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TEMPERATURE, HUMIDITY AND AIR MOVEMENT VARIATIONS INSIDE A FREE-STALL BARN DURING HEAVY FROST*

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Abstract

The paper presents results of research on the variability of temperature, humidity and air movement in selected areas of a free-stall barn during heavy frost. The study revealed the occurrence of unfavourable factors influencing microclimate in the barn. Some areas of the barn suffered from draughts, some were excessively exposed to sun or too shaded, which resulted in significant temperature and relative humidity fluctuations during the day as well as changes in air movement velocity. All these factors exerted an impact on cattle welfare. The conclusion points out the need to determine zones in the barn characterized by clearly different microclimatic conditions. In the studied example, these conditions were influenced by weather changes and depended on the orientation of the building to cardinal points as well as wall construction materials.

Key words: dairy cows, free-stall barn, temperature, relative humidity, air movement, low temperature

Dairy cow welfare and milk productivity are largely influenced by barn microclimate. High production cows need significant amounts of fresh air. Insufficient amount of oxygen slows down metabolic processes, which in turn affects milk production. Moreover, insufficient air exchange ratio inside the barn results in increased air humidity as well as concentration of noxious gases produced as a result of animal waste decomposition. High air humidity may have a negative impact on animal welfare and lead to bacteria development (Albright and Timmons, 1984; Zähner et al., 2004).

Natural ventilation is the most popular ventilation system used in free-stall barns. Air movement is mainly driven by thermal displacement, wind and difference between the level of inlet and outlet openings (Reppo et al., 2004). Already at the de-

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sign stage, the priority is to ensure suitable amount and quality of air inside the barn, which does not mean that this aim is always fully realized.

According to Romaniuk (Romaniuk et al., 2005), air flow velocity inside a barn should remain within the range 0.2–0.5 $m \cdot s^{-1}$ depending on the time of year. When air velocity inside a building exceeds recommended values, cows may suffer from overcooling, which influences milk production levels.

The study aimed at determining temperature, humidity and air movement parameters in the selected free-stall barn during heavy frost waves.

Material and methods

The measurements were conducted inside a modernized cow barn (Fermbet construction system) adapted as a free-stall barn for 176 Holstein-Friesian cows divided into three technological groups. The building is located in the village of Kobylany, the Małopolska region. It is oriented along the east-west axis. From the south, the building is extended with some additional social rooms for employees and milking parlour with the holding area. It is a typical building constructed from pre-fabricated reinforced concrete with a double-pitched roof (gradient 45%). The building is fitted with a natural gravitational ventilation system, an adjustable curtain wall on longitudinal walls and outlet openings in the form of ridge vents. Technical parameters of the researched barn are presented in Table 1.

Table 1. Technical parameters of the cow barn in Kobylany (source: own calculations)

Parameter	Unit	Value
Usable floor area	m^2	1580
Population	head	176
Usable floor area per head	$m^2 \cdot head^{-1}$	9
Cubic capacity per head	$m^3 \cdot head^{-1}$	53
Total outside wall area	m^2	992
Curtain wall area	m^2	207
Door area	m^2	54

The measurements and observations were carried out from December 2011 to March 2012. Six measurement points were located inside the barn, with 2 points per technological group (Fig. 1). Each measurement point was located 1 m above floor level and was equipped with sensors, forming automatic measurement devices recording air temperature, humidity and air movement velocity at 6-minute intervals. Measurements of the air movement velocity were made using sensor HD 103T, Delta Ohm with a measuring range of 0–5 $m \cdot s^{-1}$ and accuracies of 0.04 $m \cdot s^{-1}$ in the measuring range 0–0.99 $m \cdot s^{-1}$ and 0.02 $m \cdot s^{-1}$ in the measuring range 1–5 $m \cdot s^{-1}$. The temperature and relative air humidity were measured using an integrated sensor LB-710 Label with a measuring range of –40 to +85°C and relative humidity from 0 to 99.9%, accurate to 0.1°C and 0.1%. During the test the momentary measurements were also performed using a manual thermo-anemometer to validate the results obtained from the automatic measurement stations.

Outside the barn, a meteorological mast was installed to record the changeability of weather conditions. Information about hourly average solar radiation intensity was obtained from the nearest meteorological station owned by the Institute of Meteorology and Water Management.

