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A Literature Review of Swine Heat and Moisture

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Current ASAE standards of heat and moisture production are based primarily on data collected nearly four decades ago. Feedstuffs, swine practices, growth rate, and lean percentage have changed considerably in that time period and have a substantial effect on both heat and moisture production. In fact, recent research has shown that high-lean gain swine are more susceptible to high environmental temperatures – partially due to increased heat production. This increase in heat production cannot be met physiologically through increased sensible heat loss (i.e. surface area); therefore, latent heat loss must increase. Furthermore, synthetic amino acids can more closely match diet composition with swine nutrient requirements, and reduce heat production and nitrogen loss. This paper reviews the genetic, nutritional, and environmental effects on heat and moisture production of growing-finishing swine, and identifies the areas that need further investigation.

Keywords

Genetics, Nutrition, Temperature, Growth, Calorimetry

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Comments

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A Literature Review of Swine Heat and Moisture Production

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Abstract

Current ASAE standards of heat and moisture production are based primarily on data collected nearly four decades ago. Feedstuffs, swine practices, growth rate, and lean percentage have changed considerably in that time period and have a substantial effect on both heat and moisture production. In fact, recent research has shown that high-lean gain swine are more susceptible to high environmental temperatures – partially due to increased heat production. This increase in heat production cannot be met physiologically through increased sensible heat loss (i.e. surface area); therefore, latent heat loss must increase. Furthermore, synthetic amino acids can more closely match diet composition with swine nutrient requirements, and reduce heat production and nitrogen loss. This paper reviews the genetic, nutritional, and environmental effects on heat and moisture production of growing-finishing swine, and identifies the areas that need further investigation.

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Introduction

Fifty years ago, pigs were almost exclusively raised outdoors—that practice has changed due to several factors including: food safety, manure management, handling ease, and to increase well-being and performance. Raising pigs indoors instead of outdoors takes a great deal of engineering and animal know-how. Many years of research have been dedicated to building design and understanding the building and animal interaction. Important criteria include understanding the interaction of the animal heat and moisture production and how these components are impacted by the changing genetics, nutrition, and thermal environment. Since the swine housing standards are based on data that dates back to 1959, a critical evaluation of the data is needed to assess the need to update these standards.

Literature Review

Heat production (HP) and moisture production rates (MP) constitute important criteria in the overall building design. These HP and MP values are the basis of design capacity for fans and heaters to accurately control the temperature and the moisture load in the building; this is important not only to maximize animal well-being and production, but to prolong the life of the structure. Environmental temperature and animal size effects on HP and MP values can be found in published standards books (ASAE, 2001; ASHRAE, 2001). The standards are based on data taken between 27 and 43 years ago (growing-finishing and breeding stock—[Bond et al., 1959]; nursery— [Ota et al., 1975]).

The difficulty in comparing HP values from different studies is that so many parameters affect HP. Besides the animal weight, additional parameters will be discussed, including genetic potential, feeding level, composition of the feed, ambient temperature, acclimation to a given temperature, and activity level.

Genetic/Composition Changes

Swine production has seen significant changes in the past 50 years. Besides the production system aspects, genetic potential has changed considerably. According to the National Pork Board (2002), dressing percentage has steadily increased from 69.5% in 1960 to 73.9% in 2002. The retail meat yield has increased 5.1% from 1960 to 2000. The most significant change reported was the decrease in lard yield. In 1960, the lard yield from a carcass was 14.6 kg or 13.6% of the live weight, but by 1988, this had dropped to 4.8 kg or 1.9% of the live weight. After 1988, there was no lard yield reported. It is difficult to track production traits back farther than 10 years because either no standard measurements were taken or no information was collected for the industry. However, significant changes have occurred in the last decade. Changes in production performance statistics have been reported on four commercial breeds of pigs over a 10 year period (Table 1) (Anderson, 2002).

Table 1. Reported change in production statistics in four commercial breeds of pigs.

