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Environmental indicators for assessing the welfare of dairy cattle housed indoors

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The objective of the research was to evaluate the microclimate and environmental indicators used to assess the welfare of dairy cattle housed indoors in a tie-stall barn located in the Kuyavian-Pomeranian Voivodeship. Microclimate conditions were analysed using the physical parameters of the microclimate and selected environmental indicators characterizing the level of livestock welfare. The study showed that the temperature in the barn during autumn and winter corresponded to recommendations, whereas in the spring, when the outdoor temperature was high, the indoor temperature exceeded the optimum temperature by about 7°C. In the autumn and winter, when high levels of outdoor humidity were noted, the relative humidity inside the barn was also very high, which is an undesirable effect. The average relative humidity in the spring did not exceed recommendations. The excessive relative humidity inside the barn was indicative of poorly functioning natural ventilation. To improve the temperature and humidity conditions, the door was opened to ventilate the building, thus affecting other parameters of the microclimate. It was concluded from the microclimate indicators that the building had good heat insulation and ensured the welfare of the animals during low temperatures. However, the research showed that the natural gravity ventilation system did not work properly, which during some periods may have a detrimental effect on the welfare of dairy cattle.

KEY WORDS: animal welfare / dairy cows / indoor housing

The welfare of farm animals directly or indirectly determines their productivity and health and influences the quality of animal-derived products [1, 3, 8]. Animals must be raised in conditions that meet their biological and behavioural needs and enable them to adapt to changes in their environment without difficulty. Due to the complexity of the concept of animal welfare, it is difficult to establish criteria for its assessment, and therefore the widest possible range of indicators should be used for this purpose. The most common are physiological indicators (blood parameters, body temperature, blood pressure and pulse), behavioural indicators (behaviour in specific environmental conditions), and health and production indicators (appearance and condition of the animal, bodily injury, morbidity, mortality, productivity and reproduction).

One of the premises of animal welfare is the need to provide appropriate housing conditions, including optimal environmental conditions. For this reason additional indicators, having to do with the technical and technological solutions applied in livestock buildings, are significant. These include available area, type of floor and litter, the means of restricting the animals' free movement, and the microclimate of the barn [8, 9]. The microclimate of a livestock building depends on many external and internal factors. External factors include climate and weather conditions, which are influenced by the season of year, the quality of materials used for construction, the technology used, and type of terrain in which the building is located. Internal factors influencing the quality of the microclimate include stocking density and a fully functional ventilation system. Heat insulation of the walls, ceilings and floors is vital to the overall climate of barns, as this is where the greatest heat losses from the building take place [8, 9, 14, 17, 18].

Assessment of the microclimate includes not only thermal conditions, which are usually the basic criterion in assessing animal housing conditions, but also relative humidity. The combined impact of these two parameters may result in one of four adverse combinations: low temperature and low relative humidity, low temperature and high relative humidity, high temperature and low relative humidity, or high temperature and high relative humidity [2]. Furthermore, thermal sensations are influenced by the speed of air flow.

According to animal welfare recommendations, the temperature in a cowshed should be kept between 8ºC and 16ºC and the optimum temperature is +12ºC [2, 5, 10]. At this temperature the largest proportion of the energy taken in with feed is used for production. It should also be noted that if temperatures are too high or too low, animals may have difficulty dissipating heat or suffer excessive heat loss [5, 6, 13], resulting in reduced productivity and poorer health.

The optimal relative humidity in the cowshed should be within the range of 60--80%. Humidity that is too high or too low humidity has an adverse impact on animals. Humidity exceeding 80% intensifies heat stress and causes vapour to condense on the construction elements and walls of the building. This promotes the growth of mould and leads to the spread of numerous diseases, mainly of the respiratory system, and has a detrimental effect on the heat insulation of buildings [7, 9, 14, 17, 18, 19].

Air movement is an effect of differences in temperature and pressure. If air speed is greater than 0.3 m/s it exerts a negative impact on the body by increasing heat dissipation. It may also have a positive effect, by increasing heat dissipation when temperatures are high. It can be induced by either natural ventilation of the building or mechanical ventilation using fans [2, 4, 14]. Ventilation is important for animals and for maintaining the quality and utility of the building. The role of ventilation is to remove used air and supply fresh air. It should also maintain optimal microclimatic conditions without creating draughts or causing heat loss [2, 14, 16, 17].

