2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation
DOI: 10.13031/aim.20162454577
Paper Number: 162454577

Thermal Environment Performance and Uniformity Assessment for a Novel Swine Breeding and Gestation Facility

Brett C. Ramirez[1], Graduate Research Assistant**, Steven J. Hoff[1],** Professor, **Jay D. Harmon[1],** Professor, **and John P. Stinn[2],** Environmental Projects Manager

[1]Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA, USA

[2]Iowa Select Farms, Iowa Falls, IA, USA

Written for presentation at the
2016 ASABE Annual International Meeting
Sponsored by ASABE
Orlando, Florida
July 17-20, 2016

Abstract. *The Thermal Environment (TE) inside swine facilities has a substantial impact on animal performance and facility energy usage; therefore, proper control and measurement are required to maintain the optimal TE that maximizes performance and consumes minimal energy. Currently, controllers only monitor and describe the TE with dry-bulb temperature (t_{db}); however, t_{db} does not account for all the factors that influence the TE. Therefore, a novel Thermal Environment Sensor Array (TESA) network and accompanying data acquisition systems were developed for a preliminary investigation inside a commercial, ~800 hd, positive pressure ventilated, filtered breeding facility located in central Iowa. Data from the TESA network and from various ventilation system components from the installed controller would allow for control and distribution performance to be evaluated. Hence, the objectives of this research were: (1) evaluate the Thermal Environment Modification System (TEMS) controller response to seasonal and diurnal fluctuations; (2) implement and evaluate TESA and accompanying DAQ system performance; and (3) assess TE spatial uniformity across three pens. Six TESAs (two suspended per pen), each with: t_{db}, black globe temperature, airspeed, and relative humidity measurements were deployed since November 2015 to initially evaluate the performance and the robustness of this new system, as well as, explore the effectiveness and distribution of the facility's thermal environmental modification and control system.* Overall, the TESAs performed well, except for some dust accumulation on the t_{db} and black globe sensors. *Results showed that t_{db} inside the facility was within ±1°C and ±2°C of the set point 36.3% and 75.3% of the monitoring period, respectively. A maximum 10.6°C above the set point and 5.2°C below the set point were recorded. The preliminary findings from this study will be useful for developing functional performance tests to commission livestock and poultry facilities. These functional performance tests will analyze fan performance, heater distribution, TEMS controller abilities, spatiotemporal TE uniformity, etc. The information obtained will allow facility operators to make better management practices that ultimately decrease production costs and improve the thermal comfort for the animals.*

Keywords. *ventilation, pigs, energy, environmental control, sensor network.*

Introduction

Thermal Environment Modification (i.e., fresh air ventilation, heating, cooling systems, etc.) and Air Distribution (i.e., inlets, baffles, side/end wall curtains, etc.) Systems (TEMADS) for livestock and poultry production systems are designed to provide acceptable thermal comfort, fresh air, and indoor air quality inside the building for the animals. However, the implementation, operation, and control of these systems can deviate from the original design goals. This deviation between design and operation can result in poor animal growth performance, excess facility energy usage, and places the animals at an increased risk for adverse health effects (Curtis, 1983; DeShazer, 2009). Hence, throughout the operation of TEMADS, continuous monitoring and performance analysis are required to ensure that an optimum thermal environment and air quality is provided for the animal, as well as sufficiently accomplish the objectives of the operator.

Modern commercial Thermal Environment Modification System (TEMS; or more commonly known as “ventilation”) controllers have extensive Data Acquisition (DAQ) and control capabilities that allow data from numerous systems, devices, sensors, etc. to be continuously monitored and recorded at user selectable frequencies during operation of the facility. For example, TEMS controllers feature analog inputs (e.g., sensors) and outputs (IOs; e.g., variable speed devices), digital IOs (e.g., relay actuation or position), frequency inputs, pulse inputs, etc. The increase in technological and DAQ capabilities has led to an increase in the amount of available data for livestock and poultry facilities. In addition, this also provides a new and unique opportunity to explore TEMS, associated controller performance, and thermal comfort spatiotemporal uniformity. Analysis of these data could help identify poorly performing system components and promote more informed management decisions.

