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Control algorithm development and simulation for comparing evaporative pads and sprinklers for grow-finish pigs

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ABSTRACT. *Seasonal variability attributed to heat stress (HS) has a large economic impact on the US swine industry by reducing daily gain and finishing market weights. Strategies to mitigate HS lack evidence showing effectiveness in different climates and have not been adequately controlled to provide a thermally optimum environment for pigs. Hence, the goal of this study was to describe the initial experimental design and instrumentation as well as develop innovative control algorithms for operating evaporative pads (EPs) and sprinklers. Located in northeast Iowa, a four room (~1,875 head per room) grow-finish facility featured side-by-side rooms separated by a hallway. Three thermal environment sensor arrays (TESAs) quantifying dry-bulb and globe temperature, relative humidity, and airspeed were placed in each room and served as feedback for control system to evaluate the thermal environment and potential HS conditions. The newly developed housed swine heat stress index (HS2I) combines TESA measurements and optional wetted skin to assess the potential for HS onset. Custom software interfaced with a multifunction data acquisition board was used to condition TESA signals and control EP pumps and sprinkler solenoids. A control algorithm was developed and simulated using data collected during a 23-d period in July 2017 to preliminarily evaluate the robustness and potential control decisions. Linear models developed to predict indoor dry-/wet-bulb temperature showed good agreement with measured data and will be critical for developing a control systems to selects the best cooling system given forecasted ambient conditions.*

Keywords. growth performance, heat stress, swine, temperature, ventilation.

Introduction

The severity of heat stress on pigs has been well documented with St-Pierre, Cobanov, & Schnitkey (2003) estimating economic losses of about $300 million per year for the U.S. pork industry as well as herd productivity being diminished for about 40% of the year (Hostetler, 2015). Voluntary feed intake was estimated to reduce by 40 to 80 g d^{-1} per °C between 20°C and 30°C (Le Dividich, Noblet, Herpin, Van Milgen, & Quiniou, 1998). In addition, Renaudeau et al. (2011) estimated from numerous studies, the reduction in average daily gain for a 50 kg pig was about 18 g d^{-1} per °C when temperature increases from 20°C to 30°C. Heat stress has and will continue to have a negative impact of pig performance and therefore, requires alleviation strategies to reduce performance penalties.

There are three common techniques for reducing heat stress in grow-finish pigs: elevated airspeeds, direct (wetted skin), and indirect cooling (reduced dry-bulb temperature). Elevated airspeeds (via forced convection) remove excess heat when the dry-bulb temperature is less than the skin temperature of the pig. Both indirect and direct cooling utilize a phase change at some part of the process (most commonly water) to extract heat from a source (pig, air, evaporative pad, refrigerant, etc.). The main difference between indirect and direct cooling is that indirect cooling conditions the air surrounding the pig (primarily convection) compared to direct cooling, where heat is removed from the pig by directly evaporating water from its skin. All three methods are used in commercial pig production and require further exploration.

The goal of this paper is to introduce the initial phases of a research project aimed at developing novel control techniques for and assessing the effectiveness of indirect (evaporative pad; EP) and direct (sprinklers) cooling systems for grow-finish pigs. Both the control and effectiveness of these cooling systems lacks literature support and would benefit from the integration of modern electronics to reduce water consumption while maximizing pig performance. Hence, the objectives of this paper are to: 1) describe a new data acquisition system for monitoring the parameters that describe the thermal environment (except conduction) and 2) introduce the development of a control system for operating two cooling systems independently based on local climate and predicted pig performance penalty.

Materials and Methods

Site description

A 7,500 hd commercial, deep-pit, grow-finish facility located in northeast Iowa, USA was instrumented in mid-summer 2017. The facility featured four rooms: two side-by-side rooms located across from each other with a common hallway in between. Room dimensions (L × W × H) were 61 × 20 × 2.54 m and each room housed ~1,875 hd in 12 large pens. The length of the building was orientated along the North-South axis. The negative pressure ventilation system was fully mechanical with 100% of fresh air distributed through ceiling inlets (bi-flow) by six exhaust fans in each room. On each end of the building, fresh air entered through a 0.1524 m thick EP and into a common spray-foam insulted attic plenum that is shared by all the rooms. The attic plenum was separated in half with plastic sheets – effectively dividing the airspace for the North and South set of side-by-side rooms. This was to prevent air mixing between the North and South attic plenums; hence, different conditioned fresh air treatments would only be applied to two rooms, while the other two rooms could be controlled differently.

