November, 1991

Swine responses to constant and modified diurnal cyclic temperatures

Hongwei Xin, *University of Arkansas*
James A. DeShazer, *University of Idaho*

SWINE RESPONSES TO CONSTANT AND MODIFIED DIURNAL CYCLIC TEMPERATURES

H. Xin, J. A. DeShazer
MEMBER ASAE FELLOW ASAE

ABSTRACT

Ad libitum fed and individually penned crossbred gilts (39 ± 2 kg) were exposed to a constant air temperature of 30.8° C (CON) and equal-mean diurnal cyclic temperatures cycling from 26° to 33° C (RPK) and from 23.4° to 40° C (RNT). Fluorescent lighting with an intensity of 800 to 1100 L/m/m^2 was provided from 0600 h to 2100 h. Measurements of feed intake, heat loss rates, water usage, growth, and ingestion behavior were made for a five-day period and replicated six times.

Daily average heat loss rates, water usage, and feed conversion of the RPK and RNT pigs could be predicted with those of the CON pigs. However, daily feed intake and growth of the RNT pigs, 1.56 kg and 0.70 kg, respectively, were reduced ($p < 0.01$) compared to the CON pigs (1.71 and 0.82) and the RPK pigs (1.78 and 0.84).

Ingestion patterns of the pigs for all treatments were characterized by a meal size of 160 to 170 g/meal-pig, drink size of 250 to 270 g/drink-pig, meal frequency of 9 to 11 meals/day, drink frequency of 36 drinks/day-pig, meal duration of 13 to 14 min/meal, and drink duration of 0.6 min/drink. Hourly feed intakes of the pigs were unevenly distributed throughout the 24-h period. Total heat production generally increased about two to three hours after an increase in feed intake and declined accordingly.
KEYWORDS. Temperature, Swine.

INTRODUCTION

Air temperature plays a major role in evaluating thermal environments of swine production units. Although maintaining constant temperatures in swine facilities is generally impractical, limited data regarding the effects of fluctuating temperatures on swine are available. A summary of published studies temperatures on swine is presented in Table 1. It appears that an increase in cycle range tends to reduce pig performance, particularly when temperatures during the daily cycle went outside of the thermoneutral zone. However, this tendency is not consistent from one study to another. Therefore, the variety of differences in fluctuating environments such as duration and magnitude of change needs further investigation.

The objective of this study was to compare the responses of growing pigs to two different simulated cooling schemes in a facility under a typical midwestern United States summer diurnal cyclic temperature. The two cooling schemes involved the temperature profiles of the same mean temperature but different cycling ranges. The temperature designs were derived by removing the same amount of energy (degree hours) from the air at different segments of the natural diurnal cycle. Pig responses to the simulated cyclic temperatures were further compared to those under a constant temperature of the cyclic mean to determine if the constant mean temperature could be used to predict cyclic temperature responses.

MATERIALS AND METHODOLOGY

AIR TEMPERATURE REGIMENS

A hot summer diurnal cyclic temperature of 33 ± 7° C, typical to Southeast Nebraska (AGNET, 1984) was mathematically simulated (fig. 1). The cyclic temperature was then modified to reduce all temperatures higher than 33° C (occurring from 1000 to 2200 h) to 33° C with the remaining cycle unchanged. This modified temperature pattern, cycling from 26° to 33° C, was designated as reduced daytime peak temperature (RPK). Another modification, cooling the same amount of degree hours as in RPK, was the reduction of all temperatures lower than 33° C (occurring from 2200 to 1000 h) to 23.4° C except for the hours of 2200 to 2300 h and 0900 to 1000 h. During 2200 to 2300 h, temperature was linearly decreased from 33° to 23.4° C and during 0900 to 1000 h, temperature was linearly increased from 23.4° to 33° C. This modified temperature pattern, cycling from 23.4° to 40° C, was thus designated as a reduced nocturnal temperature (RNT). The cooling schemes were selected to represent possible production management practices and thus could have an impact on the on-farm load management. Since both cyclic temperatures had the same mean of 30.8° C, a constant temperature treatment (CON) of 30.8° C was identified. Dew-point temperature of the incoming air to the animal area was maintained at 10° to 12° C to result in a relative humidity of 45% at the dry-bulb temperature of 31° C. The relative humidity was allowed to vary as a function of air

Article was submitted for publication in April 1991; reviewed and approved for publication by the Structures and Environment Div. of ASAE in September 1991. Presented as ASAE Paper No. 89-4518.