A novel swine breeding and gestation facility was monitored over an 8-month period (November 2015 – June 2016) using the installed TEMS controller and a custom developed Thermal Environment Sensor Array (TESA) network. The commercial TEMS controller data will provide initial methods to monitor facility performance according the operator’s needs. Further, this study deployed the TESA network and accompanying DAQ to collect preliminary data on the sensor network performance, as well as, analyze the spatiotemporal uniformity among three pens inside the facility. The data obtained from the TEMS controller and novel TESA network can be used to enhance the design and control of TEMADS, such that existing systems can be adjusted to enhance and maintain the optimal Thermal Environment (TE) for improved animal production efficiency and thermal comfort. Hence, the objectives of this research were: (1) evaluate the TEMS controller response to seasonal and diurnal fluctuations, and (2) implement and evaluate TESA and accompanying DAQ system performance.

Materials and Methods

Facility Description

The commercial swine breeding and gestation facility with interior dimensions (L by W by H) 96.9 by 15.9 by 2.4 m was located in central Iowa and housed approximately 800 sows/gilts in 54 pens (figure 1). The facility featured a filtered, positive pressure ventilation system accomplished by a dormer extended from the side of the building (ground to roof peak), where six variable speed fans pulled fresh air through an open area controllable by a curtain, across an evaporative cooler, through a filter bank, to positively pressurize the attic; hence, continuously forcing filtered air through the ceiling inlets. Air inside the building was allowed to exhaust through shutters with an external curtain that could be adjusted to modify exhaust flow. Two of the aforementioned dormer setups (i.e., evaporative coolers, filter bank, fans, etc.) were positioned at the east and west regions on the north side of building. The interior was zoned into three regions (east, middle, and west) inside the facility for the TEMS controller. One t_{db} sensor was located in each zone. The TEMS controller adjusted inlet open area to control for t_{db} and fan speed and exhaust curtain height for static pressure control inside the attic (with respect to ambient) and between the attic and the room. The t_{db} set point was 18.9°C for all three zones during the spring and summer monitoring months of the facility. The TEMS controller recorded t_{db}, set point t_{db}, heat run time, percent inlet open, room static pressure, attic static pressure, and variable speed output, at 2 min intervals. Data was obtained from the TEMS controller from May 9th, 2016 to June 16th, 2016.

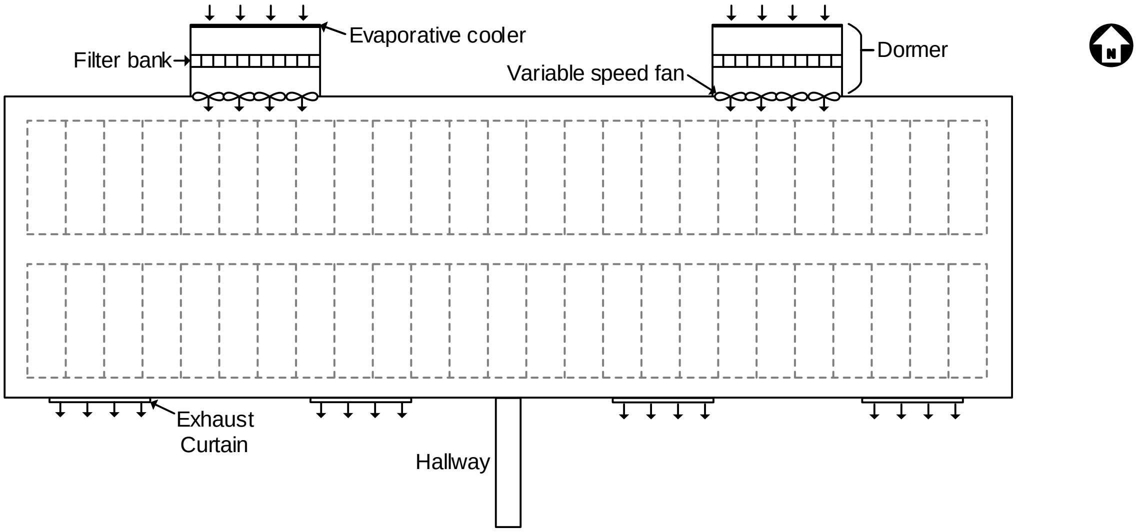

Figure 1. Schematic of commercial swine breeding and gestation facility with interior dimensions (L by W by H) 96.9 by 15.9 by 2.4 m was located in central Iowa and housed approximately 800 sows/gilts in 54 pens.