	Change reported from 1991 to 2001		
Swine Breed	Days to reach 114 kg	Backfat (mm)	Lean (kg/pig)
Duroc	-3.8	-4.8	1.77
Landrace	-2.2	-4.6	1.41
Hampshire	-4.3	-3.6	1.64
Yorkshire	-4.2	-6.1	2.23
Average Change	-3.6	-4.8	1.76

Body Composition Effects on Heat Production

As lean tissue accretion rate increases, so does the total heat production rate. Tess et al. (1984) showed that a 2.1% increase in lean percentage resulted in an increase in fasting heat production (FHP) of 18.7% when comparing low fat and high fat genotypes. Therefore, for every 1% increase in lean percentage, FHP increased approximately 9.4%. Using the average body lean tissue rate of 1.76 kg/114 kg or 1.55% shown in Table 1, FHP would have increased 14.6% between 1991 and 2001. The actual FHP through the years of 1936 and 2002 can be seen in Figure 1.

Comparisons were made between four FHP studies (Breirem, 1936 [as referenced by Holmes and Breirem, 1974]; Holmes and Breirem, 1974; Tess et al., 1984; Noblet, 2002). Non-linear regression analyses were performed on data sets from Tess et al. (1984) and Noblet (2002) using a power equation (Microsoft® Excel 2002). Because Breirem (1936) and Holmes and Breirem (1974) were originally power equations, the equations were modified only to change the units of measure. The resulting equations, predicted FHP, and percent increase from 1936 are shown in Table 2. Using the predicted FHP for 50 kg and 100 kg pigs from Tess et al. (1984) and Noblet (2002), FHP has increased 19.1% in those 18 years. This is comparable to the 14.6% increase predicted earlier from the increase in lean percentage over a 10-year period.

Table 2. Prediction equations for fasting heat production from four studies.

Author, year	Equations	R^2	FHP per pig of 50 kg (W)	% change from 1936	FHP per pig of 100 kg (W)	% increase from 1936
Breirem, 1936	$FHP=7.49wt^{0.569}$	--	69.4	--	102.9	--
Holmes and Breirem, 1974	$FHP=11.09wt^{0.515}$	--	83.2	19.9	118.8	15.5
Tess et al., 1984	$FHP=13.93wt^{0.512}$	0.9999	103.2	48.7	147.2	43.1
Noblet, 2002	$FHP=6.98wt^{0.710}$	0.9976	112.2	61.7	183.6	78.4

Feed Intake and Diet Composition Effects on Heat Production

In the most fundamental sense, if an animal consumes food it will produce additional heat. This additional heat originates from the activity of eating, digestion of the feedstuff, and absorption and utilization of the nutrients. Therefore, an ad-lib fed pig will have a higher HP than a limit-fed or fasted counterpart. Close and Mount (1978) illustrated the changes in heat loss with changing temperature and feed intake (fig. 2). Not only does the amount of feed change HP, so does the composition of that feed. Each component of the feed has an associated heat increment which is the heat resulting from digestion, absorption, and utilization of the feed ingredients. A diet high in fiber has a higher heat increment than a diet high in fat. The heat increment of fat (percentage of the energy converted to heat) is approximately 15%, while the heat increment of carbohydrate is 22% and protein is approximately 36%. However, these numbers are not constant and change with feeding level (below maintenance requirements) (Blaxter, 1989). One important item to note is that if diet composition (amino acid profile) is closely matched to the pig's growth requirements, heat increment of the diet and HP of the animal will be minimized since deamination of excess amino acids results in unproductive heat generation. Because this subject is a complex one, only this brief discussion to invoke the thought process is included.

Heat Production Data in Thermoneutral Conditions

Literature data, used in the evaluation from this point on, include data only from fed (unfasted) animals. Data extracted from each paper included: author, year of publication, days of exposure to the given environment, feeding level (ad libitium or restricted feeding), calorimetry type (direct, indirect, or slaughter), number of animals used during each calorimetry run, temperature, feed intake (kg/day), body weight (kg), total heat production (W/kg), sensible heat production (W/kg), latent heat production (W/kg), and the gain (kg/day) of the animals under given temperature.

