A LITERATURE REVIEW OF SWINE HEAT PRODUCTION

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ABSTRACT. *Current ASAE standards of heat and moisture production (HP, MP) for swine are primarily based on data collected nearly four decades ago. Feedstuffs, management practices, growth rate, and lean percentage of swine have changed HP and MP considerably in that time period. Literature data shows that lean percent increased 1.55% in the last 10 years, resulting in an increase in HP by approximately 15%. Data were compiled into two categories: prior to 1988, and 1988 to present. Analysis of this data revealed that HP increased 12.4% to 35.3% between the two categories, with the largest differences occurring at higher temperatures. The results also revealed lack of HP and MP data for greater than 90 kg pigs. The HP and MP standards for design of swine housing systems should be updated.*

Keywords. *Calorimetry, Genetics, Growth, Moisture production, Nutrition, Temperature.*

Fifty years ago, pigs were almost exclusively raised outdoors; today pigs are predominantly raised indoors to improve food safety, manure management, handling ease, and animal well-being and performance. Raising pigs indoors instead of outdoors takes a great deal of engineering and animal expertise. Many years of research have been dedicated to building design and understanding the building and animal interaction. Important criteria in facility design are animal heat and moisture production responses to the changing genetics, nutrition, and thermal environment. Heat and moisture production standards should be re-examined.

Heat production (HP) and moisture production (MP) rates are important criteria in building design. These HP and MP values provide the basis of design capacity for fans and heaters to control temperature and moisture in buildings. Temperature and humidity control is important, not only to maximize animal well-being and production, but also to prolong the life of the structure. Environmental temperature and animal size effects on HP and MP values can be found in published standards (*ASAE Standards*, 2001; ASHRAE, 2001). The standards are based on data taken 29 years ago (nursery; Ota et al., 1975) and 45 years ago (growing-finishing and breeding stock; Bond et al., 1959).

Comparing HP values from different studies is difficult because many parameters affect HP. The objective of this article is to discuss the changes in swine HP from the late 1950s to the present. Animal mass and other parameters affecting HP will be discussed, including genetic potential, feeding level, composition of the feed, ambient temperature, and acclimation to a given temperature.

GENETIC/COMPOSITION CHANGES AND BODY COMPOSITION EFFECTS ON HEAT PRODUCTION

Swine production has seen significant changes in the past 50 years. Genetic potential has changed considerably, along with the changes in production systems. According to the National Pork Board (Pork Facts, 2001), dressing percentage (the ratio between carcass weight and live weight) has steadily increased from 69.5% in 1960 to 73.9% in 2002. The retail meat yield has also increased 5.1% from 1960 to 2000. The most significant change reported was the decrease in lard yield. In 1960, 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. Lard yield has not been reported since 1988. It is difficult to track production traits further back than 10 years because either no standard measurements were taken or no information was collected by the industry. Additional 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.

Swine Breed	Change Reported from 1991 to 2001[a]: 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

[a] Anderson (2002).

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Heat production increases with increases in lean tissue accretion rate. Tess et al. (1984) reported that a 2.1% increase in lean percentage correlated with an increase in fasting heat production (FHP) of 18.7%. Using the body lean tissue rate increase of 1.76 kg/114 kg (1.55%) between 1991 and 2001 shown in table 1, FHP increases of 14.6% can be predicted from the correlations of Tess et al. (1984). Literature values published for FHP through the years of 1936 and 2002 are shown 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) originally used power equations, the equations were modified only to change the units of HP. 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 18.1% in those 18 years (average increase in HP in 50 and 100 kg). This is comparable to the 14.6% increase predicted, based on the increase in lean percentage over a 10-year period.

Feed Intake and Diet Composition Effects on Heat Production

If an animal consumes more 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 rate than a limit-fed or fasted counterpart. Close and Mount (1978a) illustrated the changes in heat loss for different temperatures and feed intakes (fig. 2). The amount of feed and the composition of feed change HP. Each feed component has an associated heat increment resulting from digestion, absorption, and utilization of that ingredient. 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 that of protein is approximately 36%. However, heat increments are not constant and change with feeding level, especially when animals are fed below maintenance requirements (Blaxter, 1989). It is also important to recognize that if a diet's amino acid profile is closely matched to the pig's growth requirements, then heat increment of the diet and HP of the animal will be minimized. Excess amino acids result in unproductive heat generation to deaminate the extra amino acids. The relationships among amino acids, feed energy content, and HP are complex and will not be discussed further here.

CIGR Heat Production Equations

The International Commission of Agricultural Engineering (CIGR) formed a working group on the climatization of animal houses. The group established guidelines for animal heat and moisture production for designing ventilation and heating equipment for animal houses. Their 1992 report was published in the CIGR Handbook (CIGR, 1999) and was updated in 2002 (CIGR, 2002).

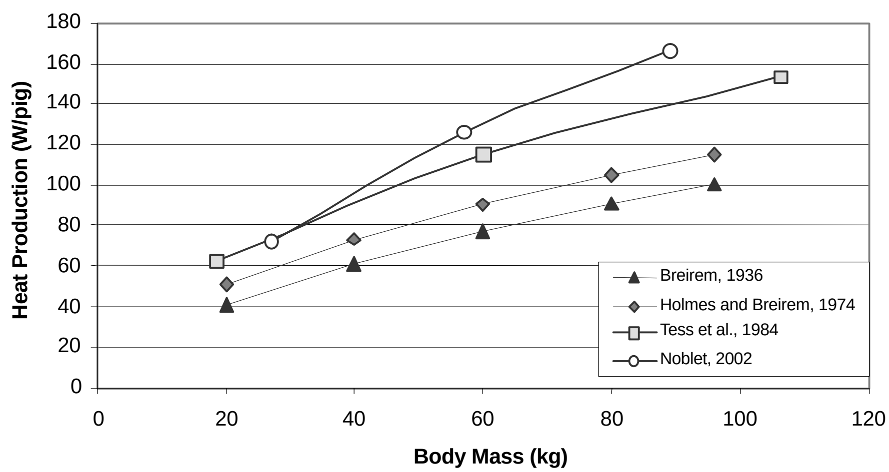

Figure 1. Fasting heat production of swine as reported by four studies from 1936 to 2002.

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

Source	Equations (W/pig)	R^2	50 kg Pigs: FHP per Pig (W)	50 kg Pigs: % Change in FHP from 1936	100 kg Pigs: FHP per Pig (W)	100 kg Pigs: % Change in FHP from 1936
Breirem, 1936	FHP[a] = $7.49m^{0.569}$	--[b]	69.4	0	102.9	0
Holmes and Breirem, 1974	FHP = $11.09m^{0.515}$	--	83.2	19.9	118.8	15.5
Tess et al., 1984	FHP = $13.93m^{0.512}$	0.9999	103.2	48.7	147.2	43.1
Noblet, 2002	FHP = $6.98m^{0.710}$	0.9976	112.2	61.7	183.6	78.4

[a] FHP = fasting heat production in W/pig; m = mass in kg.
[b] -- = previously developed.

