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Conditions for cold stress development in dairy cattle kept in free stall barn during severe frosts

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ABSTRACT: The impact of low temperatures combined with higher velocity of ventilated air in winter during severe frost in a free stall barn on the development of cold stress in Holstein-Friesian breed dairy cattle was studied. The study included measurements of outside and inside air parameters and cows' milk yield. Cold stress was evaluated in three technological groups (TG) using the WCT (Wind Chill Temperature) index. During the research, significant temperature and wind velocity differences (by up to 5°C and 0.5 m/s) were recorded in three zones of the barn occupied by the individual TG. All this resulted in different values of WCT. During most severe frosts lasting for 9 days, the average air temperature in the barn was −8.9°C (the lowest value was −17.3°C). The calculated average operative temperature for cows from all TG was as follows: −7.0°C for TG1, −11.1°C for TG2, and −12.3°C for TG3. It was also observed that animals from TG2 suffered from mild cold stress, which resulted in milk yield reduction by approximately 2 kg. It was concluded that there is a strong correlation ($r = 0.72–0.89$ with $P < 0.05$) between milk production and the WCT index. The measurements of most important microclimate parameters in the barn were conducted during winter seasons over the period of 2 years. They led to the conclusion that cattle kept in free stall barns are not vulnerable to the combination of low temperature and increased air movements. Research results of the present as well as of other authors were the basis for developing a table determining operative temperature for cows depending on the temperature of the environment and air movement velocity. Yet, the calculations and analysis of results show that there is a need to improve the applied calculation formula for operative temperature during cold weather.

Keywords: winter; cows; wind chill; milk production; housing

INTRODUCTION

The purpose of dairy farming is to achieve the highest possible milk yield while maintaining the welfare of the animals by, for example, suitable microclimate of the building (Albright and Timmons 1984; Cook et al. 2005) especially in the case of meeting the essential cows' needs, such as constant access to food and water and/or relative changeless time of milking (Adamczyk et al. 2011; Horky 2014).

Temperature variations in the range between −0.5°C and +25°C insignificantly affect milk production (West 2003). The assumed range of neutral temperatures for dairy cattle is −5 to 25°C (Knizkova et al. 2002). High milk production is connected with high heat production. However, in the presence of low air temperature and velocity of ventilated air, cows maintain proper body temperature thanks to their own body heat which helps them avoid hypothermia. It is also observed that cows develop thicker hair coat. Excessive cooling of cow bodies may lead to thermoregulation or fertility impairments, cold stress, and lower milk production accompanied by increased feed intake (Broucek et al. 1991).

Cold stress in cattle is a problem mainly faced by cattle breeders who keep their cattle on pastures. However, it can also occur in free stall barns with curtain walls. It is mostly conditioned by factors affecting barn microclimate: temperature, relative humidity, and air velocity. What mitigates operative temperature sensations during frost is solar radiation in unshaded areas of the barn (Kadzere et al. 2002).

Apart from lower critical temperature, cold stress is also described with the help of the WCT (Wind Chill Temperature) index. This index was initially

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used to evaluate thermal comfort for people (Siple and Passel 1945). However, it was quickly recognized that the index can be also used to assess thermal conditions for a variety of animal species (Mader et al. 2010). Over the past years, the WCT index has undergone some modifications, which enabled its application for determining cold stress in cattle (Graunke et al. 2011). One of the most commonly used algorithms for the calculation of WCT is the formula according to Tucker et al. (2007) taking into consideration the velocity of ventilated air movement.

The aim of the study was to determine the impact of low temperatures combined with higher velocity of ventilated air in winter in a free stall barn on the development of cold stress in Holstein-Friesian breed dairy cattle. The study included the measurements of outside and inside air, wind velocity, ventilation air velocity, and cows' milk yield. Based on the obtained results and WCT calculations, it was possible to determine the development of cold stress. The obtained calculation results were referred to the values obtained by other researchers.

MATERIAL AND METHODS

Cows. The measurements were conducted in winter of 2012 and 2013, in a free stall barn for 174 Holstein-Friesian cows. The average thickness of an animal's winter coat was 1.27 cm and the average weight of an animal was 583 kg. Cows were allocated into three technological groups (TG). In TG1, there were cows with an average milk yield of 31.5 kg, TG2 included cows with an average milk yield of 21.6 kg, and in TG3 there were cows with an average milk yield of 12.7 kg.

Cows in gestation period constituted 13.8% of TG1, 50% of TG2, and 72.4% of TG3.