Instrumentation

Specific instrumentation information details are included herein for detailed clarity of systems used and does not imply endorsement of specific products.

Three thermal environment sensor arrays (TESAs; Ramirez, 2017a) quantifying dry-bulb (T_{db}) and black globe (T_{bg}) temperature (nominal 10 kΩ at 25°C, NTCLE413E2103F, Vishay), relative humidity (RH; HIH-4000, Honywell), and airspeed (Gao et al., 2016) were placed in each room and served as feedback to the control system for evaluating the thermal environment and potential HS conditions. A +5 VDC adapter powered each TESA via 120 VAC receptacles in the rooms. TESA construction was modified from Ramirez (2017) to feature an improved weatherproof housing and additional sensor protection to prevent direct contact with water from the sprinkler system. Five analog signals plus ground for each TESA were connected via 6-connducter shielded wire to one multifunction data acquisition system (MDAQS; U6, LabJack Corp.) with a 16-bit analog to digital converter. Four terminal boards (CB37, LabJack Corp.) were connected to an analog input expansion board (Mux80, LabJack Corp.) to accommodate the 60 analog signals from the 12 TESAs.

Custom software (Python 2.7, Python Software Foundation) was developed in an integrated development environment (PyCharm 2017.3.4, JetBrains) on a portable computer interfaced with the MDAQS. The software was capable of collecting analog voltages at a user specified frequency and could be integrated with relays to control pumps and solenoids for the EP and sprinkler systems.

For each half of the facility, two T_{db}/RH dataloggers (UX100-003, Onset Computer Corp; standard uncertainty: ±0.14°C; ±2.1%) were used to monitor the incoming ventilation air directly downstream of the EP and three T_{db}/RH sensors were evenly disturbed along the length of the attic in the center. One ambient T_{db} and RH datalogger (T_a/RH; MX2301, Onset Computer Corp.; standard uncertainty: ±0.12°C; ±1.6%) was placed outside and near the facility.

Algorithim Development

Data were collected from July 7, 2017 to July 30, 2017 in order to develop the preliminary algorithms to the control the sprinkler and EP cooling systems and to simulate the control logic prior to implementation. A program developed in MATLAB (R2017b, MathWorks Inc.) processed *.txt files and filtered irregular values. Data from each source were synchronized using linear interpolation to a uniform 5-min interval time vector.

Conceptually, each day, given the ambient weather forecast, the control system would model pig performance penalty using the three aforementioned cooling system methods to subsequently determine the best strategy to minimize the impact of heat stress. Heat stress impact was calculated using the Housed Swine Heat Stress Index (HS2I; Ramirez, 2017a) which accounts for bodyweight, group size, T_{db}, RH, airspeed, and wetted skin. The HS2I was developed to convert the simulated mean body temperature (physiological response; Ramirez et al., 2017b) difference from 39°C (the assumed mean body temperature of a pig existing within its thermal comfort zone) into a dimensionless indexed value ranging from 0 (thermally comfortable) to 10 (severely heat stressed), with intermediate values 3 to 6 as moderately heat stressed.

The initial objective was to estimate room T_{db} and wet-bulb temperature (T_{wb}; ASHRAE, 2013) given ambient conditions and EP operation (i.e., on/off). The EP was independently operated to turn on at a room temperature of 23.9°C. Data from the 23-d period was sorted between evaporative cool pad on and off for the two North and South rooms. Least squares regression was used to develop relationships to estimate North and South room T_{db}, T_{wb} with EP on, and T_{wb} with EP off. Measured and predicted conditions for the aforementioned six parameters were compared.

Results and Discussion

During the 23-d period, a range of hot T_{db} with varying levels of RH were experienced (fig. 1). Since the EP was controlled independently, most of the EP ‘off’ data originated during nighttime conditions when it was cooler; however, the ventilation system continuously operated at the maximum ventilation stage; thus, any heat accumulation was assumed to be the same as daytime and nighttime (the entire attic was spray foamed to minimized solar gain).

