Ukrainian Journal of Ecology

Ukrainian Journal of Ecology, 2020, 10(3), 56-62, doi: 10.15421/2020_133

ORIGINAL ARTICLE

Effectiveness of additional mechanical ventilation in naturally ventilated dairy housing barns during heat waves

O. Izhboldina[1]*, R. Mylostyvyi[1], O. Khramkova[1], O. Pavlenko[1], N. Kapshuk[1], O. Chernenko[1], A. Matsyura[2], G. Hoffmann[3]

[1] Dnipro State Agrarian and Economic University, S. Efremov St. 25, 49600, Dnipro, Ukraine
[2] Altai State University, pr. Lenina 61, 656049, Barnaul, Russia
[3] Department of Engineering for Livestock Management, Leibniz Institute for Agricultural Engineering and Bioeconomy, 14469 Potsdam, Germany
**Corresponding author E-mail: izhboldinaalena@gmail.com*

Received: 12.06.2020. Accepted 29.07.2020

We presented an algorithm to predict the temperature-humidity index in a naturally ventilated barn. We found that use of additional accelerating fans reduced the temperature-humidity index in a naturally ventilated barn by 0.4-1.0 units and surface temperature of dairy cows by 0.4-0.5 °C in the hottest period. We also revealed the limitations of suggested model in assessing the effectiveness of additional mechanical ventilation in the barns. Slight decrease of temperature-humidity index in animal keeping area and cooling of cattle body surface should be further enhanced, especially during the heat waves.

Key words: microclimate of barn, body temperature of cows, cooling, modeling, algorithm.

Introduction

The variability of climatic conditions is manifested by the numerous heat waves in Central and Eastern Europe (Tomczyk et al., 2019). Dairy farming in these regions is especially vulnerable because dairy cattle are kept mainly in naturally ventilated barns (Milostiviy et al., 2017; Hempel et al., 2018; Poteko et al., 2019), which microclimate directly depends on the external weather conditions (Yi et al., 2018 Ji et al., 2019). Additional mechanical ventilation by accelerating of axial fans in NVBs, sometimes is insufficient during the heat waves (Wang et al., 2018; Hempel et al., 2019). This is caused by uneven distribution of air flows in naturally ventilated barn (NVB) (Schüller et al., 2016; Bustos-Vanegas et al., 2019) and large influence of external weather conditions (Wang et al., 2018) on these processes. There are also problems due to a large number of uncertainties in climate monitoring in NVBs (Hempel et al., 2018) and insufficient methods for assessing and predicting the reaction of dairy cows to heat (Herbut et al., 2018; Müschner-Siemens et al., 2020; Hoffmann et al., 2020).

Hempel et al. (2019) and Mylostyvyi, et al. (2019a) reported that additional mechanical ventilation in NVBs was not effective, which was associated with a high probability of occurrence of heat stress in animals. To prevent it, sprinklers are used as well as a variety of ventilation systems, which is very expensive. Therefore, these measures should be economically justified. This requires additional efforts by the researchers to study microclimate conditions during periods of heat waves. The aim of our study aims was to check and model the possibility of increasing the comfort of dairy cows in NVBs using additional mechanical ventilation in hot summer period.

Material and methods

Characteristics of barns and methods to register microclimate parameters

Studies were conducted in summer of 2018 in the barn of hangar type at the dairy farm of the private Joint-Stock Company Agro-Soyuz (48°28'44"N, 35°36'46"E) and in a NVB of frame type of the dairy farm by Yekaterynoslavskyi (48°34'03.1"N, 34°54'47.0"E). The barn of hangar type of Argo-Soyuz had an awning covering from textile, the dimensions in the axes were 230 × 32 m, the internal height was 9.2 m at the gable peak and 3.6 m at the eaves. The lying cubicles (n= 768) were placed in four rows. Their size was 2.24 m^2 (1.0 m × 2.24 m) per cow (herd size: 600 cows). The sections also had water troughs designed for an animal's group. The barn had feeding alley were equipped with side regulated curtains made of canvas on the two long sides and in the cubicles they used sand as bedding. Holstein cows (n=548) of middle lactation (days in milk: 91 to 210) were kept in the barn of hangar type during the study. Their number in sections, designed for 150 cows, was between 127 and 143. The average daily milk yield for this technological group was 24-26 kg.

