.53	76.82	22.13	21.39	22.68
B2	77.32	75.90	78.55	23.09	22.34	23.74
B3	77.23	76.07	77.94	23.13	22.42	23.50
B4	77.92	77.23	78.64	23.60	23.16	24.06
B5	77.95	76.71	78.64	23.57	22.86	23.95
B6	**75.89**	**75.26**	**77.04**	**21.74**	**21.61**	**22.22**
B7	**75.92**	**75.35**	**76.65**	**21.52**	**21.39**	**21.81**
B8	**75.92**	**75.46**	**76.35**	**22.01**	**21.91**	**22.82**
B9	77.05	75.59	77.94	22.93	22.07	23.35
B10	75.92	76.42	78.31	23.31	22.55	23.69

Additional measurements along the longitudinal axis of the building in the area of the pillars showed that the air flow velocity in the feeding corridor (Tab. 4) is, in all places, v>0.3 ms^{-1}, which are uncomfortable for humans and its effect is less accessible to animals through the metal barriers.
All measurements conducted in the animal zone at heights of 700 mm and 1500 mm (according to the measurement locations in Fig. 1 and Fig. 2) showed more critical values than the central measurement. They also pointed to the suitability of moving the fans to the animal zone and a possible method of improving the effect of the installed technology by reducing their mounting height. In this way, its cooling effect could be achieved closer to the animals, which, in excessive heat and with insufficient heat dissipation from their body core, need airflow speeds above 1.0 ms^{-1}, with the benefit of speeds even reaching 2.0 ms^{-1} (*Berman et al. 2019*). In areas where people move (locations 6, 7, and 8 in building B), additional measurements showed even higher airflow speeds (Tab. 4). According to the method of central data collection and calculation of THI and ETIC indices, the cooling effect in hall B is comparable to building A, and there is no apparent need to modify the ventilation units and more accurately deliver the cooling effect directly to the cows, which was not confirmed by the ambulatory method.

Tab. 4 Example of results of additional measurements of microclimatic parameters at points 7 of barn B at a height of 1500 mm (area of movement of people and machines) along the building, at the level of twenty middle columns S1 to S20. T is temperature, °C; RH is relative humidity, %; v is air flow velocity, ms^{-1}; ETIC is thermal load index (-).

	v, ms^{-1}			ETIC, (-)		
	AVG	MIN	MAX	AVG	MIN	MAX

S1	0.88	0.51	1.38	21.42	21.69	21.14
S2	0.99	0.14	2.04	21.55	22.12	21.16
S3	1.59	0,38	3.65	21.33	22.08	20.29
S4	1.12	0.40	2.05	21.44	22.00	20.86
S5	2.22	1.40	298	20.70	21.05	20.44
S6	2.15	1.79	2.60	20.82	21.00	20.58
S7	1.95	1.72	2.10	20.92	20.92	20.95
S8	2.93	2.62	3.91	20.53	20.59	20.10
S9	2.49	2.13	2.81	20.74	20.78	20.86
S10	2.48	1.51	3.12	20.94	21.39	20.79
S11	3.44	2.58	4.24	20.48	20.82	20.22
S12	2.66	1.28	3.28	20.88	21.69	20.62
S13	2.34	1.56	2.96	21.11	21.39	20.91
S14	2.36	1.33	3.05	21.19	21.60	21.14
S15	2.08	1.52	2.53	21.58	21.79	21.52
S16	1.60	0.38	2 29	22.04	22.72	21.86
S17	2.82	1.78	3.77	21.00	21.51	20.63
S18	2.45	1.80	3.29	21,14	21.39	20.76
S19	2.42	185	2,64	21.19	21.38	21.17
S20	2.39	1.22	3,23	21.54	22.07	21.35

In Slovakia's Central European climate, air temperatures of $T \geq 30°C$ and relative humidity of $40 < RH < 60$ are typical during the summer months, corresponding to a THI of 77 to 80 (calculated according to NRC 1971). Due to the natural production of heat and moisture from a large number of animals in barns, as well as the permanent production of additional moisture from movement corridors and feeding systems, the THI inside the barn is always higher than the THI outside (*Herbut et al., 2018*). Therefore, not only the mathematical indicators reported in many scientific studies (*Mader et al., 2010; Da Silva et al., 2015; Wang et al., 2018),* but also the logical need to provide ventilation and cooling of overheated and contaminated air, there is a common need to ventilate livestock buildings with a concentrated number of large animals. Through intensive research and modern scientific techniques for modeling processes in barns, natural and forced ventilation systems are constantly being improved (*Kic 2022; Yan et al., 2020*). Our research has demonstrated the importance of method selection and measurement accuracy in assessing the quality of the animal husbandry environment.

CONCLUSIONS

The work builds on scientific research dedicated to preventing the consequences of excessive heat stress in dairy cows, which for farmers is often associated with an unfair decrease in productivity, health, and negative effects on animal behavior. In our study, we found that when comparing two methods of cooling animals in two identical buildings with the same ventilation technology, the same effect was not achieved for animals in barn A and barn B. More effective heat removal from the cows' bodies and a higher air exchange rate were found in barn A in the animal zone. In barn B, the installed fans provided the greatest improvement in the area unreachable by animals. This was demonstrated by the results of calculations based on data measured using the ambulatory mesh method, which the central method did not detect. The research showed the importance of precision data collection in tasks related to improving animal welfare in the summer.