For the analysis of thermoneutral HP, the thermoneutral conditions (ideal temperature) were first calculated for each data point entered in the table, based on recommendations from the Midwest Plan Service (1983) by Equation 1:

$$t_{ideal} = 0.0015*wt^2 - 0.2969*wt + 30.537 \quad (1)$$

Data points were eliminated from the first analysis if the ambient conditions were more than 2°C higher or lower than the ideal temperature as calculated. The data were then divided into two groups, early-weaned pigs (3 – 10 kg) and grow-finish pigs (10 – 100 kg). The data were divided into these two weight ranges because immediately after weaning the HP (W/kg) increases as the pigs reach a full feed situation. Both sets of data are shown in Figure 3. All regression analyses were completed using Microsoft Excel®.

$$\text{Early weaned pigs:} \quad HP\ (W/kg) = 3.35 \pm 1.21\ wt\ (kg)^{0.16 \pm 0.10} \quad (2)$$

$$\text{Grow-Finish pigs:} \quad HP\ (W/kg) = 14.95 \pm 1.08\ wt\ (kg)^{-0.40 \pm 0.02} \quad (3)$$

These data were then divided into two populations: old and current genetic lines. The old genetics were defined as literature data between 1957 and 1987, and the current genetic line was defined as 1988 through 2002. The line was drawn at 1988 for several reasons. First, about half the studies were reported before 1987 and half of them after. Second, there was a natural break in the data between 1988 and 1993. Third, it was decided the data reported by Nienaber et al.(1987) was obtained using moderate growth genetics, and the data reported by Verhagen et al. (1988) used a high lean genetic line, and the data support that theory. Figures 4 and 5 show the data trend lines of the two categories and compare the data to the CIGR Handbook, 1999.

The prediction equation for HP of the early-weaned pigs prior to 1988 is given in Equation 4. Data from a total of four independent studies were used in this analysis.

$$HP\ (W/kg) = 3.24 \pm 1.22\ wt\ (kg)^{0.16 \pm 0.11} \quad (4)$$

Equation 5 is the prediction equation for HP of the current genetic lines (1988 – present). Unfortunately, only one study was conducted on early-weaned piglets during this time frame

$$HP\ (W/kg) = 4.30 \pm 1.14\ wt\ (kg)^{0.15 \pm 0.07} \quad (5)$$

The new genetic lines represent approximately a 32% increase in HP for the early-weaned pigs. There is a great deal of variation in the data, most likely due to the different age/weights of weaning through the years. The CIGR equation using the constant given in Pederson (2002) doesn't accurately predict HP in these early-weaned pigs.

Equation 6 represents the CIGR Handbook in a similar form as the literature data for purposes of comparison.

$$HP\ (W/kg) = 15.49\ wt\ (kg)^{-0.36} \tag{6}$$

The prediction equation for HP of the grow-finish pigs prior to 1988 is given in Equation 7. Data from a total of seven independent studies were used in this analysis.

$$HP\ (W/kg) = 16.11 \pm 1.14\ wt\ (kg)^{-0.44 \pm 0.04} \tag{7}$$

Equation 8 is the prediction equation for HP of the current genetic lines (1988 – present). Data from a total of seven independent studies were used in this analysis.

$$HP\ (W/kg) = 14.11 \pm 1.09\ wt\ (kg)^{-0.38 \pm 0.02} \tag{8}$$

The new genetic lines have a maximum increase in HP of approximately 15%. However, according to this analysis there is little difference in the two groups of data at the lower end of this weight range. This is possible due to the variation in the data at the lower end and the fact that a large portion of the data at the lower end of the weight range was taken from Verhagen et al., 1988, which is the oldest of the data in this category. The CIGR equation using the constants given in Pederson (2002) seems to over-predict HP in the lighter weight pigs; however, this equation does a fairly good job in the heavier weight range.

Equation 9 represents the CIGR Handbook in a similar form as the literature data for purposes of comparison.

$$HP\ (W/kg) = 27.58\ wt\ (kg)^{-0.54} \tag{9}$$

Temperature Effects on Heat Production

A classic graph (fig. 6) shows the relation of HP to increasing temperature (adapted from Esmay, 1967). The lower and upper critical temperatures shown in Figure 6 are dependent on several parameters including age, feed intake, and prior thermal conditioning. The dashed line indicated the effect of acclimation to heat stress (reduced feed intake) on HP. The effect of acclimation is an important factor to consider when comparing HP values and planning experiments.

The temperature impact on HP and pig weight was analyzed using the general linear model procedure in SAS. The effect of acclimatization was not considered, due to the lack of balanced data. Using the natural logarithm of P, the effects of temperature, weight, and weight squared were all found to be significant ($P<0.001$). The data were again divided into two categories; prior to 1988 (representing older moderate lean growth genetics), and data reported from 1988 to the present (representing the newer high lean growth genetics). The effect of genetic potential is shown as Equations 10 and 11 and graphically in Figure 7.