The barn of frame type for 600 dairy cows (Yekaterinoslavsky) had an insulated roof and was placed along the longitudinal axis from the northeast to the south-west relative to the cardinal points. Its dimensions were 240.0 m × 32.4 m. This barn had four separate sections for 150 cows each and 150 lying cubicles (1.2 × 2.5 m) per section located in two rows. The sidewalls with a height of 3.0 m had a reinforced concrete base with fastening for canvas curtains. The opening and closing of the curtains was automatically controlled depending on the inside barn temperature.

A NORSOL WH-T-42 recorder (Norsol Electronics, St. Hubert, QC, Canada) recorded internal barn temperature; its temperature sensors were placed indoors at a height of 3.5 m from the floor (above the suspended horizontal axial fans). The gable roof was made of sandwich panels. The height of the barn in the ridge was 9 m. At the time of the study, 142 to 148 cows of the Schwyz breed of middle lactation (days in milk: 91 to 210) were in each sections; their average daily milk yield was between 25-27 kg. Indoor and outdoor temperature (AT) and relative humidity (RH) in these barns were evaluated using a thermohygrometer (Ambient Weather WS-10, Ambient LLC, Chandler, AZ, USA) for more than 30 hours continuously, with sensor readings every 5 to 20 minutes. The remote sensors (F007TH) included in the Ambient Weather WS-10 were placed at the resting level of the animals (at a height of 50 cm from the floor) directly between the first and second lying cubicles on the side of the end sections (from the south-east and northwest) and in the central part (between the first and second lying cubicles). The external WS-10 thermohygrometer was placed outside the barn in shade at a height of 2 m from the floor.

Based on AT and RH, we calculated the temperature-humidity index (THI) according to the level provided by Kibler (1964), and also used the principles of THI modeling for NVBs of different designs (Mylostyvyi et al., 2019 b), which were described earlier. The air velocity in the animal keeping area (lying cubicles) and near the feeding alley was determined by hot-wire anemometers (Benetech GM 8903, Shenzhen Jumaoyuan Science and Technology Co., Ltd, Shenzhen, China) in the NVB with conditions of both without and with support of circulation fans. The design of the vertical axial fans was similar in all types of barns. They were suspended at a height of 3.0 m from the floor in a vertical position with a slope at an angle of 10°. All fans were 90 cm diameter circulation fans, and were rated for airflow of 318 m3/min. Their power was 0.7 kW. The distance between the fans was 10-15 m. In the barn of hangar type (Agro-Soyuz), they were located both above the lying cubicles and over the manure passage from the side of the feeding alley (alternating in a checkerboard pattern); in the barn of frame type with insulated roof (Yekaterinoslavsky), they were located above the lying cubicles.

Measuring cows body temperature and animal handling

The cow body temperature was measured in the middle third of the neck and was recorded with a thermal imaging pyrometer (FLIR TG165, FLIR Systems, Wilsonville, OR, USA) with an emissivity of 0.98 at a distance of about 1.5 m from the animal. The cows were fixed in headlocks after returning from the milking, when they started to feed. When working with animals, we adhered to the requirements of the "European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes" (Council of Europe, 1986), as well as the Law of Ukraine "On the Protection of Animals from Cruelty" No. 3447 of 02.21.2006.

Statistical analysis

We used regression analysis to find a functional relationship between dependent (response) and independent variables (predictor). In LR, the function is linear equation and dependent variable can be expressed as a function of independent variable(s) in the form of (Bilgili & Sahin, 2010):

$$Y = \beta_0+\beta_1 X_1+\beta_2 X_2 +\ldots+ \beta_n X_n$$

where Y is dependent variable, β_0 to β_n are equation parameters for linear relation and X_1 to X_2 are independent variables.

Data processing and construction of LR models was performed using STATISTICA v. 10 (StatSoft, Inc., USA). The data were presented as medians. The differences between the samples was determined by U-test of Mann-Whitney and considered significant at P <0.05.