Weather Data

Ambient weather data (t_{db}, t_{dp}, wind speed, and wind direction) were obtained in 1 h intervals from the Automated Surface Observing System (ASOS) located approximately 63 km from the facility at Waterloo Regional Airport (ALO).

Thermal Environment Sensor Array

A novel thermal environment sensor array (TESA) network and DAQ system were developed and deployed in the facility to collect preliminary information on the performance and robustness of this novel network of TESAs, as well as monitor the spatiotemporal distribution of the TE (Ramirez, Gao, & Hoff, 2016). An individual TESA (figure 2) consisted of four sensors to perform four measurements: t_{db}, relative humidity (RH), airspeed, and globe temperature ($t_{g;}$ via a black globe thermometer to calculate mean radiant temperature; t_{mr}). Sensor signals from a TESA were connected via a single, ten-conductor wire to screw terminals mounted on the TESA data acquisition, transmission, and control custom printed circuit board. The serial data communication network featured bidirectional data transfer between a notebook computer and each deployed TESA. More detailed information regarding TESA and its communication network can be found elsewhere (Gao, Ramirez, & Hoff, 2016).

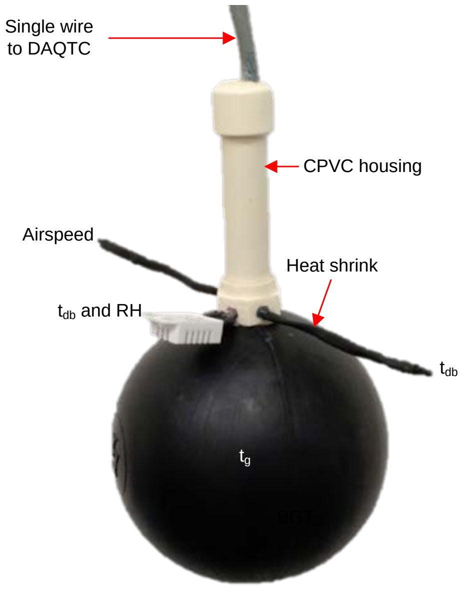

Figure 2. Image of a Thermal Environment Sensor Array (TESA) featuring dry-bulb temperature (t_{db}), relative humidity (RH), airspeed, and black globe thermometer (BGT) sensors. Globe temperature (t_g) is obtained from a t_{db} sensor at the center of the BGT and used to calculate mean radiant temperature (t_{mr}).

Six TESAs were deployed inside the facility (figures 3 and 4) as a preliminary evaluation of the system, with two TESAs suspended 1.8 m above the partially slatted floor in a pen with about 15 animals housed within each pen. Sixty analog voltage measurements from aforementioned sensors were collected between 60 to 180 s intervals. Text files with the raw data were saved every hour and collected from the computer inside the facility every two to three weeks. Data from the TESAs was collected over an 8-month period from November 23rd, 2015 to June 24th, 2016.

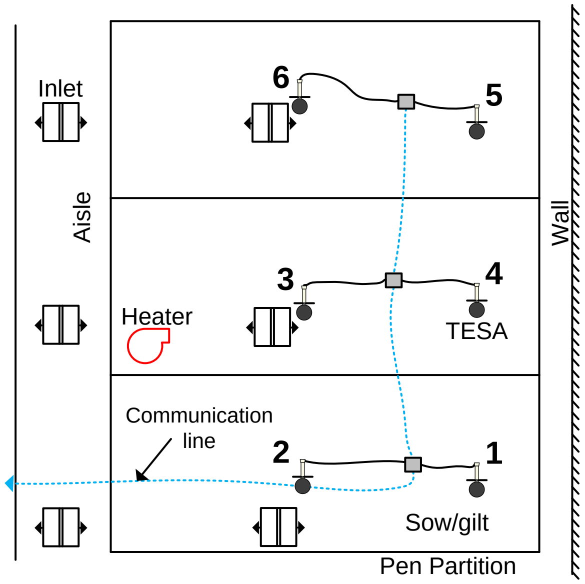

Figure 3. Schematic of the location of the six TESAs and thermal environment modification and air distribution systems components in three pens.

