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The use of temperature-humidity index (thi) to evaluate temperature-humidity conditions in free-stall barns

Wykorzystanie indeksu termiczno–wilgotnościowego (THI) do oceny warunków termiczno-wilgotnościowych w oborach wolnostanowiskowych

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Abstract

The objective of this study was to evaluate temperature/humidity conditions in free-stall barns with different types of gravity ventilation and to determine the risk of heat stress in cows based on the temperature-humidity index. The study was carried out during summer months (June/July) in two free-stall barns located in north-eastern Poland. The buildings for the study were selected based on the natural ventilation and animal housing systems used. One building was equipped with supply ducts mounted over windows and a roof ridge gap, and the other had flat roof exhaust ducts and side curtain. It was found from this study that the barn having flat roof exhaust ducts and air supply from side curtain was characterized by more favourable temperature/humidity conditions and presented a lower risk of heat stress to cows compared to the barn with roof ridge and air inlets. It was also found that cows in the barn with side curtain had comfortable conditions and those in the roof ridge barn were exposed to mild and moderate stress.

Keywords: dairy cows, heat stress, microclimate, THI, ventilation

Streszczenie

Celem pracy była ocena warunków termiczno – wilgotnościowych w oborach wolnostanowiskowych o różnych rozwiązaniach wentylacji grawitacyjnej i określenie ryzyka wystąpienia stresu cieplnego u krów w oparciu o indeks termiczno – wilgotnościowy THI. Badania przeprowadzono w miesiącach letnich (czerwiec/lipiec) 2010 roku w dwóch oborach wolnostanowiskowych, zlokalizowanych w północno-wschodniej części Polski. Głównym kryterium wyboru budynków do badań był zastosowany system wentylacji naturalnej i system utrzymania zwierząt. Jeden z obiektów wyposażony był nadokienne kanały nawiewne oraz szczeliną kalenicową, natomiast drugi posiadał stropodach z kanałami wywiewnymi i kurtynę boczną. W wyniku przeprowadzonych badań stwierdzono, że w oborze ze stropodachem z kanałami wywiewnymi i nawiewem z kurtyny bocznej panowały korzystniejsze warunki termiczno-wilgotnościowe i ryzyko stresu cieplnego u krów było mniejsze niż w oborze z kalenicą i otworami nawiewnymi. Stwierdzono także, że w oborze z kurtyną boczną na ogół panowały warunki komfortowe, podczas gdy w oborze z kalenicą krowy narażone były na słaby i średni stres.

Słowa kluczowe: bydło mleczne, mikroklimat, stres cieplny, THI, wentylacja,

Detailed abstract

Indeks termiczno-wilgotnościowy THI (Temperature-Humidity Index) jest powszechnie stosowanym narzędziem do oceny stopnia stresu cieplnego u bydła. Stanowi on miarę temperatury odczuwalnej, która wyraża łączny wpływ temperatury i wilgotności względnej powietrza na subiektywne odczucie gorąca i duchoty. Celem pracy była ocena warunków termiczno – wilgotnościowych w oborach wolnostanowiskowych o różnych rozwiązaniach wentylacji grawitacyjnej i określenie ryzyka wystąpienia stresu cieplnego u krów w oparciu o indeks termiczno – wilgotnościowy THI. Badania przeprowadzono w miesiącach letnich (czerwiec/lipiec) w dwóch oborach wolnostanowiskowych, zlokalizowanych w północno-wschodniej części Polski. W badanych oborach zastosowano różne rozwiązania wentylacji naturalnej. Jeden z obiektów wyposażony był nadokienne kanały nawiewne oraz szczeliną kalenicową, natomiast drugi posiadał stropodach z kanałami wywiewnymi i kurtynę boczną.

