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Thermal environment assessment and controller performance comparison for a wean-finish barn

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ABSTRACT. ***The thermal environment (TE) inside swine facilities has a substantial impact on animal growth performance and facility energy usage; therefore, proper control and measurement are required to maintain the optimal TE that maximizes feed efficiency and consumes minimal resources. An inexpensive and novel network of 44 thermal environment sensor arrays (TESAs) capable of capturing the spatial and temporal distribution of the TE were deployed in August 2016 inside a two-room (designated as North; N and South; S), wean-finish barn (~1200 hd and 22 TESAs per room) and placed about 1.8 m above the slatted floor. All TESAs simultaneously measured and averaged 20 samples of dry-bulb temperature, back globe temperature, airspeed, and relative humidity at 1 min intervals. The objectives of this research were to: (1) summarize the TE observations from this monitoring period and (2) develop some preliminary analysis methods to quantitatively compare the TE in each room. Each room of the fully mechanically, power-tunnel ventilated facility featured independent TE control (i.e., fan, heater, inlet, and tunnel curtain operation) by a unique ventilation controller. A set point uniformity coefficient (γ_{SP}; binned by ambient temperature; t_a) was used to assess ventilation controller performance and a two-sample (from random subsampling of t_a bins) t-test was used to test if γ_{SP} in each room was statistically different. Results showed a statistically significant difference between N and S room γ_{SP} for t_a bins <8°C ($p < 0.01$; $p < 0.01$; $p < 0.01$). No statistically significant difference was found between N and S room γ_{SP} for t_a bins >8°C ($p = 0.26$; $p = 0.07$; $p = 0.73$; $p = 0.31$). This is a preliminary and novel approach to assessing ventilation controller performance and future approaches will need incorporate all parameters of the TE.***

Keywords. ***Facility, Sensor array, Swine, Ventilation***

Introduction

The thermal environment (TE) inside swine facilities has a substantial impact on animal growth performance and facility energy usage; therefore, proper control and measurement are required to maintain the optimal TE that maximizes feed efficiency and consumes minimal resources. The TE describes the parameters (i.e., dry-bulb temperature; t_{db}, relative humidity, airspeed, and mean radiant temperature) that impact the sensible and latent modes of heat exchange between a pig and its surroundings (ASHRAE, 2013; DeShazer, 2009). The effects of t_{db} have been well-assessed (Mount, 1968) and is typically the only parameters used describe and control the TE. Hence, an accurate evaluation of the TE requires measurement of all four TE parameters.

The TE inside a swine facility is often a function of management decisions, integrity and materials in the building envelope, and the ventilation controller. Management dictates the settings programmed into the ventilation controller, which is a standalone control system capable of managing fans, inlets, curtains, furnaces, sprinklers, cool cells, etc. The performance of these ventilation controllers is poorly defined and no quantitative method for determining the impact of the how the ventilation controllers functions and its impact on the animals.

The goal of this study to establish some preliminary methods on quantitatively assessing the performance of a ventilation controller. A quantitative assessment will provide the necessary information for improving control decisions for a given facility based on data and identify areas for improvement for existing ventilation controllers. The objectives of this research were to: (1) summarize the TE observations from this monitoring period and (2) develop some preliminary analysis methods to quantitatively compare the TE in each room.

Site Description

As part of a larger study, monitoring was conducted at a deep-pit, wean-finish swine facility located within 8.9 km of Pocahontas, IA, USA (42°44'04.2"N, 94°40'18.4"W) from August 8th, 2016 to January 25th, 2017. The length of the building was orientated along the East-West axis. The facility featured two side-by-side rooms (designated as North; N and South; S rooms), with room dimensions (L × W × H) of 61 m × 15.2 m × 2.54 m and each housing ~1200 hd in 12 pens. Each room featured independent TE control (i.e., fan, heater, inlet, and tunnel curtain operation) by a unique ventilation controller. The negative pressure ventilation system was fully mechanical with power (i.e., fresh air distributed through ceiling inlets in cold to mild conditions) to tunnel (i.e., fresh air pulled the length of the building from the tunnel curtain at the one end wall to fans at the other end wall in hot conditions) operation. Ambient temperature (t_a) and RH were recorded at the facility by the ventilation controller every 15 min.

Instrumentation

An individual Thermal Environment Sensor Array (TESA) was developed to measure dry-bulb temperature, relative humidity, airspeed (Gao, Ramirez, & Hoff, 2016), and estimate mean radiant temperature from the globe temperature of a black globe thermometer (Ramirez, Gao, & Hoff, 2016). Sensor signals from a TESA were connected via a 3.05 m long, nine-conductor wire to screw terminals mounted on a data acquisition custom printed circuit board, both secured in a weatherproof housing. Exactly 22 TESAs were suspended about 1.8 m above the fully-slated concrete floor in each room. A text file containing the comma-separated data from all 44 TESAs at a 1 min sampling interval was created and saved every hour on removable flash memory.

Data Analysis

Text files were imported into Matlab (R2017a, The Mathworks, Inc., Natick, Massachusetts, USA) and preprocessed to remove garbled text and verify measured values. A non-weighted uniformity coefficient (γ_x) for a given TE parameter (x) was used to describe the spatial uniformity of the TE throughout the N and S rooms. At least 16 of the 22 measurements were used in the computation of γ for a given time point. In addition, a set point uniformity coefficient (γ_{SP}) was used to describe the spatial uniformity of t_{db} with respect to the desired t_{db} set point programmed on the controllers in the N and S rooms. Total (i.e., sum) uniformity for γ_x and γ_{SP} was determined for each room. Summary statistics for γ_{SP} for nine t_a bins ranging from <8°C by 8°C to >32°C were calculated. For each t_a bin, 60 random sub-samples were taken to perform a two-sample *t*-test to test null hypothesis at the 5% significance level that γ_{SP} comes from normal distributions with equal means and equal but unknown variance.