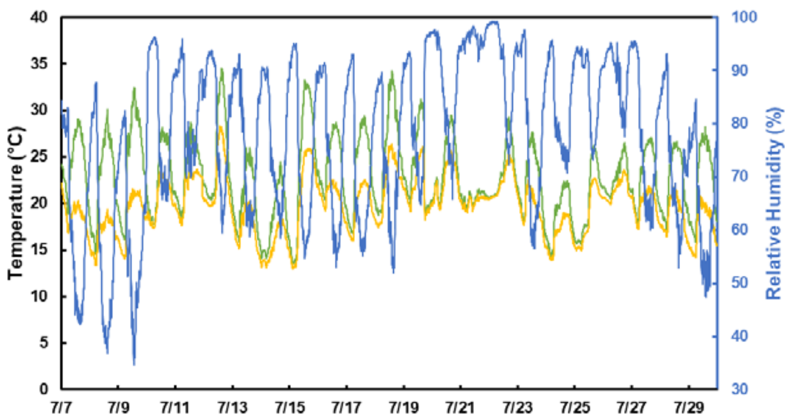

Figure 1. Ambient dry-bulb (green), wet-bulb (yellow), and relative humidity (blue) for the 23-d period in July 2017.

Primary factors for predicting room T_{db}/T_{wb} were ambient conditions, heat accumulation, and EP efficiency. An example 6-h afternoon period with the EP operational is depicted in fig. 2. This example was typical of a hot and humid day for northeast Iowa. T_{db} and RH, as well as the difference between locations is shown for ambient, directly downstream of the EP, three locations in the attic plenum (increasing distance from EP), and three locations in both the North side-by-side rooms. A -6°C was observed downstream of the wetted EP and a subsequent increase in RH. T_{db} increases as air flows through the attic and into the rooms, as expected. However, the overall difference from ambient was -1.5°C and +14.8% RH, resulting in an average room HS2I = 7.3. In another example (not shown), when ambient conditions were hot (T_{db} = 31.7°C) and moderately dry (38% RH), resulting in a room average HS2I = 3.7.

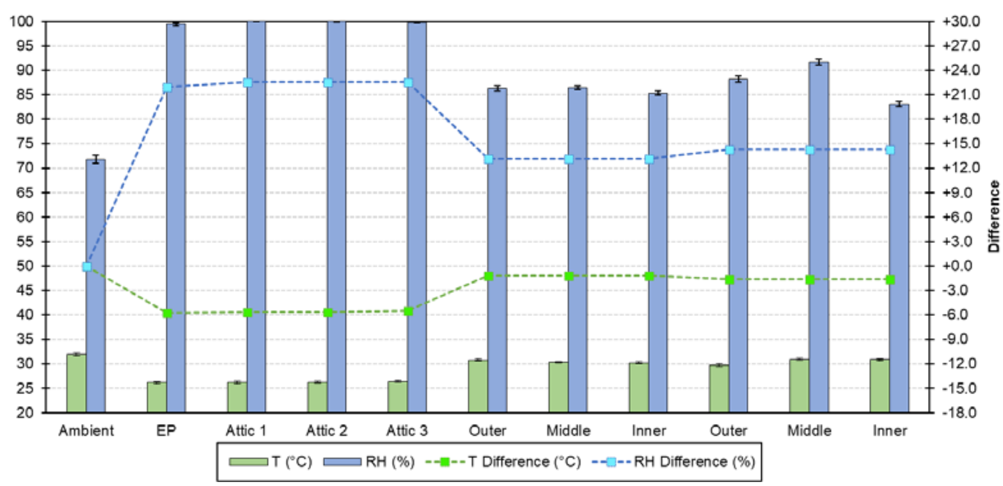

Figure 2. Example (12:00 to 18:00) illustrating T_{db} (T) and RH at ambient, directly downstream of EP, three locations in attic plenum (Attic 1, 2, and 3), and three locations in the two North rooms. Error bars represented the 95% CI. Room airspeeds ranged from 0.25 to 0.75 m s^{-1}.

Average room T_{db} was predicted from T_{db} directly downstream of the EP, while average room T_{wb} was predicted for ambient T_{wb}. Example data is shown in fig. 3. Table 1 contains the summary of the linear regression coefficients and statistics determined to estimate individual room T_{db} and T_{wb} for EP: ‘on’ and ‘off’. Coefficients of determination were >0.88 for all regressions and slight variations in the regression parameters could be attributed to differences in stocking density. The intercept term is greater for the South room, which may be attributed to the increased sun exposure.