W wyniku przeprowadzonych badań stwierdzono, że w oborze ze stropodachem z kanałami wywiewnymi i nawiewem z kurtyny bocznej panowały korzystniejsze warunki termiczno-wilgotnościowe i ryzyko stresu cieplnego u krów było mniejsze niż w oborze z kalenicą i otworami nawiewnymi. Stwierdzono także, że w oborze z kurtyną boczną panowały na ogół warunki komfortowe (średnio THI=66,7 ± 5,5), podczas gdy w oborze z kalenicą krowy narażone były na słaby i średni stres (średnio THI=74,6±3,1). Nie mniej jednak w obu obiektach odnotowano chwilowe wysokie wartości THI, które według danych literaturowych, również w znacznym stopniu mogą przyczyniać się do spadku wydajności mlecznej. Dlatego też konieczne wydaje się zastosowanie w oborach urządzeń takich jak wentylatory i mieszacze powietrza (zraszacze nie powinny być wykorzystywane w obiektach z wysoką wilgotnością powietrza) lub podjęcie innych działań pozwalających na zredukowanie stresu cieplnego. Jest o tyle ważne, że w Polsce w ostatnich latach temperatura powietrza latem dochodzi do 38ºC, a tym samym ryzyko narażenia bydła na stres cieplny wzrasta.

Introduction

The main function of a livestock building is to protect farm animals against adverse and variable atmospheric conditions and to raise them in a way that ensures herd health and welfare as well as profitability of production. This is possible when the building is equipped with technological, functional and structural solutions that largely determine indoor microclimate conditions.

Air temperature and humidity are the basic factors of microclimate in livestock buildings, which have direct and indirect effects on the health and productivity of animals. Temperature/humidity conditions and air quality in livestock buildings depend to a large extent on the ventilation system and its efficiency (Reppo and Mikson, 2006; Głuski, 2008; Marciniak, 2009). Efficient ventilation enables microclimate parameters to be maintained at a relatively stable level appropriate for each animal species. This may largely limit the negative consequences of high air temperature on the animals, especially when it is accompanied by high humidity. This combination of temperature and humidity limits the amount of heat that animals lose to the environment and the occurrence of heat stress (Smith et al., 2006; Głuski, 2008).

Considering that summer air temperatures in Poland have recently reached values found in hot climate areas (Anonymous, 2010), it should be expected that livestock breeders will have to deal with heat stress increasingly often.

The negative impact of heat stress on productivity and reproductive performance of dairy cattle and the associated economic consequences have been well documented (Fuquay, 1981; Omiński et al., 2002; Ravagnolo and Misztal, 2002; de la Casa and Ravelo, 2003; St-Pierre et al., 2003; Bryant et al., 2007; Jordan, 2003; Garcia-Ispierto et al., 2007). However, most of this research has focused on hot regions while paying little attention to temperate zone countries such as Poland (Jaśkowski et al., 2005; Głuski and Michalczyk, 2008).

The degree of heat stress in cattle is typically evaluated using the temperature-humidity index (THI). It is a measure of apparent temperature, caused by the combined effects of air temperature and relative humidity on the subjective perception of heat and sultry weather. There are several classifications of heat stress that use the THI value, of which those developed by Thom (1959) and Armstrong (1994) are the most popular. Thom (1959) categorized THI as 70 ≤ THI ≤ 74 uncomfortable, 75 ≤ THI ≤ 79 very uncomfortable, and THI ≥ 80 serious discomfort. Armstrong (1994) identified THI <71 as comfort zone, 72≤THI ≤79 as mild stress, 80≤THI≤89 as moderate stress, and THI>90 as severe stress involving the risk of animal mortality.

The objective of this study was to evaluate temperature/humidity conditions in free-stall barns with different types of gravity ventilation and to determine the risk of heat stress in cows based on the temperature-humidity index.

