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

Paper Number: 131618879

Heat Production of Nursery and Growing Piglets

Tami M. Brown-Brandl, [1]; John A. Nienaber [1]; Roger Eigenberg[1]; Hongwei Xin [2]; Morgan D. Hayes [1]

[1]EMRU, USDA-ARS,MARC Clay Center, NE

[2]Agricultural and Biosystems Engineering, Iowa State University, Ames IA

.

Written for presentation at the

2013 ASABE Annual International Meeting

Sponsored by ASABE

Kansas City, Missouri

July 21 – 24, 2013

Abstract.

Heat and moisture production (HMP) values are used to size ventilation fans in animal housing. The HMP values that are currently published in the ASABE standards were from data published in 1975. This study is one of a series of studies being conducted to update the HMP values for the ASABE and ASHRAE (American Society of Heating Refrigeration, and Air Conditioning Engineers) Standards. This study focused on the HMP measurements on nursery and growing pigs in the weight range of 8 to 44 kg. Ninety-six nursery pigs were randomly assigned to one of 24 pens (4 pigs /pen) and subjected to one of four temperatures between 25 and 35°C. Forty-eight growing pigs were penned in groups of 2 and subjected to one of four temperatures between 18 and 33°C. Heat production rate (HP) was determined using indirect calorimetry methods, after the animals were acclimated for a minimum of 1 week to a particular temperature. Each measurement was made on a pen of animals (either 2 or 4 pigs/pen) over a 21-hr period. It was determined that HP decreased and moisture production (MP) increased as environmental temperature increased. In the nursery age piglets, the level of feed consumption had a greater impact on HP than temperature. Dynamic measurements showed a diurnal HP pattern; HP was higher during light period than during dark period, with an immediate increase as the lights were turned on.

Keywords. *Heat production, Heat stress, Swine, Dynamic heat production, Ventilation loads, Circadian rhythm*

Introduction

Maintaining building environments is critical for efficient pig growth and well-being especially for nursery and small growing piglets (Midwest Plan Service, 1987). In order to maintain proper building environment, ventilation systems are designed using heat and moisture production rates from animals and their environments. Many factors influence heat and moisture production including animal genetics, nutrition (diet composition and level of feed consumption), and type of production facility (heater type, waste handling system, sprinkle cooling, etc.).

American Society of Heating, Refrigeration, and Air Conditioning Engineers and the American Society of Agricultural and Biological Engineers publishes standards, which report the heat and moisture production data for different species and different weights of livestock and poultry. The heat and moisture production data for nursery age piglets is a result of a study published by Ota et al., (1975). A literature review published by Brown-Brandl et al., (2004) found heat production rates of the swine have increased with the increase of lean tissue accretion of the modern swine. The results of the literature review suggested that heat production rates have increased between 12 and 35% between data collected prior to 1988 and from 1988 to 2004. In addition, a study by Harmon et al., (1997) found that heat production of early-weaned pigs was substantially higher than reported in the standards.

The objectives of this study were to determine the heat and moisture production rates of nursery age piglets and growing pigs with respect to weight and environmental temperature.

Material and Methods

Ninety-six piglets (½ Landrace, ¼ Duroc & ¼ Yorkshire) averaging 6.4 (±1.2) kg were selected on the basis of weight and health status, and randomly assigned to one of 24 pens (1.3m x 1.3m each; 2 gilts and 2 barrows per pen) in one of four environmental chambers (6 pens/chamber). The piglets within a single chamber were exposed to one of four environmental temperature treatments (20, 25, 30, 35°C). After a minimum of 7 days of adaptation to the assigned environmental temperature, over a two-week period each pen of 4 piglets was moved to the adjacent indirect calorimeters operated at the same environmental temperature and humidity where heat and moisture production rates were quantified for a 21-hr period. Each day, one pen of piglets from each of the four chambers was moved to the calorimeters. Calorimetry measurements were taken three days per week. After the calorimetry measurements were completed, the temperature treatment was changed in such a way that all groups of pigs were exposed to 2 of the 4 treatments during this 4-week experiment. The lighting schedule was set to provide a 12-hr photoperiod of 6:00 AM to 6:00 PM in all chambers and calorimeters. Pigs had *ad libitum* access to feed and water at all times.