Average content of fat and protein in milk from all cows was 4.07% and 3.97%, respectively.

Cows were maintained in individual lying boxes which were padded with straw once a day (5 kg straw per cow daily). Manure was removed mechanically from manure corridors twice a day (during milking time).

The total mixed ration was supplied twice a day. Feeding was allowed throughout the 24-hour period, except during milking. The energy content in feed ration for the cows in TG1 was 7.05 MJ net energy of lactation (NEL)/kg dry matter (DM), in TG2 it was 6.54 MJ NEL/kg DM, and in TG3 it was 6.31 MJ NEL/kg DM. The composition of the total mixed ration (TMR) remained the same throughout the year and included corn silage, haylage, alfalfa hay, corn grain, wheat, concentrate mixture, and mineral and energetic components.

Table 1. Technical parameters of the barn for dairy cows (n = 174) in Kobylany

Parameters	Value (m^2)
Usable floor area	1580
Usable floor area per animal	9
Usable cubage per animal	53
Total area of outside walls	992
Curtains area	207
Door area	54
Ridge ventilation area	32.5

Climate. The research was conducted in free stall barn, which was located in the village of Kobylany (50°8'59''N, 19°45'12''E), south-eastern region of Poland. For this region, the climate characteristics averaged for the last five winter seasons (5 months each) were as follows: air temperature 5.1°C, relative air humidity 79.7%, winds (from western direction) of 1.85 m/s velocity, precipitation 550 mm.

Barn. The building of 1580 m^2 usable floor area was oriented along the east-west axis. The building was equipped with a natural gravitational ventilation system in longitudinal walls and outlet openings in the form of ridge vents. Technical parameters of the researched barn are presented in Table 1.

Measurement methodology. Temperature was measured by LM-710 sensors (Label, Reguly, Poland) with the measurement range from –40 to +85°C. Air movement velocity was measured using HD 103T sensors (Delta Ohm, Padua, Italy). Their measurement range was 0–5 m/s, with the measurement accuracy of 0.04 m/s in the range of 0–0.99 m/s and measurement accuracy of 0.02 m/s in the measurement range of 1–5 m/s. The sensors were placed in the zone occupied by animals at the height of 1.0 m above the floor. The first measurement point was located in the shaded part of the barn, occupied by the most productive animals of TG1. The second measurement point was located in the south-western part of the barn, occupied by TG2. This area was exposed to sunlight. The third measurement point was located in the northern part of the barn, where the least productive TG3 was situated. Each TG consisted of 58 cows (Figure 1).

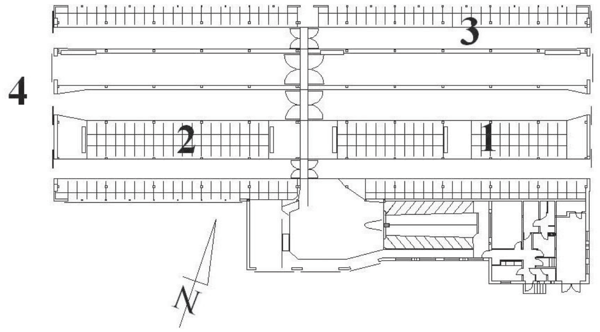

Figure 1. Distribution of measurement points inside and outside the barn

1 = technological group (TG) 1 with the highest milk production, 2 = TG2 with medium milk production, 3 = TG3 with low milk production, 4 = meteorological mast

The variability of outside weather conditions, such as temperature, relative air humidity, air speed and direction, was recorded with the help of a meteorological station located at the west side of the barn. All measurements were recorded automatically every 6 min.

Two winter seasons, lasting from December to March. An analysis focussed on periods of the most severe frosts, including several days preceding and following the frosts. The detailed analysis was performed for the most representative period (January 30–February 7, 2012) of extremely severe frosts for Polish conditions.

During the winter period, the exchange of ventilated air was limited because the main door was closed and the curtains in longitudinal walls were raised in order to protect the cows from excessive cooling. Additionally, the longitudinal walls were protected against the wind with straw bales (1.0 m thick and 2.0 m high). This protection was important because strong winds are characteristic for winter periods in Polish climatic conditions.

Values on average daily milk yield of each cow were based on data provided by the dairy management software Afimilk (Version 2.3, 2010).

