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The impact of ventilation type on the heat load of dairy cows

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Abstract. Heat load in cattle causes deterioration of health and reduced production of milk. Therefore, it is necessary to protect cows by appropriate passive and active means and monitor the air quality in barns. Based on several indicators of environmental quality, is possible to make a more comprehensive assessment of the microclimate and more precise conclusions. This study, was monitoring the values of air temperature, relative humidity, and air velocity in two barns with the same volume and layout with floor dimensions of 26.6 m × 62.1 m. In barn 1, roof ridge of which had underwent only partial reconstruction, there were installed fourteen basket fans with a total fan performance $Q(1)_{fans} = 218{,}400$ m^3 h^{-1}. In barn 2, there were twelve panel fans with a total fan performance $Q(2)_{fans} = 289{,}320$ m^3 h^{-1}. The resulting THI, HLI and ETIC values were compared in relation to each other and in relation to the recommended values.
Despite the operating ventilation technology and enlargement of wall openings, the above-limit values of climatic characteristics were observed in both barns during tropical days. There were no differences between the barns ($p > 0.05$), in barn 1: THI(1) = 83.10 ± 0.51; HLI(1) = 85.62 ± 1.42; ETIC(1) = 27.24 ± 0.31, and in barn 2: THI(2) = 83.12 ± 0.34; HLI(2) = 85.77 ± 1.50; ETIC(2) = 27.29 ± 0.28, however, there were found significant differences in values of temperature indices obtained in the detailed measurements at points arranged perpendicularly, as well as parallelly, to the direction of air velocity in the animal zone ($p < 0.05$).

Key words: air flow speed, cattle, heat load index, temperature - humidity index.

INTRODUCTION

Currently, climate change is becoming topical issue, because high temperatures adversely affect health and productivity of livestock (Sheikh et al., 2017). Reduced production and decrease of health cause significant economic losses in animal husbandry (Fournel et al., 2017). Several climate models calculate that, at the end of the 21st century, surface air warming can rise from 1.1 °C to 6.4 °C. Global warming is concerning not only for tropical and southern regions, but also countries with a temperate climate (Bernabucci, 2019). Cattle is housed in buildings with natural ventilation, and therefore, these objects are so dependent on the weather (Hempel et al., 2019). In last decades, many studies have observed the heat load of dairy cows and confirmed that it affects the cow's health (Kovács et al., 2018), production (Broucek et al., 2019), behaviour (Nordlund et al., 2019).

Animals react to their environment through physiological indicators (respiratory rate, rectal temperature) and behavioural indicators (activity, rest, feed intake); these indicators are mostly used for detecting of heat stress (Galan et al., 2018). The other indicators used to identify heat load in cows are heart rate, body weight, water intake and rumination (Hoffmann et al., 2019). Milk production can fall by up to 50% due to reduced feed intake. Heat load affects not only the quantity, but also the quality of milk (Sheikh et al., 2017).

According Fournel et al. (2017), Brown-Brandl (2018), the environment affects the thermal comfort of animals and is characterized by basic physical elements (microclimatic parameters), such as air temperature, relative humidity, air flow speed and sunlight. The heat load can be evaluated by calculating and measuring of microclimatic parameters.

The temperature humidity index (THI) is the most used index for assessing thermal comfort in cattle. This index combines air temperature and relative humidity into one value to estimate the heat load (Hoffmann et al., 2019). Heat stress have several levels: mild heat stress $72 < \text{THI} < 79$, moderate stress $80 < \text{THI} < 89$ and severe heat stress $\text{THI} > 89$ (Armstrong, 1994; Akyuz et al., 2010).

High temperatures negatively affect high-yielding cows, which are more sensitive than cows with average milk production (Pragna et al., 2017). According to recent studies by Heinicke et al. (2018), the threshold value for dairy cows begins at a THI value of 67. According to Pinto et al. (2020), the threshold value for the heat load of dairy cows is THI 65.

Fournel et al. (2017) claim, that THI does not consider other factors that may affect the thermal comfort of dairy cows, such as air velocity and solar radiation. The environmental index that considers not only temperature and humidity, but also the air flow speed and solar radiation is the Heat load index (HLI). According to Gaughan et al. (2008), HLI have four categories: thermoneutral zone $\text{HLI} \leq 70$, warm environment area $70 < \text{HLI} < 77$, hot environment area $77 < \text{HLI} < 86$, very hot environment area $\text{HLI} > 86$.

Another index for air flow evaluation is Equivalent temperature index for cattle (ETIC). According to Hempel et al. (2019), equivalent temperature index has 4 categories: mild category $18 \leq \text{ETIC} < 20$, moderate category $20 \leq \text{ETIC} < 25$, severe category $25 \leq \text{ETIC} < 31$, emergency category $31 \leq \text{ETIC}$. Monitoring of climate and indoor microclimatic parameters could help to mitigate the effects of heat stress in cattle (Herbut et al., 2019). Buildings for livestock do not always have the technical capabilities to protect against weather conditions and animals are forced to deal with heat on their own (Lendelova et al., 2019).