Materials and methods

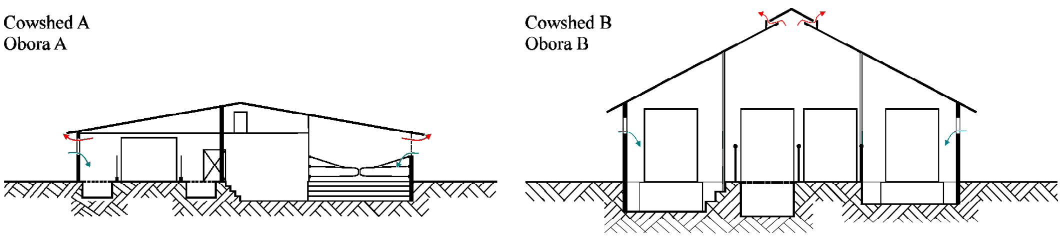
The study was carried out during summer months (June/July) 2010 year, with the exception of August when it was not full stocking in two free-stall barns located in north-eastern Poland. The characteristics of the analysed facilities are given in Table 1. The buildings for the study were selected based on the natural ventilation and animal housing systems used.

Tabela 1. Charakterystyka badanych obór
Table 1. Characteristics of the examined barns

ITEM	FACILITY	
	A	B

Stocking density (head)	70	50
Breed	Jersey	Black-and-White HF
Mean annual milk production	6800	6000
Housing system	deep litter	deep litter
Barn usable area [m^3]	680	505
Barn capacity per large animal [m^3]	40	51
Type of ventilation	gravity ventilation with flat roof exhaust ducts; wind-protection side curtain	gravity ventilation with roof ridge gap and supply ducts mounted over windows
Wall and roof insulation	–	+

Continuous measurements of air temperature and relative humidity inside and outside of the buildings were made using type 710 Lab-El thermohygrometers with data logging at 2-hour intervals. Uncertainty of measurements was ±0.1℃ for temperature, and ±2.0% (in the range of 10…90%) and ±4.0% (outside the range of 10…90%) for humidity. The meters were equally spaced in the living area of animals in such a way that every meter covered an area smaller than 30 m^2. Thermohygrometers were placed 0.5 – 2 m above the floor or litter, and at least 2 m away from ventilation holes and building partitions. During the study, the buildings were stocked to capacity.



Rysunek. 1. Przekroje poprzeczne obiektu A i B
Figure 1. Cross-sections of buildings A and B

Data obtained were used to calculate THI using the following formula (West, 1994):

$THI = T_{(°F)} - [0.55 - (0.55 \times RH/100) \times (T_{(°F)} - 58.8)]$

where: $T_{(°F)}$ – air temperature in degrees Fahrenheit ($T_{(°F)} = 9/5 \times T_{(°C)} + 32$)

RH – relative air humidity in %

The results were analysed statistically using Statistica software (Statsoft Inc., ver. 7.1). Differences in temperature/humidity conditions and THI between the examined barns were evaluated using the non-parametric Mann-Whitney U test. Differences were considered significant if $p<0.01$. Spearman’s rank correlation coefficients (r_S) were calculated to evaluate the relationship of air temperature and indoor relative air humidity with outdoor temperature/humidity conditions.

Results and discussion

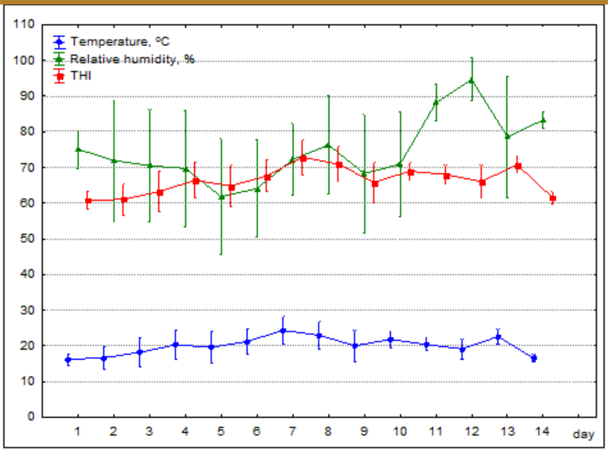
Gravity ventilation is the most common type of barn ventilation used in Poland. According to many authors, this is the most suitable system for cattle facilities (Kavolelis, 1995; Graves and Brugger, 1995; Reppo and Mikson, 2006). In the examined barns, different types of this system were used. One building was equipped with supply ducts mounted over windows and a roof ridge gap, and the other had flat roof exhaust ducts and side curtain (Table 1). The measurements of air temperature and relative air humidity in both barns and the resulting THI values are presented in Table 2 and in Figures 2 and 3.

