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# Heat stress measuring methods in dairy cows

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ABSTRACT
The most widely used predictor to assess the incidence of thermal stress in livestock is THI, the temperature humidity index. However, it is an indicator that disregards the individual animal and the specific farm conditions. This review aims to list and summarize other thermal stress predictor factors, by using non-invasive and cost-effective strategies, in particular with the aid of Precision Livestock Farming technologies. When it comes to dairy animals the metabolic load is already increased by milk production, so the effect of heat stress can exacerbate the overall welfare of the cow. Therefore, the animals enact copying mechanisms that may result in physiological, behavioral and productive alterations. Those animal-based parameters can be used as early predictors of heat stress, allowing the farmer to collect real time data and address the condition operating management strategies in order to prevent further detrimental effect on the performance and consequent economic losses.

**Section:** RESEARCH PAPER

**Keywords:** Heat stress measurement; dairy cows; non-invasive techniques

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## 1. INTRODUCTION

Climate change globally challenges animal husbandry leading to heavy economic losses [1]. One of the factors that jeopardizes livestock is represented by heat stress, which can be detrimental to overall animal welfare, therefore productivity and production traits are negatively affected [2]. Heat stress is a condition in which the animal is not able to efficiently dissipate excess heat and the body temperature is beyond its normal range, thus the animal activates mechanisms to maintain its thermal balance [3]. Thermal stress is influenced by environmental factors, such as dry bulb temperature, relative humidity, wind movement, precipitation, atmospheric pressure, ultraviolet light, dust and solar radiation, amongst others [4]. Some of these factors are not easily detectable, hence the most widely used indicator is THI [5], a simple index combining dry bulb temperature and relative humidity. Heat stress deeply affects lactating animals due to the metabolic heat load generated for milk production in addition to nutrient digestion [2]. Studies have been conducted on Brown Swiss cows where the individuated THI threshold is 74 [2] and on Holstein cows, in this breed the threshold at which the animal undergoes heat stress is slightly lower: 72 [6]. It was also pointed out the effect of heat on cattle behavior [7] and productions [6]. When in stress conditions animals can respond in several ways: a decrease in food intake can occur. The effect of the reduced feed intake, combined with negative energy balance during early lactation, can decrease milk production and alter milk composition [8]. Therefore, without using THI, heat stress can also be detected by observing the animal and by evaluating its parameters. Different methods of evaluation have been investigated using animal-based cues [9]. Predictive parameters can be collected from cattle in several ways, which can be divided dichotomously in invasive and non-invasive methods. The first approach can result in supplementary stress for the animal and tends to be more time and energy consuming, hence the use of non-invasive alternatives, along with the aid of Precision Livestock Farming (PLF) technologies [10]. Some authors describe PLF as: “the application of process engineering principles and techniques to livestock farming to automatically monitor, model and manage animal production” [11]. This work aims to enunciate different non-invasive methods that can be used as a tool in order to detect and assess heat stress in dairy cows.

## 2. HEAT STRESS EVALUATION

Heat stressed animals often show alterations of physiological parameters that can be detected in blood [12]; this action can result in more stress added to the cow, since handling and restraint are required in order to collect blood samples, usually from the median coccygeal vein [13]. Hence, methods that do not require manipulation and proximity are researched and increasingly widespread. The idea of a non-invasive method to evaluate heat stress focuses mainly on behavioral and physiological reactions that may be seen without any human influence and consequent increased stress of the animal [14]. The majority of the physiological and behavioral responses displayed by animals in reaction to heat stress, including respiration rate, body temperature, heart rate, and pulse rate, are well correlated. The idea of a non-invasive method for measuring heat stress focuses largely on animal reactions that may be seen without human intervention [10].