One of the solutions to alleviate heat stress in cattle are cooling systems such as shades, ventilation, evaporative cooling, or their combination (Becker & Stone, 2020). To make dairy production more efficient, it is necessary to adjust the indoor environment in the form of ventilation (Fournel et al., 2017). Measuring the air velocity in housing facilities is quite demanding (Bustos-Vanegas et al., 2019). The performance of a ventilation system is affected by several factors that disturb the efficiency of ventilation equipment such as animal concentration or structural elements (Mondaca et al., 2019). The air flow speed should be directed to the zone where the animals are located and thus improve the cooling effect of the fans (Zhou et al., 2019).

MATERIALS AND METHODS

The research took place at an experimental dairy farm located in southern Slovakia at an altitude of 220 m above sea level. Records were collected in the summer of 2018 from two identical barns with floor plan dimensions of 26.6 m × 62.1 m and a volume of 7,943 m^3.

Both barns were reconstructed from a tie- to free-housing, while the openings in the side walls were enlarged to improve natural ventilation and a ridge slots (55 m × 1.2 m) with deflectors were built. Due to the frequent occurrence of tropical days, motor ventilation was additionally installed to both buildings. In both barns, there are 4 groups of animals of 32 with an average annual milk yield of 9,520 kg per animal in the given year and the feed corridors, straw bedding, and system and frequency of cleaning are the same.

In barn 1, fourteen basket fans (each with fan performance of 15,600 $m^3 h^{-1}$) with a total fan performance of 218,400 $m^3 h^{-1}$ were installed. The fans were arranged in two rows 3.5 m away from the longitudinal axis of the building. They were mounted to the ceiling structure at a height of 2.8 m above the floor and inclined to the animal zone at an angle of 10° (Fig. 1).

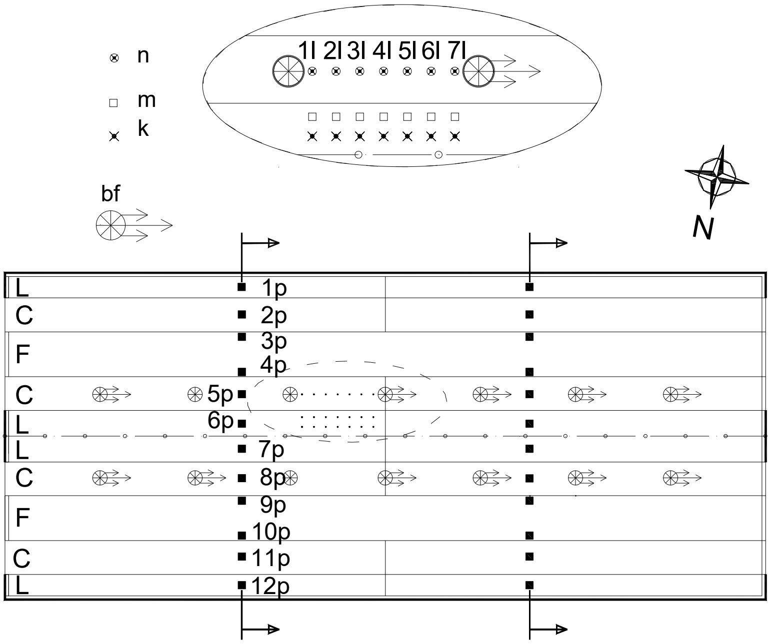

Figure 1. Layout of barn 1 with locations of basket fans and measuring points.

(bf Brangule basket fan; 1l–7l are measuring points in the longitudinal direction of the object spaced 1,200 mm apart; k – places of lying area with measurements at a height of 500 mm; m – measuring places of lying area with measurements at a height of 1,200 mm; n – moving alley with measurements at a height of 1,200 mm; 1p – 12p are measuring points in the direction perpendicular to the longitudinal axis of the object; L – lying zone; C – movement corridor; F – feeding corridor).

In barn 2, twelve panel fans were installed (4 devices with fan performance of 36,530 m^3 h^{-1} and 8 devices with fun performance of 17,900 m^3 h^{-1}) with a total fan performance of 289,320 m^3 h^{-1}. All fans were mounted to the existing steel columns located at the longitudinal building axis (Fig. 2).