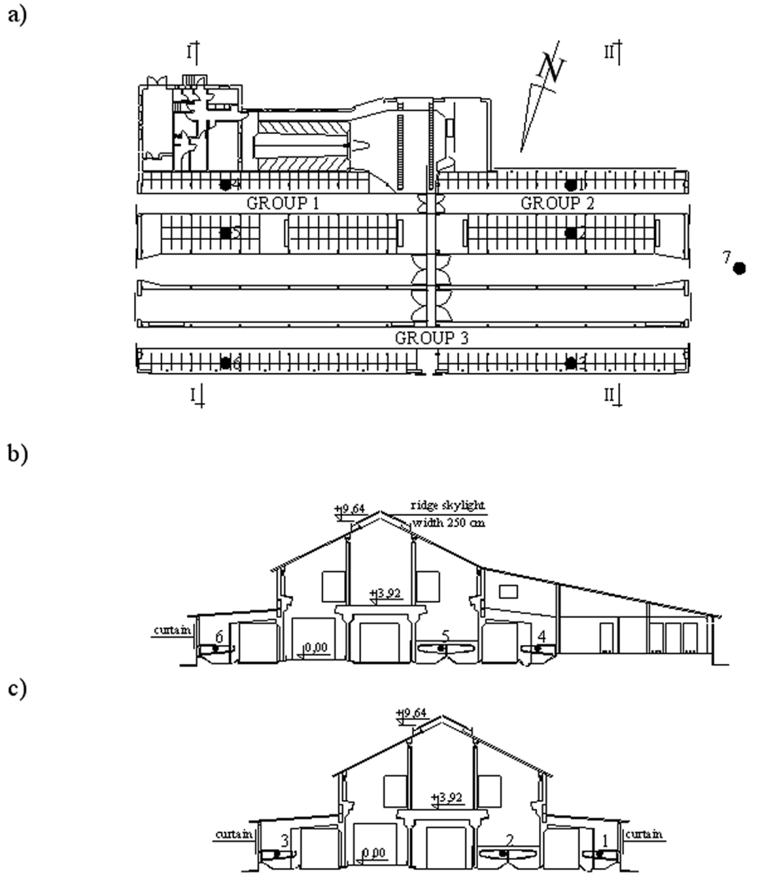

Figure 1. Location of measurement points: temperature, relative air humidity and air movement; a) horizontal projection, b) cross-section I–I, c) cross-section II–II, 1–7 – measurement points (own source)

Results

Research results presented in the charts below are discussed with reference to particular technological groups inside the barn. This paper focuses on measurements obtained during heavy frost waves when outside air temperature fell below –20ºC and inside temperature was below –15ºC. Such conditions occurred on 3, 4 and

7 February 2012. Average daily air temperature in that period equalled –14ºC and average wind velocity was 1.47 m·s^{-1}. RH fluctuations inside the barn were between 30 to 90% at daily average of 53%. Air movement velocity inside the building was between 0 and 0.4 m·s^{-1}.

On 3 February 2012 outside air temperature ranged between –21 and –15ºC, and relative air humidity was between 40 and 80% (Fig. 2). The day was sunny and at 2 pm solar radiation intensity was 375 W·m^{-2}. This was particularly noticeable in the zone occupied by the second technological group. The temperature at noon on the sensor placed on the southern wall was –3ºC. This also influenced relative air humidity which fell to 40%. In the remaining zones of the barn relative air humidity was approximately 60%. In the remaining measurement points the following temperature values were registered: –6ºC in the second technological group and –8ºC in the third technological group (Fig. 2). Temperature distribution differed in particular groups depending on the time of day. At night, the highest temperature was recorded in the zone occupied by the first technological group and ranged between –7 and –13ºC. In the second technological group, the temperature ranged between –13 and –15ºC; in the third it even reached –17ºC. The highest daily amplitudes were registered in group 2, especially on sensors Θ1 and Θ2 (Fig. 2).

