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Modelled performance of energy saving air treatment devices to mitigate heat stress for confined livestock buildings in Central Europe

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ABSTRACT

Intensive pig and poultry production are predominantly performed in confined livestock buildings which are equipped with mechanical ventilation systems. The frequency of heat stress will increase due to climate change. Heat stress events are accompanied by performance depressions (e.g. daily weight gain, egg production, mortality, feed conversion rate). Consequently, appropriate air treatment devices can become necessary to optimise the indoor climate of confined livestock buildings because of a high inlet air temperature. In this study, we analysed the effects of three energy saving air treatment devices: (1) earth-air heat exchanger, (2) direct evaporative cooling by cooling pads, and (3) indirect evaporative cooling systems which combine evaporative cooling (e.g. by cooling pads) with a subsequent heat recovery system. All systems are compared to a reference ventilation system without air treatment, which is today's typical housing system. The results show that the earth-air heat exchanger (1) is the most efficient air treatment device. It eliminates heat stress and can also be used during wintertime to increase the inlet air temperature. The two adiabatic cooling systems (2) and (3) can reduce heat stress by about 90%. Cooling pads can lead to a high relative humidity of the inlet air between 75% and 100%, which can

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cause problems inside the livestock buildings, e.g. increasing the moisture content of the bedding material. The indirect cooling device can avoid this disadvantage at the expense of a reduced temperature reduction of the inlet air temperature and higher investment costs.

1. Introduction

The majority of pigs and poultry in mid-latitudes are kept in confined livestock buildings (Robinson et al., 2011). A strong positive relationship between intensive livestock production and national gross domestic product has been shown worldwide (Gilbert et al., 2015). Intensive production systems in confined livestock buildings can be found predominantly in mid-latitudes (Robinson et al., 2011). Due to the high animal density, confined livestock buildings are usually equipped with mechanical ventilation systems fulfilling two major goals (1) to provide sufficient air quality during the winter season in combination with an inside air temperature close to the thermoneutral zone of the animals despite restricted ventilation rates, (2) to remove the sensible heat of the animals by high ventilation rates to avoid high indoor air temperatures during the summer season. As the optimum environmental temperature range for most farm animals lies considerably above the annual mean temperature, which is ~5 °C in North Europe (about 60°N) and ~15 °C in South Europe (about 40°N), the design of the buildings and the ventilation systems is aligned today to guarantee the lower limit of the thermal neutral zone of the animals. Therefore they are frequently termed *warm confinement livestock buildings* (Zulovich, 1993).

For pig and poultry farmers, economic losses can result from a reduction of feed efficiency, growth rate, egg and meat production, semen quality as well as infertility, reproductive disorders or increasing death rates (Dittrich, Wreford, Topp, Eory, & Moran, 2017; Fouad et al., 2016; Renaudeau et al., 2012; St-Pierre, Cobanov, & Schnitkey, 2003).

Miller, Howden, and Jones (2010) listed climate control measures inside buildings through natural air conditioning (i.e. evaporative cooling) as one out of several potential climate change adaptation options for intensive livestock production. In our model calculations, comparable adaptation measures of the ventilation system in confined livestock buildings are evaluated with respect to their potential to avoid or reduce heat stress for pigs and poultry.

Air treatment devices modify the thermodynamic properties of the inlet air. In principle, there are few technical constraints to guarantee a certain indoor climate, expressed by temperature and humidity. Limitations result from economic constraints due to high investment, energy and maintenance costs. Therefore we selected only systems which do not need supplementary energy for cooling and/or dehumidification: (1) earth-air heat exchange tubes (Bisoniya, Kumar, & Baredar, 2014; Tzaferis, Liparakis, Santamouris, & Argiriou, 1992), (2) direct evaporative cooling devices i.e. cooling pads (Renaudeau et al., 2012; Valiño, Perdigones, Iglesias, & García, 2010; Xuan, Xiao, Niu, Huang, & Wang, 2012), and (3) indirect evaporative cooling systems which combine evaporative cooling (e.g. by cooling pads) with a subsequent heat recovery system (Heidarinejad, Bozorgmehr, Delfani, & Esmaeelian, 2009; Sax, van Caenegem, & Schick, 2012; Struck, Külpmann, Sax, & Hartmann, 2014; van Caenegem, Sax, & Schick, 2012).

For each air treatment device, we model the inlet air condition behind the air treatment device in comparison to a ventilation system without air treatment as a reference. Interactions between animals, ventilation system and building are neglected to concentrate on the features of the air treatment devices. The efficacy of such devices can be evaluated by the thermodynamic state functions for sensible and latent heat (air temperature and an appropriate humidity measure like vapour pressure). However, these parameters have a limited relevance in relation to farm animals if considered separately, because thermoregulation is related to both of these two variables. Therefore, several established indices (for example the temperature humidity index THI) are selected to quantify the heat stress of animals. These parameters combine air temperature and humidity in one measure, taking into account the restrictions of the heat release of the animals, which vary with animal species (e.g. capability of sweating). The performance of each air treatment device is described by the exceedance of heat stress parameters beyond a preselected threshold value in terms of frequency of exceedance, area of exceedance (analogue to degree-hours) and frequency of consecutive exceedance of a certain duration.

The goal of the paper is to estimate their appropriateness by establishing whether the selected energy saving air treatment devices are effective to reduce heat stress in confined livestock buildings for the climatic situation in Central Europe.

2. Materials and methods

2.1. Meteorological data

For the calculation of the inlet air temperature which is modified by air treatment devices, meteorological data are needed on an hourly basis (air temperature and relative humidity). The Austrian Meteorological Service ZAMG (Zentralanstalt für Meteorologie und Geodynamik) provided measurements for the weather station close to the city of Wels (48.16°N, 14.07°E) for the time period 1981 to 2010. Following the climate classification of Köppen and Geiger (c.f. Kottek, Grieser, Beck, Rudolf, & Rubel, 2006), the station is located within class Cfb (warm temperature, fully humid, warm summers) which is representative for large areas in Central Europe excluding the Alps. The annual mean temperature is 8.8 °C and the mean annual precipitation amount is 979 mm year^{-1}. For the whole area of Upper Austria in the future a