

EFFECT OF AVERAGE DIURNAL BARN AIRSPACE TEMPERATURES ON PREDICTION OF THEIR DEVELOPMENT DURING THE DAY

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Abstract

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A year-round (i.e. 365 days) experiment was performed at the Mendel University Training Farm in Žabčice, Czech Republic (GPS 49°0'51.967"N and 16°36'14.614"E, the altitude 179 m) with the aim to quantify the effect of the variation of average diurnal barn airspace temperatures on prediction of their changes during the day. Barn airspace temperatures were monitored daily in one-hour intervals and the recorded values were used for calculations of average diurnal temperatures. These were classified into 7 categories (i.e. below 0 °C; 0.1 to 5 °C; 5.1 to 10 °C; 10.1 to 15 °C; 15.1 to 20 °C; 20.1 to 25 °C and above 25 °C). Regarding this classification system, all differences between temperatures measured at identical hours but within various limits were statistically highly significant. The statistical analysis involved also the calculation of the third degree polynomial regression equations, which enabled to characterise the relationship between the temperature and the hour of measurement within the aforementioned categories of diurnal temperatures. Individual equations were markedly different and ranged from $y = -0.0019x^3 + 0.0596x^2 - 0.3797x - 1.2169$ (for temperatures below 0 °C) to $y = -0.0108x^3 + 0.3297x^2 - 1.9367x + 24.3931$ (for temperatures above 25 °C). Correlation coefficients (r) and coefficients of determination (R^2) of these regression equations were generally very high and ranged from 0.872 to 0.976 and from 0.760 to 0.953, respectively. Regarding high values of both coefficients it can be concluded that the calculated equations enable a good and reliable prediction of the diurnal development of barn airspace temperatures.

barn airspace temperature, prediction, heat stress, regression equations

There are many papers (e.g. Goubanova & Li, 2007) dealing with the development and simulation of possible effects of the global warming and the greenhouse effect on the climate and life on Earth. For example, this fact was confirmed also Bartholy & Pongrácz (2007) who referred to an increasing annual numbers of hot days and warm nights in the Carpathian Basin during the second half of the 20th century. According to these authors, the occurrence of extreme precipitation events increased as well while the sums of precipitation decreased. Data published by many other authors also suggest the existence of a marked climatic change and for that reason it is necessary to take this new situation into account also in the domain of animal husbandry (Thomassen & Boer, 2005; Bartholy & Pongrácz,

2007; Delarue *et al.*, 2007; Goubanova & Li, 2007; Levy *et al.*, 2007).

In dairy cows, the thermoneutral zone is generally defined for ambient temperatures ranging from 3 to 12 °C and it is known that the heat stress occurs at temperatures higher than 25 °C. This is the reason why, from the phylogenetic point of view, cattle are classified among arctic animals. At present, the heat stress can be justly characterised as a factor causing production disturbances, similarly as mastitis, ketosis, acidosis etc. Heat stress deteriorates welfare of animals, negatively influences their health condition and reproduction (Thompson *et al.*, 2006) and reduces the quality of animal products (Dolejš *et al.*, 1996 a, b, 2000 a, b; Illek *et al.*, 2007; Vokřálová *et al.*, 2007). Also Hanuš *et al.* (2008)

highlighted negative effects of high barn airspace temperatures on milk performance of dairy cows. Vokřálová & Novák (2005) related the upper limit of temperatures causing the heat stress of animals to their performance and concluded that in high-yielding dairy cows the heat stress could occur already at 21 °C. This fact must be permanently kept in mind, above all with regard to a permanent increase in milk performance of cattle breeds raised in the Czech Republic (Hanuš *et al.*, 2007). The rank of lactation also plays a certain role because Walterová *et al.* (2008) observed that the average barn airspace temperature of 22 °C already stressed dairy cows on the second lactation while in older animals the trigger of stress were temperatures above 25 °C.