COM S3121 data loggers were installed in both buildings and outdoors for continuous climate measurements, and ambulant measurements were performed-using ALMEMO 2490-1L instruments with temperature range of -20 °C ÷ + 60 °C, relative humidity range of 0% ÷ 100% and measurement accuracy 0.03% with hot-wire thermoanemometric probe with air flow velocity measuring range of 0.08 ÷ 2 m s^{-1} measurement accuracy ± 0.04 m s^{-1} ± 1% and omnidirectional probe of the appropriate range with air flow velocity measuring range of 0.05 ÷ 5 m s^{-1} and measurement accuracy ± 0.02 m s^{-1} ± 1.5%.

Ambulant measurements were performed on days when the outside air temperature exceeded 30 °C and the air speed did not exceed 2.0 m s^{-1}. The measurements usually took place between 1:00 pm and 5:00 pm. During the measurements, the same procedure was always followed in both objects (at the measuring points according to (Fig. 1; Fig. 2), and, following the same order, the measurements were alternated in the lines of observation points arranged perpendicularly to the object axis and longitudinally to the object axis).

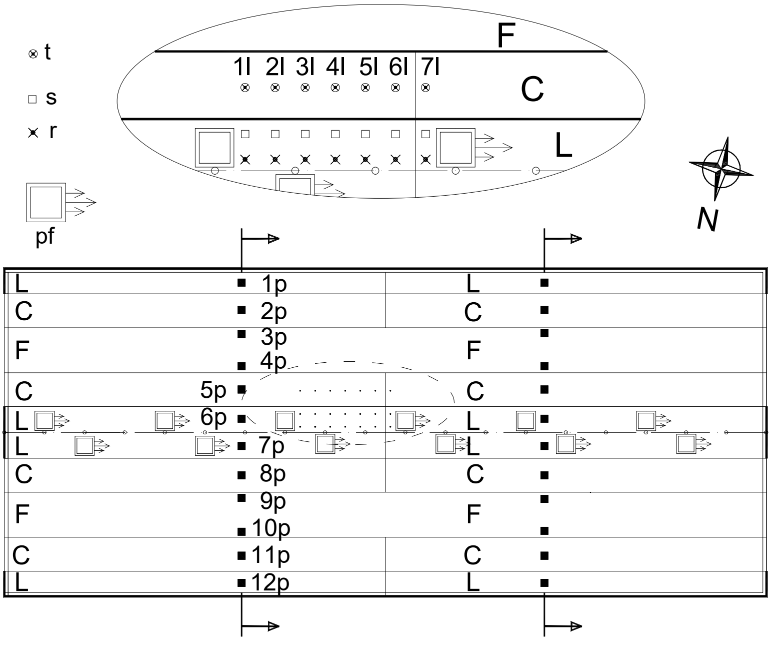

Figure 2. Layout of barn 2 with locations of panel fans and measuring points.

(pf – panel fan; 1l–7l are measuring points in the longitudinal direction of the object spaced 1,200 mm apart; r – places of lying area with measurements at a height of 500 mm; s – measuring places of lying area with measurements at a height of 1,200 mm; t – moving alley with measurements at a height of 1,200 mm; 1p – 12p are measuring points in the direction perpendicular to the longitudinal axis of the object; L – lying zone; C – movement corridor; F – feeding corridor).

The average values of climatic parameters were used for the calculation part to determine selected thermal indices THI, HLI and ETIC (Eq. 1; Eq. 2; Eq. 3). Index calculations were performed according to the recommendations of Fournel et al. (2017) and Wang et al. (2018a). The following equations for the Temperature humidity index (THI), Heat load index (HLI) and Equivalent temperature index for cattle (ETIC) were used:

$$\mathrm{THI} = (1.8 \cdot \mathrm{Tdb} + 32) - \left((0.55 - 0.0055 \cdot \mathrm{RH}) \cdot (1.8 \cdot \mathrm{Tdb} - 26.8)\right) \quad (1)$$

where Tdb – The dry bulb temperature, °C; RH – Relative humidity, % (Kelly & Bond, 1971)

$$\mathrm{HLI}(\text{if}\ \mathrm{Tbg} \geq 25) = 8.62 + (0.38.\mathrm{RH}) + (1.55.\mathrm{Tbg}) - (0.55.\mathrm{WS}) + e^{2.4-\mathrm{WS}} \quad (2)$$

where Tbg – Black globe temperature, °C; RH – Relative humidity, %, WS – Wind speed, m s^{-1} (Gaughan et al., 2008)

$$\begin{aligned}\mathrm{ETIC} = {} & \mathrm{Tdb} - 0.0038 \cdot \mathrm{Tdb} \cdot (100 - \mathrm{RH}) - 0.1173 \cdot |\mathrm{WS}|^{0.707} \cdot (39.2 - \mathrm{Tdb}) \\ & + 1.86 \cdot 10^{-4} \cdot \mathrm{Tdb} \cdot \mathrm{SR}\end{aligned} \quad (3)$$

where Tdb – Black globe temperature, °C; RH – Relative humidity, %; WS – Wind speed, m s^{-1} (Wang et al., 2018a).