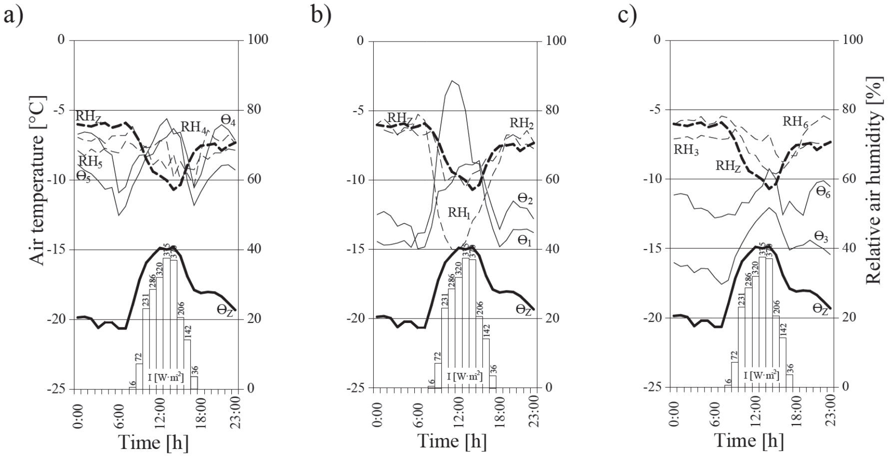

Figure2. Temperature (Θz, Θ$_{1–6}$), relative air humidity (RH$_z$, RH$_{1–6}$) and radiation intensity observations (I) on a sunny day of 3 February 2012 inside the barn in Kobylany; a) group 1, b) group 2, c) group 3 (own source)

Air movement velocity values (Fig. 3) also differed significantly in particular technological groups. The lowest values, from 0.2 to 0.5 m·s^{-1}, were recorded in group 1, occupying the zone near the permanent longitudinal wall with no curtains. In turn, the highest values, exceeding 0.5 m·s^{-1}, were recorded in groups 2 and 3 on sensors V_2 and V_3 (Fig. 3).

On 4 February 2012, solar radiation had an intensity of 195 W·m^{-2}, which is half lower than on the previous day. The temperature was still freezing but wind and air movement values were lower. Relative air humidity was also lowest (58%) in the zone occupied by the second technological group around noon. Lower values were also observed on sensors RH4 and RH5 as well as RH3 and RH6 referring to the first and third technological group. The intended humidity range was between 62 and 78%. The highest values, exceeding 62%, were recorded in the first technological group, in which highest productivity was also noted (Fig. 4).

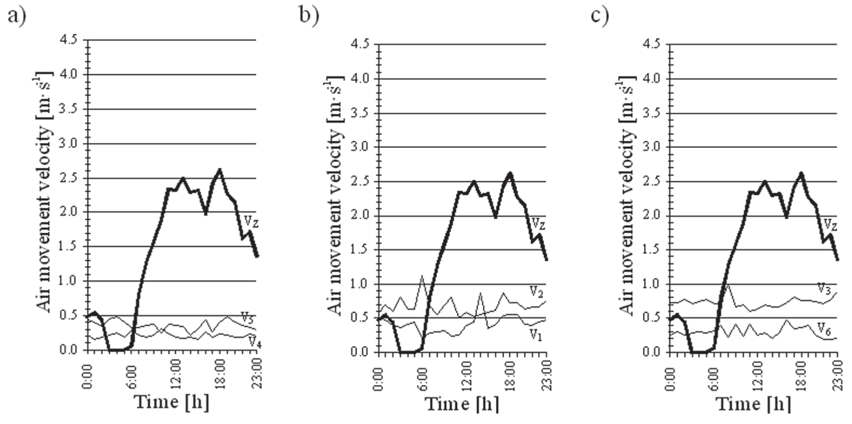

Figure 3. Wind velocity measurements (V_z) and air movement measurements ($V_{1–6}$) in particular measurement points on 3 February 2012 inside the barn in Kobylany for three technological groups; a) group 1, b) group 2, c) group 3, V_z – wind velocity, $V_{1–6}$ – air movement velocity (own source)