Prior to 1988 ($R^2=0.823$)

$$Ln\ (HP\ (W/kg)) = 2.084 \pm 0.044 - 0.0173 \pm 0.002 * t_a(C) - 0.0164 \pm 0.0007 * wt\ (kg) + 0.000051 \pm 0.000005 * wt^2\ (kg) \tag{10}$$

1988 to Present ($R^2=0.868$)

$$Ln\ (HP\ (W/kg)) = 2.036 \pm 0.044 - 0.0113 \pm 0.002 * t_a\ (C) - 0.0136 \pm 0.0011 * wt\ (kg) + 0.000031 \pm 0.00001 * wt^2 (kg) \tag{11}$$

These equations predict an increase of 8.3 to 28.7% in HP for the newer genetic lines. According to these predictions, the largest differences are seen in the higher temperatures. This seems to indicate a lower upper critical temperature of the new genetic lines of pigs. This conclusion is supported by data from Nienaber et al. (1997) who showed that the threshold temperatures of an older genetic line of pigs was 4°C higher than the newer genetic line.

Latent Heat Production

In the literature review completed to gather information for this paper, a total of nine papers out of 22 were found to have reported latent heat production rate. Four of those papers were by the same author. Latent heat production is very dependent, not only on temperature but also on the experimental setting. Whether the experiment is conducted to find the latent heat of the animal only, or whether it was intended to give the latent heat of the production setting, will yield very different results. The production setting makes an important contribution to latent heat production load to building designers, but it is difficult to determine experimentally due to the multitude of different animal facilities. Because of the lack of sufficient data and the variable experimental design, an analysis of the latent heat production could not be performed.

CONCLUSIONS

The review of literature revealed that FHP has changed 19.1% from 1984 to 2002 as a result of increased lean tissue accretion rates. Heat production of pigs under thermoneutrality during the period 1988 to 2002 was found to be 17.4% higher than that during the period prior to 1988. When all experimental temperature conditions were included, the HP increase varied from 8.3 to 28.7%, with the largest differences seen in the higher temperatures. There is a serious lack of latent heat production data for all weight ranges of pigs.

It was concluded that the swine HP and MP values are not adequate to accurately design modern swine housing facilities, and need systematic updating.

FUTURE STUDY CONSIDERATIONS

When the experiments are designed to update the swine housing standards, several questions need to be addressed by a panel of researchers. What genetic line should be used, or can lean tissue accretion rate be factored into the HP values? It was shown that lean tissue accretion rate directly impacts HP. Should the standard be split by sex? The current convention is separating out the barrows and gilts, because the gilts have a high percentage of lean tissue. What temperature range should be considered? The housing standard used a temperature range from 5 to 30°C. With very few swine facilities being built without heating, a minimum temperature of 10 or 15°C is probably sufficient. However, with a large percentage of pigs being raised in areas where the maximum temperature exceeds 30°C, a higher temperature might be appropriate. The current cooling systems include direct wetting of pigs and tunnel ventilation, so the effects of direct wetting of the pigs and various wind velocities should be considered. Because acclimation to a hot environment can dramatically change the HP, the experimental protocol should be carefully planned.

Calorimetry methods can be used to obtain the swine HP and MP data, however, field data will need to be used to supplement the moisture production data. This will ensure that the MP value reported will reflect the actual production system.

The final area of HP and MP that needs to be addressed is the lack of information available on breeding stock. Out of the 22 studies listed in the appendix, five of the studies were conducted on pigs less than 10 kg (early weaned or nursery age pigs), 16 of the studies were conducted on grow-finish pigs (20 -100 kg), and only one was conducted using pigs greater than 100 kg, which would be comprised of the breeding stock animals.

REFERENCES

1. Anderson, D. L. National Swine Registry. 2002. National Swine Registry. 9-26-2002.

2. ASAE, 1991. Standards of the American Society of Agricultural Engineers. ASAE, St. Joseph, MI.

3. ASHRAE Handbook of Fundamentals. 1997. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, GA.

4. Blaxter, Kenneth. 1989. Energy Metabolism in Animals and Man, pp. 256-289. Cambridge University Press, New York, NY.

5. Bond, T. E., C. F. Kelly, and H. Heitman, Jr. 1959. Hog house air conditioning and ventilation data. Transactions of the ASAE 2:1-4.