Statistical analyses were under taken using STATISTICA 10. These involved descriptive statistics followed by an analysis of variance (ANOVA).

RESULTS AND DISCUSSION

The level of heat load in both buildings was first evaluated using the THI Temperature-humidity index. The measurement results obtained from measuring points 1 to 12, which were arranged in a line perpendicular to the direction of air flow, are shown in Figs 3 and 4.

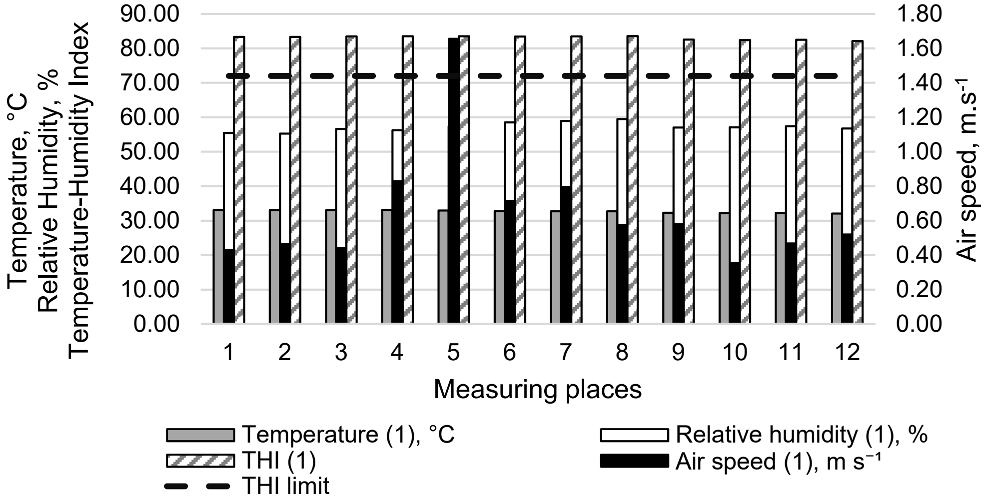

Figure 3. Results of the measured microclimatic variables in barn 1 with the corresponding temperature-humidity index THI (1).

It was found that the average air temperature measured (in 1p – 12p according to Figs 1 and 2 in the animal zone in two cross sections) was $T(1)_{ai,avg} = 32.69 \pm 0.40$ °C in barn 1 and $T(2)_{ai,avg} = 32.85 \pm 0.31$ °C in barn 2. The temperature detected in 1p and 2p located at the left longitudinal barn wall was higher than the temperature at 11p and 12p at the right wall due to its exposure to sun and partial penetration of solar radiation through the left wall openings.

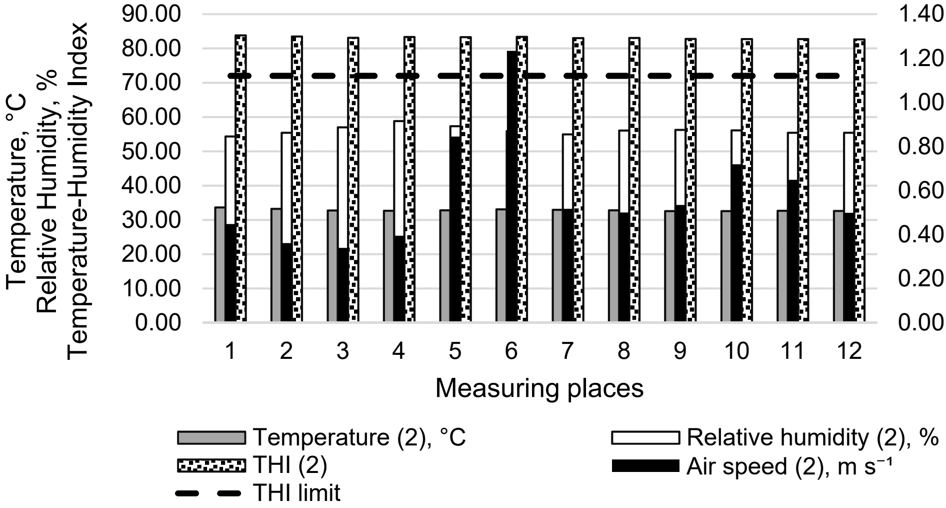

Figure 4. Results of the measured microclimatic quantities in barn 2 with the corresponding temperature-humidity index THI (2).

The air temperature near the longitudinal perimeter walls in barn 1 was even lower (but not significantly, $p > 0.05$) than the temperature in barn 2 (in all places 1p, 2p, 11p and 12p), however, the ventilation of fan performance in barn 2 was higher by 32% (289,320 $m^3 h^{-1}$ vs. 218,400 $m^3 h^{-1}$). The air temperature measured at locations of groups housed in the middle of barn at 5p, 6p, 7p and 8p showed more balanced-values: from $T_{ai} = 32.18$ °C to $T_{ai} = 33.07$ °C.

