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EVALUATION OF DAIRY BUILDING CLIMATE CONDITIONS TO MEET COW WELFARE REQUIREMENTS

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The aim of the study was to assess the microclimate and the zoohygienic indicators in the context of cow welfare during the period of indoor keeping in a tie-stall barn located in the Podlaskie voivodeship. The temperature and humidity conditions in the building in autumn and winter corresponded to the recommendations and ensured the correct level of dairy cow welfare. The relative air humidity in the spring period was too low in relation to zoohygienic standards. During the total period of study, the average value of cooling exceeded the recommended standards. In the present study, the air velocity in the barn throughout the indoor period was within the recommended values. The excessively low humidity inside the barn in spring suggested that the natural ventilation was not operated correctly, which could have caused a reduction in the welfare level of dairy cows. Taking into account the level of microclimate indicators, it was found that the analysed barn has good heat insulation, ensuring the animals' proper housing conditions during low outdoor temperatures.

Key words: indoor housing, dairy cows, animal welfare, microclimate, tie-stall barn

Livestock building microclimate is one of the main factors affecting the animal welfare. The aim of dairy farming is to reach the highest milk yield of cows maintaining the welfare of the animals by keeping proper microclimate of the building (Cook et al., 2005). Due to the complex character of the term "welfare" it is difficult to determine unambiguous criteria of its assessment. The criteria have been broken down into objective (clinical and laboratory diagnostics, statistical analyses) and subjective ones (animal behaviour observations, individual perception of the environmental situation) (Kondracki et al., 2014). The breakdown of the welfare into physiological, behavioural and health indicators is common (Wójcik et al., 2017). In addition to building the microclimate, animal welfare is determined by nutrition, type of housing, and animal handling (Fragonesi and Leaver, 2001; Szewczyk et al., 2016). Barn climate conditions are major reasons for animal stress in moderate climate zones (Legates et al., 1991). To maintain the welfare it is important to determine if the livestock housing ensures optimal parameters of the interior microclimate, if the temperature and humidity conditions are correct, if it is well lit, what the air composition is, and if the proper ventilation is provided (Cook et al., 2005).

Among the microclimate factors, those having the greatest impact on the level of welfare and comfort of livestock are the air temperature and humidity inside the housing (Kadzere et al., 2002). Temperature and humidity should be analysed together as thermal conductivity depends on air humidity. At low temperatures the excessive air humidity increases the cooling intensity and may lead to inflammation of the airways (Broucek et al., 1991). At high relative air humidity and high temperature heat dissipation from the animal body is more difficult (Gauly et al., 2013). Heat accumulation and animal body temperature rise are observed (Allen et al., 2015). That may lead to heat stress (Hill and Wall, 2015). According to Du Preez et al. (1990) a cow feels the heat stress at the temperature of 22°C and relative air humidity of 100%, 25°C at 50% humidity, or 28°C at 20% humidity. Increased air humidity combined with high temperature disturbs the metabolism, decreases the efficiency and deteriorates the health condition of the animal (Herbut et al., 2018).

In dairy cow housing, especially in tie-stall barns it is recommended to maintain the temperature in the range of 8°C to 16°C, and the optimal temperature should be 12°C (Kołacz and Dobrzański, 2006). Very significant worsening of the dairy cow welfare can be observed after exceeding the temperature of 24–27°C (Broucek et al., 2009). According to the international standards, the relative air humidity in the livestock housing should be 60–80% (St-Pierre et al., 2003; West, 2003). Maintaining the optimal air humidity makes it possible to avoid the ceiling moisture and building structure, to clean the livestock and to ensure correct working conditions for people (Matković et al., 2006). In colder buildings and during the winter a drier environment is more favourable, however, on hot days it is recommended to increase the air humidity.

The movement of the air is the required condition for the ventilation and cooling of the animal bodies. For optimum air movement value, movement of the air in livestock housing should not exceed 0.3 $m \cdot s^{-1}$ (Kołacz and Dobrzański, 2006). However, a higher air speed helps to cool the animal down. In hot weather, the movement of the air may have favourable effects and improve the livestock welfare (Kaczor et al., 2014). In the USA, the effective air velocity recommended for dairy livestock during heat stress is from 1.8 to 2.8 $m \cdot s^{-1}$ (Bailey et al., 2016). To ensure the welfare ventilation devices must efficiently remove air that is humid and contaminated with gas additives and provide the flow of fresh air (Kondracki et al., 2014).

The purpose of this research was to assess the microclimate and the zoohygienic indicators in the context of dairy cow welfare during the period of indoor keeping in a tie-stall barn located in the Podlaskie voivodeship.