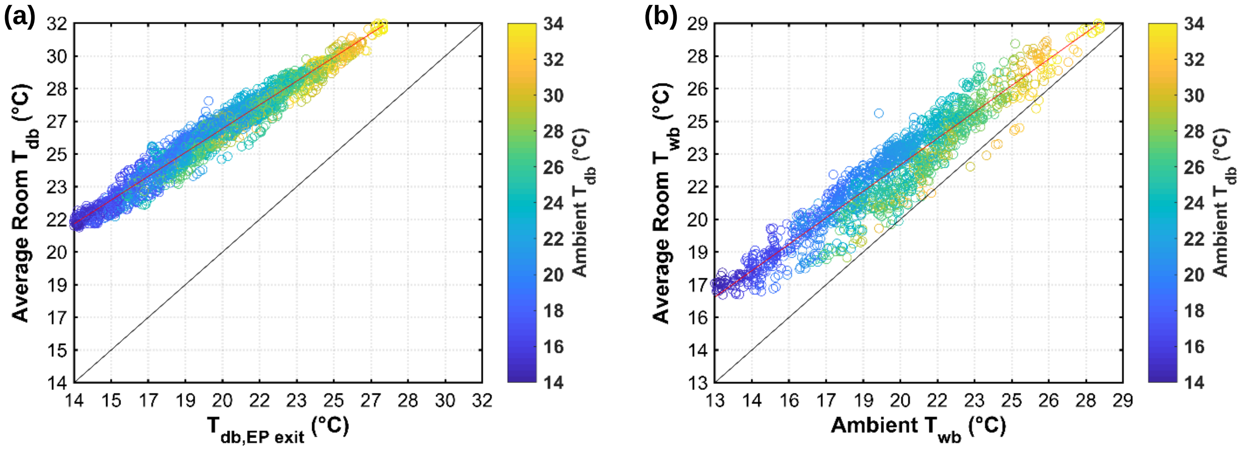

Figure 3. South Room average room T_{db} as a function of EP exit T_{db} (a) and North room average T_{wb} as a function of ambient T_{wb} (b).

Table 1. Summary of linear regression coefficients ($\hat{y} = y_0 + y_1\ x$) for predicting conditions inside the rooms.

	Predicted room parameters ($\hat{y}$)	EP status	y_0	x	y_1	R^2	RMSE (°C)
N Room	T_{db}	On or off	10.7028	$T_{db,exit}$	0.7437	0.955	0.461
	T_{wb}	Off	6.0133	$T_{wb,ambient}$	0.8223	0.898	0.808
		On	6.1816	$T_{wb,ambient}$	0.8134	0.902	0.809
S Room	T_{db}	On or off	11.5995	$T_{db,exit}$	0.7290	0.960	0.428
	T_{wb}	Off	7.1653	$T_{wb,ambient}$	0.7916	0.886	0.848
		On	7.1879	$T_{wb,ambient}$	0.7909	0.894	0.819

Predicted average room conditions from the developed regression models, expressed as dimensionless HS2I (combination of measured T_{db}, RH, and airspeed), showed reasonable agreement (R^2 = 0.892; RMSE = 0.32; fig. 4) with measured HS2I during the 23-d period. The quality in the linear regression agreement is important to ensure predictions given only forecasted ambient conditions are reasonable.

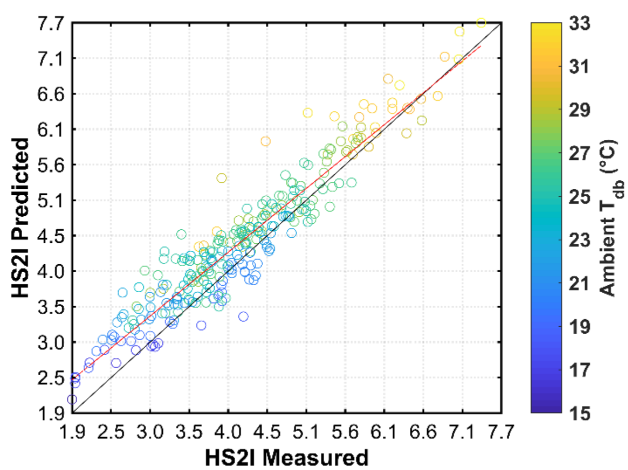

Figure 4. Comparison of average measured HS2I and predicted average HS2I (EP on).

To determine which cooling system would be most effective for the day, total H2SI for a 12-h period (i.e., sum of hourly HS2I) was used. Total and average H2SI for a 12-h period (i.e., sum of hourly HS2I) was used to illustrate which cooling system would be most effective. Fig. 5 shows total and average H2SI for each day and that while sprinklers always resulted in the lowest total and average HS2I, there were some days where total and average H2SI were similar for

EP on and off, due to high ambient T_{wb}.