The average relative humidity in the barn 1 was $RH(1)_{avg} = 57.18\%$, and $RH(2)_{avg} = 56.08\%$ in the barn 2, while the highest values were found in the middle barn areas (from places of 4p to 8p). With the exception of the left feed corridor area (3p, 4p and 5p), the relative humidity in the animal zone was always higher ($p < 0.05$) in barn 1 compared to barn 2, which corresponds to the size difference of openings in the side walls $A(1)_{op} = 77.82$ m^2 in barn 1 in contrast to, $A(2)_{op} = 212.5$ m^2 in barn 2.

The average air flow speed from cross sections was $v(1)_{avg} = 0.65$ m s^{-1} and $v(2)_{avg} = 0.59$ m s^{-1}. The air velocity in the middle barn area, were significantly higher ($p < 0.05$) in both buildings, especially in measuring points 5p, 6p, 7p and 8p (the average air speed was $v(1)_{(5,6,7,8)} = 0.93$ m s^{-1} and $v(2)_{(5,6,7,8)} = 0.77$ m s^{-1}) in barn 2 in contrast to points at the perimeter walls ($v(1)_{(1,2,11,12)} = 0.47$ m s^{-1} in barn 1 and $v(2)_{(1,2,11,12)} = 0.49$ m s^{-1} in barn 2).

Based on the determined performance of operating fans, the theoretical air exchange in objects with the same air volume was $ACH(1)_{theor} = 27.49\ h^{-1}$ for barn 1, and $ACH(2)_{theor} = 36.43\ h^{-1}$ for barn 2, however, based on results acquired, there was worse air exchange in main animal zone in barn 2 in comparison to barn 1 even though it is equipped with ventilation technology with higher performance.

For the calculations from experimental measurements in the animal zone, two simplified logical assumptions were introduced: 1) the velocity vector direction is the same in all places of the animal life zone (identical to the air pressure direction driven by fans); 2) if there is the same number of animals housed in-in barn 1 and barn 2, then the extent of the cumulative resistance that the animals present by their bodies as the partial barriers affecting the air flow rates in both barns will be the same.

However, the barn 2 showed worse ventilation ($ACH(1)_{exp} = 37.74\ h^{-1}$, $ACH(2)_{exp} = 34.25\ h^{-1}$) using the average air velocity ($v(1)_{avg} = 0.65\ m\ s^{-1}$ in barn 1; $v(2)_{avg} = 0.59\ m\ s^{-1}$ in barn 2).

By subsequent determination of selected temperature indices (THI, HLI and ETIC according to the methodology, using formula 1, 2 and 3, it was found that the heat load levels in the interior of both barns, which were calculated using the measured data from all measuring points, are in the equally dangerous category.

In barn 1, $THI(1) = 83.1 \pm 0.51$ and in barn 2, $THI(2) = 83.12 \pm 0.34$ (it means that, in both barns, there is a category of severe stress with conditions of $80 < THI < 89$). However, observed level of THI indicates that the environment in both barns is equally risky in terms of animal heat load, despite the better ventilation capacity in barn 2.

Based on the calculations of HLI, it was found that $HLI(1) = 85.62 \pm 1.42$ for barn 1 is almost identical to $HLI(2) = 85.77 \pm 1.51$ for barn 2 (Fig. 5). This index also confirmed the high level of heat load in both barns when the animals - despite the establishment of technical measures in the summer - were exposed to the so-called category of hot environment ($77.1 \leq HLI \leq 86$) in both barns.

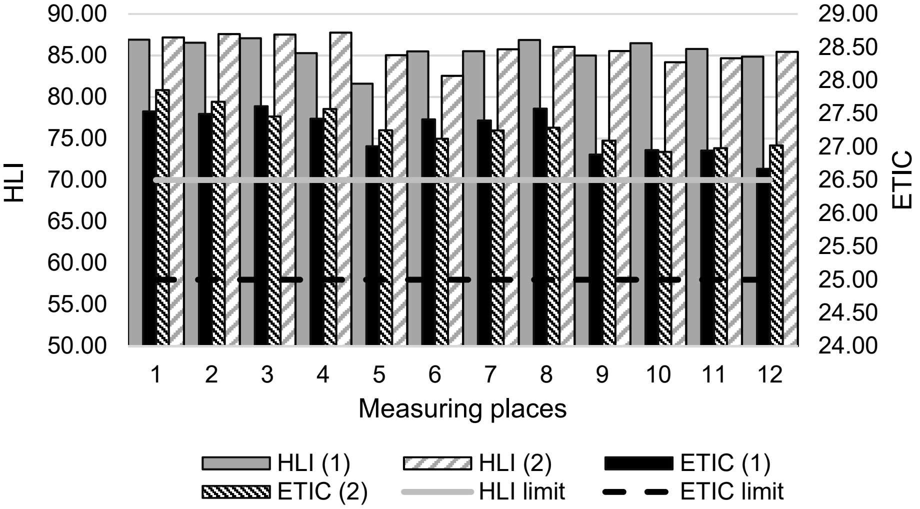

Figure 5. Results of environment evaluation state using HLI and ETIC in both barns.