For these reasons, in addition to temperature, relative humidity and air movement, assessment of the living environment of animals should take into account indicators of the combined impact of several microclimate factors [5, 6, 7, 13, 18, 19, 20]. These include cooling, perceived temperature, temperature comfort factor, and evaporation index.

The objective of the research was to evaluate microclimate and environmental indicators used to assess the welfare of dairy cattle housed indoors in a tie-stall barn located in the Kuyavian-Pomeranian Voivodeship.

Material and methods

The research was carried out on a farm located in Jabłonowo Pomorskie commune, Brodnicki county, Kuyavian-Pomeranian Voivodeship. The barn, built in 1999, is a brick building with walls 30 cm thick and an insulated pent roof. It has eleven windows, measuring 1.0 x 0.8 m and facing northeast. Insulated metal gates with built-in lights are located in the end walls (4 gates measuring 3.0 x 2.5 m). The long axis of the building runs north-south, with a 10% deviation towards the east. The western side of the building adjoins an old cowshed from 1967. The cowshed, with an area of 251 m^2 and 804 m^2 cubature, is used for dairy cattle kept in a tie-stall system on straw litter (27 stalls with dimensions of 1.85 x 1.15 m). Gravity ventilation with four ventilation shafts is installed in the cowshed. Air flows into the building through tilt windows. Low vegetation grows near the cowshed, and at a further distance trees and bushes form a protective belt neutralizing harmful effects on the environment.

The herd consisted of 21 Polish Holstein-Friesian cows and 6 crossbreds of the breeds Simmental, Montbéliarde and Brown Swiss. They were in good health and had milk yield of 8,600 litres. Their mean production period was 4 lactations.

Environmental welfare indicators were analysed during the period when the cows were kept indoors:

– 1–30 November (autumn)
– 1–28 February (winter)
– 1–31 May (spring)

Environmental conditions in the cowshed and outside were monitored according to the methodology of research on environmental conditions affecting animal welfare [2, 10]. Twice a week at 7 a.m., 1 p.m. and 9 p.m., instantaneous measurements were taken of temperature and relative air humidity (AZ8857 Infrared Psychrometer), as well as cooling and air movement (Hill's 'dry' and 'wet' kata-thermometer). Furthermore, electronic Lab-el 520 thermos-hygrographs with a 521 interface were used to register the temperature and relative humidity inside and outside the cowshed. These parameters were recorded in the device's memory every hour.

The instantaneous measurements of temperature, relative humidity, cooling and air movement were used to determine additional microclimate indicators, providing a more complex assessment of the bioclimatic conditions of the building [2, 10]:

– Perceived temperature (equivalent-effective temperature, EET°), which defines perceived thermal conditions arising from the air temperature, humidity, and velocity. EET° was calculated using Missenard's formula [2]

– Heat insulation coefficient (HIC), expressed as the quotient of external and internal cooling, which specifies how many times lower the cooling is inside the building than outside it, i.e. the heat insulation value of the indoor facility [2, 10]

– Temperature comfort factor (B), expressed as the quotient of the temperature and cooling measured with a dry kata-thermometer, used to determine whether animals are kept in optimal conditions [2, 10]

– Draught index (DI), expressed as the product of the air velocity and the difference in the highest and lowest temperature over the course of a day [2, 10]

– Kata-thermometric evaporation index (EI), expressed as the quotient of 'wet' and 'dry' cooling, which characterizes the degree of air moisture and indicates the drying potential of the air in livestock buildings [2, 10].

The results were statistically analysed using Statistica ver. 12.5 PL software [15]. The differences in temperature and relative humidity (registered without interruption using Lab-el 520 thermo-hygrographs) between the outside environment and the cowshed were verified by Student's t-test. Tables 1 and 2 present the arithmetic mean ($\bar{x}$), standard deviation (±SD) and extreme values (min. and max.).

Results and discussion

Dairy cattle can be kept in an indoor or pasture system. In Poland, the pasture season for cows lasts on average 160-170 days. From the moment the outside temperature falls to below +5ºC (the beginning of November), the cattle remain indoors all day; this is the indoor system. Animals are thus housed in this system during three seasons of the year: late autumn, winter and early spring. Accordingly, our research, involving assessment of environmental indicators of dairy cattle welfare, was carried out during the three seasons when the cows were kept in the tie-stall barn. During the first research period, in November (autumn), the average temperatures in the cowshed were in the optimal range for dairy cattle and did not fluctuate by more than 5ºC, which is beneficial for the animals. In the second half of November a statistically highly significant difference was noted between the temperatures outside and inside the building. This indicates good heat insulation and stocking density (Table 1).