Results

We assumed that the operation of axial fans (mechanical ventilation) should lead to decrease in THI values in dairy barns. It means that the THI forecasts made during natural ventilation in barns should have been higher than the values obtained during observation under conditions with a working mechanical ventilation. This is the principle of comparison that we decided to apply in this study. Initially, we measured the AT and RH of the air inside a barn of hangar type to calculate THI by Kibler (1964) (Table 1) from 12:00 to 14:00 h periodically in the summer season over four consecutive days. Based on the THI data calculated outside the barn, the THI values inside the barn were also predicted (using equation by Mylostyvyi et al., 2019b). Afterwards we compared these data (Fig. 1) with the THIs observed inside this barn (marked as experiment).

Table 1. Median of air temperature (AT), relative humidity (RH) and temperature-humidity index (THI) in a barn of hangar type with additional mechanical ventilation in the summer season (12:00 to 14:00 h)

No / n	Outside			Inside		
	AT, °C	RH, %	THI, units	AT, °C	RH, %	THI, units
1/ 119	30.1	30.4	75.2	28.0	38.2	74.0
2/ 29	34.9	26.5	79.7	33.5	27.9	78.4
3/ 58	35.8	24.7	80.3	32.8	30.9	78.3
4/ 29	36.9	23.0	81.0	34.2	26.8	79.4

No - measurement day, n - number of measurements

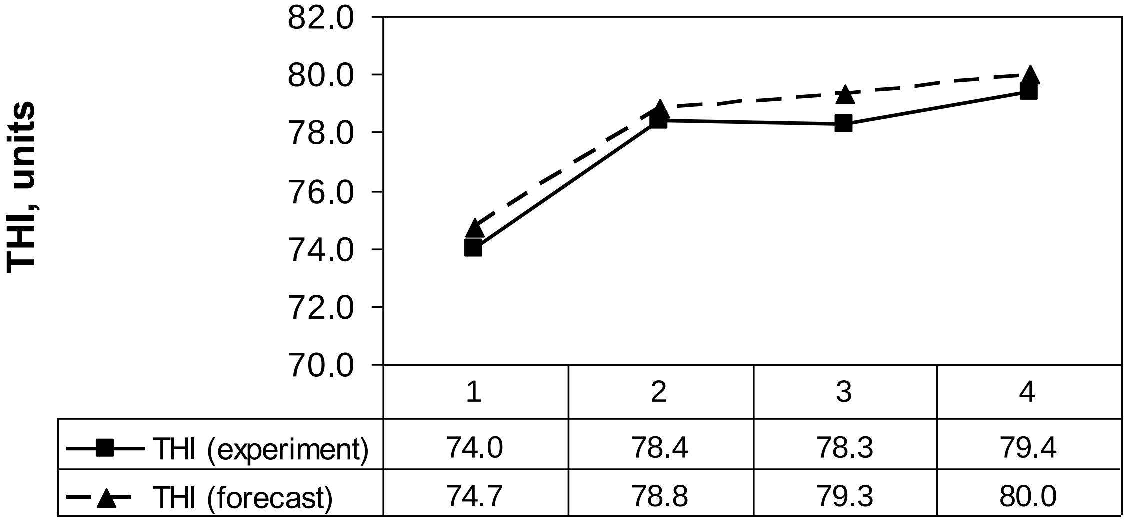

Fig 1. Comparison of the temperature-humidity index (THI) during the observation (experiment, data measured inside) and with the forecast (based on outside data) in the barn with mechanical ventilation

The data (Fig. 1) indicate that the operation of axial fans contributed to a decrease in the THI in the barn of hangar type by 0.4-1.0 units in the hottest period of the day. We attribute this to an increase in air velocity (Table 2), additionally created by mechanical ventilation in the dairy barn of hangar type.

Table 2. Air velocity (ms^{-1}) during mechanical ventilation in a barn of hangar type, median (min–max)

Place of measurement	Types of ventilation	
	natural	Mechanical
Animal keeping area (in cubicles):		
at height of 0.5 m from the floor	0.3 (0.2–0.4)	0.4 (0.1–1.8)*
at height of 1.2 m from the floor	0.4 (0.2–0.5)	0.6 (0.1–1.5)*
Area to remove manure (side of the feeding alley) at height of 1.2 m from the floor	0.6 (0.2–0.9)	1.9 (0.5–3.6)*

* significant difference (*P* <0.05) between natural and mechanical ventilation

To assess the effectiveness of mechanical ventilation in a barn of frame type with an insulated roof, we first needed to build the necessary LR model (Fig. 2) to determine the THI inside the barn with natural ventilation through open curtains, based on its values outside the building (initial data for this model were taken from Table 2); and then to compare the estimated values (designated as forecast) with the observed (experiment).