Besides the temperature, also some other climatic factors play a very important role (e.g. air flow and humidity, draughts etc.; Louda *et al.*, 1999). Air humidity further amplifies the negative effect of increased temperatures (Koukal, 2001). According to Doležal (2003), the higher the relative air humidity, the worse the tolerance of heat and stress. Kic *et al.* (1995) recommended for dairy cows as an optimum values of relative barn airspace humidity ranging from 50% to 70%. The value of 80% is a maximum that should occur only exceptionally during the winter when the outside air temperatures decrease to a very low level. According to Doležal *et al.* (2002), the tolerance of dairy cows to high temperatures decreased from 28 °C at 40% of air humidity to only 23 °C at 80%. The temperature-heat index (THI) combines effects of air temperature and relative humidity West (2003). Kendall *et al.* (2006) used the THI in an attempt to determine the thermal comfort, i.e. the situation when the value of THI is equal to or exceeds 72 (this corresponds to 25 °C and 50% of relative air humidity). For dairy cows, THI of 72 is generally accepted as the upper limit of environmental temperature and values above it cause a decrease in milk performance. According to Kadzere *et al.* (2002) values below 70 are considered as comfort, 75 to 78 stressing, and above 78 extremely dangerous to lethal. Similar values were mentioned also by Brouček *et al.* (2006), cit. Du Prezz *et al.* (1990). According to Bouraoui (2002) the milk performance is a function of THI: with increasing values of THI milk yields decrease and in the zone above 69 each unit change in THI causes a decrease in milk yield by 0.41 kg per head and day. It results from studies performed by Erbez *et al.* (2010) and Walterová *et al.* (2009) that under Central European conditions high values of THI are predominantly influenced by high temperatures and that the effect of relative air humidity is substantially lower. The above authors observed in their studies that during hot summer months the values of relative air humidity were lower while in winter they were much higher.

From the viewpoint of prevention and/or attenuation of negative effects of heat stress on dairy cows it is important to be able to predict the diurnal course of barn airspace temperatures so that it would be possible to take necessary preventive measures. These measures should prevent and/or attenuate negative effects of heat stress and can be directed either to those parts of the day when the temperatures are at their maxima (e.g. a forced air circulation or evaporative cooling) or at their minima (changes in feeding technology). The aim of this study is an attempt to quantify effects of average diurnal temperatures in barns and to predict their course during the day.

MATERIAL AND METHODS

A year-round (i.e. 365 days) experiment was performed at the Mendel University Training Farm in Žabčice, Czech Republic (GPS 49°0'51.967"N and 16°36'14.614"E, the altitude 179 m). The aim of this experiment was to quantify the effect of average diurnal barn temperatures on prediction of their development during the day. Barn airspace temperatures were monitored daily in one-hour intervals and the recorded values were used for the calculation of average diurnal temperatures, which were classified into 7 categories (i.e. below 0 °C; 0.1 to 5 °C; 5.1 to 10 °C; 10.1 to 15 °C; 15.1 to 20 °C; 20.1 to 25 °C and above 25 °C).

These average diurnal temperatures were calculated as an arithmetic mean of temperatures recorded during the day at one-hour intervals within the period from 0:00 to 23:00 hours. Further, the value of minimum diurnal temperature was calculated as a mean of three minimum temperatures, which were recorded at different hours on the experimental day. The maximum average diurnal temperature was calculated in a similar manner (i.e. as a mean of 3 maximum temperatures recorded also at different hours of the day). These minimum and maximum diurnal temperatures were thereafter used to calculate the difference between the maximum and minimum temperatures. Further, the third degree polynomial regression equations were calculated to characterise relationships existing between the temperature and the hour of measuring within the aforementioned intervals of average diurnal temperatures. For these equations, coefficients of correlation (r) and determination (R^2) were calculated using the programme package UNISTAT, Version 5.1.

RESULTS AND DISCUSSION

Selected thermal characteristics of the experimental barn are presented in Tab. I. As one can see, the highest number of days (82) fell into the temperature interval of 5.1 to 10 °C, while the lowest one (14) into the interval involving days with temperatures above 25 °C. Average diurnal temperatures ranged from -0.88 °C (interval < 0 °C)

I: Some selected thermal characteristics of the barn under study

Interval of average daily temperatures (°C)	Number of cases (n)	Mean (°C)	Minimum temperature		Maximum temperature		Difference Max. – Min. (°C)
			Temperature ¹⁾ (°C)	Time ²⁾ (Hour)	Temperature ³⁾ (°C)	Time ⁴⁾ (Hour)	
> 0	25	-0.88	-2.26	3; 4; 5;	0.41	12; 13; 14;	2.67
0.1 to 5	46	3.38	1.34	3; 4; 5;	5.74	13; 14; 15;	4.40
5.1 to 10	82	7.29	4.74	3; 4; 5;	10.48	13; 14; 15;	5.74
10.1 to 15	71	12.40	9.24	3; 4; 5;	15.80	14; 15; 16;	6.56
15.1 to 20	64	17.09	12.35	3; 4; 5;	21.66	14; 15; 16;	9.31
20.1 to 25	63	22.44	17.02	3; 4; 5;	27.56	14; 15; 16;	10.54
< 25	14	27.15	20.82	3; 4; 5;	33.87	15; 16; 17;	13.05

¹⁾ Average of three minimum daily temperatures

²⁾ Hour of recording of three minimum temperatures

³⁾ Average of three maximum daily temperatures

⁴⁾ Hour of recording of three maximum temperatures

to 24.01 °C (interval > 25 °C). As far as minimum temperatures were concerned, these were always recorded at 3:00, 4:00 and 5:00 and ranged from -2.26 °C (interval < 0 °C) to 20.82 °C (interval > 25 °C). In case of maximum temperatures, the moment of their recording moved to later hours of the day in dependence on their increasing category: within the interval 0 < °C maximum temperatures of 0.41 °C were recorded at 12:00, 13:00 and 14:00 hours while in the interval > 25 °C the maximum temperatures of 33.87 °C, were recorded at 15:00, 16:00 and 17:00 hours. As far as the differences between minimum and maximum temperatures were concerned, these also increased simultaneously with increasing average (but also with maximum or minimum temperatures), from 2.67 °C (within the interval < 0 °C) to 13.05 °C (within the interval > 25 °C).