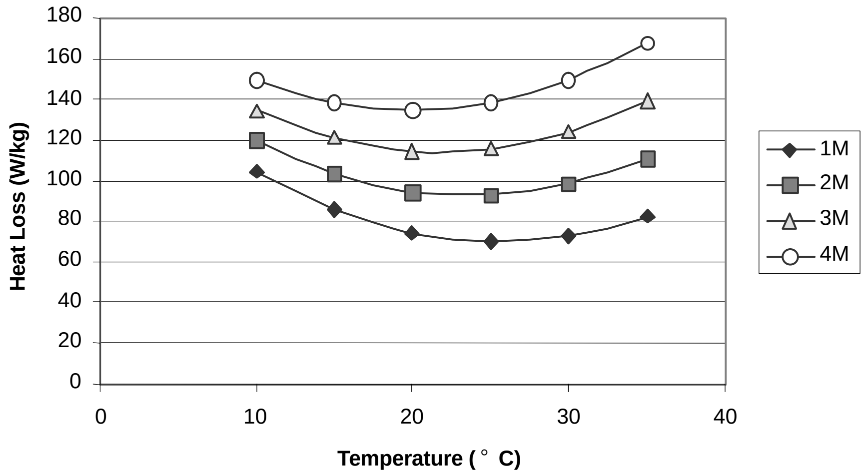

Figure 2. Changes in heat loss of swine (30 to 40 kg) with temperature at different feeding levels: M is approximate maintenance requirements (70 W/kg); therefore, 1M = 70 W/kg, 2M = 140 W/kg, 3M = 210 W/kg, and 4M = 280 W/kg (Close and Mount, 1978a).

CIGR prediction equations are based on the biological principles of heat loss, and not just on literature data. Each of the prediction equations can be broken down into two parts. The first part of the equation is the calculation of maintenance requirements ($\hat{O}_m$), and the second is heat dissipation due to production (growth in the case of growing animals, and pregnancy and milk production in the case of sows). Therefore, all growing pigs have the same basic equation:

$$\Phi_{tot} = \Phi_m + (1 - K_y)(\Phi_d - \Phi_m) \quad (1)$$

where

Φ_{tot} = total animal heat dissipation (W)
Φ_m = heat dissipation due to maintenance (W)
Φ_d = daily feed energy intake (W)
K_y = coefficient of energy utilization's efficiency for weight gain.

For piglets:

$$\Phi_m = 7.4m^{0.66} + [1 - (0.47 + 0.003m)][n\ 7.4m^{0.66} - 7.4m^{0.66}] \quad (2)$$

For grow-finish pigs:

$$\Phi_m = 5.09m^{0.75} + [1 - (0.47 + 0.003m)][n\ 5.09m^{0.75} - 5.09m^{0.75}] \quad (3)$$

where

m = body mass (kg)
n = daily feed energy in relation to $\hat{O}_m$. Values of n vary with animal mass; see table 3 for the values used in the comparisons below.

Table 3. Coefficients used in the CIGR heat-production equations.

Mass (kg)	n[a]
2	4.1
20	3.0
30	3.42
90	2.65

[a] Pedersen (2002).

Heat Production Data in Thermoneutral Conditions

Literature data reported in the rest of this article include data only from fed (unfasted) animals. References used in the analysis were selected on the basis of experimental design and the type of data reported. Some of the references are unpublished data, and some are from non-refereed sources. Appendix A is a list of references used in the following analysis. Appendix B contains data extracted from several references including: reference number (as listed in Appendix A), year of publication, days of exposure to the given environment, feeding level (ad libitum or restricted feeding), calorimetry type (direct, indirect, or slaughter; Blaxter, 1989), number of animals used during each calorimetry run, temperature, feed intake (kg/day), body mass (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.

Thermoneutral conditions (ideal temperature) were calculated for data in Appendix B, based on equation 4:

$$t_{ideal} = 0.0015m^2 - 0.2969m + 30.537 \quad (4)$$

Equation 4 was developed based on recommendations from Midwest Plan Service (MWPS, 1983). Data points were eliminated from the analysis of TN if the ambient conditions were more than 2°C higher or lower than the calculated TN temperature. The HP data were divided into two mass groups: early-weaned pigs (3 to 10 kg), and grow-finish pigs (10 to 100 kg). Young pigs, especially weaned pigs (7 to 14 d), are usually limited by gut fill or some undetermined factor instead of energy intake. Above 10 kg, energy appears to be the factor-limiting intake. Heat production data were analyzed separately to account for these differences between pigs weighing less than 10 kg (fig. 3) and heavier pigs weighing more than 10 kg (fig. 4). Regression analyses were completed using Microsoft Excel to predict HP (coefficients ±standard errors are given):

Early weaned pigs ($R^2 = 0.062$; $P = 0.125$):

$$HP\ (W/kg) = (3.35 \pm 1.21)m^{(0.16 \pm 0.10)} \quad (5)$$

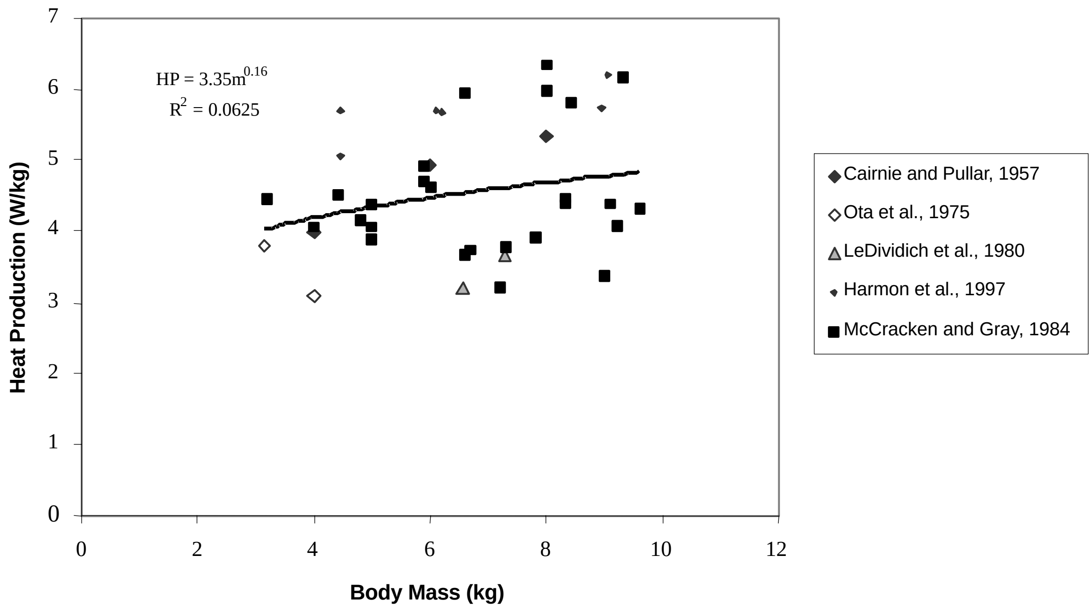

Figure 3. Swine heat production data for early-weaned pigs with a mass (*m*) of less that 10 kg from five independent studies from 1957 through 1997. Regression model was not significant (P = 0.125). Data used in this analysis were originally reported in references 1, 3, 5, 7, and 15 as defined in Appendix A.

