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IMPACT OF BARN ORIENTATION ON INSOLATION AND TEMPERATURE OF STALLS SURFACE*

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Abstract

The aim of this study was to determine the effect of free-stall barn orientation relative to cardinal points on the insolation area and on the surface temperature of selected stalls in the summer period. The results of the experimental research were subjected to model analysis of the distribution of area of insolation into a barn. The studies showed that the surface of insolated stalls is heated to a temperature of 40°C, and in extreme cases up to 58°C. Taking into account the body temperature of cows (38–39°C), it can be concluded that the heat transfer from animals' body to the environment, and thus the possibility of their cooling, were difficult. This is confirmed by observations of the behaviour of cows obtained from the video monitoring. Large differences were found in thermal conditions in the southern and northern stall areas, which in the midday hours were up to 10°C. The impact of clouds occurring during observations, included in the studies, contributed to the reduction of temperature of the stalls surface. During hot weather, short, ten-minute appearance of clouds, caused a decrease of the temperature of stalls surface by approx. 2.5°C. On this basis, it can be concluded that the use of shadings in building environment in the noon hours could limit the heating up of stalls and thus contribute to improving the living conditions of cows in barn.

Key words: welfare, barn, dairy cattle, insolation, temperature

Dairy cattle spend their whole life in a barn with free-stall housing system. The tasks of the breeders include ensuring appropriate cow nutrition (Horky, 2014; Alba-Mejia et al., 2016) and indoor microclimate that contribute to optimal conditions for rest and comfort of cows living there (Tucker et al., 2009; Herbut and Angrecka, 2013).

Cows spend from 8 to 16 hours lying down per day (Tucker et al., 2003) and according to Radoń et al. (2014) from 12 to 14 hours daily. Optimization of undisturbed lying time is very important for cows because it affects their health, including

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the exclusion of hoof diseases and lameness (Manninen et al., 2002; De Palo et al., 2006).

The comfort of lying cows, including getting up and lying down, depends among others on: the size and type of stall surface, the type of stall barriers, resting area, and feeding. Cows prefer soft bedding lined with dry and balanced material of sufficient quality, which is safe during getting up (van Gastelen et al., 2011). Equally important is also the temperature of bedding material, which is dependent on the air temperature, the type of the material itself, and its depth (Meng et al., 2015).

The optimum temperature for lactating cows is in the range of 5–25°C (Kadzere et al., 2002). However, during the summer period, these conditions may deteriorate. The combination of high temperature and relative humidity of air along with low speed of the ventilation air causes discomfort in cows. Prolonged exposure of animals to such conditions, contributes to the occurrence of heat stress, which, among others, results in decline in milk productivity (Herbut et al., 2015).

Research carried out in different parts of the world shows a need for solutions that improve the living conditions of cows. Next to sprinklers and air mixers various forms of shadings are increasingly cited, such as woodlots, extension of roof eaves, installation of nets reducing insolation (Angrecka and Herbut, 2012). Also, Schutz et al. (2009) list the solutions used by other researchers, for example shade cloths, choko vines and iron roof. Belts of trees and shrubs and the increase of eaves are stable solutions, in contrast to the shading nets or fabrics, where there is a possibility of their interim assembly (Angrecka and Herbut, 2012). Permanent shading methods are most often mentioned in the context of improving the conditions of cows staying on pastures. However, the results obtained by Herbut and Angrecka (2013) showed that also in barns it is necessary to take into account insolation, which has a significant influence on temperature and humidity conditions.

In Poland the solar radiation has a very uneven distribution in terms of the different areas of the country, as well as in terms of time. 80% of the total annual insolation falls in a period of six months in spring and summer, and the estimated maximum duration of sunshine in the summer period is 16 hours. The annual solar radiation density in Poland on the horizontal plane is in the range of 950–1250 kWh·m^{-2} (Zochowska et al., 2012).

Taking into consideration the circulating motion of the Earth and the dominant westerly wind direction it is recommended that the barns orientation should be with longitudinal axis in north-south direction with a possible several degree deviation (Herbut et al., 2013). Such location of the building, in relation to the sides of the world, is also important in determining the optimum shading capabilities of the stalls.