A comparison of differences between the values of THI, HLI and ETIC indices found in the peripheral areas (1p, 2p, 11p and 12p) and the inner areas (5p, 6p, 7p and 8p) of the animal zone showed better results for barn 1 with basket fans in terms of heat load in the vicinity of the longitudinal masonry walls. The deviation in HLI index ($\Delta HLI_{avg} = 1.32\%$) were larger than the deviations in THI and ETIC ($\Delta THI_{avg} = 0.50\%$ and $\Delta ETIC_{avg} = 0.56\%$, respectively), however, a significant difference in the objects was not confirmed ($p > 0.05$).

It was found that the heat load calculated by means of ETIC, which, takes into account the multifactor influence of the environment in addition to temperature, showed almost the same heat load in both buildings. In barn 1, $ETIC(1) = 27.24 \pm 0.31$; $ETIC(2) = 27.29 \pm 0.81$ in barn 2.

The differences were also demonstrated in the control calculation of the partial air exchanges in the building determined according to the evaluated speed levels at individual measuring points and in the recalculation of the ETIC coefficient in the network of points arranged parallelly to the axis of the fan arrangement (in 3 rows of places 1l–7l). According to these results, the level of heat load was lower in barn 1, however, the above-limit values were observed in both buildings (severe stress, ETIC > 25).

For adding more motor ventilation devices, different fan mounting points were selected in the buildings, which used the existing steel structural elements. In barn 1, basket fans were installed at a height of 2.8 m and inclined at an angle of 10° towards the animals. In the barn 2, panel fans were used to move the air horizontally from the entrance to the in-farm dungstead.

In barn 2, the panel fans were concentrated directly along the longitudinal axis at a height of 3.8 m above the opposite heads of the lying animals. Although their higher performance ensured a more intensive air exchange in its entire, it did not affect the environment of the animal life zone to any significant extent.

The course of ETIC coefficient values is shown in Fig. 6. The average value in the longitudinal measuring field $ETIC(1)_{long}$ at the height of 1,200 mm was $ETIC(1)_{avg,\,long} = 27.01$ in barn 1, and $ETIC(2)_{avg,\,long} = 27.70$ in barn 2. For measurements at 500 mm, $ETIC(1)_{avg,\,long} = 27.71$ in barn 1, and $ETIC(2)_{avg,\,long} = 27.69$ in barn 2. The values obtained by measurements in the direction of air flow between adjacent fans carried out successively at seven places located 1.2 m apart from each other (in compliance with the bed size) ranged from $ETIC(1)_{min} = 26.14$ to $ETIC(1)_{max} = 27.9$ in barn 1, and from $ETIC(2)_{min} = 26.87$ to $ETIC(2)_{max} = 28.61$ in barn 2 (Fig. 6).

Based on the ETIC results obtained from measurements along the air flow between adjacent fans, it was found that the reduction of the heat load occurs especially in areas located 2 to 5 m from the fan.

An average decrease of this index was in barn 1, $\Delta ETIC(1)_{avg} = 1.67$ and $\Delta ETIC(2)_{avg} = 1.38$ in barn 2. Furthermore, the lowest values of $ETIC(1)_{min} = 26.17$ were achieved in barn 1, the maximum values were obtained in barn 2, $ETIC(2)_{max} = 28.16$.

The ETIC values inversely corresponded to a gradual decrease in the air flow rate in the direction along the air flow between the fans. This development did not correspond to the development of ETIC in the peripheral barn areas near the perimeter walls, in which no changes in the air flow in the longitudinal direction initiated by the fans were observed. Insufficient air exchange in the peripheral barn areas creates unequal living conditions for housed animals, which should be further addressed by a multi-level process of heat load modification, including the utilization of computer climate modeling.

