Biometeorological investigations in dairy cowsheds

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Abstract

The aim of this study was to investigate heat stress of dairy cows with regard to the current situation and the definition of evaluation parameters that evaluate heat stress of dairy cows. For this reason climate measurements (e.g. air temperature, air humidity, globe thermometer temperature, wind speed) in- and outside of dairy stables in northeastern Germany has been carried out. A common method for heat stress evaluation in animals is to determine the temperature humidity index (THI). This however does not consider the wind speed nor the radiation fluxes. Findings from the RayMan model have been applied in order to interpret the conditions of the stable in respect of the animal's thermal comfort.

1. Introduction

Modern dairy cows generally spend the entire day in the stable. The welfare of animals depends critically on the indoor environment. Dairy cows are most comfortable e.g. at air temperatures between 0° and 15° C. Therefore an optimal indoor environment must be created with a sufficient air ventilation to satisfy both, the air temperature and air humidity in the optimum zone. Additionally a good ventilation leads to a good air pollution control in the building and hence contribute to the welfare of animals. The DIN 18910-1 (2004) provides minimum air flow rates for dairy cows in the summer of 413 $m^3 h^{-1}$. Nevertheless, there may be situations (e.g. large heat waves in summer) in which - despite exceeding the minimum ventilation rate - the great thermal output of high performance animals can not be compensated. This can lead to heat stress of the animals.

An annual economic loss of $900 million have been estimated for US dairy industry due to heat stress (Collier et al., 2006). But even in moderate climate the influence of heat stress in dairy cows is discussed. The increasing importance of heat stress is often associated with the global warming (e.g. more expected heat waves). Another reason is caused by the rising milk yield of the cows, which goes along with a metabolic energy performance. Lactating dairy cows produce a large quantity of metabolic heat and accumulate also additional heat through radiant energy. This two effects combined with insufficient cooling capability because of environmental conditions, result in heat load for the cow and finally a decreased productivity of the cow (West, 2003). This leads to an observed decrease of food intake which in turn results in reduced milk yield and quality.

2. Experimental set-up and methods

2.1 Investigated cowsheds

During summer 2008 the Leibniz-Institute for Agricultural Engineering Potsdam-Bornim (ATB) carried out a field measurement campaign to investigate the environmental conditions inside and outside two naturally ventilated cowsheds in northeastern Germany. Aim of the study was to evaluate several parameters that should describe possible heat stress of dairy cows.

These two cowsheds (cowshed 1 and cowshed 2) are located parallel with a distance of 8 m to each other and are nearly identical in construction. The main difference between both investigated cowsheds consists of the roofs design: the roof of cowshed 1 is equipped without thermal insulation while the roof of cowshed 2 is thermal insulated. The two cowsheds can be described in more detail as follows:

Room size: length: 76.68 m (cowshed 1 and 2); width: 31.49 m (cowshed 1) and 28.50 m (cowshed 2); the roof top ranges from the side: 2.7 m (cowshed 1) and 2.5 m (cowshed 2) to 5.40 m (for both cowsheds) at the gable top, enclosing a volume of 10685 m^3 (cowshed 1) and 8648 m^3 (cowshed 2)

The keeping system is a lying box loose housing for both cowsheds. The liquid manure system (slurry channel) in cowshed 1 contains a slatted floor, while cowshed 2 is equipped with winch drawn dung channel cleaner.

Number of cows: 215 cows in each cowshed

Ventilation: At both cowsheds the natural ventilation is driven by adjustable openings in the side walls, by open doors in the gable walls and by permanently open ridge slots. Additionally cowshed 1 is equipped with a ceiling fan (diameter 4.30 m) near the gable door above the feeding alley for test purposes.

2.2 Measurements

Within the two cowsheds the following indoor environmental parameters were measured:

- Air temperature and air humidity
- Globe thermometer temperature
- Surface temperature of the structure by an infrared camera
- Air velocity measured by an ultrasonic anemometer in order to determine the air movement in the animal zone
- Air volume flow by using CO_2-balance model and a tracer gas technique by using radioactive gas Krypton 85 (Kr-85)

The external meteorological conditions were recorded by a measurement tower which was located at a distance of ~10H of the two cowsheds (H= height of the cowshed). The tower was equipped with two Ultrasonic anemometers (GILL wind master pro) at heights of 7.5 m and 10 m, respectively. Local wind of all three velocity components were sampled at a frequency of 10Hz and their turbulent quantities, e.g. turbulence intensity, were derived. Additionally, air temperature and relative air humidity sensors (Rotronic) were mounted at three heights (3, 6 and 9 m). The globe thermometer outside temperature was measured between the two cowsheds.