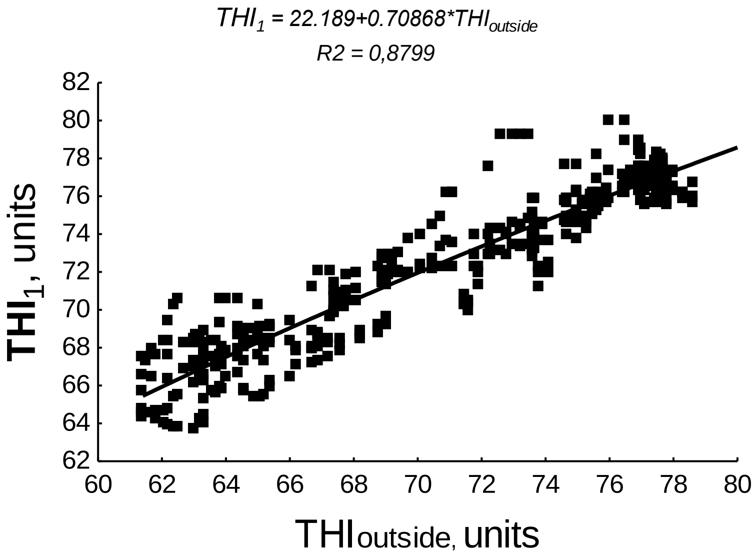

Fig. 2. Scatter plot of the dependence of the temperature-humidity index in a frame barn with an insulated roof (THI$_1$) on the value of THI outside the barn (THI$_{\text{outside}}$) under natural ventilation.

Table 3. Daily dynamics of the temperature-humidity index in dairy barns during the summer

Day time	Naturally ventilated dairy barns			
	BH (n=402)		BFI (n=414)	
	outside	inside	outside	Inside
1:00	68.0	68.0	63.7	67.2*
2:00	66.5	66.7	62.5	65.5*
3:00	66.4	66.7	61.5	64.5*
4:00	64.3	64.6	61.6	67.0*
5:00	64.6	64.6	63.1	68.3*
6:00	65.5	65.3	66.7	68.0*
7:00	67.9	69.7*	70.2	70.4
8:00	70.2	72.6*	73.0	73.1
9:00	73.4	75.8*	73.7	74.8
10:00	76.1	78.7*	75.9	76.3
11:00	77.9	80.1*	75.3	75.2
12:00	79.4	80.8*	75.5	75.7
13:00	78.9	79.8*	77.0	76.1
14:00	78.5	78.7	77.6	76.5*
15:00	78.1	79.7	78.0	76.5*
16:00	76.8	78.5*	77.4	77.2
17:00	76.7	78.5*	77.0	77.1
18:00	76.6	78.2*	77.0	77.2
19:00	76.1	75.7	76.5	78.4
20:00	73.4	73.1*	74.6	75.6*
21:00	72.2	71.5*	70.8	73.2*
22:00	71.5	70.6*	68.1	71.4*
23:00	72.6	69.6*	66.0	68.9*
24:00	69.1	69.4	64.8	68.3*

BH is a barn of hangar type, BFI is a barn of frame type with insulated roof; * - significant difference (P <0.05) between outside and inside

The LR equation obtained for predicting the THI for a barn with natural ventilation based on its values outside the barn will look like this:

$$THI_1 = 22.189 + 0.70868*THI_{outside} \qquad (1)$$

where THI_3 is the temperature-humidity index inside the barn with natural ventilation through open curtains, and $THI_{outside}$ is the temperature-humidity index in the environment, calculated by Kibler (1964).

We assumed that the observed THI values calculated with AT and RH data inside the barn from 12:00 to 16:00 h during the mechanical ventilation (Table 4) should be lower than the estimated THI values due to an increase in the air velocity in the dairy barn (Table 5). The data obtained in this study indicate a decrease in THI by 0.5 units.

