Characterization and modeling of the innovative cooling water mattress for heat stress mitigation in cattle

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ABSTRACT

Climate change has an important impact on the natural environment, by making climate warmer or more variable, which affects cattle breeding in many parts of the world. The heat extremes and prolongate heat wave periods caused by climate change can be especially dangerous for those animals, affecting their day-today life by the heat stress episodes. Dairy cattle are especially susceptible to such conditions, due to their high metabolic heat production caused by the lactation processes. High relative humidity and temperature of the air, which often characterize the cowshed environment in heat stress periods, make cattle' natural thermoregulation processes insufficient in heat dissipation, being a cause of numerous and potentially serious health, fertility and welfare problems. At the same time, those environmental conditions are difficult to optimize, concerning both, the animals' needs, as well as energy consumption of applied systems. Cooling cowsheds is very complex, expansive and not well established, especially taking into account the immense thermal losses from their structures. For that reason, an appropriate cooling mechanism as an effective heat abatement strategy applied to the cowshed becomes crucial for cattle breeding, especially considering the lowest possible environmental effect. That is why within this PhD thesis, an innovative cooling water mattress for cattle, based on conductive heat transfer between the lying animal and chilled water circulating inside the water mattress, was developed. Such an approach to cooling enables local heat removal during animals' resting period (for dairy cattle normally varying between 12-14h), especially when the applicability of other available cooling solutions is limited or less effective.

The geometry of the developed water mattress was selected within four different propositions, which were simulated as the Computational Fluid Dynamic models in the Ansys Fluent environment. Such a preliminary study enabled the selection of the most promising geometry in terms of the water distribution inside the water mattress, and heat transfer on its surface. Chosen geometry was then developed as the prototype test stand and experimentally tested in both, laboratory conditions, as well as real barn conditions, during two different experimental campaigns conducted in the summer periods of 2022 and 2023. The developed water mattress was supplied with the chilled water produced and distributed by the conventional chiller-based hydraulic system, supervised by the control and data acquisition system. It enabled the regulation of the operational parameters of the developed water mattress, intended to follow the individual needs of the animal.

Conducted experimental campaigns enabled observation of the developed water mattress' cooling effect on animals' bodies for different chilled water temperature setpoints, and changing environmental conditions, compared to the commercially available non-cooled water mattress. For this purpose, an infrared thermography was used to observe the local change in cows' skin temperature. The selection of the most suitable for the animal mattress' operational parameters, became an important aspect of this research, influenced by the natural thermoregulatory mechanisms of the cow. For that reason, the second experimental campaign was extended not only by the second cooling water mattress applied to the test stand with the main goal to obtain the comparative results, but also a novel measurement strategy of the cows' physiological responses, informing about active thermoregulatory processes. Such data were also expected to be significant in early heat stress detection in cattle, being decisive, when an appropriate cooling strategy needs to be applied.

The conducted in this PhD thesis study proved the cooling effectiveness of the developed water mattress, indicating its potential as a novel cooling solution for cattle, especially for environmental conditions, in which the application of other available technologies is limited. Due to the frontier character of this study area, and considering the knowledge from different disciplines, at this moment there is a lack of available sensors, apparatus, and methodology, to bring into light, one specific parameter defining the threshold of the heat stress level. Nonetheless, such a parameter would be significant to better understand heat stress effects on health and well-being that occur when cows are exposed to thermally challenging environments. The future potential of the developed water mattress is especially oriented to its operational algorithm, adapting it to the individual needs of the animal for changing environmental conditions. Furthermore, it could be coupled with hybrid systems based on renewable energy sources, such as the photovoltaic system, geothermal system, or absorption chiller, based solely on the use of alternative energies that surpasses the performance of existing solutions, thereby advancing the state of the art and helping to mitigate global climate change.

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