Material and methods

The research was conducted in a barn located in Siemiatycze municipality, Podlaskie voivodeship, Poland (52˚25'9''N; 22˚57'8''E). The measurements were conducted during autumn (October), winter (January) and spring (April) in the years 2018–2019. The building has brick 45 cm-thick walls with its long axis situated in the north-south direction. There are 9 windows on both sides: six windows on the eastern side and three on the western side. On the northern wall there are two windows on both sides of the door. The barn with the area of 300 m^2 and the volume of 900 m^3 is used by tie-stall barn dairy cows on straw litter (31 stands with dimensions of 1.85 × 1.1 m). The building has natural ventilation with 3 exhaust chimneys. The air flows into the building through tilt windows and through a fan installed in one of the windows, which during the winter is replaced with a solid window pane. The used air flows through the exhaust ducts on the ceiling and through 9 ceiling pipes embedded in the walls. The herd consists of 31 Polish Black-and-White Holstein-Friesian cows. The cows were characterized by good health and productivity. Average milk yield was around 8,500 litres/cow.

The analysis of zoohygienic welfare level indicators was carried out during the period of indoor keeping for dairy cows:

– From 1 October to 31 October (autumn);
– From 1 January to 31 January (winter);
– From 1 April to 30 April (spring).

The technical assessment of the barn and its equipment was carried out using the zoohygienic inventory method according to the methodology of Dobrzański and Kołacz (1996) and Kośla (2011). The measurements of the zoohygienic parameters were made three times a day (at 07:00 AM, 01:00 PM and 09:00 PM). The measurements of the air temperature and relative humidity as well as the measurements of cooling and air velocity were conducted. The air temperature and relative humidity were identified using D3121 hygrothermometer (Comet, Poland), while cooling was measured with a dry Hill's cathathermometer. The air velocity was measured with a thermal anemometer TA35 (Airflow™, United Kingdom). Additionally, with the use of thermo hygrographs the air temperature and relative humidity were registered outside and inside the barn. On the basis of the temperature, relative humidity, cooling and air velocity measurements the microclimate indicators were determined. The indicators can be used for the comprehensive assessment of bioclimate conditions in the livestock housing (Dobrzański and Kołacz, 1996; Kośla, 2011):

– The wind chill temperature (WCT) that determines the felt thermal conditions resulting from the air temperature, its humidity and velocity. The wind chill temperature calculations were conducted using the Missenard formula (Dobrzański and Kołacz, 1996);

– The thermal comfort factor (B) expressed by the temperature-to-cooling ratio measured with a dry cathathermometer (Dobrzański and Kołacz, 1996; Kośla, 2011);

– Heat insulation coefficient (HIC) describes how many times lower the cooling is inside the building than outside, i.e. the heat insulation value of the indoor facility. Heat insulation coefficient is usually expressed as the quotient of external and internal cooling (Dobrzański and Kołacz, 1996; Kośla, 2011).

The results were statistically analysed using the Statistica software ver. 12.5. The differences in the air temperature and relative humidity between the external environment and the barn were verified using the t-Student test ($P \leq 0.05$).

Table 1. Average air temperature and relative humidity in particular weeks in the autumn season (October 2018) (means ± SD)
Tabela 1. Średnia temperatura powietrza i wilgotność względna w poszczególnych tygodniach w okresie jesiennym (październik 2018) (średnia ± odchylenie standardowe)

Parameter Parametr	Week Tydzień							
	I		II		III		IV	
	outdoor na zewnątrz	indoor wewnątrz	outdoor na zewnątrz	indoor wewnątrz	outdoor na zewnątrz	indoor wewnątrz	outdoor na zewnątrz	indoor wewnątrz
Temperature (°C) Temperatura (°C)	9.09±3.92	11.06±2.11	7.83±2.81	9.84±1.57	6.76±4.87	10.13±2.28	1.44 a±3.21	8.14 b±0.69
Relative humidity (%) Wilgotność względna (%)	66.61 a±4.07	68.24 b±3.75	56.7 a±4.22	63.61 b±3.81	56.71±4.22	74.86 b±4.18	81.14 b±6.49	75.91 a±5.94

a, b – means in rows with different lower-case letters differ significantly at P≤0.05.
a, b – średnie w wierszach oznaczone różnymi literami różnią się istotnie przy P≤0,05.