Table 4. Temperature-humidity index (THI) values in a barn of frame type with an insulated roof and additional mechanical ventilation, calculated (experiment) with equation according to Kibler (1964) and estimated (forecast) with equation (2), n = 72.

Time	Experiment (inside)	Forecast	Difference[1] (+/-)
12:00	78.5	78.2	-0.3
13:00	78.6	78.6	0.0
14:00	78.5	79.0	+0.5
15:00	78.7	78.2	-0.5
16:00	78.4	78.0	-0.4

[1] A designation less than (-) or more (+) indicates how much the predicted THI values (forecast) differ from those observed (experiment)

These data indicate that such regression modeling is reliable only until 15:00 h, since when warming and maintaining heat in the barns with natural ventilation, the models that considering outdoor temperature and THI will not work properly due to faster cooling barn outside area.

Table 5. Air velocity (ms^{-1}) during mechanical ventilation in a barn of frame type with insulated roof, median (min–max)

Place of measurement	Types of ventilation	
	natural	mechanical
Animal keeping area (in cubicles):		
at height of 0.5 m from the floor	0.2 (0–0.3)	0.4 (0.1–0.9) *
at height of 1.2 m from the floor	0.3 (0.1–0.6)	0.5 (0.1–1.4) *
Area to remove manure (from the side of the feeding alley) at height of 1.2 m from the floor	0.5 (0.1–0.7)	1.4 (0.8–2.3) *

* significant difference ($P<0.05$) between natural and mechanical ventilation

Thus, LR models allow us to evaluate the effectiveness of mechanical ventilation using the values of THI in dairy barns; in our case, the cooling efficiency was up to 0.5-1.0 units, depending on the type of barn.

We determined how mechanical ventilation can be effective in cooling the cattle, comparing the observed (in the experiment) and predicted (LR) values of the dairy cattle body temperature. The cattle body temperature (n = 1634) was measured in a dairy barn of hangar type with natural ventilation throughout the year. The AT and RH were determined with THI calculation according to Kibler (1964) (Table 6). The LR model (Fig. 3) was constructed on these data and explained the dependence of the body temperature of the animals on the magnitude of the THI in a barn.

Table 6. Cattle body surface (BT) temperatures in the barn of hangar type with natural ventilation under different climate conditions

N	Microclimate in the barn			BT (°C)
	AT (°C)	RH (%)	THI (units)	
114	-5.4	63.0	29.6	16.9
12	-3.2	68.0	31.8	18.4
49	-2.5	68.0	32.9	16.7
286	5.1	69.5	44.0	18.5
418	12.9	64.6	55.7	27.3
365	22.5	54.9	68.8	32.7
390	30.7	46.0	78.4	34.4

AT - air temperature, RH - relative humidity, THI - temperature-humidity index, n - number of cows

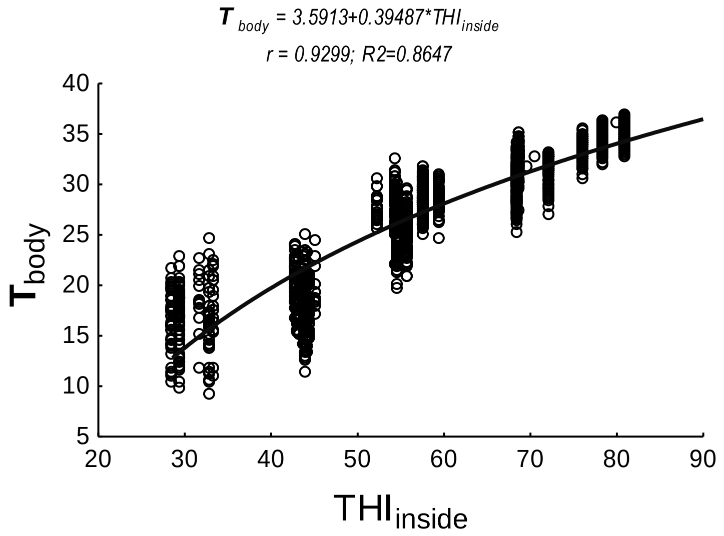

Fig. 3. Scatter plot showing the dependence of the body surface temperature of cows (T_{body}) on the value of the temperature-humidity index (THI_{inside}) in a barn with natural ventilation.