Calculation of WCT and statistical analysis. The WCT index was calculated according to the formula of Tucker et al. (2007) with the help of own measurement results:

$$\mathrm{WCT} = 13.12 + 0.6215\,\mathrm{T_{air}} - 13.17\,\mathrm{V}^{0.16} + 0.3965\,\mathrm{T_{air}}\,\mathrm{V}^{0.16}$$

where:
WCT = wind chill temperature (°C)
$\mathrm{T_{air}}$ = air temperature (°C)
V = wind speed (km/h); air velocity (km/h)

The obtained data were statistically processed using STATISTICA (Version 10.0, 2010) software. The Pearson's correlation coefficient (*r*) between daily results of milk yield and daily average WCT (each cow's living zone) in the barn were calculated. The Student's *t*-test was used to estimate the statistical significance of the obtained values. Data were considered significant at $P < 0.05$.

RESULTS

During the research period, the wind was very strong and despite raised curtains it increased the inside air velocity to the level of 0.2 m/s. There were also significant differences between inside and outside temperatures over the 24-hour daily cycle. Averaged results of temperature and air movement velocity in 4 measurement points for the winters of 2012 and 2013 and the selected study period are presented in Table 2.

The results of measurement conducted from January 30 to February 7, 2012 made it possible to calculate WCT for cows in particular TG.

The results of outside air measurements (from the meteorological box T4) and WCT4 calculations presented in Figures 2–4 show that the lowest recorded temperature at night was –21.7°C. However, the calculated WCT4 was much lower, due to high wind. The largest disparity between the two was 11.0°C.

In TG1, localized in the vicinity of the wall without curtains, the temperature did not fall below –14.0°C, while the WCT1 value was lower than the measured T1 value by maximally 3.3°C (0.3°C on average). The largest disparities between the measured and calcu-

Table 2. Average temperatures and air velocities in the winter of 2012 and 2013

Reasearch period	T1	T2	T3	T4	V1	V2	V3	V4
Winter 2012	2.5	0.1	–0.6	–3.9	0.19	0.36	0.26	2.43
Winter 2013	2.8	2.6	1.8	–1.8	0.19	0.25	0.26	1.76
30/1–7/2, 2012	–6.7	–9.5	–10.7	–15.1	0.29	0.47	0.46	1.89

T1, T2, T3, T4 = air temperatures (°C) for each measurement point, V1, V2, V3, V4 = air velocities (m/s) for each measurement point

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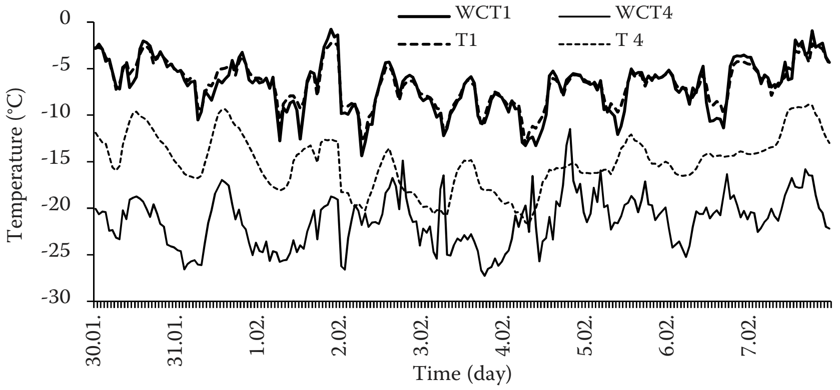

Figure 2. Exterior air temperature (T4) and inside air temperature (T1) in zone 1 of the first technological group, exterior wind chill temperature (WCT4) and wind chill temperature inside the barn (WCT1) in the zone occupied by the first technological group

lated temperatures were noted during the day (3.2°C) while during the night, they were 2.0°C (Figure 2).

In the area occupied by TG2, which was located by the southern wall equipped with curtains, the temperature fell down to –16.5°C. The WCT2 value calculated for the parameters of air registered in the given period was by 4.6°C lower than the T2 value. It is important to note that during the day this difference did not exceed 3.2°C (Figure 3).

The lowest air temperatures inside the barn were recorded in the area occupied by TG3. They were as low as –17.3°C. WCT3 calculated for this zone was by 4.2°C lower during the day and by 3.4°C during the night if compared to T3 (Figure 4).

Based on the analysis of Figures 1–3, it can be concluded that the most severe conditions for cattle were observed in the area occupied by TG3. The WCT3 values ranged from –6.0°C to –21.5°C. In fact, the results for TG2 have a similar bottom value for WCT3 (–20.0°C), yet during the day, and particularly during sunny days, WCT2 was higher, which is reflected in its value equalling –0.6°C.