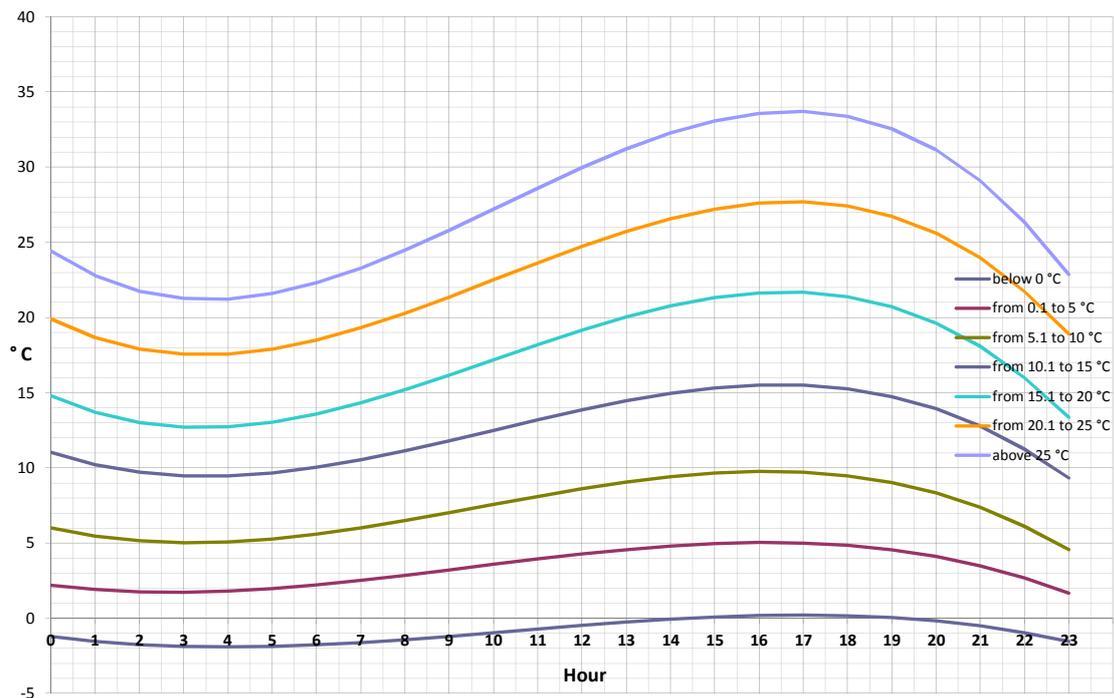
Regression equations describing relationships between temperatures and hours of measuring performed within individual intervals of average diurnal temperatures are presented in Tab. II. This table also contains coefficients of correlation (r) and determination (R²), as calculated for these regression equations. Equations presented in this table indicate that there was a dynamic trend in the course of diurnal temperatures which was associated with an increase in intervals of their average values. This increased dynamics of the course of regression equations was associated also with an increase

in values of their correlation and determination coefficients from 0.872 and 0.760 to 0.976 and 0.953, respectively. The dynamics of the diurnal course of predicted temperatures is illustrated in Fig. 1.

As already mentioned in the survey of literature, several authors share the opinion that in cattle the heat stress is triggered by temperatures above 25 °C; however, in some cases (e.g. in high-yielding animals or in females on the first lactation) the heat stress may occur already at 21 °C (Vokřálová & Novák, 2005; Walterová *et al.*, 2008 and others). Our results indicate that a massive overpassing of diurnal temperatures of 21 °C may occur within the heat intervals of 20.1 to 25 °C and/or > 25°C. In our study, this involved altogether 77 days. However, short-term fluctuations can be expected also within the interval of 15.1 to 20 °C (another 64 days) and they are not excluded even in the interval of 10.1 to 15 °C (potentially another 71 days). This means that, under climatic conditions of the Czech Republic, dairy cows may be exposed to temperatures higher than 21 °C for more than half a year. These temperatures are considered to be potentially stressing and causing negative changes in the animal organism (Hanuš *et al.*, 2008; Bouraoui, 2002; Thompson *et al.*, 2006). They also can deteriorate the quality of animal products (Dolejš *et al.*, 1996 a, b, 2000 a, b; Illek *et al.*, 2007; Vokřálová *et al.*, 2007).