6. Breirem, 1936. [Maintenance metabolism of growing pigs.] No. 70., Bertni. Forsogslab. København.

7. Brown-Brandl, T. M., 2002. Unpublished Data.

8. Brown-Brandl, T. M., R. A. Eigenberg, J. A. Nienaber, and S. D. Kachman. 2001a. Thermoregulatory profile of a newer genetic line of pigs. Lvstk. Prod. Sci. 71:253-260.

9. Brown-Brandl, T. M., and J. A. Nienaber. 2001b. Group size effects on heat production measurements. ASAE Paper #01-4047. ASAE. St. Joseph, MI.

10. Brown-Brandl, T. M., J. A. Nienaber, and L. W. Turner. 1998. Acute heat stress effect on heat production and respiration rate in swine. Transactions of the ASAE 41:789-793.

11. Cairne, A. B., and J. D. Pullar. 1957. The metabolism of the young pig. J. Phys.139:15P.

12. CIGR Handbook of Agricultural Engineering. 1999 ASAE. St. Joseph, MI.

13. 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 critical temperature. Brit. J. Nutr. 40:413-421.

14. Collin A., J. van Milgen, S. Dubios, and J. Noblet. 2001. Effect of high temperature and feeding level on energy utilization in piglets. J. Anim. Sci. 79:1849-1857.

15. Esmay, M.L. 1967. Principles of Animal Environment. AUI Publishing Co., Westport, Connecticut.

16. Feddes, J. J. R., and J. A. DeShazer. 1988. Energetic responses of growing pigs to high cyclic and constant temperatures. Transactions of the ASAE 31:1203-1210.

17. George, R. M. 1987. Total, sensible, and latent heat produced by 13 to 40 lb nursery pigs on wire floors with flush gutters. American Society of Agricultural Engineers/International Commission of Ag Engineers, Latest Developments in Livestock Housing CIGR, pp. 296-302. University of Illinois, Urbana-Champaign, Illinois.

18. Harmon, J. D., H. Xin, and J. Shao. 1997. Energetics of segregated early weaned pigs. Transactions of the ASAE 40:1693-1698.

19. Henken, A. M., H. A. Brandsma, W. van der Hel, and M. W. A. Verstegen. 1993. Circadian rhythm in heat production of limit-fed growing pigs of several breeds kept at and below thermal neutrality. J. Anim. Sci. 71:1434-1440.

20. Holmes, C. W., and K. Breirem. 1974. A note on the heat production of fasting pigs in the range 16 to 96 kg live weight. Anim. Prod. 18:313-316.

21. Le Dividich, J., M. Vermorel, J. Noblet, J. C. Bouvier, and A. Aumaitre. 1980. Effects of environmental temperature on heat production, energy retention, protein, and fat gain in early-weaned piglets. Brit. J. Nutr. 44:313-323.

22. McCracken, K. J., and R. Gray. 1984. Further studies on the heat production and effective lower critical temperature of early-weaned pigs under commercial conditions of feeding and management. Brit. J. Nutr. 39:283-290.

23. Midwest Plan Service Structures and Environment Handbook, MWPS-1. 1983. Midwest Plan Service, Iowa State University, Ames, Iowa.

24. Nienaber, J. A., G. L. Hahn, and R. A. Eigenberg. 1997. Development of an upper temperature threshold for livestock. ASAE Paper #974010, ASAE, St. Joseph, MI.

25. Nienaber, J. A., G. L. Hahn, and J. T. Yen. 1987. Thermal environment effects on growing-finishing swine part I -- growth, feed intake, and heat production. Transactions of the ASAE 1772-1775.

26. Pedersen, S. 2002. Heat and moisture production for pigs on animal and house level. ASAE Paper #024178, ASAE: St. Joseph, MI.

27. Pork Facts 2001/2002. 2001. National Pork Board, Des Moines, Iowa.

28. Noblet, J. 2002. Personal communication.

29. Noblet, J., and J. Le Dividich. 1982. Effect of environmental temperature and feeding level on energy balance traits of early-weaned piglets. Lvstk. Prod. Sci. 9:619-632.

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

31. Quiniou, N., J. Noblet, J. van Milgen, and S. Dubios. 2001. Modelling heat production and energy balance in group-housed growing pigs exposed to low or high ambient temperatures. Brit. J. Nutr. 85:97-106.

32. Tess, M. W., G. E. Dickerson, J. A. Nienaber, and C. L. Ferrell. 1984. The effects of body composition on fasting heat production in pigs. J. Anim. Sci. 58:99-110.