Table 2. Average air temperature and relative humidity in particular weeks in the winter season (January 2019) (means ± SD)
Tabela 2. Średnia temperatura powietrza i wilgotność względna w poszczególnych tygodniach w okresie zimowym (styczeń 2019) (średnia ± odchylenie standardowe)

Parameter Parametr	Week Tydzień							
	I		II		III		IV	
	outdoor na zewnątrz	indoor wewnątrz	outdoor na zewnątrz	indoor wewnątrz	outdoor na zewnątrz	indoor wewnątrz	outdoor na zewnątrz	indoor wewnątrz
Temperature (°C) Temperatura (°C)	–5.68 a±4.68	8.29 b±1.18	0.96 a±3.55	8.99 b±1.50	–3.44 a±5.52	9.44 b±2.04	–4.95 a±2.95	9.20 b±1.30
Relative humidity (%) Wilgotność względna (%)	80.10 b±6.63	61.58 a±2.43	77.38 b±2.45	64.29 a±3.23	77.84 b±3.47	68.15 a±3.90	73.55 b±4.65	60.54 a±4.90

a, b – means in rows with different lower-case letters differ significantly at P≤0.05.
a, b –średnie w wierszach oznaczone różnymi literami różnią się istotnie przy P≤0,05.

Table 3. Average air temperature and relative humidity in particular weeks in the spring season (April 2019) (means ± SD)
Tabela 3. Średnia temperatura powietrza i wilgotność względna w poszczególnych tygodniach w okresie wiosennym (kwiecień 2019) (średnia ± odchylenie standardowe)

Parameter Parametr	Week Tydzień							
	I		II		III		IV	
	outdoor na zewnątrz	indoor wewnątrz	outdoor na zewnątrz	indoor wewnątrz	outdoor na zewnątrz	indoor wewnątrz	outdoor na zewnątrz	indoor wewnątrz
Temperature (°C) Temperatura (°C)	7.75±4.44	11.03±1.85	9.53±4.68	12.36±2.46	7.68 a±8.63	13.29 b±1.18	15.45±7.28	15.14±4.36
Relative humidity (%) Wilgotność względna (%)	54.68 b±1.73	42.44 a±4.28	58.35 b±2.04	53.01 a±3.01	61.88 b±2.26	45.26 a±5.54	54.98 b±3.93	45.21 a±4.89

a, b – means in rows with different lower-case letters differ significantly at P≤0.05.
a, b – średnie w wierszach oznaczone różnymi literami różnią się istotnie przy P≤0,05.

Table 4. Mean values of selected zoohygienic indicators in the autumn, winter and spring period
Tabela 4. Średnie wartości wybranych wskaźników zoohigienicznych w okresie jesiennym, zimowym i wiosennym

Parameter Parametr	Autumn Jesień				Winter Zima				Spring Wiosna			
	Week Tydzień				Week Tydzień				Week Tydzień			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
WCT (°C) EET°	9.40	7.83	8.26	6.20	7.50	7.94	7.93	7.90	9.27	10.21	10.84	12.16
Air movement ($m \cdot s^{-1}$) Ruch powietrza	0.16	0.21	0.17	0.16	0.09	0.14	0.15	0.13	0.15	0.18	0.21	0.30
Cooling ($mW \cdot cm^{-2}$) Ochładzanie	39.53	43.80	42.64	42.89	38.40	40.15	40.30	39.40	39.94	40.81	43.75	47.29
HIC WOC	2.47	2.13	2.22	2.17	2.18	2.44	2.49	2.45	2.25	2.57	2.38	2.58
TCF B	0.28	0.20	0.23	0.20	0.21	0.24	0.23	0.23	0.27	0.30	0.31	0.32

WCT – wind chill temperature; HIC – heat insulation coefficient; TCF – temperature comfort factor.
EET° – temperatura odczuwalna; WOC – współczynnik ochrony cieplnej; B – współczynnik komfortu temperaturowego.

Results

Tables 1–3 show the mean thermal and humidity values in the months of indoor keeping system (October, January and April). The results of temperature measurements in the analyzed building prove the differentiation of that parameter in particular seasons. The analysis of results shown in Table 1 indicates that in autumn (October), the mean temperatures inside the barn were maintained within the range of zoohygienic standards, from 8.14 to 11.06°C. In October, the mean temperatures inside and outside the barn during the first, second and third week were not statistically different. In the fourth week a statistically significant difference between the temperatures registered inside and outside the building was found ($P \leq 0.05$). The relative air humidity registered in the dairy barn in autumn was within the recommended range. It was found that during the first, second and third week of October the mean values of the relative humidity were significantly higher inside the barn when compared to the mean values registered in the atmospheric conditions ($P \leq 0.05$). During the fourth week, the average relative humidity value outside was 5.23% higher than inside the barn ($P \leq 0.05$). In the winter period the mean temperature values were within the optimal range for dairy cattle. Statistically significant average temperature differences were found between the temperatures registered inside and outside the barn ($P \leq 0.05$) (Table 2). Statistical differences were found between the relative air humidity inside the barn and the humidity outside ($P \leq 0.05$). Mean air temperatures in the barn in spring (April) did not exceed the zoohygienic recommendations for dairy cows (Table 3). The average spring air temperature in the barn ranged from 11.03°C to 15.14°C. Statistically significant differences between the temperatures registered inside and outside the building were found only in the third week of April ($P \leq 0.05$). In the spring the lowest relative air humidity value during the period of indoor keeping system was found. Relative air humidity in the spring period ranged from 42.44% to 53.35% (Table 3).