This manuscript has been assigned Journal Series No. 9307, Agricultural Research Division, University of Nebraska, Lincoln. This research was partially funded through Regional Research Project NC-179: "Modeling Responses of Growing Swine to Environmental and Nutritional Conditions", conducted at the University of Nebraska, Lincoln. Equipment or company names are cited for clarity of the paper and do not imply approval by the authors or the universities of exclusion to any other products that may be suitable.

The authors are **Hongwei Xin**, Research Associate, Dept. of Biological and Agricultural Engineering, University of Arkansas, Fayetteville; and **James A. DeShazer**, Professor and Head, Dept. of Agricultural Engineering, University of Idaho, Moscow. (Funding provided by the Biological Systems Engineering Dept., University of Nebraska, Lincoln.)

TABLE 1. A summary of previous studies on cyclic temperature effects on swine

Source (year)	Temp. (° C)	ABM (kg)	ADG (kg / d)	FI (kg / d-hd)	FC (KgF / kgG)	Exposure* Duration
Bond et al.	21	68.0	0.76a	2.66	3.50	7 days
(1963)	21 ± 5.6	69.0	0.66ab	2.56	3.88	7 days
	21 ± 11.1	70.5	0.49c	3.01	6.15	7 days
Morrison et al.	opt (22-24)	63	0.78a	2.75a	3.53	35 days
(1975)	opt ± 5	63	0.71a	2.49a	3.50	35 days
	opt ± 10	63	0.72a	2.46a	3.42	35 days
	opt + 6	63	0.62b	2.08b	3.35	35 days
	opt + 6 ± 5	63	0.65b	2.02b	3.10	35 days
	opt + 6 ± 10	63	0.52c	1.87c	3.59	35 days
Brumm & Shelton	CT†	nursery	0.34b	0.54b	1.59	4-6 wks
(1988)		G-F	0.69	2.22	3.23	15-17 wks
	MRNT†	nursery	0.36a	0.58a	1.61	4-6 wks
		G-F	0.69	2.23	3.32	15-17 wks
Feddes & DeShazer	33	36	0.51a	1.28a	2.51a	7 days
(1988)	33 ± 7	36	0.48a	1.25a	2.60a	7 days
Nienaber et al.	5	30	0.60b	1.84a	3.05	4 wks
(1989)	5 ± 12	30	0.55b	1.67a	3.03	4 wks
	20	30	0.70a	1.53b	2.20	4 wks
	20 ± 12	30	0.70a	1.49b	2.13	4 wks
	5	82.5	0.78b	3.49a	4.47	7 wks
	5 ± 12	82.5	0.70c	3.39a	4.84	7 wks
	20	82.5	0.93a	3.19b	3.14	7 wks
	20 ± 12	82.5	0.76b	2.90b	3.81	7 wks

* ABM = average body mass during the exposure period
ADG = average daily gain
FI = average daily feed intake
FC = feed conversion
Exposure Duration = duration of the treatment exposure from which the measures were obtained
† CT = constant temperature, starting at 30° C and reducing 2° C / wk
MRNT = modified reduced nocturnal temperature, 6° C lower at night (1900 to 0700 h) than the daytime constant temperature
Column values followed by different letters are significantly different (P < 0.01).

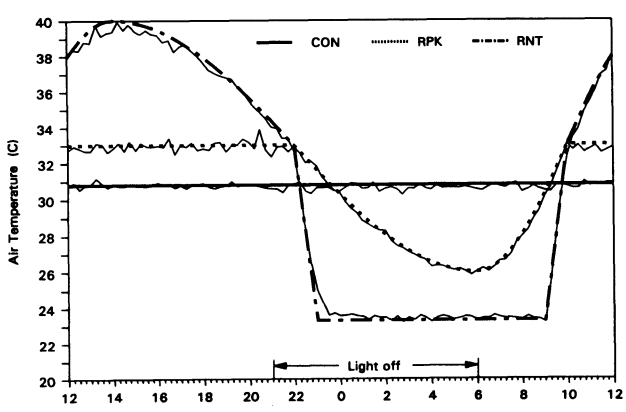

Figure 1–Air temperature treatment regimens: constant temperature of 30.8° C (CON); reduced peak temperature cycling from 26° to 33° C with mean of 30.8° C (RPK); and reduced nocturnal temperature cycling from 23.4 to 40° C with mean of 30.8° C (RNT). Intended regimens are designated by the smooth lines in the legend; actual temperatures are shown as the solid lighter lines above each smooth line.

temperature. Fluorescent lighting with an intensity of 800 to 1100 Lm/m^2 was provided from 0600 to 2100 h.