Aiming to reduce the risk of heat stress occurrence in dairy cattle is also related to the search for new methods of predicting that stress (Adamczyk et al., 2016). So far, for predicting heat stress there has been used measurements of air parameters in different parts of the barn (Herbut, 2013), on the basis of which the different indexes were estimated, usually THI (Herbut et al., 2015). However, in determining the risk of heat stress, infrared thermography gains more and more popularity. This method allows checking the temperature of the cows’ body surface, the flow of their blood or the measurement of the eye temperature (Godyń et al., 2013), which change along with changes in barn temperature and humidity conditions. Infrared photos also allow to control the temperature distribution on the surface of the stalls.

The aim of this study was to determine the effect of free-stall barn orientation relative to cardinal points on the insolation area and on the temperature of surface of selected stalls in the summer period. For the results of obtained field tests there has been conducted model analysis of the distribution of area of insolation into a barn.

Material and methods

Measurements were carried out in the village of Kobylany (N 50°08′51″, E 19°45′29″) on the dairy cow farm in the free-stall barn littered with straw (4 kg/day/cow) designed for 174 cows of Holstein-Friesian breed. The barn was located with its longitudinal axis in the east-west direction. Fixed measurements were covered temperature (Ti_S, Ti_N, Te) and relative air humidity (RHi_S, RHi_N, RHe) inside and outside of the building (Figure 1).

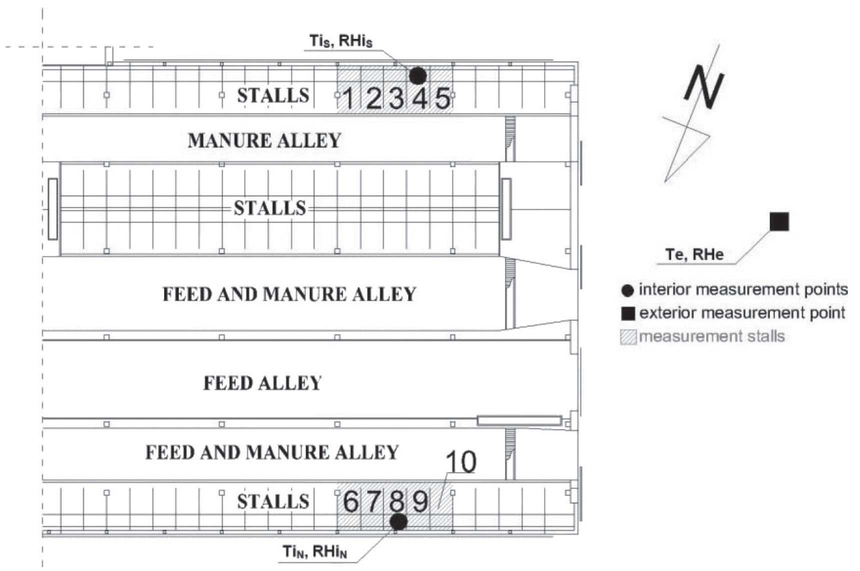

Figure 1. Projection of the barn with the arrangement of the examined stalls (1–10) and measurement points

In the western part of the barn 10 stalls were set (Figure 1), on which the measurements and observations of insolation were carried out. Stalls 1–5 were situated on the southern side, while stalls 6–10 on the northern side of the building. All stalls covered by measurements were located with open longitudinal walls and were separated for cows. Cows were lying in all areas for their technological group without those ten stalls.

The range of incidence of solar radiation on the surface of the selected stalls was obtained from the observation, constant vision system, measurements made by infrared camera and from the angles of incidence of solar radiation for each day of the research period.

The temperature distribution on the surface of stalls was measured by means of the FLIR i7 infrared camera (FLIR Systems, Wilsonville, Oregon/USA) with a detector resolution of 140x140, 19,600 pixels, the measuring range from –20°C to +250°C, thermal sensitivity (NETD) 0.1°C and a measurement accuracy of ±2°C. Measurements and observations were carried out during the summer months (July – August 2013). Record of the measurement results, in the form of thermograms, was held every 10 minutes.

Measurements of temperature and relative air humidity at 6-minute intervals were performed by means of LB-710 integrated sensors (Label, Reguły, Poland), with a measuring range from –40°C to +85°C and relative humidity from 0% to 99.9% . The accuracy of the measurement for temperature was 0.1°C and 0.1% for relative humidity.

The intensity of solar radiation was recorded by means of LP PYRA03 AC M12 pyranometer (Delta Ohm, Padua, Italy) with a measuring range of 0–2000 $W \cdot m^{-2}$ and the measurement sensitivity of 10 $W \cdot m^{-2}$.