After the completion of the nursery piglet study, half of the piglets were selected to remain on the study. Forty-eight piglets averaging 21.6 (± 0.44) kg were selected on the basis of weight and health status. Piglets retained for this study were used in a previous set of measurements, and remained in the previously assigned pen – two piglets were removed from each pen leaving 2 piglets in each of 24 pens (1.3m x 1.3m each; 1 gilt and 1 barrow per pen) in one of four environmental chambers (6 pens/chamber). The piglets within a single chamber were exposed to one of four environmental temperature treatments (18, 23, 28, 33°C). After a minimum of 14 days of adaptation to the assigned environmental temperature, each pen of 2 pigs was moved to the one of four indirect calorimeters operated at the same environmental temperature and humidity where heat and moisture production rates were quantified for a 21-hr period. As in the previous study, three days each week, one pen of pigs from each of the four chambers was transferred to the corresponding calorimeter. After the 21-h calorimetry measurements were completed, each pen of pigs was assigned to a different temperature treatment such that all groups of pigs were exposed to 2 of the 4 treatments during this 4-week experiment. The lighting schedule was set to provide a 12-hr photoperiod of 6:00 AM to 6:00 PM in all chambers and calorimeters. Pigs had *ad libitum* access to feed and water at all times.

Quantification of heat and moisture production was completed in the 4-chamber, multiple temperature indirect calorimeter as described in Brown-Brandl et al. (2011). On each day of calorimetry measurement, four pens of either 4 pigs/pen or 2 pigs/pen were moved from their pens into a predetermined calorimeter set at the same temperature and humidity as their respective chamber. Each of the pigs was weighed individually before and after each calorimeter run. A known amount of fresh feed was added to the feeder before the animals were placed in the calorimeter. The feed was removed and weighed and the calorimeter pen was cleaned after each run. Calorimeter runs began at 10:30 AM, and ended at 7:30 AM the following morning. Approximately one-hour was needed to move and weigh pigs and clean pens, and then two hours were needed to allow the gas concentrations to equilibrate within the calorimeters.

Two cumulative gas samples from each calorimeter and one fresh air sample were collected over the 21-hr run time and analyzed as a single sample. Additionally, dynamic samples (every 10 minutes) were analyzed during the calorimetry run. Calorimeter accuracy was verified prior to the conducting the experiment with alcohol lamps. All calorimeter chambers were verified to be within a target goal of 98.5 to 101.5% accuracy. All calorimeters were again verified to be within the expected accuracy range after the study was completed.

Heat and moisture production data were analyzed using the general linear model procedure in SAS/STAT®. The effects of weight, calorimeter, feed intake, the number of times through the calorimeter, and ambient temperature were tested. A second analysis was completed to using proc GLM to develop a prediction equation for heat and moisture production based on weight and ambient temperature. The third analysis was completed to discern differences in dynamic responses. A repeated measures analysis was conducted to test the effects of time (average hourly HP) and ambient temperatures.

Results and Discussion

Nursery Piglets

Over a 4-wk period, 48-measurements (each measurement is one 21-hr period in the calorimeter) of heat and moisture production were made on groups of four piglets held at average treatment temperatures of (average ± standard deviation) 19.6±0.62, 24.6±0.57, 29.3±0.7, and 33.9±0.4, with respective dew-point temperatures of 10.5±0.81, 11.5±0.99, 12.7±0.97, and 13.4±1.85°C.

The piglet gained 269±90 g/day prior to the first calorimetry measurement, and 475±99 g/day between the two-calorimetry measurements. During the first period, there were no differences between the temperature treatments. However, during period 2, the gain of the pigs in the 35°C treatment was significantly lower than the other temperatures.

Table 1. Average daily gain (ADG, g/day) for period 1 – time period entering the chambers to first calorimetry run, period 2 – time period between the two calorimetry runs, and overall average throughout experiment.

	Period 1	Period 2	Overall
Temp, °C	ADG, g/day	ADG, g/day	ADG, g/day
20	273±20	$512±19^{a}$	$392±14^{a}$
25	283±19	$485±19^{a}$	$384±14^{ac}$
30	253±19	$478±19^{a}$	$366±14^{abc}$
35	266±19	$426±19^{b}$	$346±14^{b}$

A summarization of HP (W/kg), MP (W/kg), feed consumption (kg/day), and RQ as affected by environmental temperature is shown in table 2. Live body weights averaged 9.23±0.6, 16.0±0.9 kg at each of the two 2-week periods.

Table 2. Mean and standard errors of heat production (HP), Latent heat production (w/kg), moisture production (MP), feed intake (FI), and respiratory quotient (RQ = CO_2/O_2) of Nursery pigs averaged over the entire weight range at different environmental temperatures (T_{dp}= 10 – 13 °C).