Table 1
Air temperature in different weeks of research during indoor housing

Experimental period		Statistical measures	Temperature (°C)			
Season	Week		outdoor		ondoor	
Autumn	I	$\bar{x}$;±SD	7.6^{B}	±0.35	14.6^{A}	±0.12
		min.; max.	1.3	15.2	7.9	17.3
	II	$\bar{x}$;±SD	7.8^{B}	±0.42	14.7^{A}	±0.11
		min.; max.	3.8	12.0	7.4	17.6
	III	$\bar{x}$;±SD	2.4^{B}	±0.08	11.8^{A}	±0.10
		min.; max.	0.2	5.4	9.3	13.6
	IV	$\bar{x}$;±SD	–0.4^{B}	±1.12	10.3^{A}	±0.09
		min.; max.	–8.5	5.3	6.6	14.0
Winter	I	$\bar{x}$;±SD	–1.9^{B}	±0.25	13.5^{A}	±0.07
		min.; max.	–9.7	2.2	9.9	15.0
	II	$\bar{x}$;±SD	2.3^{B}	±0.53	12.7^{A}	±0.85
		min.; max.	–4.8	5.5	10.2	14.0
	III	$\bar{x}$;±SD	5.0^{B}	±1.20	12.7^{A}	±0.74
		min.; max.	–5.3	7.7	9.9	14.0
	IV	$\bar{x}$;±SD	3.7^{B}	±0.38	14.9^{A}	±1.20
		min.; max.	0.0	8.3	12.2	16.4
Spring	I	$\bar{x}$;±SD	8.9^{B}	±0.98	15.2^{A}	±0.85
		min.; max.	2.0	23.6	12.0	21.4
	II	$\bar{x}$;±SD	12.8^{B}	±1.11	18.1^{A}	±1.65
		min.; max.	1.7	20.7	14.0	20.6
	III	$\bar{x}$;±SD	13.1^{B}	±1.65	17.4^{A}	±1.21
		min.; max.	6.3	24.8	12.0	22.5
	IV	$\bar{x}$;±SD	22.5^{B}	±1.10	23.4^{A}	±0.87
		min.; max.	11.2	33.3	18.1	28.4
	V	$\bar{x}$;±SD	14.7^{B}	±1.23	18.5^{A}	±1.05
		min.; max.	6.1	27.4	14.6	24.2

A, B – means in rows with different lower-case letters differ significantly at $P \leq 0.01$

The relative air humidity registered in the cowshed in November was well above the recommendations for cows. The mean humidity was statistically significantly higher inside the building than outside (Table 2). These results may be linked to the fact that the cowshed was ventilated during the day (open gates) and closed at night throughout the first three weeks of November.

Table 2
Relative air humidity in different weeks of research during indoor housing

Experimental period		Statistical measures	Relative humidity (%)			
Season	Week		outdoor		indoor	
Autumn	I	$\bar{x}$;±SD	80.53[B]	±15.68	91.96[A]	±9.56
		min.; max.	66.10	94.80	67.20	99.90
	II	$\bar{x}$;±SD	82.72[B]	±15.42	97.25[A]	±7.66
		min.; max.	70.50	97.90	88.60	99.90
	III	$\bar{x}$;±SD	79.92[B]	±14.21	96.23[A]	±15.74
		min.; max.	67.40	91.10	79.70	99.90
	IV	$\bar{x}$;±SD	78.13[B]	±18.20	90.34[A]	±16.25
		min.; max.	72.50	96.50	54.30	99.90
Winter	I	$\bar{x}$;±SD	82.12[B]	±18.20	98.99[A]	±17.36
		min.; max.	68.70	94.00	75.10	99.90
	II	$\bar{x}$;±SD	93.83[A]	±15.68	91.66[B]	±18.45
		min.; max.	63.30	96,40	78.80	99.90
	III	$\bar{x}$;±SD	91.90[B]	±18.32	97.30[A]	±13.87
		min.; max.	40.40	69.21	81.90	99.90
	IV	$\bar{x}$;±SD	83.59[B]	±23.45	96.28[A]	±19.63
		min.; max.	65.50	93.60	61.30	99.90
Spring	I	$\bar{x}$;±SD	57.00[B]	±22.12	59.40[A]	±19.54
		min.; max.	26.70	83.90	37.20	71.30
	II	$\bar{x}$;±SD	75.10[A]	±23.14	72.00[B]	±16.89
		min.; max.	28.50	97.10	48.20	74.70
	III	$\bar{x}$;±SD	72.00[B]	±21.10	77.70[A]	±16.23
		min.; max.	41.30	99.20	55.90	95.70
	IV	$\bar{x}$;±SD	60.70[B]	±21.22	65.60[A]	±17.32
		min.; max.	25.60	95.30	41.60	80.80
	V	$\bar{x}$;±SD	70.30[B]	±22.11	77.10[A]	±19.41
		min.; max.	33.70	96.60	48.60	87.10