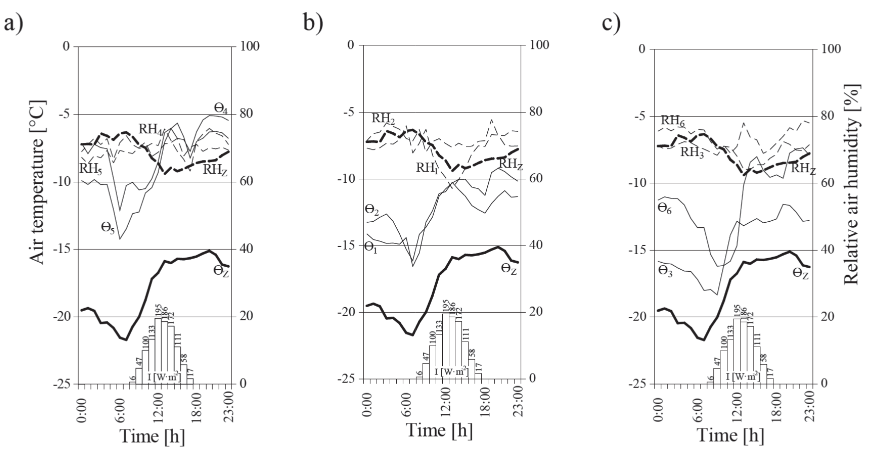

Figure 4. Temperature (Θ_z, $\Theta_{1–6}$), relative air humidity (RH_z, $RH_{1–6}$) and solar radiation intensity (I) on a cloudy day of 4 February 2012 inside the barn in Kobylany for three technological groups; a) group 1, b) group 2, c) group 3 (own source)

During heavy frost periods, all longitudinal curtain walls were raised and all doors leading to manure and feeding corridors were closed in order to decrease air velocity and limit the cooling of animal bodies. Air movement velocity charts presented in Fig. 5 reveal that the values ranged between 0.2 to 0.8 m·s^{-1}. It can be also noted that from 9 am to 1 pm the values for group 3, as seen in charts V_3 and V_6, were higher and reached 1 m·s^{-1}. This was the time when the doors to the feeding corridor were open.

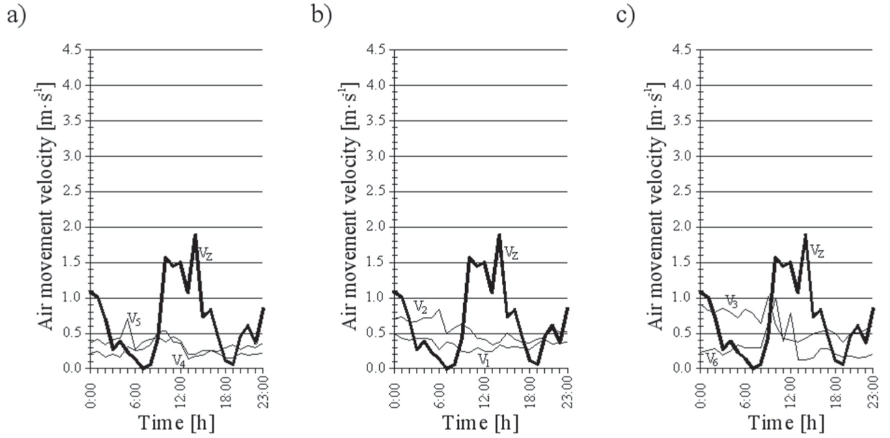

Figure 5. Wind velocity (V_z) and air movement velocity ($V_{1–6}$) in particular measurement points on 4 February 2012 inside the barn in Kobylany for three technological groups; a) group 1, b) group 2, c) group 3 (own source)

It should be noted that when all partitions and doors where "closed" air movement velocity inside the barn was relatively stable, not only under no-wind circumstances but also when wind velocity exceeded 2.5 m·s^{-1} on 7 February 2012 (Fig. 6). In the area occupied by the first technological group, air movement velocity did not exceed 0.5 m·s^{-1}. In group 2, this value was higher but did not exceed 0.7 m·s^{-1}. The highest air velocity variations were recorded in group 3.

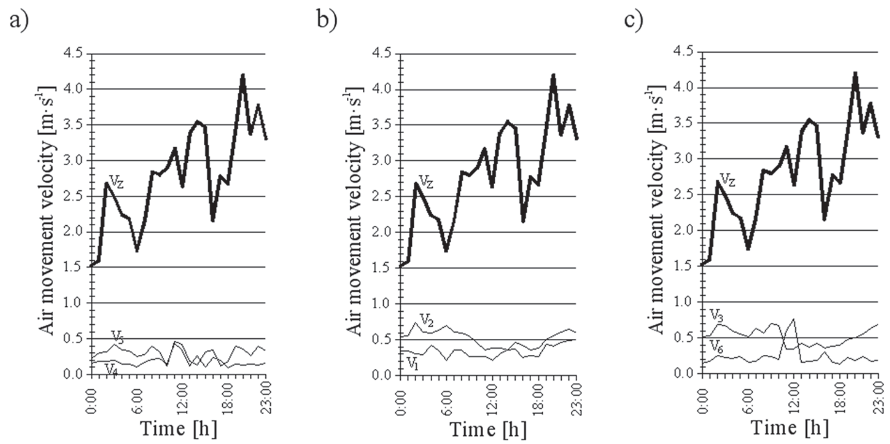

Figure 6. Wind velocity (V_z) and air movement velocity ($V_{1–6}$) in particular measurement points on 7 February 2012 inside the barn in Kobylany for three technological groups; a) group 1, b) group 2, c) group 3 (own source)