The LR equation obtained for predicting the body surface temperature of cows in a barn with natural ventilation based on the climate inside the barn will look like this:

$$T_{body} = 3.5913 + 0.39487*THI_{inside} \quad (2)$$

where T_{body} is the body surface temperature of cows, and THI_{inside} is the temperature-humidity index in the barn, calculated by equation according to Kibler (1964).

Measurement of cattle surface temperatures and registration of THI indicators were carried out during the mechanic ventilation in the barn (air velocity, see Table 1). The estimated (forecast) body surface temperatures of cows was 0.4-0.5 °C higher than the observed (experiment) temperatures during the operation of axial ventilators (Table 7).

Table 7. Cattle surface temperatures during the summer heat in a barn with mechanic ventilation

n	THI (units)*	The body surface temperature of the cows (°C)			*P*-value
		forecast	experiment	difference	
193	68.5	30.6	30.2	0.4	0.001
62	72.2	32.1	31.6	0.5	0.014

* Temperature-humidity index (THI) was calculated according to Kibler (1964), body surface temperature - estimated (forecast) with equation (2) and measured with thermohygrometer (experiment), n - number of cows

Thus, the principle of comparing observed data and predictions (using regression modeling) can be one useful tool in determining the effectiveness of using additional mechanical ventilation in NVB during the summer heat. Summarizing the research results, we propose an algorithm for predicting THI values in NVBs during the summer heat using regression modeling (Fig. 4).

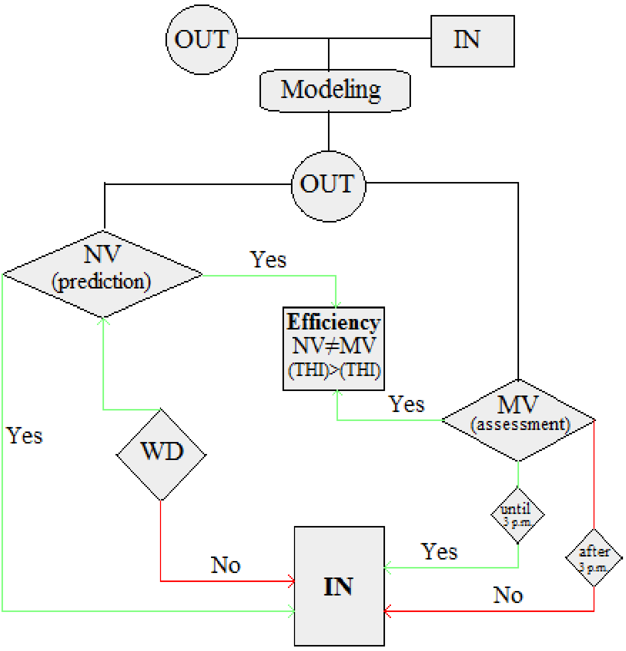

Fig. 4. Algorithm for predicting the microclimate and evaluating the effectiveness of additional mechanical ventilation in NVBs using LR (based on weather conditions outside the barn) with NV (natural ventilation), MV (mechanical ventilation) and WD (weather data).

This algorithm is a definite guide for assessing and forecasting the microclimate in dairy barns, which includes the measured parameters, influence of individual factors on the measurement, and design features of NVBs.

Discussion

Current livestock development strategies envisage the introduction of efficient resource-saving technologies. In this case, particularly in dairy cattle breeding, the construction of new lightweight cattle barns for loose housing is becoming increasingly popular (Jovović et al., 2019; Sanchis et al., 2019; Mylostyvyi & Izhboldina, 2019). Despite the high dependence of NVB climate on the environment (Yi et al., 2018; Hempel et al., 2019), their design features prevent excessive air overheating during diurnal heat (creating shady protection for animals) and lead to capture of the heated indoor air and prolonging the effects of body elevated temperatures (Mylostyvyi & Izhboldina, 2019). Therefore, we suggest to use such modeling only until 15:00 h. When heating and preserving heat in NVBs, models that take into account the values of external air temperature and THI values will have no sense since there is a faster cooling of outside temperature. Hempel et al. (2018) recommended to measure the microclimate at heights of 3-3.5 m from the floor in a NVB, where monitoring in the direct vicinity of the animals is not possible. In our case (after the cows used to the sensors for several days), the measurements of AT and RH were done in cattle keeping area at cow body height to get the most reliable results. This is significant because the animals experienced high heat load on milk productivity (Schüller et al., 2016).