A, B – means in rows with different lower-case letters differ significantly at P≤0.01

To assess the welfare of the cows an analysis of additional indicators was performed (Table 3). Despite the high relative air humidity and perceived temperature (EET°), all values were within boundaries considered optimal for dairy cattle. However, the increased air velocity noted in the third week of research may have resulted in increased heat dissipation by the animals. This is supported by the increased cooling value and lower temperature comfort factor and draught index. On the other hand, good thermal isolation is confirmed by the heat insulation coefficient, which ranged from 2.21 to 2.61.

Table 3
Mean values ($\bar{x}$) of selected environmental indicators in autumn

Experimental period	EET° (°C)	Air flow rate (m/s)	Cooling (mW/cm²)	HIC	TCF	DI	EI
I	15.2	0.20	33.50	2.44	0.44	0.30	2.28
II	16.1	0.30	35.90	2.25	0.45	0.45	2.22
III	13.3	0.40	43.60	2.61	0.30	0.10	2.17
IV	13.2	0.30	38.29	2.21	0.34	0.20	2.39

EET° – perceived temperature; HIC – heat insulation coefficient; TCF – temperature comfort factor; DI – draught index; EI – evaporation index

During the next research period (winter), the average temperature values were within the optimal range for dairy cows (Table 1). A statistically highly significant difference was determined between temperatures inside and outside the cowshed, again confirming good heat insulation of the building. As in the autumn, the lowest value of this parameter was recorded in the last week of this period, due to the increased ventilation of the cowshed necessitated by high relative air humidity inside the building, exceeding 95% (Table 2). Statistically highly significant differences were also noted between the relative air humidity inside and outside the building. Only in the second week was a higher value obtained for this parameter outside the shed, due to rapid warming (temperature above 0ºC).

The analysis of environmental indicators showed that despite the low outside temperatures the EET° value inside was again at the optimal level (Table 4). Low air movement was noted in the cowshed, and it was not a factor contributing to excessive heat dissipation by the cows. This indicates that the microclimate conditions for the animals were balanced irrespective of the conditions outside, but the high relative air

Table 4
Mean values ($\bar{x}$) of selected environmental indicators in winter

Experimental period	EET° (°C)	Air flow rate (m/s)	Cooling (mW/cm²)	HIC	TCF	DI	EI
I	11.6	0.10	34.10	2.44	0.34	0.30	2.14
II	13.1	0.10	35.10	2.94	0.35	0.40	2.18
III	14.5	0.20	33.40	2.69	0.43	0.30	2.19
IV	9.0	0.20	38.10	1.90	0.30	0.50	2.15

EET° – perceived temperature; HIC – heat insulation coefficient; TCF – temperature comfort factor; DI – draught index; EI – evaporation index

humidity shows that the ventilation system was not working properly. The cooling values and kata-thermometric evaporation index were at optimal levels and did not exceed the recommended values for the animals. It should be emphasized that despite the ventilation, the draught index was low.

The average air temperatures in the cowshed during the spring were higher than recommended for dairy cattle. Statistically significant differences were noted between temperatures outside and inside the building (Table 1). As the outdoor temperature rose, the indoor temperature increased as well. This was confirmed by the perceived temperature (EET°), which indicates how the animals actually perceive the thermal conditions (Table 5).

Table 5
Mean values ($\bar{x}$) of selected environmental indicators in spring

Experimental period	EET° (°C)	Air flow rate (m/s)	Cooling (mW/cm²)	HIC	TCF	DI	EI
I	14.7	0.04	25.50	2.53	0.57	0.10	2.52
II	18.5	0.09	23.80	1.90	0.80	0.20	2.60
III	21.3	0.20	24.90	1.90	0.86	0.30	1.32
IV	21.1	0.30	25.70	1.40	0.85	0.84	1.00
V	17.7	0.20	30.10	1.70	0.61	0.40	2.89

EET° – perceived temperature; HIC – heat insulation coefficient; TCF – temperature comfort factor; DI – draught index; EI – evaporation index

In addition to the increase in temperature, air movement in the barn was low, especially in the first two weeks of the study, which limited heat dissipation. Only in the fourth week did it reach a speed of 0.3 m/s. The low airflow and the higher temperatures than in the previous periods were accompanied by cooling values that were too low (Table 5). The relative humidity during the spring was at the lowest level of the entire indoor housing period. This demonstrates the need for improvement in the ventilation system, as this parameter was closely correlated with the microclimatic conditions (a similar level of relative humidity outside).