Temp, °C	HP, W/kg	LHP, W/kg	MP, % of HP	FI, kg/day/pig	RQ
20	$4.95±0.11^{a}$	$1.63±0.11^{a}$	$34.2±2.8^{a}$	0.61±0.6	1.00±0.015
25	$4.68±0.11^{ab}$	$2.24±0.13^{b}$	$49.6±3.3^{b}$	0.58±0.6	0.99±0.015
30	$4.74±0.10^{ab}$	$2.93±0.14^{c}$	$63.2±3.2^{c}$	0.58±0.6	1.02±0.014
35	$4.55±0.12^{b}$	$3.93±0.14^{d}$	$87.3±3.6^{d}$	0.61±0.7	1.02±0.016

[a,b,c] Means within a single column with differing superscripts are significantly different (P<0.05).

Heat production (W/kg) was significantly affected by the amount of feed consumed (P<0.0001) during the calorimetry run and tended to be affected by temperature treatment (P=0.10) and average piglet weight (P=0.0538). Respiratory quotient tended to be affected by feed consumed during the calorimetry run (P=0.073) and number of visits to the calorimeter (P=0.10). Equation 1 calculates the HP of nursery age piglets between the weights of 9 and 16 kg where HP is heat production in W/kg, ta is ambient dry-bulb temperature (°C), and wt is piglet weight in kg.

$$\mathbf{Log(HP\ [W/kg]) = 0.715\ (\pm 0.081) - 0.0025\ (\pm 0.001)}\boldsymbol{t_a} \mathbf{+ 0.0211\ (\pm 0.062) log(}\boldsymbol{wt}\mathbf{)} \qquad \textbf{(Eq. 1)}$$

The moisture generation is calculated by summing the condensate collected from the cooling coils in the calorimeter, and the difference in the moisture content of the air entering and leaving the calorimeter. While the quantification is considered to be representative of the pig's latent heat loss, there is evaporation from wet surfaces within the calorimeter, which contributes to the total MP. Therefore, the MP in the calorimeter would not be representative of a production facility, as the waste handling system can be a significant contribution to the overall moisture load within a facility and is not accurately simulated within the calorimeter. The moisture production (percent of total heat production and latent heat production (W/kg) was significantly affected by temperature treatment (P<0.0001). Table 2 summarizes the latent heat production and percent of total heat production, as a function of environmental temperature. A comparison of total heat production and latent heat production is shown in Figure 1. The MP figure was generated from the following equation where LHP is latent heat production in W/kg, wt the piglet weight in kg, t_a is the ambient dry-bulb temperature in °C:

$$\mathbf{LHP = -\ 2.26\ (\pm 1.09) + .194\ (\pm 0.042)\ t_a + 0.0679\ (\pm 0.085)\ wt - 0.0034\ (\pm 0.0034)\ t_a\, wt} \qquad \textbf{(Eq. 2)}$$

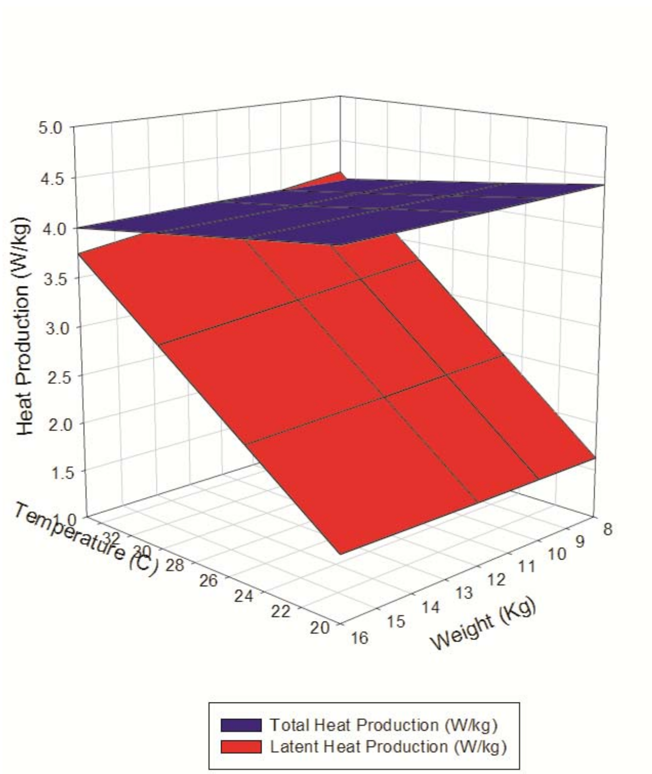

Figure 1. Comparison of total heat production and latent production of nursery age piglets as affected by environmental temperature and body weight.