Experimental Pigs

A total of eighteen randomly selected crossbred gilts at an initial body mass of 31 (± 2) kg were obtained for this study from the University of Nebraska Energy Integrated Research Farm located near Mead, Nebraska. For each replication, three pigs, one pig for each treatment, were transported 60 km from the research farm to the Bioenergetics Research Laboratory. The pigs were then randomly assigned to three temperature-controlled calorimeters. Randomized complete block design was used to remove differences in pig responses caused by non-homogeneity of the physiological state of the pigs among the six replicates. Individual penning of the pigs was designed to eliminate possible masking of dynamic responses caused by social interactions of grouped pigs. The pigs could view each other through transparent walls of the calorimeters and thus potential isolation stress was reduced. Feed and water were available *ad libitum*. The corn-soybean diet used subsequent to weaning and during the experiment contained 88.76% dry matter, 17.7%

protein, 1.0% calcium, 0.9% potassium, 1.27% lysine, and 16.04 kJ/g gross energy.

Acclimation of the experimental pigs was based on the mean housing air temperature in the swine facility of the research farm during the previous week. The mean temperature ranged from 20 to 24° C. Air temperature inside the calorimeters was linearly increased by 2.5° C per day from 0600 to 1400 h until the constant level of 30.8° C was reached. The experimental temperature regimens were then initiated at 1000 h the following day. The pigs were housed in the calorimeters for 14 to 18 days. Response data of the last five days were used to evaluate the treatment effect.

Animal Calorimeters

Three indirect animal calorimeters (1.0 w × 1.5 L × 1.2 h m) and related instrumentation were developed in an environmentally controlled chamber (3.0 w × 6.7 L × 2.7 h m). Each animal calorimeter was equipped with an aluminum slatted floor (1.2 L × 0.9 W m), providing a net floor area of 1.0 m^2 for the pig. Waste storage under each floor was covered with degummed soybean oil to eliminate water vaporization, thus preventing interference with the latent heat loss measurement. A fan/heater (model 29H30, ArvinAir Division, Arvin Industries, Inc., Phoenix, Arizona) was placed at the air inlet of each calorimeter for temperature control and uniform distribution of air inside the calorimeter. Air velocity at the animal determined with a heated filament anemometer (model 441, Kurz Instruments Inc., Carmel Valley, California), and varied from 0.05 to 0.25 m/s. Air temperature inside the calorimeter was generally controlled within 0.5° C.

Heat Production Measurement

Total heat production rate (THP) of the pig was obtained by the indirect calorimetry method. Changes in oxygen (O_2) concentration of the air before entering and after exiting the calorimeter were measured with a paramagnetic oxygen analyzer (model G2, Beckman Instruments, Inc., Process Instruments Division, Fullerton, California). Carbon dioxide (CO_2) concentration of the air was measured with an infrared CO_2 analyzer (MSA Lira models 300 and 3000, Mine Safety Appliance Company, Pittsburgh, Pennsylvania). Ventilation rate through each calorimeter, approximately 240 SLPM (standard liter per minute) was measured using air mass flow meters with a range of 0 to 400 SLPM ± 1% (Hastings model HFM-200L, Teledyne Hastings Raydist, Hampton, Virginia). Latent heat loss rate (LHL) was determined by the ventilation rate and the differential in moisture content of the entering and leaving air which was measured by an infrared analyzer (MSA Lira model 200) and a dew-point analyzer (EG&G model 911 Dew-Air, Environmental Equipment Division, Waltham, Massachussetts). Sensible heat loss rate (SHL) was calculated as the difference between THP and LHL.

The variables for heat and moisture production determination were automatically collected every five minutes by a PC interfacing with a 12-bit analog to digital converter (Remote Measurement Systems, Inc., Seattle, Washington). Entering and leaving air was sampled by switching servo valves in the following sequence: (1) common inlet; (2) outlet of the first calorimeter; (3) outlet of the second calorimeter; (4) outlet of the third calorimeter; and (5) common inlet. Thus, the time interval between two adjacent measurements for the same calorimeter was 20 minutes. Error analysis of the calorimetry system was performed and a maximum error of 4.3% was expected for the heat production calculations (Xin, 1989).

Feeding and Drinking Behavior

The mass of Smidley modified finishing feeders with 13 kg capacity (Martin MFG, Inc., Britt, Iowa) was scanned continuously with off-center load cells which had the capacity of 50 kg and sensitivity of 10 g (model 1010F, Tedea Inc., 8606 Wilbur Ave., Northridge, California). The mass of 22 kg capacity water supply tanks was monitored through shop-fabricated load cells with a sensitivity of 10 g. Output signals from the load cells were processed by a strain gage signal conditioning unit (model 10X4 DataPac with 10A70-2 strain gage cards, Daytronic Corporation, 2589 Corporate ModelPlace, Miamisburg, Ohio).