Significant differences between the measured microclimate parameters can be seen in Figure 7, which presents temperature, relative air humidity and air movement velocity values registered on 4 February 2012 at 4 am and 2 pm at all measurement points.

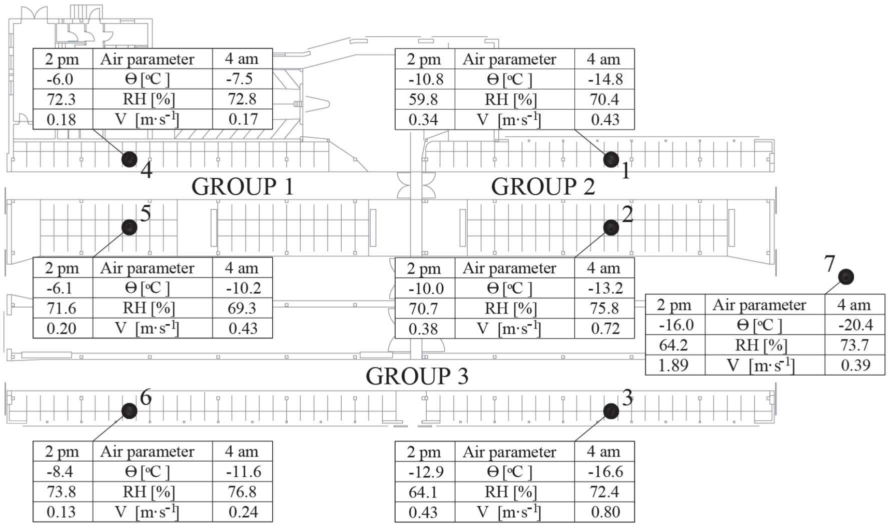

Figure 7. Layout of the building with measurement points (1–7) and hourly average values registered on 4 February 2012 at 4 am and 2 pm (own source)

As can be seen in Fig. 7, the values obtained at the same time in particular technological groups differed significantly. These variations mostly depended on the orientation of the area occupied by the given technological group, outside weather conditions and the type of partitions (full wall or curtain wall). The most stable microclimatic conditions could be observed in the area occupied by the first technological group (full partition wall, no curtains). This area was characterized by highest temperatures and lowest air movement velocity values.

In turn, highest daily temperature fluctuations were noted in the area occupied by group 2; this was mainly caused by high permeability of curtain walls. On sunny days, the air in this area heated quickly, which led to a sudden increase in relative air humidity. At night on the other hand, air temperature went down quickly. As a result, daily temperature amplitudes in this area were very high.

In the area occupied by the third technological group, air temperature had the lowest values. The main reason for that was that this area was adjacent to the shaded zone in the northern part of the building. Additionally due to increased air permeability of curtain walls, this area was characterized by higher air movement velocity values compared to the other technological groups. Another reason for that was the proximity of the feeding table, where more draughts were recorded, especially when the doors were open.

Discussion

The microclimate of free-stall barns has been widely researched with particular focus on its influence on cattle welfare (Albright and Timmons, 1984; Cook et al., 2005; Herbut, 2010; and many others). It has been concluded that cattle are able to adjust to changeable conditions but sudden changes have a negative impact on cow welfare, especially in the case of free-stall barns. Cows maintain high production levels irrespective of temperature or humidity changes, on the condition that these remain in the range between –10 and +20°C for temperature, and 50–80% for relative air humidity (Romaniuk et al., 2005; Jaśkowski et al., 2005). In the research barn, temperatures fell below –10°C during heavy frost periods, which could have caused cold stress. High temperature and relative air humidity fluctuations were recorded in all three areas under investigation. These were particularly significant for group 2 with tightly adjacent single and double lying boxes. On cloudless days, this zone was exposed to increased radiation intensity. As a result, in a relatively crowded area cows were exposed to high daily temperature and humidity fluctuations.