We revealed that the cooling efficiency was only 0.4 °C higher in the cubicles, at height of 4 m from the floor (in the area of AT recording sensors) the cooling effect was 1.8-2.1 °C higher from 12:00 to 14:00 h in daily hot period. Yi et al. (2018) indicate spatial nonuniformity in the velocity field inside the barn, which may depend on the surface wind speed (Kjellström et al., 2018). Considered the significant correlation between the milk yield and the wind speed (WS) outside the barn, Mylostyvyi & Chernenko (2019) revealed that ignoring the WS as an input to LR during modeling can be a significant of drawback in our case. Since environmental factors are mainly non-linear and the THI distribution is uneven in NVB, use of artificial neural networks (Bilgili & Sahin, 2010; Matsoukis & Chronopoulos, 2017; Hempel et al., 2019) can be more advantageous.

Conclusions

Assessment of additional mechanical ventilation can be effective when we compare predictions (based on microclimate data in natural barn conditions) with field observations in the barn with horizontal axial fans operating. Slight decrease of THI in the animal keeping area and poor cooling of cattle body surface during mechanical ventilation of barns should stimulate the search of relevant measures aimed at NVB cooling during the hot summer season.

References

Bilgili, M., & Sahin, B. (2010). Comparative analysis of regression and artificial neural network models for wind speed prediction. Meteorology and Atmospheric Physics, 109(1-2), 61–72. doi: https://doi.org/10.1007/s00703-010-0093-9

Bustos-Vanegas, J. D., Hempel, S., Janke, D., Doumbia, M., Streng, J., & Amon, T. (2019). Numerical simulation of airflow in animal occupied zones in a dairy cattle building. Biosystems Engineering, 186, 100–105. doi: https://doi.org/10.1016/j.biosystemseng.2019.07.002

Hempel, S., Menz, C., Pinto, S., Galán, E., Janke, D., Estellés, F., … Amon, T. (2019). Heat stress risk in European dairy cattle husbandry under different climate change scenarios – uncertainties and potential impacts. doi: https://doi.org/10.5194/esd-2019-15

Herbut, P., Angrecka, S., & Walczak, J. (2018). Environmental parameters to assessing of heat stress in dairy cattle—a review. International Journal of Biometeorology, 62(12), 2089–2097. doi: https://doi.org/10.1007/s00484-018-1629-9

Hoffmann, G., Herbut, P., Pinto, S., Heinicke, J., Kuhla, B., & Amon, T. (2020, in press). Review: Animal-related, non-invasive indicators for determining heat stress in dairy cows. Biosystems Engineering. doi: https://doi.org/10.1016/j.biosystemseng.2019.10.017

Ji, B., Banhazi, T., Ghahramani, A., Bowtell, L., Wang, C., & Li, B. (2019). Modelling of heat stress in a robotic dairy farm. Part 2: Identifying the specific thresholds with production factors. Biosystems Engineering. doi: https://doi.org/10.1016/j.biosystemseng.2019.11.005

Jović, V., Pandurević, T., Važić, B., & Erbez, M. (2019). Microclimate parameters and ventilation inside the barns in the lowland region of Bosnia and Herzegovina. Journal of Animal Science of bih, 1(2). doi: https://doi.org/10.7251/jas1502014j

Kibler, H.H. (1964). Thermal effects of various temperature-humidity combinations on Holstein cattle as measured by eight physiological responses. Environmental physiology and shelter engineering. Res. Bull. Missouri. Agric. Exp. Stn, 862, 1–42.

