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Computational prediction of the effective temperature in the lying area of pig pens

Bjarne Bjerg[a,*], Li Rong[b], Guoqiang Zhang[b]

[a] Department of Large Animal Science, University of Copenhagen, DK1870 Frederiksberg C, Denmark
[b] Department of Engineering, Aarhus University, Inge Lehmanns Gade 10, 8000 Aarhus, Denmark

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ABSTRACT

Using solid floor instead of drained or slatted floor in the lying areas of pig pens has distinct advantages in relation to animal welfare, odour abatement and ammonia emission, energy consumption and reduced building costs. However, pig producers often opt out of providing a solid floor due to the risk of manure fouling in the lying area during warm periods, fouling that may increase work load, reduce animal welfare and degrade the indoor environment. The risk of fouling the lying area increases as indoor temperature increases, and it is therefore recommended that the indoor temperature should be maintained at around 13 °C during the last part of the growing period if diffuse air intake is used. Undesired higher indoor temperatures still occur during about 40% of the time each year, even in the relatively cold Danish climate (where outdoor temperatures average about 8 °C).

This study aims to investigate the potential benefits of using a hinged ceiling flap inlet to control the air velocity and experienced thermal environment for pigs in the lying area of finisher units. A new equation for the effective temperature (ET) has been developed and used to express how temperature, humidity and velocity, individually contribute to the combined effect of the thermal condition raising pigs are exposed to. Computational Fluid Dynamics (CFD) simulations were conducted to estimate the relevant parameters and, finally, the ET. Furthermore, the developed ET equation was implemented in the CFD model as a Custom Field Function to calculate the distribution of ET in the animal occupied zone. It was assumed that a traditional diffuse ceiling air inlet would deliver the required airflow rate as long as the outdoor temperature was below 10 °C. At higher outdoor temperature, a ceiling-jet inlet above each pen was opened gradually depending on the cooling requirements. When the inlet was only slightly open, it formed a wall jet attached to the ceiling. After reaching the end wall, the jet of air was deflected toward the lying area. When the jet inlet was more fully open, it sent the jet directly to the lying area.

Our investigations showed that the ceiling-jet inlet could be used to control air speed in the animal occupied zone and generate the same ET in the preferred lying area at a 9-degree higher outdoor temperature than if the same ventilation rate were delivered though the defuse ceiling only. This indicates that the periods of undesired high indoor temperature can be reduced from 40% to 5% of the time under Danish climate conditions. In addition, the results showed that the largest cooling effect was obtained when the ceiling-jet inlet was opened less than 30% due to the generation of the jet's being attached to the ceiling.

1. Introduction

To promote high performance and good animal welfare in intensive livestock production, it is essential to maintain a suitable thermal environment around the animals. The specific requirements depend on the design of the housing system. Using a solid floor as an alternative to a drained or slatted floor in the lying area of pig pens has distinct advantages in relation to (1) animal welfare (reduces e.g. adventitious bursitis (Mouttotou et al., 1998) and facilitates the used of straw), (2) low odour and ammonia emission (Pedersen and Jensen, 2010), (3) low energy consumption (due to reduced temperature requirement (Mount, 1975)), and (4) reduced building costs (savings in the cost of floor construction). Nevertheless, a solid floor is usually not selected by pig producers due to the risk of manure fouling in the lying area, which may increase the workload, imperil animal welfare and adversely affect the indoor air quality. In a controlled study that looked at growing-finishing

* Corresponding author.
E-mail address: bsb@sund.ku.dk (B. Bjerg).

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pigs kept in climate respiration chambers, Aarnink et al. (2006) demonstrated that fouling on a solid floor was at a constant low level as long the room temperature was maintained below a certain inflection temperature. They also found that fouling increases at room temperatures above this inflection temperature. In addition, the experiment showed that the inflection temperature was approximately 25 °C for pigs of 30 kg, and decreased to approximately 20 °C for pigs of 100 kg.

For commercial pig units with solid floors in the lying areas, Danish room temperature recommendations (Jensen and Rasmussen, 2011) are generally 5–7 °C lower than the inflection temperature found by Aarnink et al. (2006). This recommendation is based on practical experience showing that it is necessary to remain the temperature at such a low level to minimize fouling on the solid floor. The deviation in relation to the inflection temperature determined by Aarnink et al. (2006) may be due to differences between the conditions existing in the experimental study and those that are typical to Danish commercial pig farms, differences that include the following: (1) the number of pigs per pen was 5 in the experimental study but typically 15–20 in the commercial pig farms, (2) each pig was assigned a floor area of 1.0 m^2 in the experimental study whereas each pig is typically assigned around 0.7 m^2 in Danish commercial pig farms, (3) the pigs in the experimental study were exposed to a certain temperature for periods of one day only, whereas high temperature can occur over much longer periods at commercial pig farms, (4) the metal-slatted floor used in the experimental study might be less attractive as a lying area than the concrete-slatted floor used in Danish commercial pig farms, and therefore the pigs may be more reluctant to lie on the slatted floor, and (5) varying management practices may increase the fouling tendency in some commercial units or in some pens within a commercial unit.

