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Review

Rethinking environment control strategy of confined animal housing systems through precision livestock farming

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Climate represents one of the main limiting factors of production efficiency. Thermal stress events can cause reduced performance, morbidity, and mortality, resulting in significant economic losses and animal welfare concerns. Environment control in confined animal housing systems is typically based on heat and moisture production rates at predetermined ambient temperature levels measured between 1950 and 1980. This traditional control method can fall short in meeting the true thermal needs of the animals since it does not account for factors now acknowledged as affecting the animal's productive responses to surrounding conditions, such as humidity, drafts, radiation, physiological state, and social interactions. Also, advancements in animal genetics, nutrition, and management practices have led to considerable changes in sensible and latent heat loads of modern livestock buildings. In this context, precision livestock farming technologies (sensors, detectors, cameras, microphones, etc.), enabling the automatic monitoring of environmental, physiological, and behavioural variables, can be used to continuously assess livestock performance and well-being in relation to their environment. An innovative strategy for environment control of livestock buildings could include the analysis of: (i) heat and moisture production rates using the most recent bioenergetic models; (ii) thermal stress through multi-factor animal comfort indices based on some environmental and physiological measurements; and (iii) animal behaviour as a response to changing environmental conditions. This paper presents a critical review of the state of the art of precision environment control of livestock buildings, identifying knowledge gaps, research opportunities, and technical challenges.

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Nomenclature

$\tilde{a}$	Corrected psychrometric constant, kPa °C^{-1}
ACI	Animal comfort index
ADG	Average daily gain
AET	Apparent equivalent temperature
AHL	Accumulated heat load
ASABE	American Society of Agricultural and Biological Engineers
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BGHI	Black globe-humidity index
CA	Coefficient of adaptability
CCI	Comprehensive climate index
CIGR	International Commission of Agricultural and Biosystems Engineering
D	Number of data collected per hour
DI	Discomfort index
EET	Effective environmental temperature
ETI	Equivalent temperature index
FAO	Food and Agriculture Organization of the United Nations
h	Enthalpy, kJ kg^{-1}
HLI	Heat load index
HLI_{ACC}	Actual heat load index value at a point in time
HLI_{LT}	Heat load index threshold below which cattle in a particular class will dissipate heat
HLI_{UT}	Heat load index threshold above which cattle in a particular class will gain heat
HP	Heat production, kJ kg$^{-0.75}$ h^{-1}
HR	Heart rate
HRV	Heart rate variability
HTC	Iberian heat tolerance test
IBI	Inter-beats interval
IRT	Infrared thermography
LCT	Lower critical temperature
LHP	Latent heat production
LWSI	Livestock weather safety index
MEMS	Microelectromechanical systems
p_e	Barometric pressure, mm of Hg
PLF	Precision livestock farming
p_v	Water vapour pressure, kPa
RH	Relative humidity, %
RR	Respiration rate, breaths min^{-1}
RT	Rectal temperature, °C
SET	Swine (pig) effective temperature
SHP	Sensible heat production
SR	Solar radiation, W m^{-2}
T_{bg}	Black globe temperature, °C
T_{db}	Dry-bulb temperature, °C
T_{dp}	Dew-point temperature, °C
T_s	Average afternoon hair coat surface temperature, °C
T_{wb}	Wet-bulb temperature, °C
THI	Temperature-humidity index
THI_{adj}	Adjusted temperature-humidity index
THI_{hrs}	Temperature-humidity index hours
THP	Total heat production
THVI	Temperature-humidity-velocity index
UNPD	United Nations Population Division
V_a	Air velocity, m s^{-1}
WD	Wet- and dry-bulb temperature index
WS	Wind speed, m s^{-1}

1. Introduction

According to the United Nations Population Division (UNPD), by 2050 the human population is expected to reach about 9 billion. This demographic growth, along with rising incomes and urbanisation in developing countries, will increase the pressure on the world's livestock sector to meet the growing demand for animal products. Between 2015 and 2050, the Food and Agriculture Organization of the United Nations (FAO) projects that annual consumption of meat and milk will increase by approximately 50% (Thornton, 2010). Since the number of farms is decreasing, the demand for livestock production will be met through intensification, resulting in larger farms (Pedersen, 2005). Furthermore, as consumers require that animals be raised in a more humane way, animal welfare and health are likely to put additional pressure on livestock management practices. To ensure sufficient care attention is paid to animals within economically viable businesses, there is a need for modern livestock facilities to not only monitor environmental conditions but also animal behaviour and health (Banhazi & Black, 2009; Koenders et al., 2015).

The current availability of technological developments such as smart sensors, detectors, cameras, and microphones can facilitate integrated management systems for animal husbandry that are based on continuous, real-time monitoring and control of production, animal welfare and health, as well as environmental conditions. Such management systems enable farmers to instantaneously detect thermal stress, infection, or air quality problems and take immediate actions in response. Such approaches have been referred to as precision livestock farming (PLF), whereby livestock production systems are viewed as a set of interconnected processes. These processes include animal growth and behaviour, product yield, endemic disease, and the physical environment of livestock buildings which includes their thermal microenvironment and the emission of gaseous pollutants (Banhazi et al., 2012; Berckmans, 2014; Groot Koerkamp, Bos, & van Henten, 2007; Lehr, 2014; Nääs, Carvalho, Moura, & Mollo, 2006).

Among these processes, climate in the livestock rearing area represents the main limiting production factor. Thermal stress events can, directly or indirectly, cause reduced performance, morbidity, and even mortality producing significant economic losses and animal welfare concerns