The HP found in this study is 5% higher than Ota et al., (1975), the basis of ASABE/ASHRAE standards. However, Harmon et al (1997) reported a 33% increase in HP over the standards values. The current study reported a 28% lower HP than Harmon et al (1997) report. Actually, there is little evidence that HP has increased over time from 1957 to present, unlike in the older pigs (Table 3). It appears that weaning age has a larger impact on heat production than year the experiment was conducted. Pigs weaned between 10 - 16 days had an average HP 23%, 28%, and 35% higher than pigs weaning between 22 - 28 days for pigs weighing 4-6 kg, 6-9 kg, and 9-12 kg, respectively. This difference in HP between weaning age is most likely due to the piglets acclimating to eating solid food. The more feed that is consumed the higher the heat production (Close and Mount, 1978).

Also, it was noted that temperature only tended to affect heat production in nursery age piglets, unlike the other weight ranges of pigs (Brown-Brandl et al., 2011, Nienaber et al., 2008). However after investigating several nursery piglet studies (Cairnie and Pullar, 1957, Ota et al., 1975, McCracken and Caldwell, 1980, LeDividich et al., 1980, Harmon et al., 1997), it appears that there are very little differences between temperatures. It appears feed intake tends to have the largest impact. While piglets are temperature sensitive, feed intake is not necessarily driven by temperature (Table 2) as for other weight ranges of pigs (Brown-Brandl et al., 2011; Nienaber et al., 2008).

Table 3. Comparison of heat production measurements from several nursery pig studies conducted from 1957 to current.

		4 to 6 kg		6 to 9 kg			9 to 12 kg		
	Weaning age (d)	25	30	>23	25	30	>23	25	30
Cairnie and Pullar, 1957	10	4.8	4.5	5.6	5.4	5.3	5.6	5.7	5.7
Ota et al., 1975	28	---	3.3	---	4.5	---	---	4.5	---
McCracken and Caldwell, 1980	10	5.7	---	6.1	5.5	---	---	---	---
LeDividich et al., 1980	20 - 28	---	---	4.1	3.8	3.4	---	---	---
McCracken and Gray, 1984	14	4.5	4.4	6.3	---	6.0	6.6	---	6.3
	28	---	---	---	3.7	3.6	4.7	4.5	---
Harmon et al., 1997	13 - 16	5.6	5.1	5.8	6.0	5.7	6.3	6.4	5.7
This Study*	22 - 24	---	---	---	---	---	5.0	4.7	4.6

* Pigs in this study weighed between 9 and 16 kg.

Circadian Rhythm

In addition to a daily values of heat production, a gas sample was analyzed from each of the calorimeters, and the fresh air sample every 10-minutes to give an understanding of the diurnal effects of heat production. Heat production calculations are more accurate with a carefully controlled procedure, as completed when analyzing the subsets of air collected over 21 hours. The dynamic, 10-min HP values depended on the same analyzers, air volume meters and associated line temperature and pressure sensors, however, an the oxygen analyzer is affected by changes in the barometric pressure. Therefore, all 10-min readings were adjusted by the ratio of the average of all 10-min readings to the overall HP measurement of the 21-hr subsample. Comparison of those averages and the adjustment ratios were within 5%.

Those corrected readings were summarized as hourly HP (Figure 2) over the 21-hr period from 10:30 AM through 7:30 AM the following morning. For the nursery pigs there was not a significant difference in HP based on the temperature, unlike the other weight ranges of pigs. However, the nursery pigs had a similar pattern in dynamic HP as the other weight ranges of pigs; HP increased prior the lights turning off and the minimum HP is the time which lights turn on. These increases is most likely due to active (anticipatory) feeding was observed during this late afternoon period. As this increase in heat production has been associated with changes in eating behavior (Nienaber et al., 1990) and total time spent being active (Pedersen and Rom, 2000).