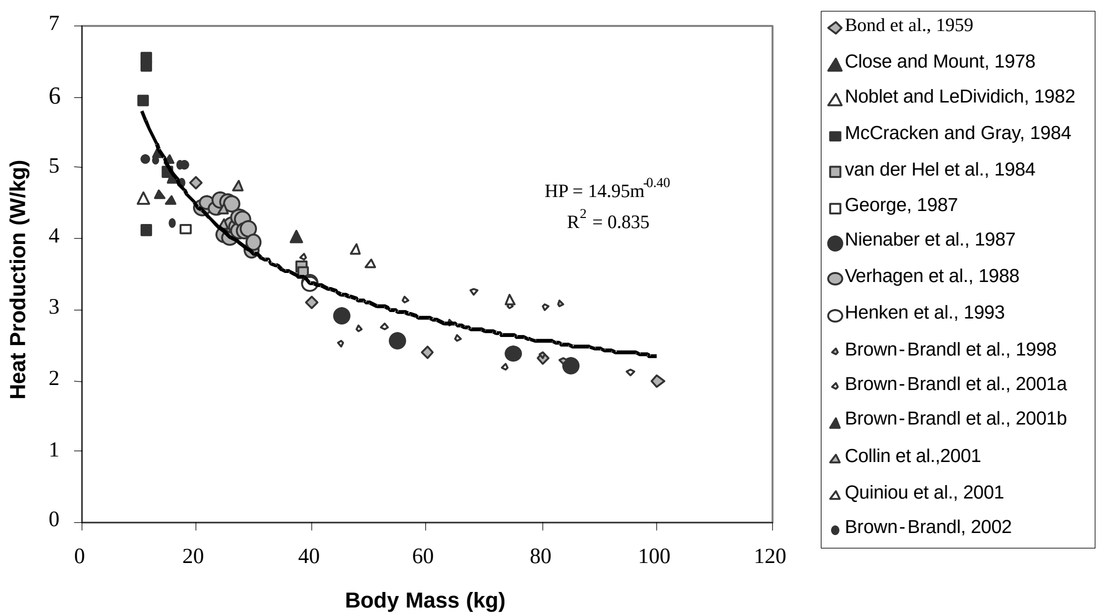

Figure 4. Swine heat production data for nursery pigs through finishing pigs with a mass (*m*) between 10 and 100 kg from 15 independent studies from 1959 through 2002. Regression model was significant (P < 0.0001). Data used in this analysis were originally reported in references 2, 4, 6, 8-12, 14, and 16-21 as defined in Appendix A.

Grow-finish pigs (R^2 = 0.835; P < 0.0001):

$$\text{HP (W/kg)} = (14.95 \pm 1.08)m^{(-0.40 \pm 0.02)} \quad (6)$$

These data were further divided into two populations: older genetics, and current genetics. The older 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 were no studies reported between 1988 and 1993. Third, it was decided the data reported by Nienaber et al. (1987) was obtained using moderate growth genetics, but the data reported by Verhagen et al. (1988) used a high-lean genetic line with similar performance to the more recent data. Figures 5 and 6 show the data trendlines of the two categories and compare the data to the CIGR Handbook (CIGR, 1999).

The prediction equation for HP of the early-weaned pigs prior to 1988 is given in equation 7. Data from a total of four independent studies were used in this analysis (R^2 = 0.066; P = 0.121).

$$\text{HP (W/kg)} = (3.24 \pm 1.22)m^{(0.16 \pm 0.11)} \quad (7)$$

Equation 8 is the prediction equation for HP of the current genetic lines (1988 to present) (R^2 = 0.526; P = 0.103).

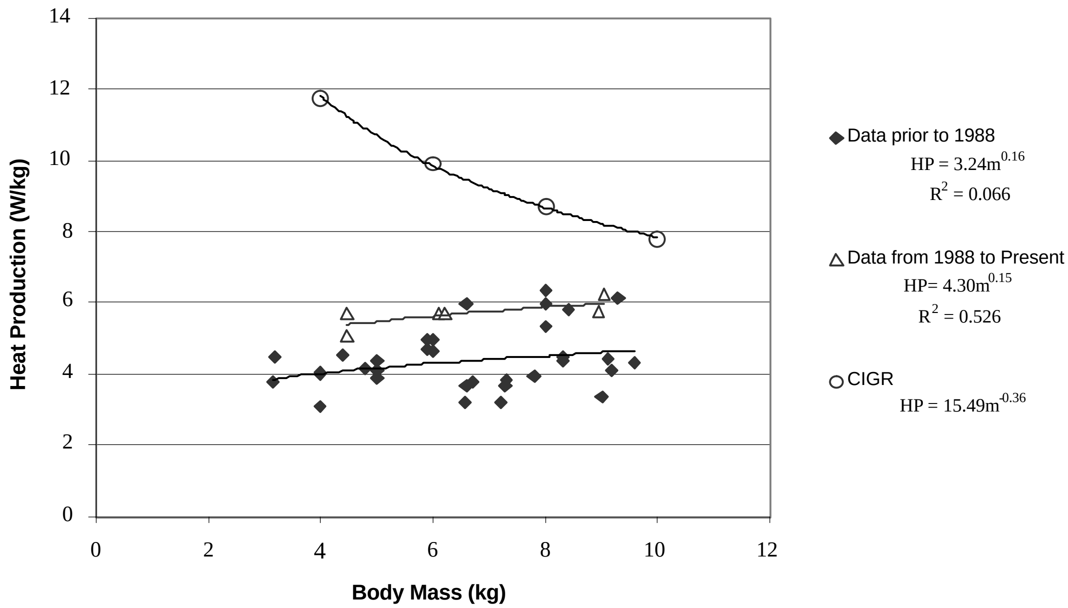

Figure 5. Early-weaned swine (up to 10 kg) heat production data from five independent studies divided into two categories: prior to 1988 (representing older, moderate-lean growth genetics) (P = 0.121), and data reported from 1988 to the present (representing the modern, high-lean growth genetics) (P = 0.103) compared to the CIGR Handbook (CIGR, 1999). Data used in the "prior to 1988" analysis were originally reported in references 1, 3, 5, and 7 as defined in Appendix A. Data used in the "1988 to present" analysis were originally reported in Harmon et al. (1997).