The temperature comfort factor was above recommended levels, indicating that the animals were at risk of overheating. This parameter and the draught index were low during this period, despite the systematic ventilation of the building. These results indicate that the air inside the building was very dry (Table 5).

The average temperature during the autumn and winter period was in accordance with recommendations [2, 5, 10, 11]. During the spring, when high temperatures were recorded outside, the inside temperature exceeded the upper limit recommended for dairy cattle. Nevertheless, the average value for this period can be considered optimal (+14.9ºC). Relative air humidity in the spring did not exceed recommendations. In the autumn and winter, when high humidity values were noted outside, the relative humidity inside the building was also high, at 99.9%, which is not beneficial for animal welfare (Table 2). In studies by Fiedorowicz and Mazur [5, 6] and by Sokołowski and Nawalany [13], heat and humidity levels inside cowsheds for dairy cattle housed indoors were similar to those noted in the present study.

Air movement is an important parameter influencing the microclimatic conditions in barns. Various authors [5, 6, 11, 17] state that if the speed of air movement exceeds 0.3 m/s inside a livestock building, this state is regarded as a draught. However, if it is too low (below 0.1 m/s) the animals can become overheated. In the present study, the air velocity in the barn throughout the indoor period averaged 0.21 m/s (Table 6.). Other authors [6, 12, 17] have also demonstrated that airflow remains at an optimal level in brick cowsheds with natural ventilation. However, in cowsheds with curtain walls and ridge ventilation, air movement speeds exceeding recommendations are often noted [6, 12, 18].

Cooling is a biometeorological measure of heat loss which describes the cooling force of an air environment. The optimal value of this indicator for dairy cows is assumed to be 27-36 mW/cm^2 [5]. During the indoor housing period, the average value of this parameter was 33 mW/cm^2 (Table 6), which may indicate that the breeding environment does not interfere with the thermoregulation system in cows. The fact that the perceived temperature (EETº) remained at an optimal level is an additional confirmation that the microclimate parameters in the cowshed were stable.

Table 6
Mean values ($\bar{x}$) of selected environmental indicators during indoor housing

Experimental period	EET[o] (°C)	Air flow rate (m/s)	Cooling (mW/cm^2)	HIC	TCF	DI	EI
Maintenance indoor	15.1	0.21	33.00	2.25	0.49	0.34	2.17

EET[o] – perceived temperature; HIC – heat insulation coefficient; TCF – temperature comfort factor; DI – draught index; EI – evaporation index

The use of additional indicators, including kata-thermometric indicators, to assess environmental conditions in barns is rare [7, 19, 20]. In our study, the indicators calculated for the entire indoor housing period confirm that the microclimatic conditions and heat insulation in the cowshed were good (Table 6). It should be noted, however, that in some weeks of the study the air humidity in the cowshed was too high due to poor functioning of the natural ventilation system, which caused the indicators to deviate from optimal values. Fluctuations in the physical parameters of the microclimate in a short period of time did not have a major impact on the productivity or condition of the cows, and thus did not affect their welfare in the context of the entire indoor housing period.

The research showed that the temperature in the cowshed in autumn and winter corresponded to recommendations, whereas in the spring period, when high temperatures were noted outside, the interior temperature exceeded optimal conditions by 7°C. During autumn and winter, when high humidity values were noted outside, the relative humidity in the interior reached 99.9%, which is an adverse phenomenon. It should be noted that the average relative air humidity in the spring did not exceed recommendations. The excessively high humidity inside the cowshed indicated that the natural ventilation was not functioning properly. The gates were opened in order to improve heat and humidity conditions, which affected other microclimate parameters.

Based on the microclimatic indicators it was concluded that the building analysed has good heat insulation and ensures proper housing conditions for the cows when temperatures are low. However, the natural-gravity ventilation was not functioning properly, which in certain periods could have an adverse effect on the welfare of the dairy cattle.

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