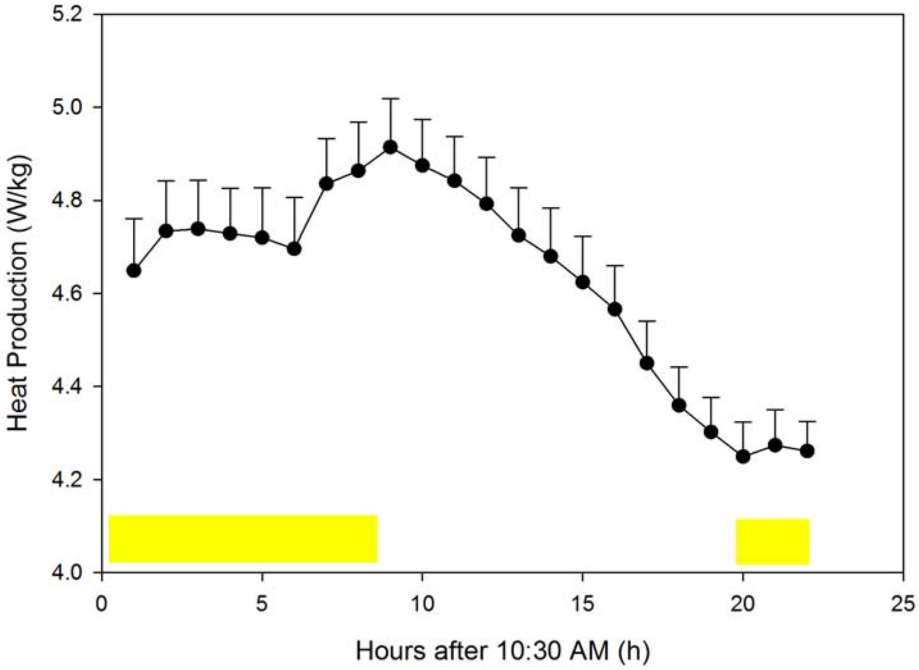

Figure 2. Circadian rhythm of heat production of nursery piglets after a minimum of a 7-day acclimation to one of four temperature treatments (20, 25, 30, 35 C), (Yellow bars indicate period of the day with the lights on.). No significant difference was found between temperature treatments

Growing Pigs

In the second study, forty-eight measurements (each measurement is one 21-hr period in the calorimeter) of heat and moisture production were made over a 4-week period on groups of two piglets. The average temperatures of the four treatments were 17.5±0.54, 22.5±0.57, 27.1±0.9, and 32.2±0.5 (average ± standard deviation), with respective dew-point temperatures of 10.1±0.44, 11.1±0.67, 11.7±0.51, and 13.0±0.90°C. Table 4 is a summarization of HP (W/kg), MP (W/kg), feed consumption (kg/day), and RQ as affected by environmental temperature. Live body weights averaged 27.4±3.7, 38.8±2.7 kg at each of the two 2-week periods.

The piglets gained 773±180 g/day prior to the first calorimetry measurement (Period 1), and 789±140 g/day between the two-calorimetry measurements (period 2). During the first period, the gain in the 33°C treatment was significantly lower than the other temperature treatments (table 5). Similar results were observed during period 2; the gain of the pigs in the 33°C treatment was significantly lower than the 18 or 23°C temperatures. Overall, a significantly lower average daily gain was observed in both the 28 and 33°C treatments.

Table 4. Mean and standard errors of heat production (HP), Latent heat production (w/kg), moisture production (MP), feed intake (FI), and respiratory quotient (RQ = CO_2/O_2) of Nursery pigs averaged over the entire weight range at different environmental temperatures (T_{dp}= 10 – 13 °C).

Temp, °C	HP, W/kg	LHP, W/kg	MP, % of HP	FI, kg/day/pig	RQ
18	4.18±0.10[a]	1.26±0.13[a]	30.5±3.0[a]	1.44±0.10[a]	1.06±0.01
23	4.07±0.09[a]	1.56±0.13[a]	39.0±2.9[b]	1.26±0.10[a]	1.08±0.01
28	3.79±0.10[b]	2.21±0.13[b]	58.2±2.9[c]	1.24±0.10[a]	1.08±0.01
33	3.66±0.10[b]	2.98±0.16[c]	83.0±3.7[d]	0.95±0.09[b]	1.05±0.01

[a,b,c] Means within a single column with differing superscripts are significantly different (P<0.05).

Table 5. Average daily gain (ADG, g/day) for period 1 – time period entering the chambers to first calorimetry run, period 2 – time period between the two calorimetry runs, and overall average throughout experiment.