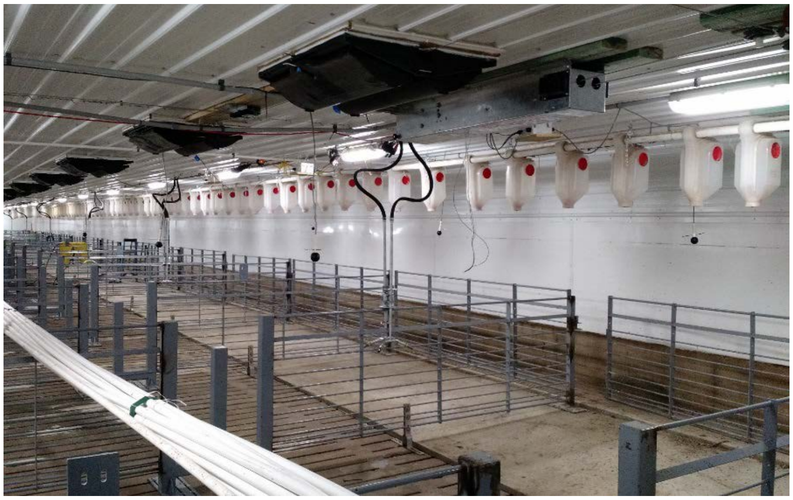

Figure 4. Six TESAs suspended 1.8 m above the partially slatted floor in three pens with about 15 animals housed within each pen.

Data Preparation and Quality Control

Prior to analysis, the raw voltages were verified to be within the output range of each sensor and at least two thirds of the 60 measurements collected from a TESA were recorded. Data from a sample (i.e., 60 raw measurements) were subjected to Chauvenet's criterion to remove outliers prior to taking the mean and standard deviation. Analog voltages were then transformed to their physical quantity and then verified to be within the physical limitations of the sensor.

Results and Discussion

Thermal Environment Sensor Array

Data was not recorded for about two weeks from December 20th, 2015 to January 7th, 2016 due to a hard drive failure on the notebook computer used to collect the TESA data. Three TESAs (#1, #4, and # 6) collected ~227,000 lines of the data from the five measurements, while, two TESAs (#3 and #5) collected ~216,000 lines data, and the remaining TESA (#2) only collected ~166,000 lines of data. The low amount of data collected by TESA #2, was most likely attributed to a poor sensor connection or a sensor failing. Erroneous data was most common for BGT sensor because during the assembly of a TESA, the thermistor is pulled through a rubber stopper. The leads on the t_{db} sensor are fragile and may have been severed or damaged when the BGT was assembled. A preliminary concern of TESA was the robustness of the RH sensor. The long-term suitability of RH sensors in high NH_3 and H_2S environments is questionable and exposure to these gases can lead to decreases in accuracy over time. Due to the high RH measured in the facility, for a 10 d period, eight additional t_{db}/RH sensors (HAXO-8, LogTag, Auckland, New Zealand) were attached to the TESAs for comparison. Within the stated accuracies of both sensors, there was no difference. Further, the accumulation of dust on the top half of the BGT and, also on the t_{db} sensor, required cleaning when the data was downloaded from the notebook computer. Dust was an issue in this facility, where feed was dropped from about 2 m above the floor, with no drop tube or stantion. Dust most likely did not affect the BGT and t_{db} sensor measurements, but possibly altered the response time of the sensors and may have slightly changed the emissivity of the BGT. The airspeed sensor had less dust than the others. This was most likely due to the thermistor being maintained at 103°C, which burned off some dust over time. Overall, the TESAs performed as expected, suggesting future use in long-term TE monitoring studies are feasible.