The zones 2 and 3 were located close to curtain walls, which made them more exposed to wind (despite bales of straw stacked by the wall). Regardless of the fact that the curtains were closed, air velocity in these zones was definitely higher than in the zone occupied by TG1. It exceeded the

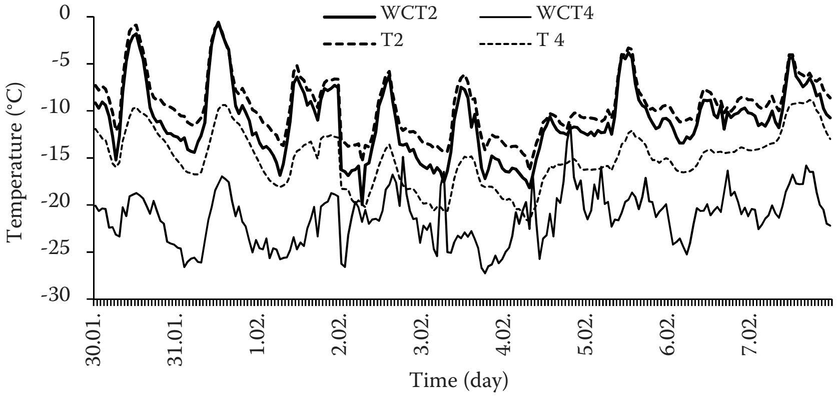

Figure 3. Exterior air temperature (T4) and inside air temperature (T2) in zone 2 of the second technological group, exterior wind chill temperature (WCT4) and wind chill temperature inside the barn (WCT2) in the zone occupied by the second technological group

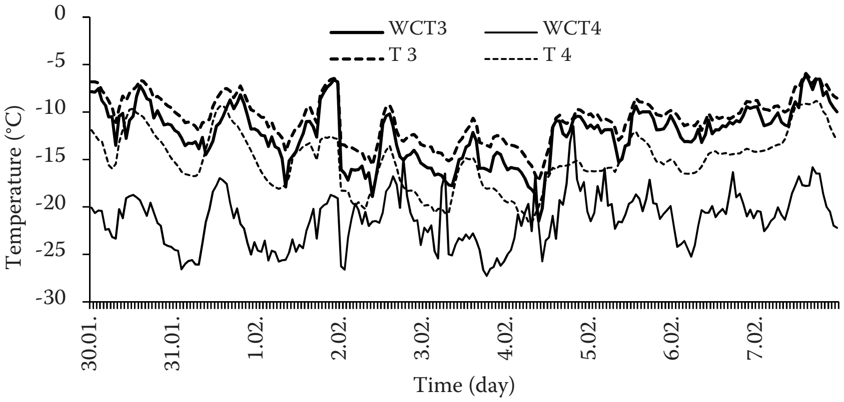

Figure 4. Exterior air temperature (T4) and inside air temperature (T3) in zone 3 of the third technological group, exterior wind chill temperature (WCT4) and wind chill temperature inside the barn (WCT3) in the zone occupied by the third technological group

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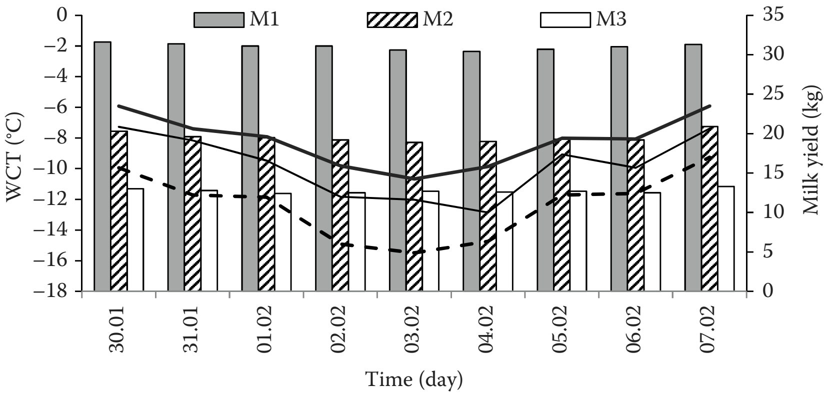

Figure 5. Milk yield (M1–M3) and average daily wind chill temperature (WCT1–WCT3) in three technological groups

limit value of 0.2 m/s recommended for cattle to sustain in winter seasons.