2.3 Evaluation methods

The main influencing factors on heat stress are air temperature, air humidity, the wind velocity and the direct solar radiation. In literature (e.g. CIGR, 2002; Mader et al., 2006) many models exist which combine the temperature and the humidity to the so called *Temperature Humidity Index* (*THI*), which can be defined as follows:

$$THI = 0.8 * T_a + \left[(RH/100) * (T_a - 143)\right] + 46.4 \quad (1)$$

where T_a is the ambient temperature in [°C] and *RH* is the relative humidity in percent [%]. Based on the daily maximum Temperature Humidity Index (THI_{max}) Brown-Brandl et al. (2005), citing Thom (1959), defined four categories to rate the level of possible heat stress: a) $THI_{max} < 74$ normal, b) $74 \leq THI_{max} < 78$ alert, c) $78 \leq THI_{max} < 84$ danger, d) $THI_{max} \geq 84$ emergency. Similar values are defined by CIGR (2006), citing Johnson et al. (1965), by a slightly different definition of the *THI*. In order to include the influence of the solar radiation effect some authors (e.g. Buffington et al., 1981; Panagakis and Deligeorgis, 2006) substitute the black globe temperature (T_{bga}) for the ambient temperature (T_a) in the *THI* equation:

$$BGTHI = 0.8*T_{bga} + [(RH/100)*(T_{bga} - 14.3)] + 46.4 \qquad (2)$$

Mader et al. (2006) adjusted the THI for wind speed and solar radiation and proposed the following Equation:

$$THIV= [4.51 + THI - (1.992 *V) + (0.0068 *RAD)] \qquad (3)$$

where V is the wind speed in [m s^{-1}] and *RAD* the solar radiation in [W m^{-2}].

Another approach to assess the climate impact on animals is to adapt the knowledge of thermal comfort for humans which has a long experience and provides special guidelines as e.g. DIN EN ISO 7730 (2003) which give guidance for the evaluation of the thermal comfort for humans. Pache et al. (2007) attempted to use this guideline to compare a light construction cowshed and a solid construction cowshed. Even though the concept for humans can not directly transferred to animal husbandry some of the parameters may be suitable for an evaluation regarding heat stress. Several studies, e.g. Pache et al. (2007) used a special measuring station for human thermal comfort to determine the *mean radiant temperature* (Eq. 4) inside the cowshed:

$$t_r = [(t_g + 273)^4 + 2.5*10^8*v_a^{0.6}*(t_g - t_a)]^{1/4} - 273 \qquad (4)$$

where: t_r: mean radiant temperature in °C
t_g: globe thermometer temperature in °C
t_a: ambient dry temperature in °C
v_a: air velocity in m/s

The *mean radiant temperature* includes the effect of solar radiation and wind speed, but neglects the humidity. However, the definition of thermal comfort for animals is much more difficult than for humans and needs further investigations. The animal response on varying climatic impact factors cannot be neglected and have to be determined.

3. Selected results

3.1 THI and BGTHI

The obtained data were used to calculate the THI, BGTHI and THIV (Eqs. 1 through 3) and compare them with threshold values from literature. In fact, only at one day of a 28-day measurement period, the THI exceeded the threshold value 74 associated with the category "danger" (Fig. 1). Figure 1 illustrates the calculated THI (Eq. 1), the BGTHI

(Eq. 2) and the THIV (Eq. 3) for a selected three day period in cowshed 1. Three different wind speeds from velocity measurements were applied for calculating THIV; the lowest measured wind speed by V= 0.2 m s^{-1}, an average wind speed by V= 0.9 m s^{-1} and the highest measured wind speed by V= 2.0 m s^{-1}. The calculated THI, BGTHI and THIV with V= 2 m/s obtained similar results (Fig. 1). For lower wind speeds, higher THIV were observed. This fact may result in a different classification of heat stress. The differences between calculated THI from cowshed 1 and cowshed 2 are nominal due to the small differences of measured air temperature and air humidity. In most cases THI of cowshed 2 (with roof insulation) revealed higher values during evening and night hours due to higher observed air temperatures. These differences of THI between cowshed 1 and cowshed 2 became smaller during day time. On this basis no significant positive effect due to the roof insulation could be found.