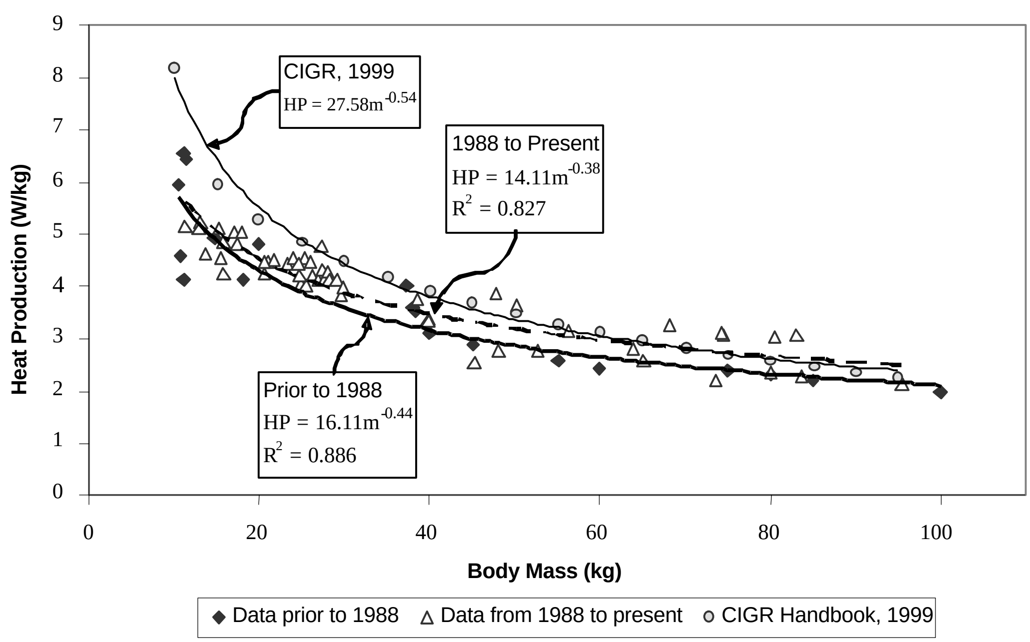

Figure 6. Grow-finish swine (10 to 100kg) heat production data from 15 independent studies divided into two ctegories prior to 1998 (representing older, moderate-lean growth genetics) (P < 0.0001), and data reported from 1988 to the present (representing the modern, high-lean growth genetics) (P < 0.0001) compared to the CIGR Handbook (CIGR, 1999). Data used in the "prior to 1988" analysis were originally reported in references 2, 4, 6, 8, 9, and 10 as defined in Appendix A. Data used in the "1988 to present" analysis were originally reported in references 11, 12, 14, and 16-21.

Unfortunately, only one study was conducted on early-weaned piglets during this time frame.

$$\text{HP (W/kg)} = (4.30 \pm 1.14)m^{(0.15 \pm 0.07)} \quad (8)$$

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, likely due to the different ages/masses of weaning through the years. The CIGR equation using the constant given in Pedersen (2002) does not accurately predict heat production in these early-weaned pigs. Equation 9 was developed by regression analysis and represents the CIGR data in a form similar to the literature data for purposes of comparison.

$$\text{HP (W/kg)} = 15.49m^{-0.36} \quad (9)$$

The prediction equation for HP of the grow-finish pigs prior to 1988 is given in equation 10. Data from a total of seven independent studies were used in this analysis (R^2 = 0.886; P < 0.0001).

$$\text{HP (W/kg)} = (16.11 \pm 1.14) m^{(-0.44 \pm 0.04)} \quad (10)$$

Equation 11 is the prediction equation for HP of the current genetic lines (1988 to present). Data from a total of seven independent studies were used in this analysis (R^2 = 0.827; P < 0.0001).

$$\text{HP (W/kg)} = (14.11 \pm 1.09) m^{(-0.38 \pm 0.02)} \quad (11)$$

The new genetic lines have a maximum increase in total 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 mass 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 mass 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 Pedersen (2002) seems to over-predict HP in the lighter pigs; however, this equation is acceptable in the heavier mass range.

TEMPERATURE EFFECTS ON HEAT PRODUCTION

Figure 7, a graph adapted from Esmay (1967), shows the general relation of HP to increasing temperature. The exact shape of the curve and the lower and upper critical temperatures shown in figure 7 depend on several parameters including age, feed intake, and prior thermal conditioning. Acclimation to a particular environment has a large impact on the animal's heat production in the environment and is important when comparing HP values and planning experiments. It is difficult to predict the amount of acclimation that takes place in a production setting due to constantly changing environments.

The impact of temperature and pig mass on HP was analyzed using the general linear model procedure in SAS. The effect of acclimatization was not considered due to the lack of balanced data. The effects of ambient air temperature (t_a, °C) and log(m, kg) were found to significantly affect log(HP) (P < 0.001). The quadratic effect of temperature was not found to be significant and was excluded from the model; this was likely due to the varying degrees of acclimation of the pigs in the data set.

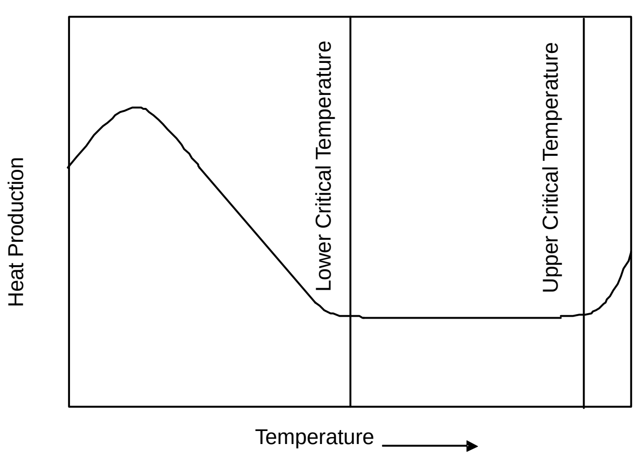

Figure 7. Effects of ambient temperature on heat production (adapted from Esmay, 1967).

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 12 and 13, and graphically in figure 8.

Prior to 1988 (R^2 = 0.739; P < 0.0001):

$$\log(\text{HP [W/kg]}) = (1.178 \pm 0.03) - (0.008 \pm 0.0008) t_a - (0.338 \pm 0.013) \log(m) \quad (12)$$

1988 to present (R^2 = 0.798; P < 0.0001):

$$\log(\text{HP [W/kg]}) = (1.189 \pm 0.03) - (0.005 \pm 0.0008) t_a - (0.345 \pm 0.012) \log(m) \quad (13)$$

These equations predict an increase of 12.4% to 35.3% in HP for the newer genetic lines. According to these predictions, the largest differences are observed at the higher temperatures. The newer genetic lines appear to have a lower upper critical temperature. This conclusion is supported by estimates of threshold temperatures for a newer genetic line of pigs that was 4°C lower than the older genetic line (Nienaber et al., 1997).