	Period 1	Period 2	Overall
Temp,° C	ADG, kg/day	ADG, kg/day	ADG, g/day
18	0.821±0.04[a]	0.849±0.04[a]	0.835±0.03[a]
23	0.870±0.04[a]	0.837±0.04[a]	0.853±0.03[a]
28	0.763±0.04[a]	0.776±0.04[ab]	0.769±0.03[b]
33	0.637±0.04[b]	0.677±0.04[b]	0.657±0.03[c]

Heat production (W/kg) was significantly affected by the amount of feed consumed (P=0.0015), temperature treatment (P=0.0040), and tended to be affected by number of times in the calorimeter (P=0.09). Respiratory quotient was significantly affected the amount of feed consumed during the calorimetry run (P=0.0004) and the number of times in the calorimeter (P=0.0357). Latent heat production was affected by temperature treatment (P<0.0001), number of times through the calorimeter (P=0.0376), and tended to be affected by the interaction of these two factors (P=0.0946). The ratio of LHP to HP (MP, % of HP) was significantly affected by only temperature treatment (P<0.0001). Piglet weight (P=0.0245), temperature treatment (P=0.0081), and number of times in the calorimeter (P=0.0092) significantly effected feed consumed during the calorimetry run. Equation 1 calculates the HP of growing piglets between the weights of 20 and 40 kg where HP is heat production in W/kg, ta is ambient dry-bulb temperature (°C), and wt is piglet weight in kg.

Growing Pigs:

$$\mathbf{Log(HP\ [W/kg]) = 1.288\ (\pm 0.090) - 0.005\ (\pm 0.001)}\,\boldsymbol{t_a} \mathbf{- 0.371\ (\pm 0.058) log(}\boldsymbol{wt}\mathbf{)} \qquad \textbf{(Eq. 3)}$$

A graphical representation of equations 3 and 4 are shown in Figure 3. It is noted that HP decreases with body weight and with increasing temperature.

Moisture production was quantified as the sum of the condensate collected over the 21-hr period within the calorimeter and the change in moisture content of the air passed through the system. While the quantification is considered to be representative of the pig's latent heat loss, there is evaporation from wet surfaces within the calorimeter, which contributes to the total MP. The MP in the calorimeter would not be representative of a production facility, as the waste handling system contributes to the overall moisture load within a facility and the waste handling system is not accurately simulated within the calorimeter. The MP figure was generated from the following equation (where LHP= latent heat production in W/kg, wt=weight in kg, t_a=ambient temperature in °C):

$$\mathbf{LHP=-1.64\ (\pm 1.42) + .173\ (\pm 0.061)\ t_a + 0.021\ (\pm 0.043)\ wt - 0.0016\ (\pm 0.\ 0018)\ t_a\,wt} \qquad \textbf{(Eq. 4)}$$

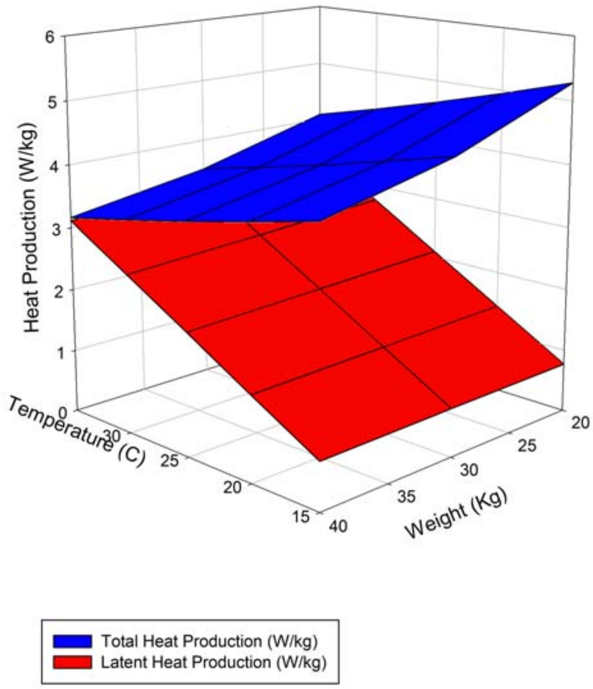

Figure 3. A comparison of total heat production and latent heat production from piglets in the weight range of 20 – 40 kg.

On average HP of growing pigs was found to be 9.5% higher than the current standards. The current HP ranges from 9% lower than the current standards to 24% higher than the current standards. It appears that the lighter weight pigs at the lower temperatures tended to match the standards. The pigs in the current study were more impacted by the higher temperatures than the standards indicate; therefore, the lighter weight pigs at 25 – 30°C were 3% and 9% lower than the standards. The heavier weight the pigs in the current study had HP close to 20% higher than the standards. The heavier pigs at the lower temperatures had the largest increase 24-23% higher than the standards, and the higher temperatures were 19% and 12% higher than the standards.