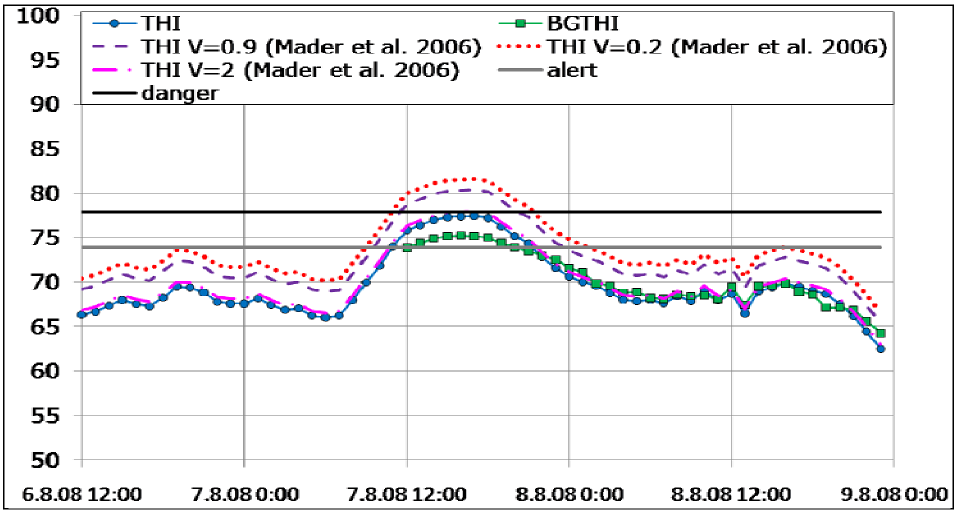

Fig. 1: Estimated THI, BGTHI and THIV in cowshed 1 for a selected period

3.2 Mean radiant temperature

Additionally to the received data, the mean radiant temperature was calculated (Eq. 4). It combined the black globe thermometer temperature, the ambient temperature and the wind speed. Figure 2 shows the run for the mean radiant temperature (with a considered wind speed of V= 0.8 m s^{-1}) for a selected period in both cowsheds and outside the cowsheds. The estimated radiation temperature ranged between 12.2 and 25.6°C in stable 1 and between 5.2 and 36.0 °C in stable 2 (with roof insulation) over the entire measurement period. For want of an adequate data set for connecting the animal response to the radiation temperature, it was not possible to define a critical threshold. Pache et al. (2007) found an increased respiration frequency and body temperature if the radiation temperature exceeded 36 °C. All data obtained within this study are beyond this value.

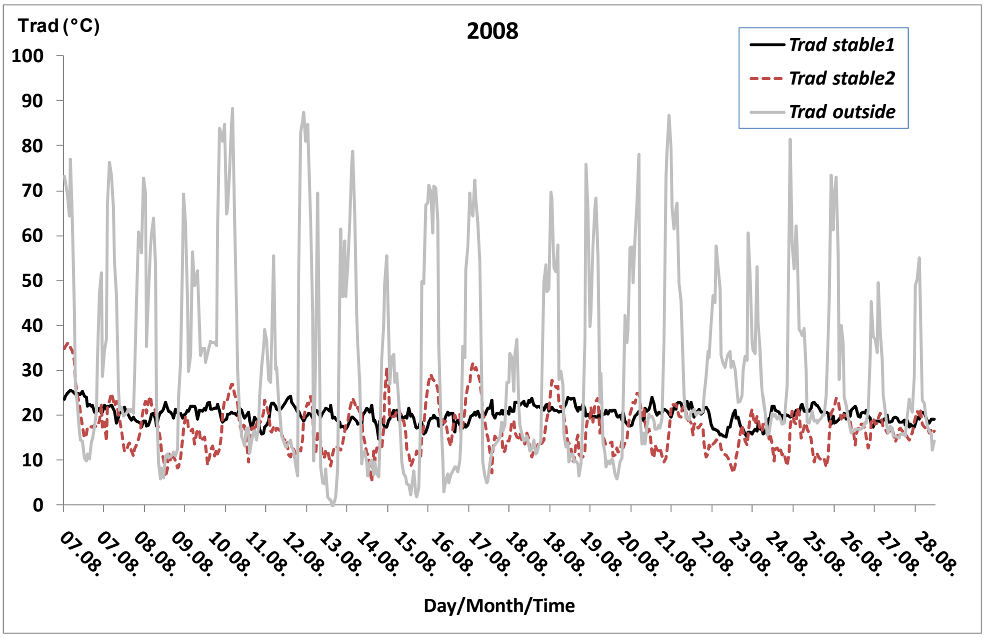

Fig. 2: Estimated in- and external mean radiant temperature of two cowsheds

4. Discussion and conclusions

The results of this study showed that the investigated roof insulation possessed only minor effects on the indoor environment. For performed temperature measurements in comparable cowsheds with and without roof insulation only differences smaller than 1 K could observed. Nevertheless, calculation of the radiation temperature mostly obtained higher values in cowshed 1 with differences up to 10 K. Thus, it should be aimed at implementing more parameters beside only air temperature and air humidity. Moreover, occurring environmental effects (e.g. air velocity) and the animal-related parameters (e.g. age, breed, milk yield and color) are crucial and have to be considered. As an outcome, further investigations over longer time periods are necessary, for defining most influencing parameters. The welfare of cows depends on many various factors including health, feeding, occupancy density of the stable and the treatment of the stable staff. Further, each animal shows different reactions toward heat as a stressful event. Therefore, more investigative methods should be developed for detecting individual stress of animals. Assessing the impact of the stable indoor environment on animal welfare, the whole husbandry system and the behavior of animals have to be considered. It is planned at first to use thermal climate indices from human biometeorology i.e. Physiological Equivalent Temperature (PET) and other radiation parameters calculated by the RayMan model, since it has a thermo physiological importance, particularly during the summer period (Matzarakis and Mayer, 1998; Mayer and Matzarakis, 1998).

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