Tabela 2. Średnia temperatura i wilgotność względna powietrza oraz THI w badanych budynkach w ujęciu parametrów statystycznych
Table 2. Mean temperature and relative humidity of air, and THI values in the examined buildings in terms of statistical parameters

Parameter	Item						
	Mean	Median	Sd	Min.	Max.	25% of cases	75% of cases
	Building A						
T_{in} [ºC]	21.4^A	20.3	4.0	12.6	29.4	17.3	23.0
RH_{in} [%]	74.2^B	77.8	15.8	43.4	99.4	59.5	86.2
THI	66.9^C	67.6	5.5	55.0	79.5	62.6	70.9
T_{out} [ºC]	19.8	19.7	5.2	4.9	27.3	15	21.3
RH_{out} [%]	70.6	73.3	19.1	31.9	99.9	51.9	87.7
	Building B						
T_{in} [ºC]	23.3^A	23.9	3.2	19.5	29.6	22.7	25.8
RH_{in} [%]	90.8^B	93.6	9.1	61.8	99.8	86.1	98.6
THI	74.6^C	74.7	3.1	67.1	80.7	72.6	77.3
T_{out} [ºC]	21.7	21.3	3.4	17.1	33.4	19.7	25.1
RH_{out} [%]	81.2	82.2	15.9	33.1	99.9	72.9	96.1

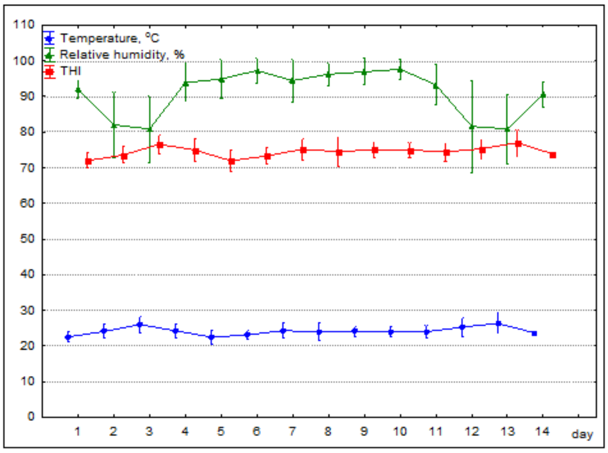
T_{in} – indoor temperature, T_{out} – outdoor temperature, RH_{in} – indoor relative humidity, RH_{out} – outdoor relative humidity, THI – temperature-humidity index
T_{in} – temperatura wewnątrz budynku, T_{out} – temperatura na zewnątrz budynku, RH_{in} – wilgotność względna wewnątrz budynku, RH_{out} – wilgotność względna na zewnątrz budynku, THI – indeks termiczno-wilgotnościowy
A, B, C – the same letters denote statistically significant differences at p<0.01
A, B, C – te same litery oznaczją różnice statystycznie istotnie przy p<0,01

The present study showed that in the barn with side curtain (building A), the mean temperature and relative humidity of air was 21.4ºC and 74.2%, respectively, being significantly (p<0.01) lower than in the barn with roof ridge gap and supply ducts mounted over windows (23.3ºC and 90.8%, respectively). When comparing temperature/humidity conditions in barns with roof ridge and duct ventilation, Głuski and Michalczyk (2008) found air temperature and humidity to reach higher values in buildings with roof ridge ventilation.