Kjellström, E., Nikulin, G., Strandberg, G., Christensen, O. B., Jacob, D., Keuler, K., … Vautard, R. (2018). European climate change at global mean temperature increases of 1.5 and 2 °C above pre-industrial conditions as simulated by the EURO-CORDEX regional climate models. Earth System Dynamics, 9(2), 459–478. doi: https://doi.org/10.5194/esd-9-459-2018

Matsoukis, A., & Chronopoulos, K. (2017). Estimating Inside Air Temperature of a Glasshouse Using Statistical Models. Current World Environment, 12(1), 01–05. doi: https://doi.org/10.12944/cwe.12.1.01

Milostiviy, R. V., Vysokos, M. P., Kalinichenko, O. O., Vasilenko, T. O., & Milostiva, D. F. (2017). Productive longevity of European Holstein cows in conditions of industrial technology. Ukrainian Journal of Ecology, 7(3), 169-179. doi: https://doi.org/10.15421/2017_66

Müschner-Siemens, T., Hoffmann, G., Ammon, C., & Amon, T. (2020). Daily rumination time of lactating dairy cows under heat stress conditions. Journal of Thermal Biology, 88, 102484. doi: https://doi.org/10.1016/j.jtherbio.2019.102484

Mylostyvyi, R. V., Chernenko, O. M., Izhboldina, O. O., Puhach, A. M., Orishchuk, O. S., & Khmeleva, O. V. (2019a). Ecological substantiation of the normalization of the state of the air environment in the uninsulated barn in the hot period. Ukrainian Journal of Ecology, 9(3), 84–91. doi: https://doi.org/10.15421/2019_713

Mylostyvyi, R., & Chernenko, O. (2019). Correlations between Environmental Factors and Milk Production of Holstein Cows. Data, 4(3), 103. doi: https://doi.org/10.3390/data4030103

Mylostyvyi, R., & Izhboldina, O. (2019). Climate assessment in modern sustainable cattle barns using temperature-humidity index. New Stages of Development of Modern Science in Ukraine and EU Countries. doi: https://doi.org/10.30525/978-9934-588-15-0-134

Mylostyvyi, R., Chernenko, O., Lisna, A. (2019b). Prediction of comfort for dairy cows, depending on the state of the environment and the type of barn. Development of Modern Science: The Experience of European Countries and Prospects for Ukraine. https://doi.org/10.30525/978-9934-571-78-7_53

Poteko, J., Zähner, M., & Schrade, S. (2019). Effects of housing system, floor type and temperature on ammonia and methane emissions from dairy farming: A meta-analysis. Biosystems Engineering, 182, 16–28. doi: https://doi.org/10.1016/j.biosystemseng.2019.03.012

Sanchis, E., Calvet, S., Prado, A. del, & Estellés, F. (2019). A meta-analysis of environmental factor effects on ammonia emissions from dairy cattle houses. Biosystems Engineering, 178, 176–183. doi: https://doi.org/10.1016/j.biosystemseng.2018.11.017

Schüller, L.-K., Burfeind, O., & Heuwieser, W. (2016). Effect of short- and long-term heat stress on the conception risk of dairy cows under natural service and artificial insemination breeding programs. Journal of Dairy Science, 99(4), 2996–3002. doi: https://doi.org/10.3168/jds.2015-10080

Tomczyk, A. M., Bednorz, E., & Półrolniczak, M. (2019). The occurrence of heat waves in Europe and their circulation conditions. Geografie, 124(1), 1–17. doi: https://doi.org/10.37040/geografie2019124010001

Wang, X., Zhang, G., & Choi, C. Y. (2018). Evaluation of a precision air-supply system in naturally ventilated freestall dairy barns. Biosystems Engineering, 175, 1–15. doi: https://doi.org/10.1016/j.biosystemseng.2018.08.005

Yi, Q., Zhang, G., König, M., Janke, D., Hempel, S., & Amon, T. (2018). Investigation of discharge coefficient for wind-driven naturally ventilated dairy barns. Energy and Buildings, 165, 132–140. doi: https://doi.org/10.1016/j.enbuild.2018.01.038

Citation:

Izhboldina, O., Mylostyvyi, R., Khramkova, O., Pavlenko, O., Kapshuk, N., Chernenko, O., Matsyura, A., Hoffmann, G. (2020). 2Effectiveness of additional mechanical ventilation in naturally ventilated dairy housing barns during heat waves. *Ukrainian Journal of Ecology, 10*(3), 56-62.