On the basis of the technical documentation and individual measurements there was also made a model of the barn in SketchUp Pro 8 program, which was used to analyse the distribution of solar radiation incidence on tested stalls. The object has been modelled on the map including the geographical orientation and GPS coordinates, so that the height of the sun and the angles of incidence of sunlight for the summer period were the same as for the actual building. In SketchUp Pro 8 program there has been made analyses of the distribution of the incidence of solar radiation on stalls covered by measurements for the barn located with its longitudinal axis in the north-south direction. The analysis was performed with a 60 minute time step.

The temperatures of stalls surface 1–5 and 6–10 corresponding with intensity of solar radiation and with indoor air temperature were analysed using analysis of the Spearman's correlation coefficient (r) (Version 12.0, 2013). 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

Table 1 presents characteristic values of temperature and relative air humidity at individual measurement points made for the research period.

On the basis of measurements of solar radiation intensity and obtained temperatures of bedding surface the chart of their average values for the entire study period was made (Figure 2).

The increase of temperature in bedding surface in southern positions happened along with an increase in the intensity of solar radiation ($r=0.80$ with $P<0.01$), especially after 11:00 when its value exceeded 500 $W \cdot m^{-2}$.

Table 1. Characteristic values of temperature and relative air humidity during the research period

Air parameters	July						August					
	Ti_S	Ti_N	Te	RHi_S	RHi_N	RHe	Ti_S	Ti_N	Te	RHi_S	RHi_N	RHe
average	21.0	20.1	19.6	68.6	71.6	72.5	21.0	19.9	19.4	64.7	69.1	69.3
maximum	35.5	35.7	35.0	93.5	95.1	97.0	36.4	35.7	36.0	93.1	95.0	96.6
minimum	9.6	8.5	6.6	33.3	34.0	34.7	11.2	10.7	9.7	26.6	28.1	27.0

Ti_S, Ti_N, Te – air temperature for each respective measurement point.
RHi_S, RHi_N, RHe – relative air humidity for each respective measurement point.

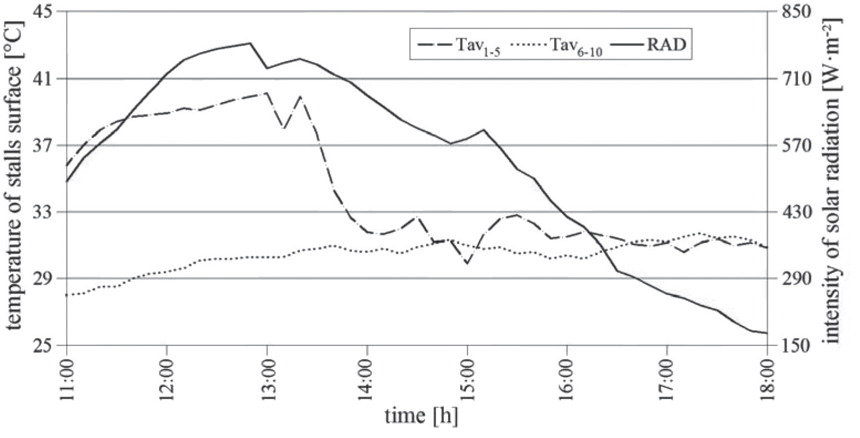

Figure 2. The course of the average temperature of surface of stalls 1–5 ($Tav_{1–5}$) and 6–10 ($Tav_{6–10}$) and intensity of solar radiation (RAD) over the study period

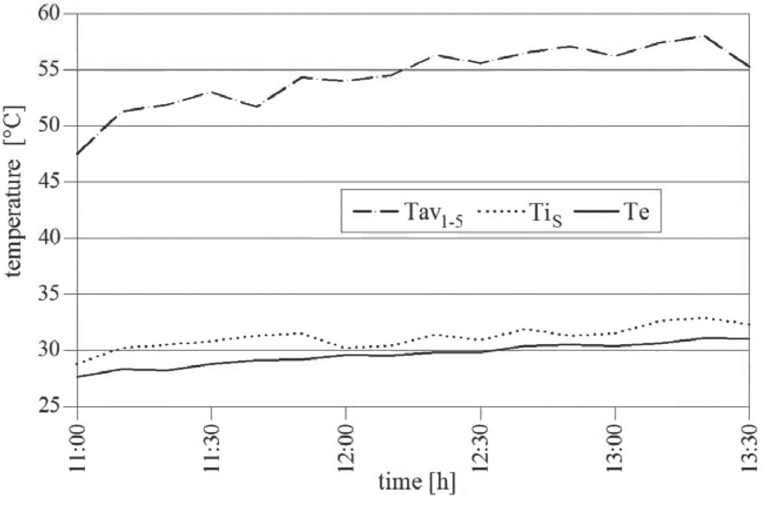

Figure 3. Indoor (Ti_S), outdoor (Te) air temperature and the average temperature of surface of southern stalls ($Tav_{1–5}$) on August 6th