II: Regression equations expressing the relationships between temperature (y) and hour of measuring (x) in individual time intervals

Interval of average daily temperatures (°C)	Regression equation y = temperature (°C) x = time (hour)	Correlation coefficient (r)	Coefficient of determination R ²
> 0	$y = -0.0019x^3 + 0.0596x^2 - 0.3797x - 1.2169$	0.872	0.76
0.1 to 5	$y = -0.0027x^3 + 0.0767x^2 - 0.3585x + 2.2009$	0.876	0.768
5.1 to 10	$y = -0.0043x^3 + 0.1251x^2 - 0.6664x + 6.0207$	0.9077	0.824
10.1 to 15	$y = -0.0056x^3 + 0.1678x^2 - 0.9710x + 11.0323$	0.956	0.913
15.1 to 20	$y = -0.0078x^3 + 0.2343x^2 - 1.3237x + 14.7841$	0.971	0.943
20.1 to 25	$y = -0.0086x^3 + 0.2606x^2 - 1.4870x + 19.904$	0.976	0.952
< 25	$y = -0.0108x^3 + 0.3297x^2 - 1.9367x + 24.3931$	0.976	0.953



1: Prediction of the development of diurnal temperatures within individual intervals of their average daily values

The observation that maximum diurnal temperatures (< 21 °C) occur in barns usually between 2 and 5 p.m. means that it is recommended to apply measures enabling an active cooling of dairy cows (e.g. switching of fans and/or application of evaporative cooling) just within this period. Similarly, it is also recommended to avoid all superfluous and unnecessary activities within the

barn. Quite on the contrary, the time interval of 3 to 5 a.m. should be used as a compensatory period of feeding. As far as the prediction of the course of diurnal temperatures is concerned, it seems that the calculated third degree polynomial represents a really suitable model. This is demonstrated also by high values of coefficients of correlation and determination.

SUMMARY

The aim of this study was to quantify the effect of average diurnal barn airspace temperatures on the prediction of their development during the day. For that reason, a year-round experiment lasting altogether 365 days was performed on the Mendel University Training Farm in Žabčice, Czech Republic (GPS 49°0'51.967"N and 16°36'14.614"E; altitude 179 m). In the course of this experiment, barn airspace temperatures were monitored daily in one-hour intervals and the recorded values were used for the calculation of average diurnal temperatures, which were classified into 7 categories (i.e. below 0 °C; 0.1 to 5 °C; 5.1 to 10 °C; 10.1 to 15 °C; 15.1 to 20 °C; 20.1 to 25 °C and above 25 °C). Average diurnal temperatures were calculated as an arithmetic mean of values recorded on experimental days from 0:00 to 23:00 hours. The minimum diurnal temperature was calculated as a mean of three minimum temperatures at different hours on the day of recording. The maximum average diurnal temperature was calculated in a similar manner (i.e. as a mean of 3 maximum temperatures recorded also at different hours). These minimum and maximum diurnal temperatures were used to calculate the difference between the maximum and minimum temperature. Further, the third degree polynomial regression equations were calculated to characterise relationships existing between the temperature and the hour of measuring within the aforementioned intervals of average diurnal temperatures. For these equations, coefficients of correlation (r) and determination (R^2) were calculated using the programme package UNISTAT, Version 5.1.

Selected thermal characteristics of the barn under study are presented in Tab. I, while Tab. II contains regression equations characterising relationships existing between temperatures and hours of measuring performed within individual intervals of average diurnal temperatures. This table also presents coefficients of correlation (r) and determination (R^2) as calculated for these equations.

Equations presented in this table indicate the dynamic trend in the course of diurnal temperatures, which is associated with increasing intervals of their average values. This increased dynamics of the course of regression equations is associated also with an increase in values of their correlation and determination coefficients (i.e. from 0.872 and 0.760 to 0.976 and 0.953, respectively). The dynamics of the diurnal course of predicted temperatures is illustrated in Fig. 1.

The observation that maximum diurnal temperatures occur in barns usually between 14:00 and 17:00 enables to recommend that measures enabling an active cooling of dairy cows (e.g. switching-on of fans and/or application of evaporative cooling) should be performed just within this period. Similarly, it would be also suitable to avoid all superfluous and unnecessary activities within the barn in this part of the day. Quite on the contrary, the time interval of 3 to 5 a.m. should be used as a compensatory period of feeding. As far as the prediction of the course of diurnal temperatures is concerned, it seems that the calculated third degree polynomial represents a suitable model. This is demonstrated by high values of coefficients of correlation and determination.

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