33. van der Hel, W., M. W. A. Verstegen, W. Baltussen, and H. A. Brandsma. 1984. The effect of ambient temperature on diurnal rhythm in heat production and activity in pigs kept in groups. Int'l. J. Biomet. 28:303-315.

34. Verhagen, J. M. F., A. A. M. Kloosterman, A. Slijkhuis, and M. W. A. Verstegen. 1988. Effect of ambient temperature on energy metabolism in growing pigs. In: J. M. F. Verhagen (Ed.) Acclimation of growing pigs to climatic environment. pp. 29-40.

35. Xin, H., and J. A. DeShazer. 1991. Swine responses to constant and modified diural cyclic temperatures. Transactions of the ASAE 34:2533-2540.

APPENDIX

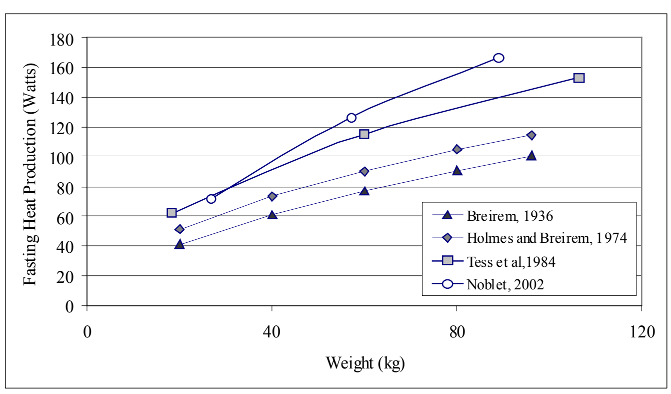

Figure 1. Fasting heat production as reported by four studies from 1936 to 2002.

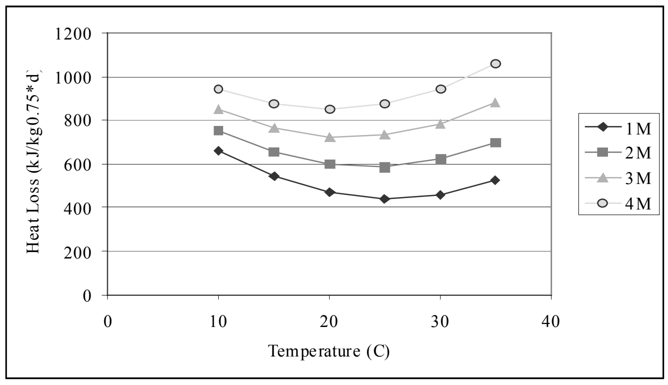

Figure 2. Changes in heat loss with temperature at different feeding levels; M is approximately maintenance requirements (440 kJ/kg$^{0.75}$), therefore 1M=440 kJ/kg$^{0.75}$, 2M=880 kJ/kg$^{0.75}$, 3M=1320 kJ/kg$^{0.75}$, 4M=1760 kJ/kg$^{0.75}$ (Close and Mount, 1978).

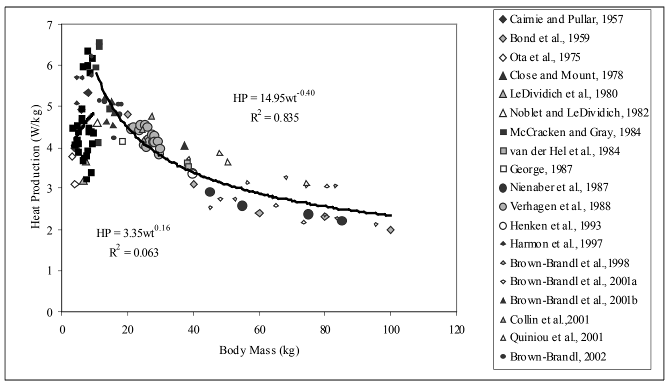

Figure 3. Swine heat production data from 19 independent studies from 1957 through 2002.