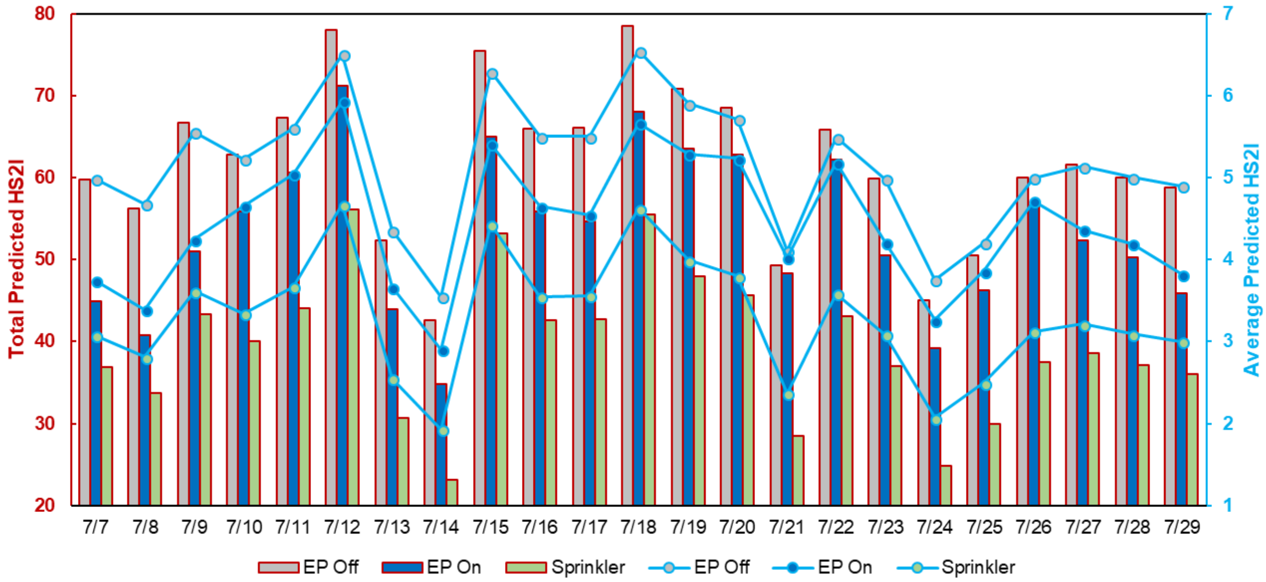

Figure 5. Total predicted HS2I (red outline columns) and average predicted HS2I (blue line) for EP off and on, as well as sprinklers.

Conclusions

- An instrumentation system was implemented in a commercial grow-finish swine facility for thermal environment monitoring to provide feedback to a novel control system.
- T_{db} and T_{wb} linear models showed good agreement and will be necessary for control system implementation.
- An initial step has been taken towards creating a novel control system for determining the optimal cooling control strategy.

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References

ASHRAE. (2013). *Handbook of fundamentals*. Atlanta, GA: America Society of Heating, Refrigeration and Air Conditioning 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*. https://doi.org/10.1016/j.compag.2016.06.011

Hostetler, C. (2015, June 16). Reduce the Impact of Summer Heat. Retrieved November 10, 2016, from http://www.pork.org/checkoff-reports/pork-fires-up-the-fun/reduce-the-impact-of-summer-heat/

Le Dividich, J., Noblet, J., Herpin, P., Van Milgen, J., & Quiniou, N. (1998). Thermoregulation. *Progress in Pig Science*, 229–263.

Ramirez, B. C. (2017a). A novel approach to measure, understand, and assess the thermal environment in grow-finish swine facilities. *Graduate Theses and Dissertations*. 16201. https://lib.dr.iastate.edu/etd/16201

Ramirez, B. C., Hoff, S. J., & Harmon, J. D. (2017b). An improved assessment of the effective environment for analysis of heat stress mitigation techniques. In Int. Symp. on Animal Environ. & Welfare. Chongqing, China.

Ramirez, B. C., Hoff, S. J., & Harmon, J. D. (2017c). Design and feasibility of a novel sprinkler control algorithm for swine heat stress alleviation. Journal of Animal Science, 95(supplement2), 5–6. https://doi.org/10.2527/asasmw.2017.012

Renaudeau, D., Gourdine, J.-L., & St-Pierre, N. R. (2011). A meta-analysis of the effects of high ambient temperature on growth performance of growing-finishing pigs. *Journal of Animal Science*, 89(7), 2220–2230.

St-Pierre, N. R., Cobanov, B., & Schnitkey, G. (2003). Economic Losses from Heat Stress by US Livestock Industries. *Journal of Dairy Science*, *86*, *Supplement*, E52–E77. https://doi.org/10.3168/jds.S0022-0302(03)74040-5