The most favourable conditions were observed in zone 1, situated by the wall without curtains. The observed differences between T1 and WCT1 were insignificant, and daily WCT1 variations ranged from –1.6 to –14.4°C. Although ventilated air velocity in this part of the barn exceeded the recommended value, it did not decrease the operative temperature for cows significantly.

The established WCT index was referred to milk yield for each TG in order to determine whether low temperatures and cold stress affect dairy cattle (Figure 5). The significance of results was established with the help of statistical analysis (Table 3).

Based on the equation applied WCT, the authors have developed Table 4 defining operative temperature in cows based on the correlation between air temperature and air velocity. The parameters included into the equation are of major significance, yet the addition of relative air humidity inside the building and solar radiation into it would certainly make it more accurate. It is worth noting that the surplus of humidity in the barn may have negative influence on cows' hair coat, which is one of the factors protecting cows from frost. Hair coat serves as thermal insulation; when it is wet, it leads to quicker heat loss, which makes cattle more vulnerable to low temperatures and high air velocities.

Table 3. Correlation indexes for milk yield, air temperature, and wind chill temperature

Milk yield	Wind chill temperature (°C)		
	WCT1	WCT2	WCT3
M1	0.72		
M2		0.89	
M3			0.62*

M1, M2, M3 = milk yield for each technological group in research period, WCT1, WCT2, WCT3 = wind chill temperature for each barn zone

$P < 0.05$, $^{*}P < 0.09$

DISCUSSION

Most scientific studies investigating the development of cold stress focus on dairy and beef cattle kept on pastures throughout the year with only simple roof structures to protect animals against severe weather conditions (Graunke et al. 2011). It is quite rare that research deals with cold stress in dairy cattle kept in barns equipped with curtain walls (Broucek et al. 1991). This may be due to an assumption that curtain-sided barns provide suitable protection against weather conditions.

Cows are well able to adapt to changeable temperature and humidity conditions throughout the year (Kadzere et al. 2002). This can be confirmed by a relatively wide range of neutral temperatures established for dairy cattle. While upper critical temperature, above which thermal stress occurs, was established at the level of 24–27°C (Herbut et al. 2015), there are significant disparities as to the lower critical temperature level, below which we can observe cold stress. Kadzere et al. (2002) determined that the lower critical temperature for cows with daily milk yield of 30 kg remains in the range –37 to –16°C. Yet, this is a very wide range, which makes it impossible to define the moment of cold stress occurrence precisely. In turn, the Internet portals for cattle breeders state that cold stress in cattle unexposed to wind but with winter coat appears at the level of 0°C.

The analysis of results obtained in this study showed that cold stress, confirmed by lower milk production, appeared when the temperature was much lower than 0°C. It is difficult, though, to refer to border values provided by Kadzere et al. (2002)

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Table 4. Wind chill temperature formula[1]

	Air temperature (°C)												
Air velocity (m/s)	−25.0	−22.5	−20.0	−17.5	−15.0	−12.5	−10.0	−7.5	−5.0	−2.5	0.0	2.5	5
0.2	−24.3	−21.8	−19.3	−16.8	−14.3	−11.8	−9.4	−6.9	−4.4	−1.9	0.6	3.1	5.6
0.3	−25.8	−23.2	−20.7	−18.1	−15.6	−13.0	−10.4	−7.9	−5.3	−2.8	−0.2	2.3	4.9
0.4	−26.9	−24.3	−21.7	−19.1	−16.5	−13.9	−11.3	−8.7	−6.1	−3.4	−0.8	1.8	4.4
0.5	−27.8	−25.1	−22.5	−19.8	−17.2	−14.6	−11.9	−9.3	−6.6	−4.0	−1.3	1.3	3.9
0.6	−28.5	−25.9	−23.2	−20.5	−17.8	−15.2	−12.5	−9.8	−7.1	−4.5	−1.8	0.9	3.6
0.7	−29.2	−26.5	−23.8	−21.1	−18.4	−15.7	−13.0	−10.3	−7.6	−4.9	−2.1	0.6	3.3
0.8	−29.8	−27.0	−24.3	−21.6	−18.8	−16.1	−13.4	−10.7	−7.9	−5.2	−2.5	0.2	3.0
0.9	−30.3	−27.5	−24.8	−22.0	−19.3	−16.5	−13.8	−11.0	−8.3	−5.5	−2.8	0.0	2.7
1.0	−30.8	−28.0	−25.2	−22.4	−19.7	−16.9	−14.1	−11.4	−8.6	−5.8	−3.0	−0.3	2.5
1.1	−31.2	−28.4	−25.6	−22.8	−20.0	−17.2	−14.5	−11.7	−8.9	−6.1	−3.3	−0.5	2.3
1.2	−31.6	−28.8	−26.0	−23.2	−20.4	−17.6	−14.8	−11.9	−9.1	−6.3	−3.5	−0.7	2.1
1.3	−32.0	−29.1	−26.3	−23.5	−20.7	−17.9	−15.0	−12.2	−9.4	−6.6	−3.7	−0.9	1.9
1.4	−32.3	−29.5	−26.6	−23.8	−21.0	−18.1	−15.3	−12.5	−9.6	−6.8	−3.9	−1.1	1.7
1.5	*−32.6*	−29.8	−26.9	−24.1	−21.2	−18.4	−15.5	−12.7	−9.8	−7.0	−4.1	−1.3	1.6