Facility Performance

Each of the four TE parameters: t_{db} (figure 5), RH (figure 6), airspeed (figure 7), and t_{mr}; collected from the six TESAs over the entire monitoring period are summarized. Overall, t_{db} inside the facility was within ±1°C and ±2°C of the set point 36.3% and 75.3% of the monitoring period, respectively. Some large temperature swings are evident in figure 5, those were attributed to operator error or an accidental change in settings. A maximum 10.6°C above the set point and 5.2°C below the set point were recorded. At the onset of the study, the RH inside the facility was relatively high until early March. By that point, the operator had been working on the issue and applying different management strategies to reduce the RH. This is shown by the declined RH and maintenance of RH at a lower level. Once the evaporative cooler was activated around mid-May, the RH in the facility increases. As expected, t_{mr} reflected t_{db} trends, but with a dampened response. Airspeeds in the facility during the winter months were low, as expected, and began to increase as the inlet gradually became more open as a higher ventilation rate was needed to maintain the set point. The omnidirectional thermal anemometer properly followed the trend of inlet percent open (figure 8).

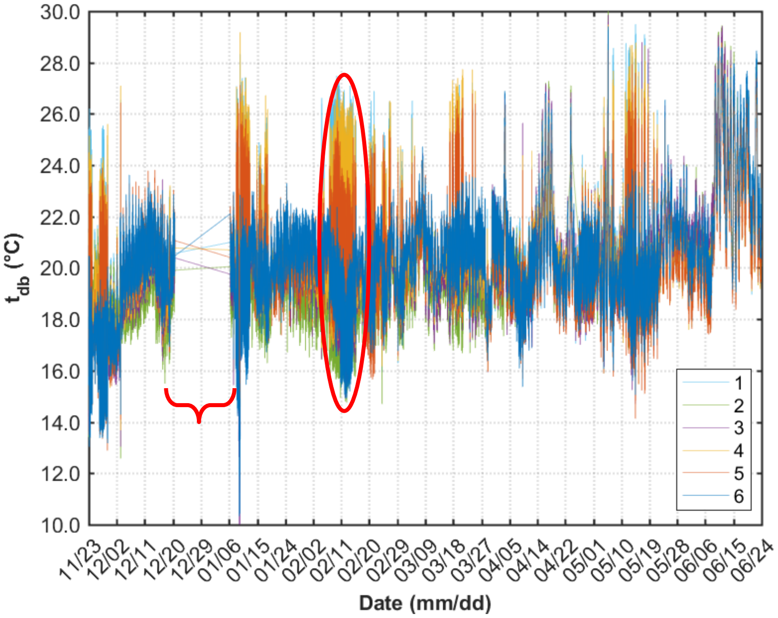

Figure 5. Summary of t_{db} over the entire monitoring period. The bracket denotes a hard drive failure on the computer and data was not recorded during this time. The circle denotes a mechanical system failure, where the inlets were opened during winter causing a decrease in indoor t_{db}.