### 2.1. Body Temperatures

Internal body temperature (38.6 °C, range 38.0–39.3) in cattle indicates the temperature of the most important body organs such as brain and heart [15]. Body temperature is most likely affected by environmental temperature, thus skin temperature represents an important index to evaluate heat stress [16]; infrared thermometry and infrared thermography (IRT) can be used for that purpose. An IRT camera records infrared pictures from one or more spots on the body while maintaining a specific distance and angle from the subject that must stand still, thereafter a software processes the images [17]. Effective minimization of confounding factors, such as those related to skin and hair color, skin emissivity, sudden moves, health conditions, feeding time, as well as external factors like environmental temperature, relative humidity, solar radiation, wind speed, distance between camera lens and the animal, and camera positioning angle, are necessary for the successful determination of temperature of external body surfaces [18], [19]. Animal movements result in rising of the peripheral blood circulation, hence at least 10 minutes acclimation interval is required, in order to avoid artificially high IRT [20], [21]. Skin color and hair density also can influence the measurements as hair functions as an insulator and reduces infrared radiation output [19], [22]. Slick hair can, indeed, have an impact on IRT measurements, despite the fact that it has been shown that animals with slick hair have better thermoregulatory capacities, perhaps as a result of higher perspiration [23] As a result, IRT at a hairless skin region, such as ocular bulb or muzzle area, often yields a greater IRT range than a hairy one [24]. Due to the higher emissivity in visible wavelengths of black hair and consequent higher IRT detected in thermograms, cattle with black hair absorb and emit more solar energy than those with white hair [25]. Depending on the color of the hair, a striking difference in the temperature of the white and black portions of the head under solar loading has been found, where the light parts of the head were 35 °C, while the dark parts were 50 °C [18]. Recent injections into the muscle and the presence of any localized lesions on the exterior body surfaces might potentially affect IRT readings because inflammation of the underlying tissues increases the amount of heat radiated by modifying metabolism and circulation in these tissues [26]. Age, physical condition, lactating stage, and reproductive status of the animals should also be taken into account as a determining factor for IRT readings. The body temperature of lactating cows is greater than that of dry cows, and the body temperature of early lactating cows is generally higher than that of late lactating cows [27]. A rise in luteinizing hormone (LH), ovulation, increased vaginal blood flow, and progesterone release during the luteal phase are all characteristics of oestrus cows that all work to raise body temperature [28], [29]. Different core body temperatures are tracked as well, such as rectal temperature (RT), vaginal temperature (VT), tympanic temperature (TT), ruminal temperature (RUT). A digital thermometer is usually used to manually measure RT and VT resulting in an industrious and time-consuming procedure [30]. Alternatives are provided by the use of PLF implantable or wearable devices like a temperature data logger (Smart Reader 8, ARC Systems, Brisbane) [31] or a stainless-steel thermistor probe (Cole Parmer Instruments, Chicago, IL, USA) [16] for RT detection. Data loggers like Water Temperature Pro V2 (Model HOBO, Onset Computer Corp., Procasset, MA.) are attached to a plastic anchor and placed in the vagina of the cow [32]. Vaginal temperatures detected with intravaginal devices were compared to data collected using a mercury thermometer. Wang, et al. [33] reported a strong relationship between the systems (R2 = 0.996). These devices, however, are not supplied with wireless transmission, hence are not capable of providing real-time temperatures [9]. In order to get continuous temperature information, an indwelling device linked to a temperature sensor (ADT7320, Analog Devices Inc., Norwood, MA, USA), a data collector and a computer system can be a useful system [33]. Important correlation between RT, environmental temperature and RUT has been proved by different studies [34]-[37]. There are other areas of interest to assess heat stress, including the reticulum and the rumen. For the purpose of measuring ruminal and reticular temperature boluses have been developed [35], [38], [39]; this tool features a temperature sensor, a telemetry system, and a battery and is placed in the reticulum or in the junction between the rumen and reticulum [40]. Bergen and Kennedy [41] have found that TT may be more predictive of environmental temperature than RT and VT due to hypothalamus closeness; hence, wireless ear sensors represent another source to detect heat stress. The data loggers must be installed in the ear canal, near to the tympanic membrane [42], [43] and have found application in beef cattle and also in dairy cows to measure heat strain [44]. Koltes et al. [40] reported that different temperature measurements might be connected to other quantitative production features of interest (e.g., growth rate, feed intake). These results are helpful also to achieve correct gestation management since it has been hypothesized that maternal heat stress may have significant long-term impacts on calf health, growth, and survival [45]. Microchip devices with body temperature sensors have been implanted in pigs and the reading can be performed using radiotelemetry and a wand. Pig body temperatures measured using microchip technologies normally range 1 °C below rectal temperatures [46]. There have been many comparable kinds of implantable devices produced, but they all need to be implanted inside of animals through invasive procedures. Kou, et al. [47] developed a technique for determining the body surface temperature of cattle using a novel wearable device placed on the animal's limb. According to reports, the technique, which monitors temperature near to the muscle, is substantially associated with RT.