Rysunek. 2. Średnia ($\bar{x}$ ± Sd) dzienna temperatura i wilgotność względna powietrza oraz THI w obiekcie 1 z wentylacja grawitacyjną ze stropowymi kanałami wywiewnymi i nawiewem z kurtyny bocznej (obiekt A)

Figure. 2. Mean ($\bar{x}$ ± Sd) daily temperature and relative humidity of air and THI in building A having gravity ventilation with flat roof exhaust ducts and air supply from side curtain



Rysunek 3. Średnia ($\bar{x}$ ± Sd) dobowa temperatura i wilgotność względna powietrza oraz THI w obiekcie 2 z wentylacja grawitacyjną ze szczeliną kalenicową i nadokiennymi kanałami nawiewnymi

Figure 3. Mean ($\bar{x}$ ± Sd) daily temperature and relative humidity of air and THI in building B having gravity ventilation with roof ridge gap and supply ducts mounted over windows

The mean daily air temperature recorded in both barns was much higher than optimum temperature which ranges from 8 to 16ºC (System Utrzymania Bydła, 2004). Although cattle are highly adaptable over a temperature range of -10 to +25ºC, dairy cows already run a risk of heat stress at 20ºC (System Utrzymania Bydła, 2004). In fact, the heat stress threshold depends on the breed and milk yield of the cow. Berman (2005) reports that high milk yield increases sensitivity to heat stress and lowers threshold temperature at which milk yield is observed to decrease.

The analysis of instantaneous measurements showed that air temperature in both barns exceeded 20ºC on all days. The number of days with temperature above 25ºC was 8 in building A and 12 in building B (Table 3).

Tabela 3. Liczba dni z przekroczonymi krytycznymi wartościami THI, temperatury (T) i wilgotności względnej (RH) powietrza w badanych oborach (okres badawczy: 14 dni)

Table 3. Number of days with exceeded critical values of THI, temperature (T) and relative humidity (RH) of air in the examined barns (study period: 14 days)

Parameter	Number of days	
	Building A	Building B
T >20ºC	14	14
T >25ºC	8	12
RH >80%	14	14
THI>72	9	14
THI>79	NS	5

NS – not found

NS – nie stwierdzono

Relative humidity of air in dairy barns should range from 60 to 80% (Dz.U., 2003; St-Pierre et al., 2003). In building A (with side curtain), the mean daily relative humidity of air was generally below 80% throughout the study (Fig. 2). However, the analysis of individual measurements revealed that these values were momentarily exceeded on all test days (Table 3). Poorer humidity conditions were prevalent in building B, in which the mean daily relative humidity of air most often exceeded 90% (Fig. 3).

Głuski (2008) reports that livestock building microclimate, especially temperature and humidity of air, are a result of the constant influence of outdoor climate, among other things, Statistical analysis of the results showed that outdoor conditions had a significant ($p<0.01$) effect on temperature/humidity conditions not only in the barn with side curtain, but also in the barn with insulated walls and roof (Table 4).

Tabela 4. Wpływ temperatury i wilgotności względnej powietrza na zewnętrz na warunki termiczno – wilgotnościowe wewnątrz badanych budynków w całym okresie badawczym

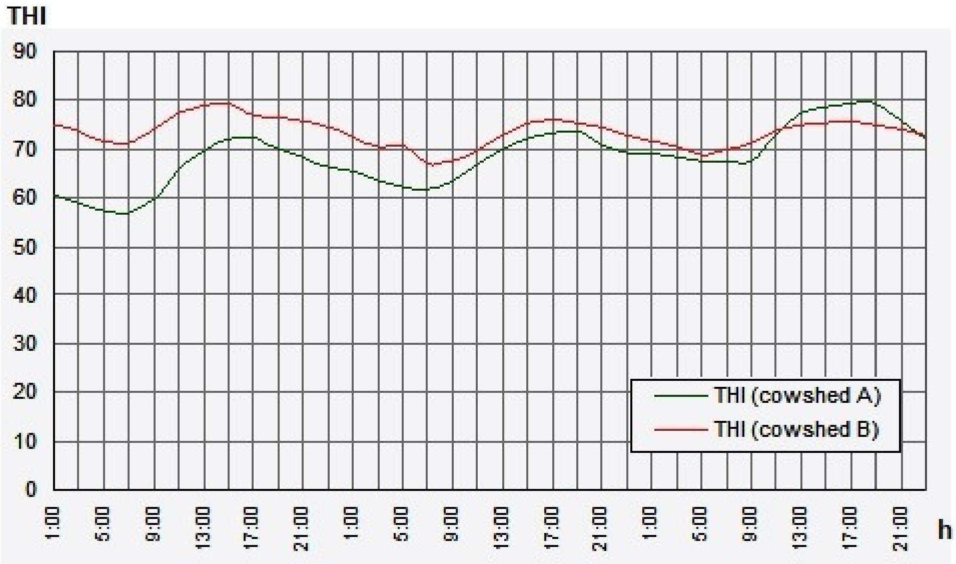
Table 4. Effect of outdoor temperature and relative humidity of air on outdoor temperature/humidity conditions in the entire study period