Circadian Rhythm

Heat production was determined at 10 min intervals over the course of the 21-hr calorimetry run. These observations were used to evaluate the circadian rhythm in HP. Average HP as computed from the analysis of the sample bags over the 21-hr period. During the analysis of these sample bags, the analyzers were carefully calibrated and the accuracy was reflected in the system recovery tests with the burning of alcohol (1.5% accuracy). The dynamic, 10-min HP values depended on the same analyzers, air volume meters and associated line temperature and pressure sensors except that barometric pressure changes could lead to erroneous oxygen concentration readings over time. Therefore, all 10-min readings were adjusted by the ratio of the average 10-min reading to the overall average measurement for each calorimetric run. Comparison of those averages and the adjustment ratios were within 5%.

Those corrected readings were summarized as hourly HP (Figure 4) over the 21-hr period from 10:30 AM through 7:30 AM the following morning. For each hourly HP value, there was a strong temperature effect (P=0.0220). The 18°C treatments consistently had the highest HP, followed by the 23°C treatment. The 28°C treatment had the third highest temperature treatment, but was similar to the 33°C treatment during several of the hours over the day. The heat production general increased until the lights were turned off 6PM (between the 7th and 8th hr measurement of the day). After the lights were turned off, the heat production gradually decreased until the lights were turn back on at 6AM (between 19th and 20th hr measurement). The general activity level of the pigs and the intake of feed during the lighted hours could explain the higher heat production during this time period. This pattern was observed in the other ages of pigs as well.

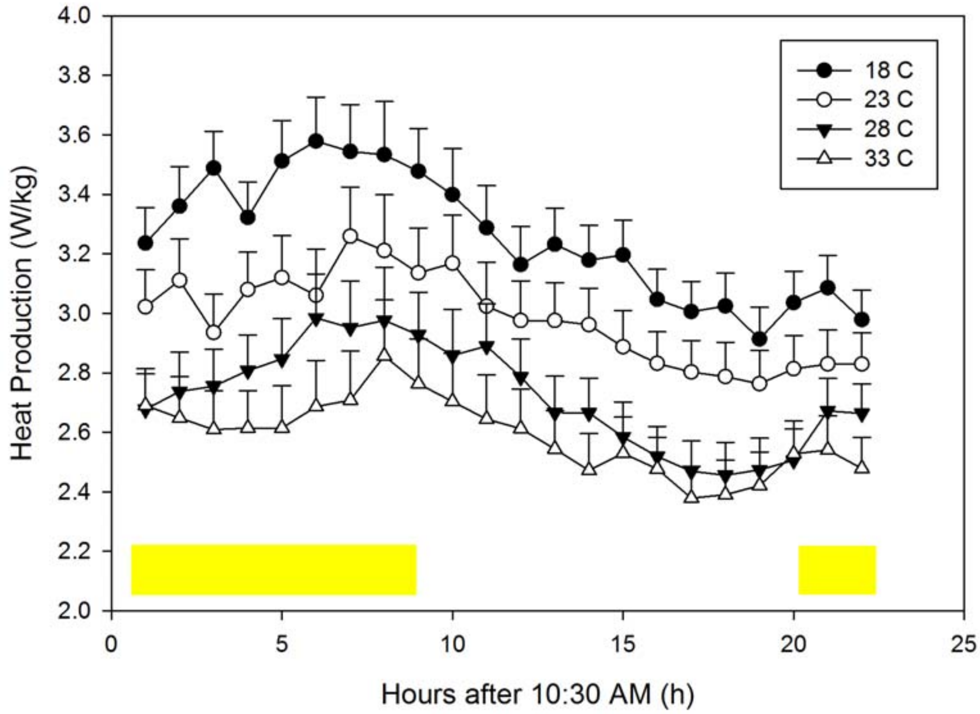

Figure 4. Circadian rhythm of heat production of growing pigs (average over the all body weights) exposed to four different temperatures after a minimum of a 7-day acclimation (Yellow bars indicate period of the day with the lights on.)