Results and Discussion

Total non-weighted uniformity for N room: γ_{tdb} = 1.6E5; S room: γ_{tdb} = 1.5E5 and N room: γ_{RH} = 9.5E4; S room: γ_{RH} = 8.7E4. The N room had greater total non-weighted uniformity than the S room; hence, this may implicate improved performance. A desired γ_{SP} = 0.8 was established (fig. 1). The practical interpretation of this is as follows, for example, 22 TESAs with t_{db} measurements within ±1°C of the set point yield γ_{SP} = 0.79. Alternatively, 11 TESAs with t_{db} measurements within ±2°C of the set point **and** 11 TESAs with t_{db} measurements equal to the set point yield γ_{SP} = 0.79. There are many different combinations of the number of t_{db} measurements and the degree in which those t_{db} measurements are different than the set point to generate $\gamma_{SP} \geq 0.8$. In essence, γ_{SP} is an index that quantifies the effect of the spatial distribution and severity of the difference from set point. There are several obvious trends, such as, when t_a was greater than set point in mid to late September, γ_{SP} for both the N and S rooms decreased substantially. This was most likely attributed to the switch from power to tunnel. Further, rapid decreases in γ_{SP} are observed when t_a quickly decreased as well, causing the controller to lag behind to sudden change in t_a.

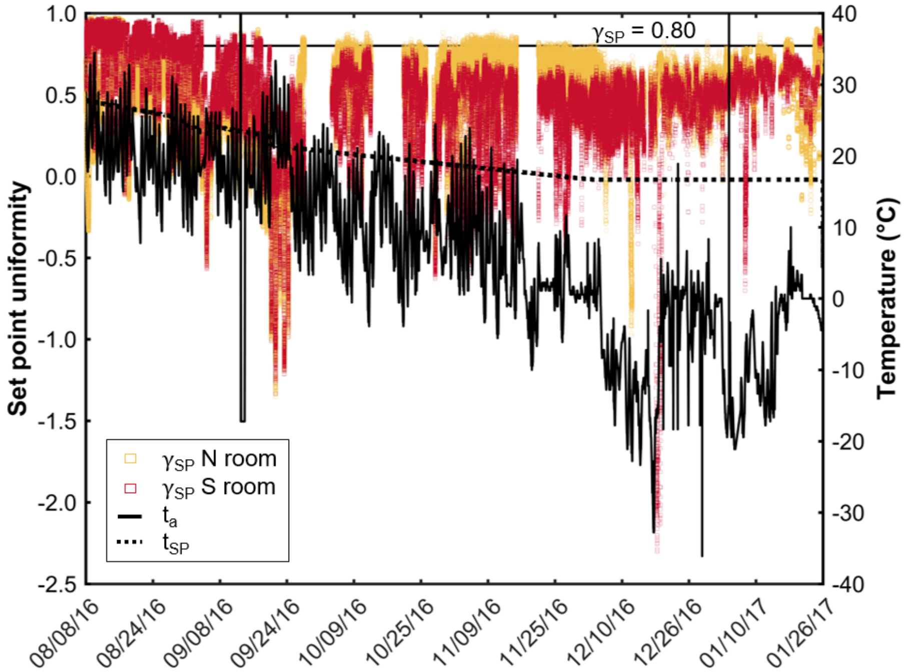

Figure 1. Room set point uniformity over the course of the study.

Analysis of γ_{SP} by t_a showed the mean N room γ_{SP} was greater for t_a <16°C. For t_a > 16°C, except 24°C to 32°C, S room γ_{SP} was greater (table 1). Results from the statistical analysis showed a statistically significant difference between N and S room γ_{SP} for t_a bins <8°C ($p < 0.01$; $p < 0.01$; $p < 0.01$). No statistically significant difference was found between N and S room γ_{SP} for t_a bins >8°C ($p = 0.26$; $p = 0.07$; $p = 0.73$; $p = 0.31$). These results seem reasonable as the controller can adjust inlet opening and heater run time to maintain set point during colder conditions. At warmer conditions, which often exceed set point, the transitions between power to tunnel can lead to a higher lack of uniformity.

Table 1. Summary statistics for set point uniformity (N room|S room).

	<-8°C	-8°C to 0°C	0°C to 8°C	8°C to 16°C	16°C to 24°C	24°C to 32°C	>32°C
Mean	0.54|0.38	0.62|0.48	0.59|0.44	0.44|0.52	0.29|0.41	-0.11|-0.10	0.50|0.59
SD	0.20|0.42	0.14|0.22	0.16|0.32	0.30|0.35	0.47|0.48	0.72|0.67	0.13|0.14
Max	0.87|0.87	0.88|0.93	0.97|0.96	0.97|0.97	0.97|0.97	0.97|0.90	0.92|0.69
Min	-0.98|-2.30	-0.23|-1.30	-0.25|-0.43	-0.52|-0.63	-1.20|-1.21	-1.35|-1.33	0.40|0.12
n	30,351	53,135	44,839	56,084	19,144	537	105

Conclusions

Set point uniformity was better during colder ambient conditions in the North room compared to the South room. This was a preliminary and novel approach to assessing ventilation controller performance. Future work requires the incorporation of the other TE parameters in the performance analysis and their relation to animal thermal balance. An improvement of our understanding of spatiotemporal uniformity and its relation to controller performance is needed. Further, criteria for acceptable uniformity during different modes of controller operation will need to be developed.

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