Table 4 shows the zoohygienic indicators used to assess the dairy cows welfare in particular periods of indoor keeping system. The wind chill temperatures (WCT) in the autumn season were within the limits considered as optimal for dairy cattle. In autumn the air velocity in the building ranged from 0.16 to 0.21 $m \cdot s^{-1}$. The air movement speed in October had a mean value of 0.17 $m \cdot s^{-1}$, corresponding to the recommendations for dairy cattle. An increased air velocity was found in the second week of October. In autumn cooling values ranged from 39.53 to 43.80 $mW \cdot cm^{-2}$. Average autumn cooling values were exceeded in the examined dairy barn. The average monthly value of cooling obtained in October was 42.21 $mW \cdot cm^{-2}$. The temperature comfort factor ranged from 0.20 to 0.28. The examined barn was characterized by good thermal insulation confirmed by the heat insulation coefficient ranging from 2.13 to 2.47. The analysis of zoohygienic indicators in winter showed that the WCT values did not exceed the allowable limits. The wind chill temperature in winter season ranged from 7.50 to 7.94. The data in Table 5 indicate that the microclimate conditions in the barn in January were balanced regardless of the outside conditions. In the studied building the air velocity values did not exceed the recommended value range. In the present study the recorded mean winter cooling values were slightly higher than recommended. The temperature comfort factor ranged from 0.21 to 0.24.

On the basis of results presented in Table 4, gradual rise of the wind chill temperature (WCT), air movement and cooling value in the following weeks of April was observed. The mean air velocity value and the wind chill temperature matched the zoohygienic recommendations. Mean spring cooling values were exceeded in the analyzed barn, especially in the fourth week of April.

Discussion

The main function of a livestock building is to maintain the appropriate microclimate, i.e. sufficient air temperature, humidity and air flow velocity (Herbut and Angrecka, 2012; Marciniak, 2014). The thermal and humidity analysis of the outdoor and indoor conditions of the barn enables the determination of heat insulation and heat autonomy of the buildings. The indoor air temperature of livestock buildings is directly related to the external temperature (Pajumägi et al., 2007). In the present study, registering similar temperatures inside and outside the cowshed in autumn could be the result of increased barn venting by opening the door and the high average temperature measured in the country in October, which was 10.2°C (Kępińska-Kasprzak, 2019). The higher average relative humidity inside the building compared to the mean values observed in the atmospheric conditions could be the result of venting the building (open door) during the day for the first three weeks of October. Similarly, Stowell et al. (2001) reported that relative air humidity inside the barn was found to be higher than that outside. The distinct difference in mean air temperature inside and outside the building in winter may prove the good heat insulation and excellent heat autonomy of the assessed barn. It should be noted that January, and specifically its third decade, was very cold. Depending on the region, during the research period, the minimal temperatures in Poland were from –7°C to approximately –17°C (Kępińska-Kasprzak, 2019).

High air humidity in combination with low temperatures has a negative impact on animals (Kośla, 2011). In winter this can lead to colds and pneumonia (Lorenz et al., 2011). Gantner et al. (2011) reported that lower temperatures and high relative air humidity may cause the heat stress in dairy cattle. At the optimal air temperature of around 15°C, the optimal relative air humidity in dairy barn should be approximately 75%. Daniel (2008) observed that the results of humidity measurements conducted in winter were 66–85%. Similar results in humidity survey were reported by Kaczor and Paschma (2008). Głuski (2008) reported that livestock building microclimate, especially the temperature and air humidity, are the result of the outdoor climate influence. According to Kołacz and Dobrzański (2006), the optimal relative humidity is 50–80%, and values below 50% have been shown to increase the incidence of respiratory problems. Low relative air humidity value in relation to the recommended standards in April could be explained with the fact that it was a warm and dry month in all regions of the country (Kępińska-Kasprzak, 2019). This suggests the necessity of improvement of the ventilation system. In relation to the examined building, actions were taken to open the door in order to increase the air exchange in the barn. Fiedorowicz and Mazur (2011) obtained similar microclimate parameters during the period of indoor keeping system. In turn, the relative air humidity in the works of these authors had a much higher value when compared to own studies.