### 2.2. Panting

Animals that experience high temperatures often exhibit increased respiratory rate (RR) and panting to facilitate heat dissipation. Panting score can be a useful observation tool, nevertheless it includes only a small number of scores, leading to poor accuracy. Respiratory rate can be observed remotely, when cattle is less than 30 m away, by recording flank motion [48] or using a PLF device that consist of a harness able to detect air temperature from the nose of the animal and to deduct the respiration rate from the variation of temperature. The device measures air temperature near the nostrils and RR is calculated as the number of oscillations of the temperature. The RR measured by the device were compared to RR observed by counting flank motion (for 60 s, repeated every 10 min) and the results reported no statistical difference between the two methods, [49].

### 2.3. Heart Rate

The metabolic energy consumption of ruminants under heat stress can be estimated using heart rate (HR), which may be recorded on farms [50], [51]. The amount of energy that is kept for production-related tasks will decrease as the energy required to maintain body temperature rises. DeShazer et al. [52], Kadzere et al. [53], and West [54] suggest that HR may be utilized to measure thermal stress. The electrocardiograph analysis is able to communicate data remotely, minimizing human proximity to the animal.

### 2.4. Behavior

Physiological alterations are some of the coping mechanisms that cattle engage in, as well as behavioral changes, including daily intake of feed and water, interactions and laying pattern changes [55]. Small farms usually happen to have trained workers to visually observe behavioral changes; this sort of solution is time consuming and difficult to achieve in larger operations, due to the number of workers that must be assigned to this specific task. Mechanized systems are useful aids that provide records for each animal and are able to detect behavioral pattern shifts [56]. Feed intake can be recorded using automated systems like Insentec feed bins (Roughage Intake Control system, Insentec B.V.) [57]. Also, in order to measure lying pattern variation, Seyfi [58] used a video recording system, the Aycan Alarm system (Security Joint Stock Company, Samsun, Turkey); while Wang, Shao, Li, Wang, Azarfar and Cao [57] collected data from sensor device HOBO Pendant G, (Onset Computer Corp.). Use of accelerometers is frequently observed in order to track activity and laying [59], but new devices have been used as well. Grinter, et al. [60] used a collar with sensors for behavior monitoring to observe any alteration such as rumination rate, eating and resting habits, and oestrus events. The findings showed that cows with metabolic disorders, mastitis, or those who were about to give birth ate and ruminated less than usual and lying time increased under thermoneutral conditions relative to heat stress.

### 2.5. Milk Production

The main concern in heat stressed dairy cows is represented by effects on production; any variation in the amount of milk production or in its quality not only represent an economic loss, but also are indicators of herd problems. Thus, the use of milk analyzers built into milking stations, such as the FT120 (Foss Electric, Hillerod, Denmark) represent a source to automatically highlight variations in milk yield and milk constituents [61]. Use of automatic milking systems (AMS) on large farms has been implemented over the years resulting in a more efficient milking routine and in a decreased interaction between animal and personnel. Milk data such as color and conductivity are collected automatically and can be used for health checks [62]. The measurement of each cow's milk temperature (MT) is one option the AMS offers; Igono, et al. [63] used temperature sensors inside the milk tube's short section to monitor MT and compare it to body temperature (BT). The findings revealed that MT and BT had a correlation that varied from 0.78 to 0.99. This correlation suggests that MT measured with the AMS might be a valid predictor of cows that are under heat load.

## 3. CONCLUSIONS

Early assessment of heat stress represents the most effective approach to prevent detrimental consequences on animal welfare and milk production. Numerous non-invasive solutions have been investigated, but frequently they are both time and labor consuming, and hence financially demanding. Wireless devices and data loggers can guarantee continuous measurements and observations that decrease the manpower need and, at the same time, increasing the necessity to have skilled workers that are capable of reading and interpreting the incoming data. It is crucial to develop software that can gather, organize, execute predictive models (using machine learning techniques), and provide data that can be available on portable device, allowing to check overall animal conditions in real time. Therefore, tools that automatically alert farmers by using settled thresholds should be developed and adopted in order to merge effectiveness and promptness in heat stress detection. Multiple choices are offered by PLF technologies, but the effective utility must be considered and evaluated in relation to environmental factors and animal's characteristics that can affect the reliability of the selected measurement. Therefore, external factors must lead to a conscious path, selecting the most suitable strategy for that specific situation and also considering the possibility to try different technologies simultaneously in order to obtain a more accurate picture of the animal's status.

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