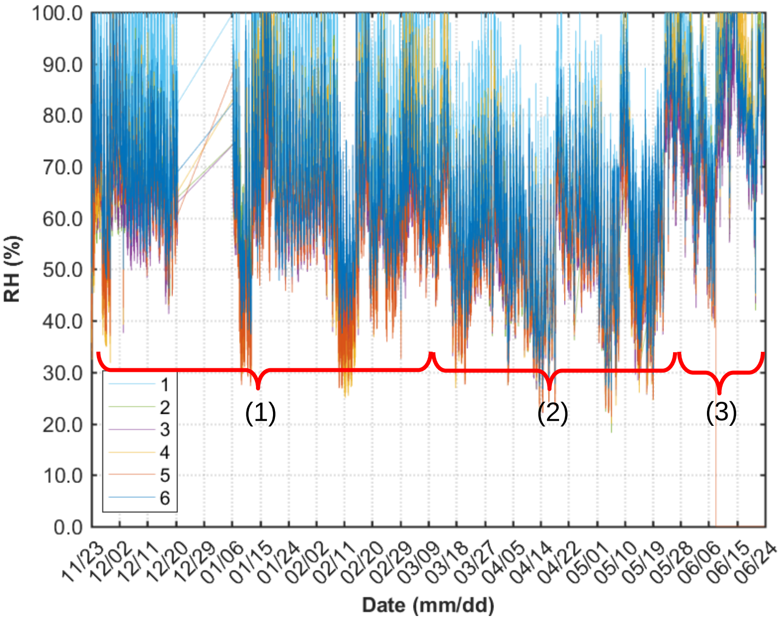

Figure 6. Summary of RH over the entire monitoring period. The leftmost bracket (1) denotes the high RH observed in the facility, while the middle bracket (2) shows modifications by the operators to reduce the RH. The rightmost bracket (3) denotes when the evaporative cooler was activated during the late spring/summer months.

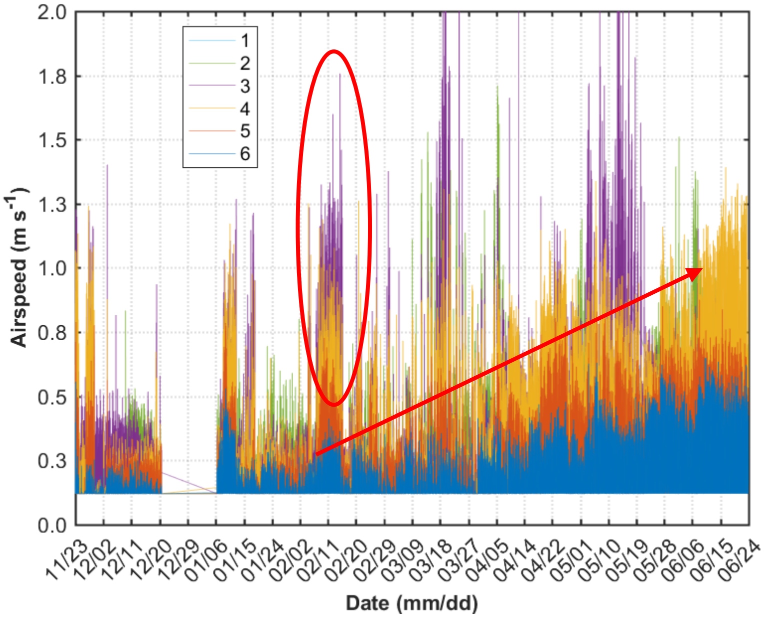

Figure 7. Summary of airspeed over the entire monitoring period. The circle denotes the corresponding increase in airspeed when an operator error caused the inlets to open substantially during the winter. The arrow shows the increase trend of airspeed as the inlets became proportionally more open and ambient temperature increased.