LATENT HEAT PRODUCTION

Only nine studies of 21 that were reviewed reported latent heat production rate. Four of those studies were by the same author. Latent heat production depends on temperature and experimental setting. The latent heat of the animal is different from the latent heat of a production system. Production facility contributions to latent heat load are important for building design. Unfortunately, it is difficult to determine a global latent HP estimate that works for the multitude of different animal facilities. An analysis of the latent heat production was not performed because of lack of sufficient data and variable experimental design.

CONCLUSIONS

The literature review showed that FHP has changed 18.1% 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 during the period prior to 1988. When all experimental temperature conditions were included, the HP increase varied from 12.4% (90 kg pigs at 15°C) to 35.3% (5 kg pigs at 35°C), with the largest differences observed in the higher temperatures. There is a lack of latent heat production data for all mass ranges of pigs.

While the CIGR equations offer good estimates in some mass ranges of pigs, additional research should be performed on heavy pigs (>90 kg) and young pigs (<20 kg). It was concluded that the swine HP and MP values are not adequate to accurately design modern swine housing facilities, and they need systematic updating.

FUTURE STUDY CONSIDERATIONS

Several issues need to be addressed by researchers in designing experiments to update HP and MP estimates for

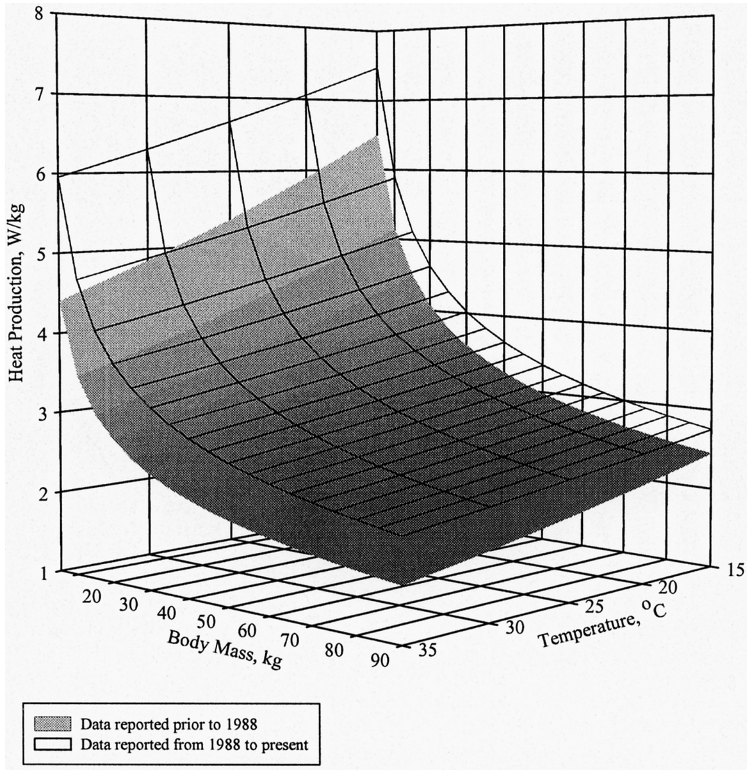

Figure 8. Multiple regression analysis of 21 studies from 1957 to present to describe the effects of temperature and mass on heat production of pigs from 5 to 90 kg. Data used in the "prior to 1988" analysis were originally reported in references 1-10 as defined in Appendix A. Data used in the "1988-present" analysis were originally reported in references 11-21.

swine housing. It was shown that lean tissue accretion rate directly impacts HP. The selection of genotype should be carefully considered, and researchers should consider factoring lean growth potential into the prediction equations. Current production conventions separate the barrows and gilts, and provide different diet regimes to meet the different tissue accretion rate requirements. For this reason, HP measurements should be conducted on barrows and gilts separately. The housing standard used a temperature range from 5°C to 30°C. This range should be adjusted to reflect current production situations, with a focus on the higher temperatures. The current cooling systems include direct wetting of pigs and tunnel ventilation; therefore, the effects of direct wetting of the pigs and various air 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 swine HP and MP data. However, field data will need to be used to supplement the MP data. Field data is needed to ensure that the MP values for ventilation design reflect actual production systems.

More information on HP and MP is needed for breeding stock. Out of the 21 studies, five were conducted on pigs less than 10 kg (early weaned or nursery age pigs), and 16 were conducted on grow-finish pigs (10 to 100 kg), of which only one included pigs greater than 100 kg.

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Appendix A: Listing of References by Reference Number

Reference No.	Reference
1	Cairne and Pullar, 1957
2	Bond et al., 1959
3	Ota et al., 1975
4	Close and Mount, 1978a
5	Le Dividich et al., 1980
6	Noblet and Le Dividich, 1982
7	McCracken and Gray, 1984
8	van der Hel et al., 1984
9	George, 1987
10	Nienaber et al., 1987
11	Feddes and DeShazer, 1988
12	Verhagen et al., 1988
13	Xin and DeShazer, 1991
14	Henken et al., 1993
15	Harmon et al., 1997
16	Brown-Brandl et al., 1998
17	Brown-Brandl et al., 2001
18	Brown-Brandl and Nienaber, 2001
19	Collin et al., 2001
20	Quiniou et al., 2001
21	Brown-Brandl, 2002

Appendix B: Summary of Heat and Moisture Production Rates of Swine Reported in the Literature

Ref. No.[a]	Year	Exposure[b] (days)	Feeding Level	Calorimeter Type	No. of Animals	Temp. (°C)	FI[c] (kg)	Mass (kg)	THP[c] (W/kg)	LH[c] (W/kg)	SH[c] (W/kg)	Gain (kg/d)
1	1957	17.5	Ad lib.	Direct	1	15.0	--	4.0	6.4	--	--	--
”	”	”	”	”	”	15.0	--	6-12	6.0	--	--	--
”	”	”	”	”	”	20.0	--	4.0	5.2	--	--	--
”	”	”	”	”	”	20.0	--	6-12	5.6	--	--	--
”	”	”	”	”	”	25.0	--	4.0	4.5	--	--	--
”	”	”	”	”	”	25.0	--	6.0	5.1	--	--	--
”	”	”	”	”	”	25.0	--	8-12	5.5	--	--	--
”	”	”	”	”	”	30.0	--	6.0	4.9	--	--	--
”	”	”	”	”	”	30.0	--	8.0	5.3	--	--	--
”	”	”	”	”	”	30.0	--	10-12	5.7	--	--	--