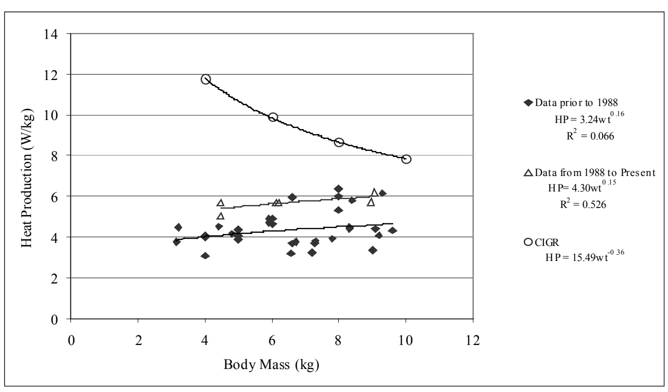

Figure 4. Early-weaned swine heat production data from five independent studies divided into two categories: prior to 1988 (respresenting older moderate lean growth genetics, and data reported from 1988 to the present (resprenting the newer high lean growth genetics) compared to CIGR Handbook, 1999.

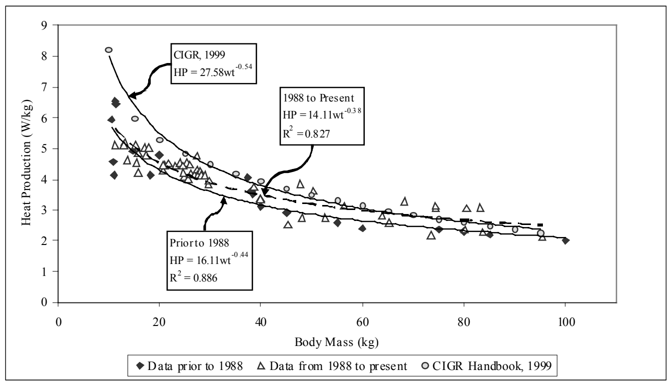

Figure 5. Grow-finish swine heat production data from 14 independent studies divided into two categories: prior to 1988 (representing older moderate lean growth genetics), and data reported from 1988 to the present (representing the newer high lean growth genetics) compared to CIGR Handbook, 1999.

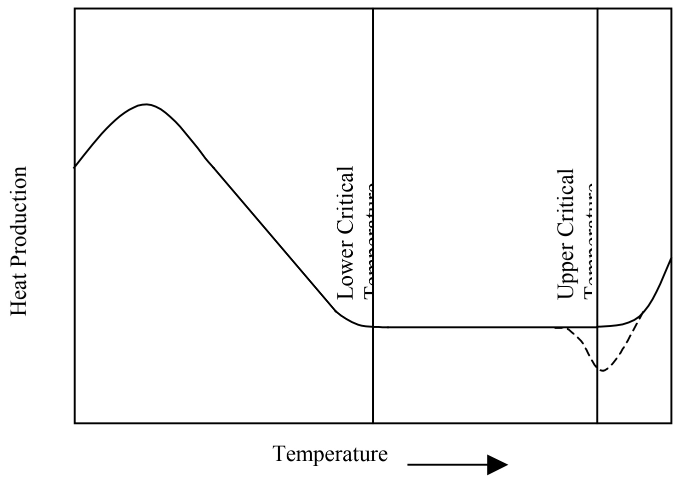

Figure 6. A schematic illustration of the effects of ambient temperature on heat production (Adapted from Esmay, 1967).

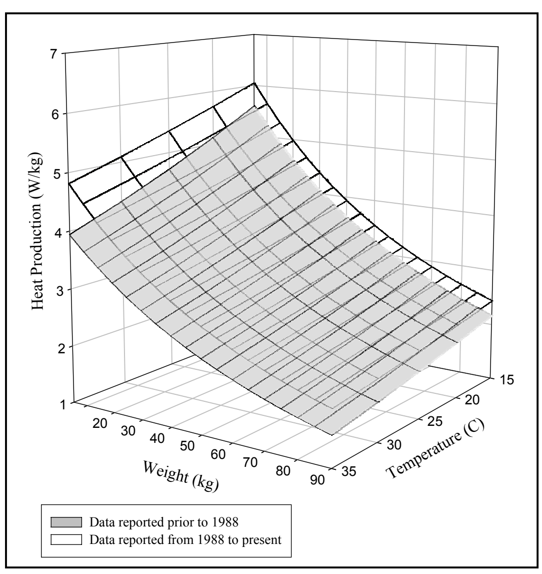

Figure 7. Multiple regression analysis of 21 studies from 1957 to present to describe the effects of temperature and weight on heat production of pigs from 5 to 90 kg.