The aforementioned Danish recommendation stipulates that for finishers the room temperature should be maintained at around 13 °C during the last part of the growing period if a diffuse-air inlet is used as the only inlet. As a consequence of this recommended low temperature, an undesirable high indoor temperature will occur about 40% of the time, even in the relatively cold Danish climate (an average outdoor temperature of around 8 °C).

Supplementary ceiling air-jet inlets can be an affordable option for increasing the air movement in the animal occupied zone during the warm periods. This measure will further cool the animals; however, the extent to which it can compensate for an undesirable high temperature is not clear.

An animal's perception of the thermal environment is affected by such physical parameters as air temperature, velocity, turbulence, humidity and the temperatures of surrounding surfaces. The integrated influences of these parameters are crucial when the animal experiences thermal stress or a change in behaviours. Over the last several decades, numerous indices or models have been suggested as ways to express the integrated effects of two or more of the above mentioned parameters. The Temperature Humidity Index (THI) is probably the most widely known of these indices and expresses the integrated influence of air temperature and humidity. Different constants of the THI equations were suggested for various categories of farm animal. For pigs, the constant can be found in investigations published by Ingram (1965) and Roller and Goldman (1969).

Bjerg et al. (2016) reviewed the publications relevant to thermal indices that include the integrated effect of at least temperature and air velocity. Seven indices were found to be related to cattle; two of these are specific to housed dairy cattle (Yamamoto et al., 1989; Baeta et al., 1987) and five to outdoor cattle (Gaughan et al., 2008; Eigenberg et al., 2005; Mader et al., 2006, 2010; Da Silva et al., 2015). In addition, Bjerg et al. (2016) found a single index concerning broilers (Tao and Xin, 2003) but none for pigs. Surprisingly, the review showed that none of the 8 published indices considered the physical heat transfer process stipulated that the expected chill effect caused by an increase in air velocity should be declined when the air temperature approaches the animal's body temperature. This serous limitation motivated us to develop a new index for estimating the extent to which an increased air velocity in the animal occupied zone can compensate for an undesired high temperature. We assessed the extent to which including supplementary ceiling air jet inlets would affect temperature, humidity, velocity and turbulence in the finishers' lying area and, consequently, we reviewed the literature searching for findings that could support the development of an index expressing the integrated effect of these four parameters. During the review, we realised that it was impossible to identify a suitable amount of data that would account for the effect of turbulence, and therefore we refrained from incorporating this effect in the model.

More than fifty years ago, Beckett (1965) suggested an effective temperature to express the combined influence that air temperature and air humidity may have on swine and determined the effective temperature to be equal to room temperature if the relative humidity were 50%. This approach inspired us to suggest that the integrated effect of the three parameters should be calculated as air temperature with separate terms for the effect of humidity and the effect of velocity, both expressed on a temperature scale. From Beckett (1965) we also adapted the name "Effective Temperature" (ET) and the value of 50% relative humidity as baseline for the effect of humidity.

Computational Fluid Dynamics (CFD) is an advanced and feasible tool for predicting the spatial distributions of the mentioned parameters in livestock rooms (Rojano et al., 2016; Rong et al., 2016). In addition, the Ansys Fluent (Ansys Inc.) software includes a component called Custom Field Functions (Ansys, 2013), which provides a user the possibility of predicting the spatial distribution of a customized parameter as a thermal index for integrating the effect of several parameters.

This study aims to investigate the potential of using a ceiling inlet to control the thermal environment, (including air speed), in the lying area of a pen for finishers. Our investigations sought to estimate the potential of a ceiling jet air inlet to reduce the number of hours of undesirable thermal conditions in the lying area.

2. Materials and methods

The first part of this section describes the development of the new ET index and the subsequent part focuses on development of a CFD model capable of predicting the spatial distribution of the developed index.

2.1. Development of an equation for ET that integrates influence of temperature, humidity and velocity

Effective Temperature (ET) is conceived by Beckett (1965) was used to evaluate the integrated effect that air temperature, humidity and velocity may have on animals. Available published data were used to develop an ET equation in which each physical property of air is considered independently, as shown in Eq. (1):

$$ET = T + E_{hum} + E_{vel} \quad (1)$$

where T is air temperature, E_{hum} and E_{vel} is the contribution of humidity and velocity to the ET, respectively, all expressed in °C. In this equation, the effect of humidity (E_{hum}) is assumed to be zero when the RH is 50%. Similarly, E_{vel} is set to be zero when the air speed is 0.2 m/s.

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