2	1959	6	Ad lib.	Direct	4-5	5.0	--	20.0	5.9	1.7	4.2	--
”	”	”	”	”	”	5.0	--	40.0	4.0	1.0	3.0	--
”	”	”	”	”	”	5.0	--	60.0	3.3	0.8	2.5	0.37
”	”	”	”	”	”	5.0	--	80.0	2.9	0.7	2.2	0.42
”	”	”	”	”	”	5.0	--	100.0	2.6	0.6	2.0	0.48
”	”	”	”	”	”	5.0	--	140.0	2.3	0.5	1.8	0.59
”	”	”	”	”	”	5.0	--	180.0	2.1	0.4	1.7	0.70
”	”	”	”	”	”	10.0	--	20.0	5.4	1.4	4.0	--
”	”	”	”	”	”	10.0	--	40.0	3.6	1.1	2.5	0.68
”	”	”	”	”	”	10.0	--	60.0	2.9	0.9	2.0	0.71
”	”	”	”	”	”	10.0	--	80.0	2.5	0.7	1.8	0.74
”	”	”	”	”	”	10.0	--	100.0	2.3	0.7	1.6	0.78
”	”	”	”	”	”	10.0	--	140.0	2.0	0.5	1.5	0.84
”	”	”	”	”	”	10.0	--	180.0	1.8	0.4	1.4	0.90
”	”	”	”	”	”	15.0	--	20.0	5.0	2.0	3.0	--
”	”	”	”	”	”	15.0	--	40.0	3.3	1.3	2.0	0.91
”	”	”	”	”	”	15.0	--	60.0	2.6	0.9	1.7	0.91
”	”	”	”	”	”	15.0	--	80.0	2.3	0.8	1.5	0.92
”	”	”	”	”	”	15.0	--	100.0	2.0	0.7	1.3	0.93
”	”	”	”	”	”	15.0	--	140.0	1.8	0.6	1.2	0.95
”	”	”	”	”	”	15.0	--	180.0	1.6	0.4	1.2	0.96
”	”	”	”	”	”	20.0	--	20.0	4.8	2.5	2.3	--
”	”	”	”	”	”	20.0	--	40.0	3.1	1.5	1.6	0.99
”	”	”	”	”	”	20.0	--	60.0	2.4	1.1	1.3	0.98
”	”	”	”	”	”	20.0	--	80.0	2.1	0.9	1.2	0.96
”	”	”	”	”	”	20.0	--	100.0	1.9	0.8	1.1	0.95
”	”	”	”	”	”	20.0	--	140.0	1.6	0.6	1.0	0.91
”	”	”	”	”	”	20.0	--	180.0	1.4	0.4	1.0	0.88
”	”	”	”	”	”	25.0	--	20.0	4.8	3.2	1.6	--
”	”	”	”	”	”	25.0	--	40.0	3.0	1.8	1.2	0.94
”	”	”	”	”	”	25.0	--	60.0	2.3	1.3	1.0	0.90
”	”	”	”	”	”	25.0	--	80.0	2.0	1.2	0.8	0.86
”	”	”	”	”	”	25.0	--	100.0	1.8	1.0	0.8	0.82
”	”	”	”	”	”	25.0	--	140.0	1.5	0.7	0.8	0.74
”	”	”	”	”	”	25.0	--	180.0	1.3	0.5	0.8	0.66
”	”	”	”	”	”	30.0	--	20.0	4.8	4.2	0.6	--
”	”	”	”	”	”	30.0	--	40.0	3.0	2.4	0.6	0.75
”	”	”	”	”	”	30.0	--	60.0	2.3	1.8	0.5	0.68
”	”	”	”	”	”	30.0	--	80.0	1.9	1.4	0.5	0.62
”	”	”	”	”	”	30.0	--	100.0	1.7	0.2	1.5	0.56
”	”	”	”	”	”	30.0	--	140.0	1.4	0.9	0.5	0.43
”	”	”	”	”	”	30.0	--	180.0	1.3	0.7	0.6	0.30
3	1975	7	Ad lib.	Direct	8	29.0	0.1	3.2	3.8	--	--	--
”	”	”	”	”	”	29.0	0.2	4.5	3.1	--	--	--
”	”	”	”	”	”	24.0	0.4	7.8	4.7	--	--	--
”	”	”	”	”	”	24.0	0.5	11.0	4.4	--	--	--
”	”	”	”	”	”	18.0	0.9	14.3	4.1	--	--	--
”	”	”	”	”	”	18.0	1.0	17.5	5.1	--	--	--
4	1978	21	Limited	Direct	1	10.0	0.6	31.2	2.9	--	--	-0.05[d]
”	”	”	”	”	”	10.0	1.2	35.0	3.6	--	--	0.31
”	”	”	”	”	”	10.0	2.0	40.7	4.0	--	--	0.72
”	”	”	”	”	”	10.0	2.4	24.4	5.3	--	--	0.70
”	”	”	”	”	”	15.0	0.5	29.7	3.0	--	--	0.00
”	”	”	”	”	”	15.0	0.8	24.6	3.5	--	--	0.25
”	”	”	”	”	”	15.0	1.8	35.3	3.6	--	--	0.71
”	”	”	”	”	”	15.0	2.1	38.3	3.9	--	--	0.82
”	”	”	”	”	”	20.0	0.5	27.5	2.5	--	--	0.07
”	”	”	”	”	”	20.0	1.0	30.4	3.0	--	--	0.38
”	”	”	”	”	”	20.0	1.6	31.7	3.9	--	--	0.64
”	”	”	”	”	”	20.0	2.1	37.3	4.0	--	--	0.83
”	”	”	”	”	”	25.0	0.5	30.3	2.1	--	--	0.10
”	”	”	”	”	”	25.0	1.0	30.5	2.4	--	--	0.40