In the present study, during the period of indoor keeping system, the average wind chill temperature (WCT) values were within the limits considered as optimal for dairy cattle (Baeta et al., 1987). Perceived temperature indicates how the animals actually perceive the thermal conditions and keeping this indicator at an optimal level is a confirmation that the climate parameters in dairy barn were stable. In the present study, the temperature comfort factor and heat insulation coefficient confirm that the microclimatic conditions in dairy barn were good. The appropriate level of zoohygienic indicators in the period of indoor keeping system was also reported by Wójcik et al. (2017).

The movement of the air is the factor that shapes thermal conditions in the building. It is the required condition for the ventilation and cooling of the animal bodies. The air movement is mainly determined by thermal deracination, wind and difference between the level of inflow and outflow (Reppo et al., 2004). Air flow in animal buildings can have either positive or negative effects (Fournel et al., 2017). In the summer time, when temperatures are high, the increased air velocity protects the animals from overheating (Kołacz and Dobrzański, 2006). High air velocity will cause unpleasant draught and lowers their welfare level. Air velocity around animals during winter should therefore not exceed 0.3 m $\cdot$ s^{-1} (Poulsen and Pedersen, 2009). In the analyzed barn, the purpose of maintaining lower air velocity in the winter was achieved thanks to good tightness of the windows. Fiedorowicz and Mazur (2011) also reported that air movements persist at an optimal level in dairy barn with natural ventilation. In the present study, an increased air velocity in the second week of October and in the fourth week of April could lead to higher heat loss from the animal bodies. The higher movement of the air in the building in these periods was the result of the need to increase the ventilation in relation to higher temperatures registered outside the barn. This is confirmed by the increased cooling value (Wang et al., 2018).

Cooling is a physiologically significant factor that results from coincident action of temperature, relative humidity, air velocity and thermal radiation. Body cooling is mainly determined by the difference between the animal body temperature and the ambient temperature. The higher the difference, the more intensive the cooling is. In the present study, particularly elevated cooling values were recorded in autumn and spring season, which may indicate the possibility of thermoregulation system disorders in cows by the breeding environment. The fact that the average autumn, winter and spring cooling values were exceeded in examined barn may contribute to the onset of colds and muscular and articular rheumatism. This is mainly due to the venting of the building with the gate open.

Conclusions

The studies showed that the temperature and humidity conditions in the barn in autumn and winter corresponded to recommendations and ensured the correct level of cow welfare. The relative air humidity in the spring period was too low in relation to zoohygienic standards. During the total period of study, the average value of cooling exceeded the recommended standards. In the present study, the air velocity in the barn throughout the indoor period was within the recommended values. The excessively low humidity inside the barn in spring suggested that the natural ventilation was not operated correctly, which could have caused a reduction in the welfare level of dairy cows. Taking into account the level of microclimate indicators, it was found that the analyzed building has good heat insulation, ensuring the animals proper housing conditions during low outdoor temperatures.

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Ocena parametrów mikroklimatu w oborze dla krów mlecznych w aspekcie wymagań dobrostanu zwierząt

STRESZCZENIE

Celem podjętych badań była ocena mikroklimatu oraz wskaźników zoohigienicznych w oborze uwięziowej położonej na terenie województwa podlaskiego w aspekcie dobrostanu krów mlecznych. Warunki termiczno-wilgotnościowe w obiekcie były prawidłowe i zapewniały właściwy poziom dobrostanu bydła mlecznego. Wilgotność względna powietrza w okresie wiosennym przyjmowała za niskie wartości w stosunku do wymogów zoohigienicznych. Intensywność ochładzania w analizowanym obiekcie podczas całego okresu badań przekraczała zalecane normy. Prędkość ruchu powietrza w badanej oborze kształtowała się w granicach zalecanych norm. Zbyt niska wilgotność względna wewnątrz obory w sezonie wiosennym wskazywała na nieprawidłowo działającą wentylację naturalną, co może wpływać na pogorszenie poziomu dobrostanu krów. Biorąc pod uwagę wartości wskaźników mikroklimatycznych stwierdzono, że obora zapewnia zwierzętom właściwe warunki utrzymania w czasie niskich temperatur oraz posiada dobrą ciepłochronność.

Słowa kluczowe: utrzymanie alkierzowe, krowy mleczne, dobrostan zwierząt, mikroklimat, obora uwięziowa