[1] based on Tucker et al. (2007)

because the temperature in southern Poland very rarely falls below −30°C.

Heat production increasing together with milk production compensates for energy losses caused by frost; as a result, when milk production increases, lower critical temperature decreases (Berman 2003). Broucek et al. (1991) states that lower critical temperature for cows during peak milk is −30°C, while with the milk yield of 36 kg it is as low as −45°C.

In the researched barn, most productive cows (TG1) occupied the zone with the most favourable thermal conditions. This resulted in insignificant milk yield decrease by approximately 1 kg (3.2%). In TG2, milk production decreased by approximately 2 kg (9.3%). This group was located by the southern curtain wall, where the temperatures ranged between −15° and −10°C and ventilated air moved with higher velocity. This resulted in lower operative temperature when compared to TG1. The decrease of milk production in TG3, with the lowest milk yield, was approximately 0.5 kg (3.9%).

Milk yield decrease was noted in all TG roughly 24 h following very low temperatures (below −10.0°C). Lower milk productions had maintained until temperatures increased and milk production returned to the previous level one day after frost had stepped back.

Broucek et al. (1991) recorded a 2-kg milk yield decrease in similar conditions (temperatures below −10°C and cows with average milk yield of 15 kg).

The research conducted by Herbut and Angrecka (2012) and Herbut (2013) confirmed that the area of the barn is not uniform in terms of the prevailing temperature and humidity conditions. Significant differences in operative temperature may occur even within the area occupied by one TG (Herbut and Angrecka 2013). During the present study period, the values of WCT were lower from those of measured air temperature in particular areas of the barn. This means that frost and high air velocity may lead to the development of cold stress in animals, even those kept in a barn. The obtained results show that cold stress in cow with annual milk yield of 31.5 kg begins when the temperature falls below −6.7°C and air velocity exceeds 0.32 m/s. In the case of TG2 with milk yield of 21.6 kg, cold stress developed when air temperature fell below −12.1°C and wind velocity exceeded 0.70 m/s. For TG3 (milk yield of 12.7 kg) it developed when the temperature was lower than −11.1°C and wind velocity higher than 0.58 m/s.

The conditions leading to cold stress occurrence in TG2 and 3 are similar, yet for TG2 the correlation between operative temperature and milk production is very strong ($r = 0.89$ with $P < 0.05$); while for TG3, the obtained correlation value is insignificant ($r = 0.62$ with $P < 0.09$).

Based on the result analysis, it can be concluded that dairy Holstein-Friesian breed cattle kept in curtain barns tolerates well severe frosts combined with high air movement. Despite the occurrence of cold stress, the animals managed to restore milk production to previous levels quickly. Therefore, it can be concluded that in the case of cattle kept in

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barns protecting animals from strong winds, cold stress is not a serious threat leading to milk production decrease.

CONCLUSION

Monitoring the temperature, humidity, and air velocity conditions in the barn in characteristic points of the living zones of each TG is necessary. In these areas, significant differences of temperatures and air movement velocity were observed, resulting in varying indicators of WCT.

The decrease in milk yield by approximately 1–2 kg in all TG occurred after a one-day temperature decrease, but the border temperature was different in each living zone of the cows. Milk production returned to the previous level one day after frost had stepped back.

Analysis of the two-year measurements allow to state that Holstein-Friesian breed cows in curtain barns with free stall system maintenance are exposed to cold stress. However, the occurrence of low temperatures combined with increased air velocity, even in the long term, is well tolerated by the cows.

Conducted calculations and analysis of the obtained results show that there is a need to improve the applied calculation formula for additional parameters for the purpose of determining operative temperature during the frost in cows in free stall barn.

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