The temperature of the surface of stalls 1–5 within two hours (11:00–13:00) increased by an average of 4.5°C, after 13:00 it started to fall, and about 16:00 it began to stabilize at about 31°C. Correlation between surface of stalls 1–5 and interior air temperature was r=0.78 (P<0.01). Stalls 6–10 were not exposed to the sun until the afternoon but the correlation between temperature of those stalls and solar radiation was r=–0.53 with P<0.01. The temperature of surface of stalls 6–10 increased by an average of 3°C along with the increase in air temperature up to midday hours.

In the analysed period, a special day was August 6th. In the noon hours the maximum temperature inside the barn was 33°C, with the intensity of solar radiation at 850–915 W·m^{-2}. As a result, the temperature of surface of southern stalls reached an average maximum value of even 58°C (Figure 3).

Decrease of temperature of stalls was only noticeable at 13:20, when the sun was setting behind the corner of the building and the angle of solar radiation was reduced.

The measurements and observations revealed that the distribution and height of the temperature on the stalls surface was dependent on their location in relation to cardinal points and the consequent exposure to insolation. In summer period southern stalls 1–5 were sunlit between 8:00 and 14:00 and stalls 1–6 after 17:00 (Figure 4).

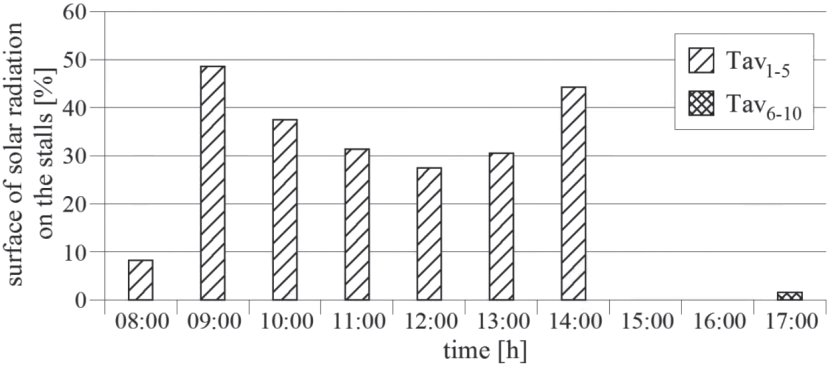

Figure 4. Percentage of sunlit area of measured stalls with existing barn orientation (longitudinal axis E-W)

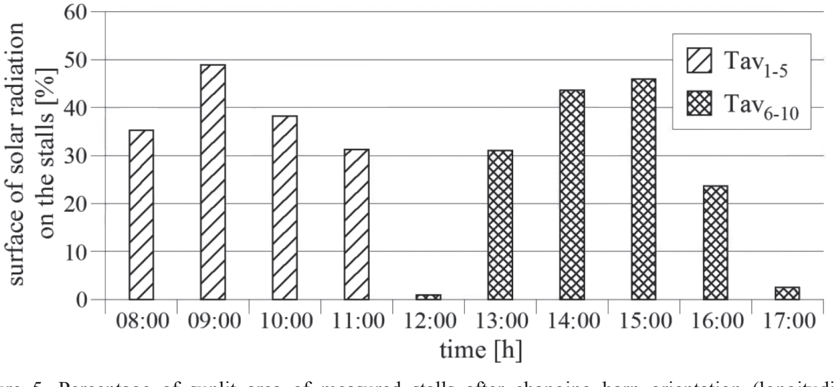

Figure 5. Percentage of sunlit area of measured stalls after changing barn orientation (longitudinal axis N-S)

A conducted simulation model to change the barn orientation (longitudinal axis N-S) showed that the warm-up time of litter on southern and northern stalls significantly changed (Figure 5).