APPENDIX B (CONTINUED): SUMMARY OF HEAT AND MOISTURE PRODUCTION RATES OF SWINE REPORTED IN THE LITERATURE

4	1978	21	Limited	Direct	1	25.0	1.8	34.7	3.6	- -	- -	0.70
”	”	”	”	”	”	25.0	1.8	37.7	3.3	- -	- -	0.71
”	”	”	”	”	”	30.0	0.5	30.4	2.4	- -	- -	0.14
”	”	”	”	”	”	30.0	1.0	29.2	3.2	- -	- -	0.38
”	”	”	”	”	”	30.0	1.4	32.5	3.7	- -	- -	0.22
5	1980	3.5	Ad lib.	Indirect	6	24.0	0.1	6.3	3.6	- -	- -	- -
”	”	”	”	”	”	20.0	0.1	6.5	3.9	- -	- -	- -
”	”	”	”	”	”	28.0	0.1	6.6	3.2	- -	- -	- -
”	”	”	”	”	”	24.0	0.2	7.0	4.1	- -	- -	- -
”	”	”	”	”	”	20.0	0.3	7.2	4.3	- -	- -	- -
”	”	”	”	”	”	28.0	0.3	7.3	3.7	- -	- -	- -
6	1982	42	Limited	Slaughter	1	25.0	0.7	9.3	4.5	- -	- -	0.36
”	”	”	”	”	”	21.0	0.9	10.0	4.8	- -	- -	0.44
”	”	”	”	”	”	25.0	0.9	10.2	4.6	- -	- -	0.43
”	”	”	”	”	”	21.0	1.0	10.3	5.2	- -	- -	0.67
”	”	”	”	”	”	29.0	1.1	10.8	4.6	- -	- -	0.44
”	”	”	”	”	”	25.0	1.1	11.3	4.8	- -	- -	0.53
”	”	”	”	”	”	21.0	1.4	12.5	5.3	- -	- -	0.5
7	1984	1.5	Ad lib.	Indirect	9	25.0	0.1	3.2	5.2	- -	- -	- -
”	”	”	”	”	9	29.0	0.1	3.2	4.5	- -	- -	- -
”	”	”	”	”	9	25.0	0.1	4.2	4.7	- -	- -	- -
”	”	”	”	”	9	29.0	0.1	4.5	4.3	- -	- -	- -
”	”	”	”	”	9	25.0	0.1	4.9	4.3	- -	- -	- -
”	”	”	”	”	9	23.0	0.1	5.0	4.3	- -	- -	- -
”	”	”	”	”	9	29.0	0.1	5.0	4.1	- -	- -	- -
”	”	”	”	”	9	23.0	0.2	5.9	4.7	- -	- -	- -
”	”	”	”	”	9	29.0	0.2	5.9	4.8	- -	- -	- -
”	”	”	”	”	9	23.0	0.2	6.0	4.6	- -	- -	- -
”	”	”	”	”	9	29.0	0.6	6.6	6.0	- -	- -	- -
”	”	”	”	”	6	21.0	0.4	8.3	4.6	- -	- -	- -
”	”	”	”	”	6	29.0	0.2	7.1	3.7	- -	- -	- -
”	”	”	”	”	6	21.0	0.4	9.1	4.4	- -	- -	- -
”	”	”	”	”	9	29.0	0.6	9.5	5.8	- -	- -	- -
”	”	”	”	”	6	21.0	0.5	11.1	4.0	- -	- -	- -
”	”	”	”	”	9	15.0	0.7	9-11	6.6	- -	- -	- -
”	”	”	”	”	6	24.0	0.2	6.6-9.0	3.7	- -	- -	- -
”	”	”	”	”	6	27.0	0.4	8.3-11.1	4.3	- -	- -	- -
”	”	”	”	”	9	17.0	0.6	6.6-8.4	6.3	- -	- -	- -
”	”	”	”	”	6	17.5	0.5	11.3	5.1	- -	- -	- -
”	”	”	”	”	6	25.0	0.5	11.3	4.8	- -	- -	- -
”	”	”	”	”	6	17.5	0.7	14.7	4.7	- -	- -	- -
”	”	”	”	”	6	25.0	0.7	14.7	4.9	- -	- -	- -
8	1984	2	Limited	Indirect	8	19.6	1.2	30.4	3.6	- -	- -	- -
”	”	”	”	”	”	12-20	1.2	31.4	3.7	- -	- -	- -
”	”	”	”	”	”	12-16	1.2	32.1	3.8	- -	- -	- -
”	”	”	”	”	”	8.4	1.3	33.8	4.1	- -	- -	- -
”	”	”	”	”	”	12-16	1.4	36.6	3.7	- -	- -	- -
”	”	”	”	”	”	12-20	1.4	36.7	3.7	- -	- -	- -
”	”	”	”	”	”	16-20	1.4	39.2	3.5	- -	- -	- -
”	”	”	”	”	”	8.5	1.5	42.0	3.8	- -	- -	- -
”	”	”	”	”	”	12-16	1.6	42.9	3.4	- -	- -	- -
9	1987	- -	- -	Direct	- -	24.2	- -	6.7	3.0	1.9	1.1	- -
”	”	”	”	”	”	24.2	- -	8.0	3.4	2.3	1.1	- -
”	”	”	”	”	”	24.2	- -	9.9	3.4	2.0	1.4	- -
”	”	”	”	”	”	24.2	- -	11.0	4.4	1.9	2.5	- -
”	”	”	”	”	”	24.2	- -	14.1	3.7	1.8	1.9	- -
”	”	”	”	”	”	24.2	- -	18.2	4.1	2.9	1.2	- -
10	1987	66.5	Ad lib.	Indirect	1	5.0	1.9	45.0	4.0	- -	- -	0.68[e]
”	”	”	”	”	”	5.0	2.2	55.0	3.4	- -	- -	0.68[e]
”	”	”	”	”	”	5.0	2.5	65.0	3.1	- -	- -	0.68[e]