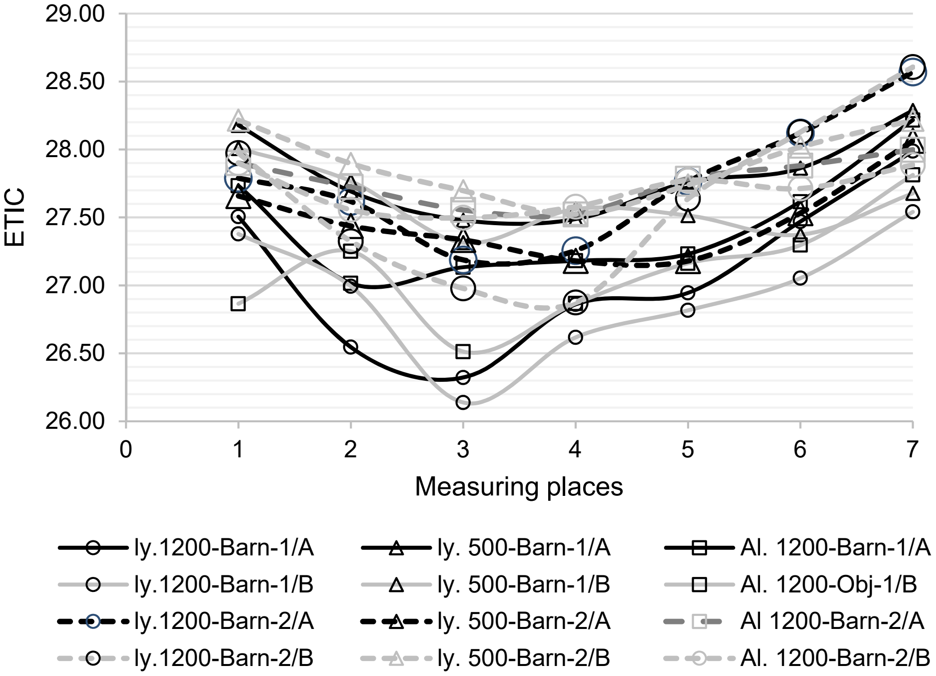

Figure 6. Results of the ETIC evaluation in the longitudinal direction of the barns in the area of adjacent fans (in the lying area at a height of 1,200 mm and 500 mm and in the movement alleys at a height of 1,200 mm – see Fig. 1 and Fig. 2).

Every year, in the Slovak lowlands, more than half of the days with air temperatures above 25 °C occur during the summer months, and the number of tropical days also increases. The limit value of the thermoneutral zone for dairy cows may vary, the older literature Berman et al. (1985) recommends a value up to 25 °C, newer articles report a threshold value up to 15 °C (Garner et al., 2017).

At higher air temperatures, heat production also increases, with high-producing cows being at greater risk of heat stress than low-producing cows (Pragna et al., 2017; Liu et al., 2019). The temperature in stables culminates especially in the afternoon when its maximum level can remain even for several hours.

In the study presented, it was found that the average afternoon indoor temperature was higher than 32 °C in both buildings ($T(1)_{ai,avg} = 32.69$ °C ± 0.40 °C in barn 1; $T(2)_{ai,avg} = 32.85 \pm 0.31$ °C in barn 2), reaching the highest level in the inner barn sections. For this reason, the location of ventilation technology is especially important in this area.

Heat load affects the reduction of feed intake, which in turn leads to lower milk production, and therefore, it is necessary to create some procedures to reduce heat stress in dairy cows (Könyves et al., 2017).

Several authors, i.e. Wang et al. (2018b) and Tyson, (2010), recommend using airflows ranging from 2.0 m s^{-1} to 3.0 m s^{-1} for cooling the cattle housing during summer. It is important to achieve a suitable speed and direction of flow in the zone occupied by animals (Wang et al., 2018b; Zou et al., 2020).

The air flow rate found in study presented did not reach the level of 2.0 m s^{-1} ($v_{max} < 2.0$ m s^{-1}). In the individual profiles of cross section, the average afternoon air velocity did not reach nor the level of 1.0 m s^{-1} ($v(1)_{avg} = 0.65$ m s^{-1} in barn 1; $v(2)_{avg} = 0.59$ m s^{-1} in barn 2), which raises the need to properly supplement the ventilation system in a manner that there would be better opportunities for cooling the animals even in the peripheral barn areas.

For the purposes of such solutions, it is advantageous to use computer modelling and effective utilization of geometric potential of the building, as well as possibility to adjust the motor ventilation capacity (Yi et al., 2019; Saha et al., 2020). The heat load in dairy cows can be assessed using several methods, but they provide different threshold values (Hammami et al., 2013; Ji et al., 2020).

THI results can be evaluated according to various recommended criteria, however, according to several studies, negative reactions to heat load already occur at values above THI = 68, Zimbelman & Collier (2011) or THI = 72, Bernabucci et al. (2014), respectively Liu et al. (2019) state that dairy cows feel a mild stress when the THI value rises above 72.

Heat stress can be alleviated by various cooling devices, such as fans and sprayers. These measures have been found to improve air quality in barns (Chen et al., 2015; Tresoldi et al., 2018; Chen et al., 2020). There are some different possibilities to solve other concept in building science, too (Kic et al., 2017; Leso et al., 2017; Salama, 2017).