ACKNOWLEDGMENT

This contribution was supported by Project No. 09I03-03-V04-00485 Identification of housed animals' activity by ultrasound. Investment No. 3. Excellent Science, funded by the European Union from the Recovery and Resilience Plan of the Slovak Republic.

REFERENCES

1. Abeni, F., Calamari, L., Stefanini, L. (2007). Metabolic conditions of lactating Friesian cows during hot season in Po Valley. 1. Blood indicators of heat stress. Int J Biometeorol 52, 87–96.
2. Baeta, F. C., Meador, N. F., Shanklin, M. D., Johnson, H. D. (1987). Equivalent temperature index at temperatures above the thermoneutral for lactating dairy cows. ASAE Paper No. 874015. St. Joseph.
3. Berman, A. (2019). An overview of heat stress relief with global warming in perspective. International Journal of Biometeorology, 63, 493–498.
4. Bernabucci, U., Lacetera, N., Baumgard, L. H., Rhoads, R. P., Ronchi, B., Nardone, A. (2010) Metabolic and hormonal acclimation to heat stress in domesticated ruminants. Animal, 4(7),1167–1183.
5. Calamari, L., Abeni, F., Calegari, F., Stefanini, L. (2007). Metabolic conditions of lactating Friesian cows during hot season in Po Valley. 2. Blood minerals and acid-base chemistry. Int J Biometeorol, 52, 97–107.
6. Ceglar, A., Zampieri, M., Toreti, A., Dentener, F. (2019). Observed northward migration of agro-climate zones in Europe will further accelerate under climate change. Earth's Future, 7, 1088–1101.
7. Da Silva, R. G., Maia, A. S., de Macedo Costa, L. L. (2015) Index of thermal stress for cows (ITSC) under high solar radiation in tropical environments. Int J Biometeorol 59(5), 551–559.
8. Gálik, R., Lüttmerding, G., Boďo, Š., Knížková, I., Kunc, P. (2021). Impact of Heat Stress on Selected Parameters of Robotic Milking. Animals (Basel). Oct 30; 11(11), 3114.
9. Herbut, P., Angrecka, S., Walczak, J. (2018). Environmental parameters to assessing of heat stress in dairy cattle—a review. International Journal of Biometeorology, 62, 2089–2097.
10. Ji, B., Banhazi, T., Perano, K., Ghahramani, A., Bowtell, L., Wang, C., Li, B. (2020). A review of measuring, assessing and mitigating heat stress in dairy cattle. Biosyst. Eng., 199, 4–26.
11. Kadzere, C. T., Murphy, M. R., Silanikove, N., Maltz, E. (2002). Heat stress inlactating dairy cows: A review. Liv. Prod. Sci., 77, 59–91.
12. Kic, P. (2022). Influence of External Thermal Conditions on Temperature–Humidity Parameters of Indoor Air in a Czech Dairy Farm during the Summer. Animals, 12, 1895.
13. Mader, T. L., Davis, M. S., Brown-Brandl, T. (2006). Environmental factors influencing heat stress in feedlot cattle. J. Dairy Sci. 84(3), 712–719.
14. Mader, T. L., Johnson, L. J., Gaughan, J. B. (2010) A comprehensive index for assessing environmental stress in animals. J. Anim. Sci. 88, 2153–2165.
15. National Research Council (1971). A guide to environmental research on animals. National Academy of Science, Washington.
16. Nordlund, K. V. - Strassburg, P. - Bennett, T. B. - Oetzel, G. R. – Cook, N. B. (2019). Thermodynamics of standing and lying behavior in lactating dairy cows in freestall and parlor holding pens during conditions of heat stress. Journal of Dairy Science, Vol. 102 (7), 6495–6507.
17. Sejian, V., Bhatta, R., Gaughan, J. B., Dunshea, F. R. and Lacetera, N. (2018). Review: Adaptation of animals to heat stress. Animal, 12 (S2), 431–s444.
18. Stegehuis, A. I., Vautard, R., Ciais, P., Teuling, A. J., Jung, M., Yiou, P. (2013). Summer temperatures in Europe and land heat fluxes in observation-based data and regional climate model simulations. Clim. Dyn., 41, 455–477.
19. Wang, X., Gao, H., Gebremedhin, K. G., Bjerg, B. S., Van Os, J. Tucker, C. B. Zhang, G. (2018a). A predictive model of equivalent temperature index for dairy cattle (ETIC). In Journal of Thermal Biology, 76, 165–170.
20. Wang, X., Gao, H., Gebremedhin, K. G., Bjerg, B. S., Van Os, J., Tucker, C. B., Zhang, G., (2018b). Corrigendum to "A predictive model of equivalent temperature index for dairy cattle (ETIC)". In Journal of Thermal Biology, 82, 252–253.
21. Yan, G., Liu, K., Hao, Z., Shi, Z. (2021). The effects of cow-related factors on rectal temperature, respiration rate, and temperature-humidity index thresholds for lactating cows exposed to heat stress. Journal of Thermal Biology, 100, 103041.

Corresponding author:
Prof. Ing. Miroslav Žitňák, PhD. Institute of Agricultural Engineering, Transport and Bioenergetics, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, SK-94976 Nitra, Slovakia, phone: +421 37 6415513, e-mail: miroslav.zitnak@uniag.sk