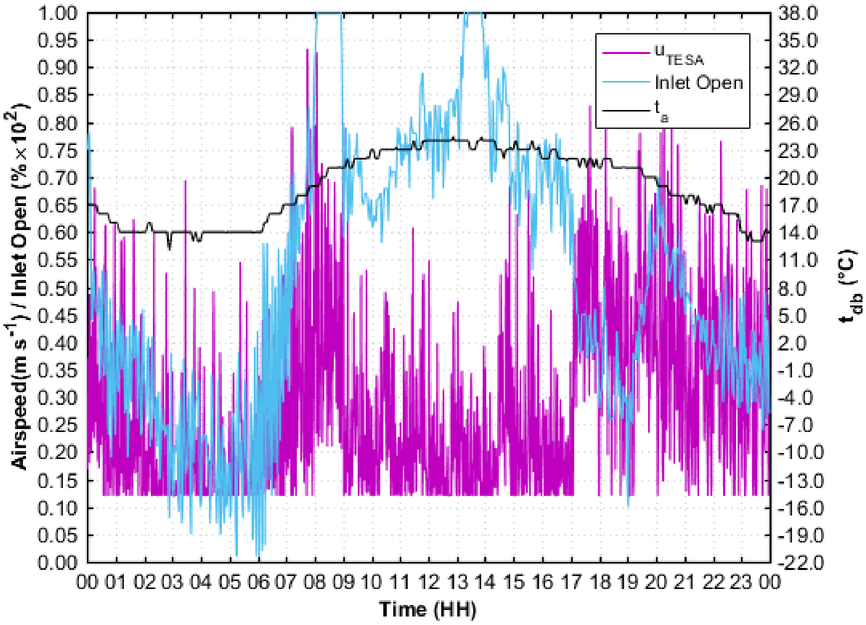

Figure 8. Example of the relationship between airspeed and inlet open percentage. The airspeed follows the inlet open percentage trend except during the hours from 9 to 17 where the sensor may have been obstructed or an external factor caused fan speed to reduce but inlets to remain open.

Since TESA has the capability to capture all the sensible and latent modes an animal can exchange heat with its surroundings (except conduction); ultimately, the four TE parameters need to be combined into one effective index or representation of the TEMS ability to dissipate heat from the animal. For swine, that does not currently exist. However, to show the potential of monitoring the entire TE, the Temperature-Humidity Index [THI = 0.8 T_{db} + RH/100 (T_{db} – 14.4) + 46.4]; was applied. The THI only combines t_{db} and RH, but does provide some insight to the TEMS ability to maintain a thermally comfortable environment for the animals. Figure 9 shows the inability for the TEMS to provide any reduction in THI when the ambient RH is high and ambient t_{db} is only mild. In fact, the ambient THI was lower for many hours of the day and using the evaporative cooler slight increased THI. Both inside and ambient THI were below the alert threshold of 75. On a day with much higher ambient t_{db}, the evaporative cooler was not functioning in the morning and was not activated until 15:30 (figure 10). Once started, the evaporative cooler reduced t_{db} and increased RH, which ultimately lowered the THI inside compared to ambient. However, late into the night, operation of the evaporative cooler was probably no longer needed as the ambient THI had reduced and had become similar to inside THI.

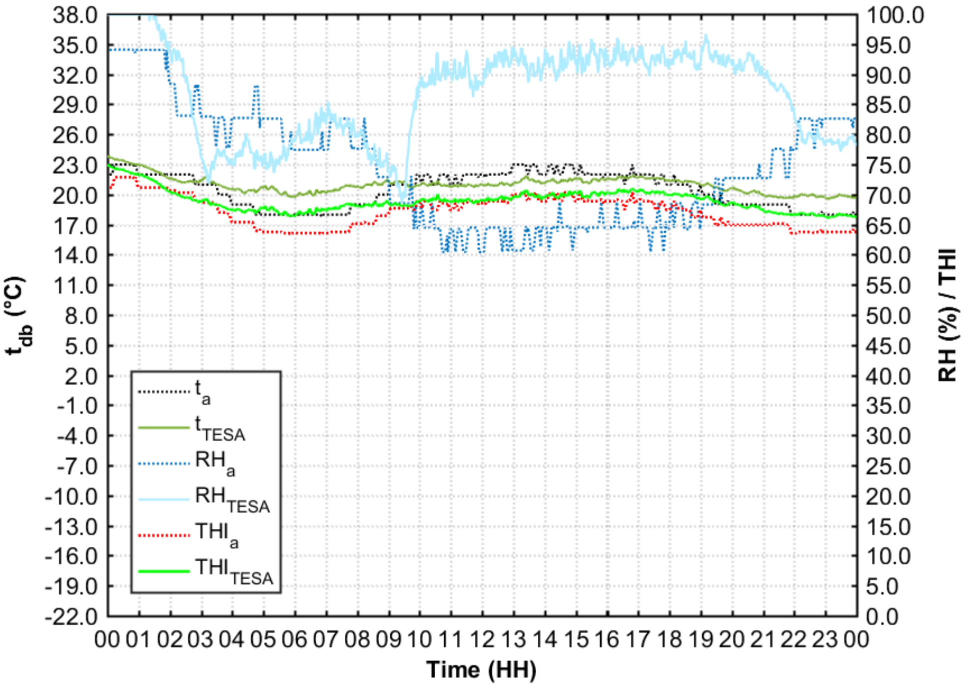

Figure 9. Minimal reduction in THI was achieved with the evaporative cooler at mild t_{db} and high ambient RH.