In the study presented, the above-limit level of THI was recorded in both barns ($THI(1) = 83.1 \pm 0.51$ in barn 1; $THI(2) = 83.12 \pm 0.34$ in barn 2) even though both objects were intensively ventilated stables with an insulated roof, causing severe stress level according to most authors (Bohmanova et al., 2007; Akyuz et al., 2010; Bernabucci et al., 2014).

Several authors, i.e., Ammer et al. (2018), Liu et al. (2019), argue that it is required to consider other factors that affect environmental indices in terms of assessing the THI.

As THI does not include the influence of air velocity and other environmental factors, both objects were further evaluated using HLI and ETIC indices.

When evaluating the heat load using the HLI index, it was also confirmed that the animals are in a stressful environment in both buildings after taking into account the flow rate ($HLI(1) = 85.62 \pm 1.42$, and $HLI(2) = 85.77 \pm 1.51$). Even the addition of motor ventilation did not improve the conditions in barn 2. It is believed that the air flow in this building was driven mainly over the animals, because the axial height of the panel fans was 3.3 m. In the windy climate situation at this level, there is better interference of the transport of air masses Yi et al. (2019), but these phenomena are rare at the farm location and do not usually take place during the hottest days.

If the external wind situation does not improve the condition inside the buildings, HLI regularly rises above HLI = 70 in the afternoon in the summer. Study by Van lear et al. (2015), examined the relationship of HLI to the production parameters of dairy cows and found that increasing HLI reduced milk yield, where, a decrease in milk was 1.0 kg per animal at a daily average HLI of 85. Vitali et al. (2019) stated that, during the summer study from June to September, the HLI values ranged from 72 to 80. They found that the incidence of clinical mastitis had also been shown to increase in connection to above-limit HLI values.

However, the ventilation technology used cannot guarantee the elimination of these risks. Furthermore, according to the evaluation of the Equivalent temperature index for cattle, the animals in both buildings were exposed to the conditions of severe heat load ($25 < \text{ETIC} < 31$), as in both buildings the $\text{ETIC} = 25$ limit was exceeded ($\text{ETIC}(1) = 27.24 \pm 0.31$ in barn 1, and $\text{ETIC}(2)= 27.29 \pm 0.28$ in barn 2).

At the measuring points arranged perpendicularly to the flow direction, there were observed $\text{ETIC}_{\text{min}} = 26.79$ and $\text{ETIC}_{\text{max}} = 27.73$. In the measurements close to the center and parallel to the driven air flow, there were observed $\text{ETIC}_{\text{min}} = 26.14$ and $\text{ETIC}_{\text{max}} = 28.67$. The differences were higher along axis of the flow, although the values at the perimeter walls were worse due to lower local air exchange. By getting closer to the fan, the differences became more pronounced, which also demonstrated by the animal behaviour - the cattle grouped at better ventilated place. However, at the place with the highest ventilation effect, it was found that the ETIC was reduced only by 1.6, which is not sufficient at this level of heat load.

CONCLUSIONS

The work aim was to investigate the relationship of ventilation technology to the heat load of dairy cows in two structurally and dispositional identical barns with different total fan performance: $Q(1)_{\text{fans}} = 218{,}400\ \text{m}^3\ \text{h}^{-1}$ and $Q(2)_{\text{fans}} = 289{,}320\ \text{m}^3\ \text{h}^{-1}$, with longitudinal air flow and fans situated around the object longitudinal axis. It was found that the values of temperature indices showed a high temperature load, but the differences between the objects were not significant ($p > 0.05$), when the Temperature humidity index was $\text{THI}(1) = 83.10 \pm 0.51$ in barn 1, and $\text{THI}(2) = 83.12 \pm 0.34$ in bar 2, as well as for Heat load index: $\text{HLI}(1) = 85.62 \pm 1.42$ and $\text{HLI}(2) = 85.77 \pm 1.50$ also for the Equivalent temperature index for cattle, which was $\text{ETIC}(1) = 27.24 \pm 0.31$ and $\text{ETIC}(2) = 27.29 \pm 0.28$.

Based on detailed climatic measurements, it was found that, according to measurements at 12 points arranged always in a direction perpendicular to the building axis, the central barn area was more cooled than the side areas near the longitudinal barn walls. However, based on the measurements in the longitudinal direction, it was found that, in the central part of the object within a direct reach of fans in almost half of the measuring points, there was sufficient reduction in heat load ($\text{ETIC} < 0.5$), but better results were obtained in barn 1 with a two–row fan arrangement.

For both barns, the calculations pointed the need to further intensify the cooling of animals in order to adequately improve the possibility of heat excess dissipation. Using computer modelling, it is possible to improve the conditions so that they are evenly available to as many animals as possible.

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