Another significant factor that had an impact on cow welfare was air movement velocity, which should not exceed 0.2 $m \cdot s^{-1}$ during the winter season (Solan and Jóźwik, 2009). Draughts lead to sudden cooling of animal bodies, which has a negative effect on morbidity rates and causes a decrease in production (Johnson, 1986). In the investigated barn, lowest air movement velocity values were noted for group 1, mainly due to the fact that this area was located farthest from the curtain walls. This area was also noticeable for most stable microclimatic conditions. Draughts, with air velocity exceeding 0.5 $m \cdot s^{-1}$, were observed in the area occupied by group 3, which was also noted for its lowest production levels. During heavy frost, it was impossible to restrain air movement to the level recommended for winter seasons even though the doors were closed and curtain walls were raised. This difficulty was mainly caused by untightness of the curtain wall on both the southern and northern side.

In the researched example, barn layout definitely had a significant impact on air movement directions and velocity values in winter (Herbut, 2010). It needs to be highlighted that this is a challenge faced by all Polish barns, since strongest winds in Poland are observed in autumn and winter (Ośródka et al., 2010), that is when it is essential to limit cooling of animal bodies. Only a limited number of publications on cattle breeding and welfare, barn ventilation or construction systems take into account the influence of climatic conditions on air movement inside barns (Brouk et al., 2001; Teye et al., 2008). Yet this factor is very important in the case of free-stall barns, especially in winter. The research revealed the occurrence of unfavourable conditions influencing the microclimate in particular barn zones. It was observed that in some areas temperature, relative humidity and air velocity values fluctuated intensively over a 24-hour period, which had a negative influence on cattle welfare.

The performed measurements of selected microclimate parameters including temperature, relative air humidity and air movement for each technological group provided more accurate information on the variability of these parameters during heavy frosts. Many researchers, such as Bouraoui et al. (2002) and West et al. (2003)

based their conclusions on instantaneous measurements at hourly intervals averaged for one day. Moreover, these measurements were carried out in only one point in the barn. Such a methodology does not fully reflect the course and scope of the examined parameters, since they fluctuate significantly during the day and their variation depends on many factors. West et al. (2003) and Bouraoui et al. (2002) report that the measurement point was located in the feeding area; Dikmen and Hansen (2008), in turn, located it at the central point of the barn. In the current study, variations in the analysed microclimate parameters between the zones were mainly due to differences in wall construction and orientation of the building to cardinal directions. With respect to wall construction, the main factor here was the longitudinal full wall adjacent to the zone occupied by group 1 and longitudinal curtain walls (groups 2 and 3). The current study also takes into account solar radiation intensity, which gives a fuller picture of the conditions prevailing in the southern part of the barn. When a barn is divided into zones with clearly differing microclimatic conditions, which change depending on atmospheric conditions, it is easier to predict temperature, air humidity and air movement changes inside the barn and prevent negative impact (Herbut and Angrecka, 2012). It is necessary to define and study microclimatic conditions in particular zones of the barn to be able to select proper areas for particular technological groups, in both winter and summer period. This would also help to establish guidelines for the design of new barns, in the context of architectural solutions.

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PIOTR HERBUT

Zróżnicowanie warunków cieplno-wilgotnościowych i ruchu powietrza w oborze wolnostanowiskowej podczas silnych mrozów

STRESZCZENIE

W pracy przedstawiono wyniki badań, które miały na celu określenie zmienności warunków cieplno-wilgotnościowych i ruchu powietrza w wybranych strefach obory wolnostanowiskowej w okresie silnych mrozów. Przeprowadzone badania wykazały jednoczesne występowanie niekorzystnych czyników kształtujących mikroklimat w poszczególnych strefach obory. Zidentyfikowano w oborze strefy: przeciągów, nasłonecznione oraz zacienione powodujące powstawanie dużych dobowych skoków temperatur i wilgotności względnej powietrza oraz zmian prędkości ruchu powietrza, które w sposób zdecydowanie niekorzystny wpływały na kształtowanie się dobrostanu bydła.

Zwrócono uwagę na konieczność wydzielania w oborach stref, w których panują wyraźnie zróżnicowane warunki mikroklimatyczne w okresie silnych mrozów. Warunki te zmieniały się razem ze zmieniającymi się dynamicznie czynnikami atmosferycznymi oraz zależne były od usytuowania budynku względem stron świata oraz rodzaju ściany obory.