Parameter	Spearman's rank correlation coefficients	
	Building A	Building B
T_{out} vs. T_{in}	0.784*	0.869*
RH_{out} vs. RH_{in}	0.950*	0.929*

* - correlation significant at p<0.01

* - korelacja istotna przy p<0,01

Figure 4 shows the distribution of THI values in the examined barns on 3 successive days. The analysis reveals that THI began to increase at 9:00 am and peaked at 5:00-6:00 pm. A similar trend was observed by Omiński et al. (2002).



Rysunek 4. Wartości THI w badanych oborach w ujęciu dobowym (losowo wybrane 3 kolejne dni badań – 72 h)
Figure 4. 24-hour values of THI in the experimental barns (randomly selected 3 consecutive test days – 72 h)

In our study we found that in the barn with side curtain and flat roof exhaust ducts (A) THI ranged throughout the study from 55 to 79.5, averaging 66.7 ± 5.5 (Table 2). Mean daily THI in the building was much below 71 (Figure 2), which according to the classification of Armstrong (1994) may suggest that animals had comfortable conditions. It is of note that there were 9 days with THI>72 (from instantaneous measurements) (Table 3). Only on one day (day 7 of the study period) did THI exceed 79 in the afternoon during the period when mean THI value was 72.9 (mild stress). Outdoor air temperature exceeded 27ºC.

Less favourable conditions were found in the barn with roof ridge ventilation (B). The mean value of the temperature-humidity index for the whole study period (THI=74.6±3.1) was significantly ($p<0.01$) higher than that found in building A. On all study days, THI values momentarily exceeded 72 (THI>72) with mean daily THI exceeding 72 (Figure 3). On days 3, 4, 7, 8 and 13, THI exceeded 79. These results are evidence that the conditions in building B were conducive to mild and moderate heat stress.

Omiński et al. (2002) reports that even short-term heat stress, to which animals in temperate zones are exposed, can cause severe health problems because they are physiologically unadapted to such conditions, and can significantly decrease milk production. Ravagnolo and Misztal (2000) estimated milk production to drop by 0.2 kg for every THI unit above 72. The production problems in cows exposed to heat stress are also due to a delay in onset of puberty and decreases in the conception and reproduction indices (Collier and Beede, 1985; Jaśkowski et al., 2005).

Conclusion

It was found from this study that the barn having flat roof exhaust ducts and air supply from side curtain was characterized by more favourable temperature/humidity conditions and presented a lower risk of heat stress to cows compared to the barn with roof ridge and air inlets. It was also found that cows in the barn with side curtain had comfortable conditions and those in the roof ridge barn were exposed to mild and moderate stress. Nevertheless, high momentary THI values were recorded in both buildings, which according to the literature may largely contribute to a decrease in milk production. For this reason, it seems necessary to equip the barns with fans and air mixers (sprinklers should not be used in buildings with high air humidity) or to undertake other measures to reduce heat stress. This is important in so far as ambient temperature in Poland reaches 38ºC in the summer, thus increasing the risk of cattle exposure to heat stress.

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