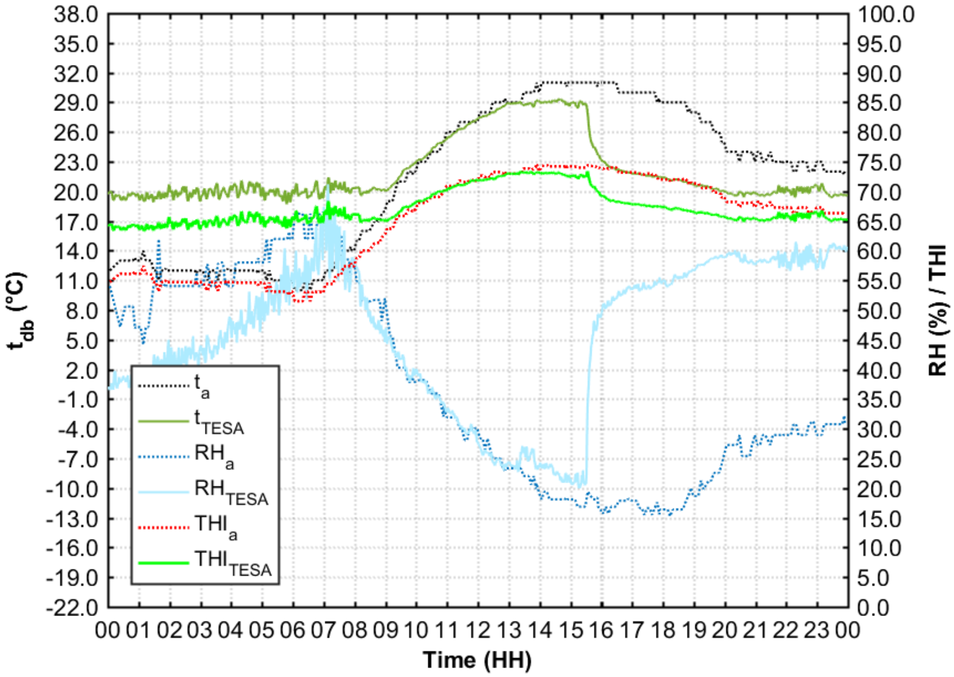

Figure 10. There was an issue with starting the evaporative cooler in the morning; however, once started, THI was reduced from ambient and returned to the normal conditions.

Conclusions

The development and preliminary implementation of the Thermal Environment Sensor Arrays (TESAs) is the initial phase in developing a collection of functional performance tests to commission livestock and poultry facilities. These functional performance tests will analyze fan performance, heater distribution, TEMS controller abilities, spatiotemporal TE uniformity, etc. The information obtained from these tests will allow facility operators to make better management practices that ultimately decrease production costs and improve the thermal comfort for the animals. Overall, this new positive pressure filtered facility adequately maintained the set point temperature provided by the operators.

Acknowledgements

This research was supported with funding provided by the Iowa Pork Producers Association (NPB 14-242). The authors would like to thank Ben Smith and all the employees at Iowa Select Farms and acknowledge the contributions of undergraduate student Grant Hoppes during the preparation and completion of this work.

References

Curtis, S. E. (1983). *Environmental Management in Animal Agriculture*. Ames, IA: The Iowa State University Press.

DeShazer, J. A. (2009). *Livestock Energetics and Thermal Environmental Management* (1st ed.). St. Joseph, MI: American Society of Agricultural and Biological Engineers.

Gao, Y., Ramirez, B. C., & Hoff, S. J. (2016). Omnidirectional thermal anemometer for low airspeed and multi-point measurement applications. *Computers and Electronics in Agriculture*.

Ramirez, B. C., Gao, Y., & Hoff, S. J. (2016). Development and Validation of a Spatial and Temporal Thermal Environment Sensor Array and Data Acquisition System. In *2016 ASABE Annual International Meeting*. American Society of Agricultural and Biological Engineers.