Conclusion

A study was completed to quantify heat and moisture production (HP, MP) of nursery and growing piglets exposed to a variety of dry-bulb temperatures (nursery: 20, 25, 30, 35; growing 18, 23, 28, 33). Heat production of the nursery age piglets was affected by feed intake with a tendency to be affect by temperature (P=0.10) and pig weight (P=0.054). While, the heat production of the growing piglets was affected by temperature and body weight (P<0.01). Two equations were developed to predict HP based on temperature and pig weight one for the nursery piglets and the other for the growing pigs. Heat production of this growing pig was found to be approximately 9.5% higher than the standards, while the heat production of the nursery piglets was approximately 5.0% higher than the standards. It was determine that weaning age impacts the heat production at a given age. The dynamic HP data was found to vary throughout the data, with the highest HP occurring prior to lights out, and the lowest heat production occurring around the time the lights were turned on. This study was in agreement with other studies that the HP of modern pigs is higher than the HP and MP values in the literature “standards”.

Acknowledgements
The authors would like to thank Dale Janssen for gas analysis, Ty Post, Todd Boman and John Holman for care of the animals and Jan Watts for help in the preparation of this manuscript. This research is being funded from a grant from the American Society of Heating, Refrigeration, and Air Conditioning Engineers, and from USDA Agricultural Research service CRIS No. 32630-006-00D.

References

Anderson, D. L. 2002. National Swine Registry Available at: www.ansc.purdue.edu/users/dlofgren/stages/index.htm.

ASABE. 1986. Design of Ventilatio Systems for Poultry and Livestock Shelters. In ABABE Standards, 1-20. St. Joseph, MI 49085-9659: ABABE.

Bond, T. E., C. F. Kelly, and H. Jr. Heitman. 1959. Hog house air conditioning and ventilation data. Trans. ASAE 2(1): 1-4.

Brown-Brandl, T. M., J. A. Nienaber, and R. A. Eigenberg. 2011. Technical Note: Temperature and Humidity Control in Indirect Calorimeter Chambers. Trans. ASABE 54(2): 685-692.

Brown-Brandl, T. M., J. A. Nienaber, H. Xin, and R. S. Gates. 2004. A literature review of swine heat production. Trans. ASAE 47(1): 259-270.

Cairne, A.B., and J.D. Pullar. 1957. The metabolism of the young pig. *Journal of Physiology* 139:15P-15P.

Close, W. H., and L. E. Mount. 1978. The effects of plane of nutrition and environmental temperature on the energy metabolism of the growing pig 1. Heat loss and critial temperature. Br. J. Nutr. 40: 413-421.

Harmon, J. D., H. Xin, and J. Shao. 1997. Energetics of secregated early weaned pigs. Transactions of the ASAE 40(6):1693-1698.

Le Dividich, J., M. Vermorel, J. Noblet, J.C. Bouvier, and A. Aumaitre. 1980. Effects of environmental temperature on heat production, energy retntion, protein, and fat gain in early weaned pigs. *Bristish Journal of Nutrition* 44:313-323.

McCracken, K.J., and B.J. Caldwell. 1980. Studies on diurnal variations of heat production and the effective lower critical temperature of early weaned pigs under commercal conditions of fedding and management. *Bristish Journal of Nutrition* 43:321-328.

Midwest Plan Service. 1987. *Midwest plan service: Structures and environment handbook*. Midwest Plan Service, Ames, IA.

Nienaber, J. A., and T. M. Brown-Brandl. 2008. Heat and Moisture Production of Growing-Finishing Barrows as Affected by Environmental Temperature. ASABE Meeting Paper No. 084168: St. Joseph, MI: ASABE.

Nienaber, J. A., G. L. Hahn, T. P. McDonald, and R. L. Korthals. 1996. Feeding patterns and swine performance in hot environments. Trans. ASAE 39(1): 203-209.

Nienaber, J. A., T. P. McDonald, G. L. Hahn, and Y. R. Chen. 1990. Eating dynamics of growing-finishing swine. Trans. ASAE 33(6): 2011-2018.

Ota, H., J. A. Whitehead, and R. J. Davey. 1975. Heat production of male and female piglets. J. Anim. Sci. 41(1): 436-437.

Pedersen, S., and H. B. Rom. 2000. Diurnal variation in heat production from pigs in relation to animal activity. ASABE Meeting Paper No. 98 - E - 025 European Agricultural Engineers.

Tess, M. W., G. E. Dickerson, J. A. Nienaber, J. T. Yen, and C. L. Ferrell. 1984. Energy costs of protein and fat deposition in pigs fed ad libitum. J. Anim. Sci. 58(1): 111-122.