10	1987	66.5	Ad lib.	Indirect	1	5.0	2.8	75.0	2.8	--	--	0.68[e]
”	”	”	”	”	”	5.0	3.1	85.0	2.6	--	--	0.68[e]
”	”	”	”	”	”	10.0	1.9	45.0	3.6	--	--	0.68[e]
”	”	”	”	”	”	10.0	2.2	55.0	3.2	--	--	0.70[e]
”	”	”	”	”	”	10.0	2.5	65.0	2.8	--	--	0.70[e]
”	”	”	”	”	”	10.0	2.8	75.0	2.6	--	--	0.70[e]
”	”	”	”	”	”	10.0	3.0	85.0	2.4	--	--	0.70[e]
”	”	”	”	”	”	15.0	1.8	45.0	3.3	--	--	0.70[e]
”	”	”	”	”	”	15.0	2.1	55.0	2.9	--	--	0.71[e]
”	”	”	”	”	”	15.0	2.3	65.0	2.6	--	--	0.71[e]
”	”	”	”	”	”	15.0	2.6	75.0	2.4	--	--	0.71[e]
”	”	”	”	”	”	15.0	2.9	85.0	2.2	--	--	0.71[e]
”	”	”	”	”	”	20.0	1.6	45.0	2.9	--	--	0.71[e]
”	”	”	”	”	”	20.0	1.9	55.0	2.6	--	--	0.75[e]
”	”	”	”	”	”	20.0	2.2	65.0	2.3	--	--	0.75[e]
”	”	”	”	”	”	20.0	2.4	75.0	2.2	--	--	0.75[e]
”	”	”	”	”	”	20.0	2.6	85.0	2.0	--	--	0.75[e]
”	”	”	”	”	”	25.0	1.4	45.0	2.6	--	--	0.75[e]
”	”	”	”	”	”	25.0	1.7	55.0	2.3	--	--	0.62[e]
”	”	”	”	”	”	25.0	1.9	65.0	2.1	--	--	0.62[e]
”	”	”	”	”	”	25.0	2.1	75.0	2.0	--	--	0.62[e]
”	”	”	”	”	”	25.0	2.3	85.0	1.8	--	--	0.62[e]
”	”	”	”	”	”	30.0	1.2	45.0	2.2	--	--	0.62[e]
”	”	”	”	”	”	30.0	1.4	55.0	2.0	--	--	0.44[e]
”	”	”	”	”	”	30.0	1.6	65.0	1.9	--	--	0.44[e]
”	”	”	”	”	”	30.0	1.7	75.0	1.7	--	--	0.44[e]
”	”	”	”	”	”	30.0	1.9	85.0	1.7	--	--	0.44[e]
11	1988	6.5	Ad lib.	Indirect	4	33	1.25	36	3.4	2.4	1.0	0.48
”	”	”	”	”	”	33	1.28	36	3.3	2.3	1.0	0.51
12	1988	1-6	Ad lib.	Indirect	10	25.0	1.3	26.6	4.1	--	--	--
”	”	7-13	”	”	”	25.0	1.6	31.5	4.1	--	--	0.82
”	”	2-6	”	”	”	25.0	1.2	22.5	4.5	--	--	0.86
”	”	7-11	”	”	”	25.0	1.3	26.7	4.4	--	--	0.87
”	”	14-18	”	”	”	25.0	1.6	31.2	4.0	--	--	0.85
”	”	21	”	”	”	25.0	1.8	37.5	4.1	--	--	0.85
13	1991	15.5	Ad lib.	Indirect	1	30.8	1.68	38.8	3.8	2.1	1.7	0.78
14	1993	2	Limited	Indirect	8	11.0	1.5	39.8	3.7	--	--	--
”	”	”	”	”	”	14.0	1.5	39.8	3.6	--	--	--
”	”	”	”	”	”	17.0	1.5	39.8	3.4	--	--	--
”	”	”	”	”	”	20.0	1.5	39.8	3.4	--	--	--
”	”	”	”	”	”	23.0	1.5	39.8	3.4	--	--	--
”	”	”	”	”	”	26.0	1.5	39.8	3.3	--	--	--
15	1997	3.5	Ad lib.	Indirect	10-11	23.3	0.3	4.4	5.6	2.6	3.0	0.25
”	”	”	”	”	”	25.6	0.3	4.4	5.1	2.6	2.5	0.22
”	”	”	”	”	”	27.8	0.3	4.5	5.1	2.7	2.4	0.24
”	”	”	”	”	”	30.0	0.3	4.5	5.2	3.1	2.1	0.25
”	”	7.0	”	”	”	23.3	0.5	6.1	5.8	2.8	3.0	0.38
”	”	”	”	”	”	25.6	0.5	6.0	6.0	3.0	3.0	0.40
”	”	”	”	”	”	27.8	0.5	6.1	5.7	3.1	2.6	0.42
”	”	”	”	”	”	30.0	0.5	6.2	5.7	3.6	2.1	0.39
”	”	10.5	”	”	”	23.3	0.7	8.8	6.3	2.6	3.7	0.50
”	”	”	”	”	”	25.6	0.7	8.7	6.4	2.9	3.5	0.50
”	”	”	”	”	”	27.8	0.7	9.1	6.2	3.0	3.2	0.49
”	”	”	”	”	”	30.0	0.6	8.9	5.7	3.3	2.4	0.46
16	1998	<1	Ad lib.	Indirect	1	18.2	1.2	84.3	2.4	0.9	1.5	--
”	”	”	”	”	”	23.6	1.5	81.6	2.3	0.9	1.4	--
”	”	”	”	”	”	28.3	0.7	82.9	2.2	1.0	1.2	--
”	”	”	”	”	”	32.1	0.9	83.9	2.3	1.6	0.7	--
17	2001	<1	Ad lib.	Indirect	1	17.9	1.5	74.5	2.6	0.4	2.2	--
”	”	”	”	”	”	24.0	1.5	66.4	2.7	0.7	2.0	--

Appendix B (continued): Summary of Heat and Moisture Production Rates of Swine Reported in the Literature

17	2001	<1	Ad lib.	Indirect	1	28.0	1.6	68.1	2.4	0.7	1.7	--
”	”	”	”	”	”	31.4	1.1	63.2	2.6	1.0	1.6	--
18	2001	<1	Ad lib.	Indirect	1	17.7	0.9	13.3	5.1	1.4	3.7	--
”	”	”	”	”	”	24.7	0.9	11.9	4.8	2.3	2.4	--
”	”	”	”	”	”	31.7	0.9	12.2	4.4	2.6	1.8	--
19	2001	2	Ad lib.	Indirect	1	23.0	1.0	24.5	4.4	--	--	--
”	”	”	”	”	1	25.0	1.0	24.7	4.2	--	--	--
”	”	”	”	”	1	27.0	1.0	24.7	4.1	--	--	--
”	”	”	”	”	6	23.0	1.5	27.3	4.8	--	--	--
”	”	”	”	”	6	33.0	1.1	24.9	4.1	--	--	--
20	2001	2	Ad lib.	Indirect	1	12.0	2.3	47.5	4.3	--	--	--
”	”	”	”	”	”	14.0	2.3	47.5	4.1	--	--	--
”	”	”	”	”	”	16.0	2.3	47.7	4.0	--	--	--
”	”	”	”	”	”	19.0	2.1	47.8	3.9	--	--	--
”	”	”	”	”	”	22.0	2.0	47.8	3.7	--	--	--
”	”	”	”	”	”	12.0	2.8	74.3	3.4	--	--	--
”	”	”	”	”	”	14.0	1.9	74.3	3.3	--	--	--
”	”	”	”	”	”	16.0	1.9	74.3	3.1	--	--	--
”	”	”	”	”	”	19.0	2.7	75.6	3.2	--	--	--
”	”	”	”	”	1	22.0	2.6	75.7	3.1	--	--	--
”	”	”	”	”	”	19.0	2.2	50.3	3.6	--	--	--
”	”	”	”	”	”	22.0	2.0	49.6	3.4	--	--	--
”	”	”	”	”	”	25.0	2.1	49.3	3.4	--	--	--
”	”	”	”	”	”	27.0	1.9	47.1	3.6	--	--	--
”	”	”	”	”	”	29.0	1.7	48.9	3.3	--	--	--
”	”	”	”	”	”	19.0	3.0	75.3	3.2	--	--	--
”	”	”	”	”	”	22.0	2.9	75.4	3.2	--	--	--
”	”	”	”	”	”	25.0	2.6	75.3	3.0	--	--	--
”	”	”	”	”	”	27.0	2.3	75.3	2.9	--	--	--
”	”	”	”	”	”	29.0	2.0	75.2	2.7	--	--	--
21	2002	<1	Ad lib.	Indirect	1	18.6	1.0	15.0	5.3	1.7	3.6	--
”	”	”	”	”	”	25.1	0.8	14.8	4.6	1.9	2.7	--
”	”	”	”	”	”	32.2	0.9	15.1	4.4	2.4	2.0	--

[a] Reference numbers are defined in Appendix A.
[b] Exposure is defined as the number of days the animals was subjected to the ambient test conditions prior to the heat production measurement.
[c] FI = feed intake, THP = total heat production, LH = latent heat, and SH = sensible heat.
[d] Gains calculated by equation reported by Close and Mount (1978b).
[e] Gains reported as average gain over the 66-day period; HP predicted based on equations.