After the model change of the position of the barn stalls 1–5 were sunlit in the morning hours, and positions 6–10 from 12:00 until late afternoon. In favour of such orientation of a building speaks an almost complete elimination of the impact of the largest intensity of solar radiation at 12:00 (midday).

The authors also conducted a computer simulation of stalls shading based on the extension of the barn roof eaves on the southern side. Analysis of the results showed that the extension of the eaves from the existing 0.45 m to 1.0 m results in a significant reduction in stalls insolation. At 13:00, that is, in time of high solar radiation values occurrence, there would be obtained an approx. 90% reduction of stalls insolation.

Discussion

The productivity of animals is affected by microclimate inside of the building. In order to maintain appropriate living conditions of cows they should be given an optimal temperature and relative air humidity (Angrecka and Herbut, 2015).

In the light of forecasting changes connected with global warming, the possibilities of reducing the negative impact of solar radiation on the welfare of dairy cattle acquires a significant role. This applies both to the breeding in pasture system (Mader et al., 2006) as well as in free-stall barns (Herbut and Angrecka, 2013).

Insolation of the inside of the building, especially the heating of the surface of stalls needs to be seen in several aspects. On the one hand, the solar radiation falling on stalls material dries it, which is reflected in the time of cows lying down and their resting comfort. Research made by Fregonesi et al. (2007) showed that the cows' lying down time, after the change of stalls material from wet to dry, can rise up to 5 hours.

However, a proper preparation of stall for the cows cannot be limited only to ensure the comfort of lying. During unfavourable temperature and humidity conditions that can cause heat stress in cows, the material used to line the position should allow draining the excess of heat and sweat from cows and thus cooling their body (De Palo et al., 2006). It is very important because, as reported by Aguilar (2013), while lying an approx. 20% of cow's body is in contact with stall.

The conducted study showed that in the summer period the surface of insolated stalls is heated to a temperature of 40°C, and in extreme cases up to 58°C, which should be regarded as an unusually negative phenomenon for the welfare of cows. The largest thermal load was noted in stalls located at the southern wall, while the smallest in stalls at the northern wall, where the solar radiation fell only in afternoon and evening hours.

Kaczor et al. (2011) in their study showed that the temperature of the skin on the abdomen of HF cows is 35°C. Taking into account a high temperature of surface of stalls and air in the research period, in relation to the body temperature of cows

(38–39°C), it can be concluded that the heat from animals body to the environment, and thus the possibility of their cooling, was difficult. This is also confirmed by observations of the behaviour of cows obtained from the cameras in accordance with the results of studies made by Schutz et al. (2008). Cows preferred lying on a wet, contaminated by faeces concrete floor of manure alley than on stalls being at least partially sunlit.

Research conducted by Schutz et al. (2009) showed that cows on pasture used the shade, especially during the most intense solar radiation. In turn, Brown-Brandl et al. (2005) found that the use of shading can reduce the thermal load of cows by 30%. The impact of clouds occurring during observations, included in the studies, contributed to the reduction of temperature of the surface of stalls. During hot weather, short, ten-minute appearance of clouds caused a decrease of the temperature of stalls surface by approx. 2.5°C. On this basis, it can be concluded that the use of shadings in building environment in the afternoon could limit the heating up of stalls.

Differentiation of stalls insolation, demonstrated in studies, helps to optimally choose the location of various technological groups in barn. The most productive cows should be kept in northern stalls, and the cows before drying off in southern parts. Such rotation will reduce the risk of heat stress occurrence in cows at peak moment of lactation. Conducted analysis of the change of the building orientation in relation to the sides of the world proved to be detrimental to the insolation of stalls. It resulted in an increase in the area and the duration of their insolation. Thus, cattle staying in stalls 1–5 and 6–10 were exposed to unfavourable conditions for their welfare for at least 4 hours a day.

Designing new barns is mainly related to the correct selection of orientation of buildings in accordance with the wind directions prevailing in that area. From the analysis of the research results it can be concluded that in the design phase of the building, angles of solar radiation incidence at different times of the year should be taken into consideration. This will allow for the complete elimination of stalls insolation (the orientation of barn, extended eaves) or for dispersal of insolation (trees, shrubs), and thus contribute to improving the living conditions of cows in barn.

In conclusion, the present orientation of the tested barn is optimal (longitudinal axis E-W). To improve cow welfare it is only needed to rotate the technological groups. However, each barn could be placed in different location so individual analysis is necessary.

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