The start and end of each feeding or drinking event were detected as follows (Nienaber, 1988). Four consecutive mass readings of a feeder or water tank were compared to detect each feeding or drinking event. The first reading was used as the reference. If the absolute difference between the reference reading and the following three readings was equal to or greater than 20 g, then the start of a feeding or drinking activity was considered to begin at the reference reading. If at least one of the absolute differences was less than 20 g, the reference reading was moved to the latter point and the process was repeated. The end reading was designated to occur when the feeder or tank mass was below the starting mass and the three differences were within the tolerance range of ± 10 g. Addition of feed or water to the feeder or water tank was detected and singled out by defining 5000 g as the upper threshold of the difference between the reference reading and the following readings. Data were scanned but not recorded when the feeder or water tank mass was constant. Scanning was continuous and each cycle took approximately 20 g. An examination of the dynamic feeding/drinking records indicated that the ingesting events could be well separated by clustering the activities that took place within three minutes. Thus, feeding or drinking events occurring in three minutes were combined as one meal or drink. In addition, feeder and water tank mass were recorded every five minutes to check the hourly feed intake and water usage against the values determined from the continuous scanning.

Body Mass and Activity Monitoring

The body mass of each pig was measured weekly using an electronic scale with a resolution of 10 g (Detecto model 5850F/738, Cardinal Detecto Scales MFG., Webb City, Missouri). Twenty four-hour video recordings were made on the last replicate pigs of the treatments to measure standing and lying behavioral patterns (Panasonic model WV-CD810 IR Camera; model TR-930B B&W Video Monitor; and model AG-6010g Time Lapse VHS Recorder. Panasonic Industrial Co., Two Panasonic Way, Secaucus, New Jersey). The tape was reviewed and data recorded as standing, lying, and duration of each event. Data were then processed as standing time in each hour throughout the 24-h period.

Energy Balance of the Experimental Pigs

Energy balance per metabolic mass unit (MMU) of the pigs was calculated based on the equations described by Thorbek et al. (1984) for growing pigs.

Metabolizable energy intake (ME).

$$ME\left[W/kg^{0.75}\right] = 0.80 \times FI \times 1000\left[g/kg\right] \times GEC \times 1000\left[J/kJ\right]/(24 \times 3600)/ABM^{0.75} \quad (1)$$

where

0.80	=	percentage of gross energy as ME,
FI	=	feed intake of the pig (kg/day-pig),
GEC	=	gross energy content of the diet (16.04 kJ/g),
24	=	hours per day,
3600	=	seconds per hour,
ABM	=	average body mass during the exposure period from which measurements were taken (kg), and
$ABM^{0.75}$	=	conversion of ABM to MMU.

ME required for maintenance (ME_m) of 40-kg pigs.

$$ME_m\left[W/kg^{0.75}\right] = 5.96 \quad (2)$$

Retained energy (RE) for growth.

$$RE\left[W/kg^{0.75}\right] = ME - THP \quad (3)$$

where THP is the total heat production rate ($W/kg^{0.75}$).

Partial efficiency of ME utilization for growth (K_g).

$$K_g = RE/(ME - ME_m) \quad (4)$$

Statistical Analysis

Analysis of variance (ANOVA) for the randomized complete block design and Duncan's multiple range mean comparisons were conducted on the average pig responses. More detailed information on instrumentation and data analysis is described by Xin (1989).

Results

Five-day average energetic and performance responses of the pigs are summarized in Table 2. There was no significant difference ($P > 0.10$) in daily feed intake between the RPK and the CON pigs (Table 2). However, feed intake of the RNT pigs was significantly less ($P < 0.01$) compared to that of the RPK or the CON pigs. Feeding and drinking behavioral characteristics of the pigs are shown in Table 3. Meal and drink size, duration, and frequency were not significantly different ($P > 0.10$) for all three treatments.

The 20-min interval THP, LHL, SHL, respiratory quotient (RQ), hourly feed intake, and water usage were unaffected by replicate or day of experiment over the five days of measurement. The data were thus compressed from six five-day responses to a one-day time domain. Hence, each value on the 24-h time domain was the result of combining 30 (i.e., 6 reps. × 5 days/rep.) respective dynamic data points.

The dynamic THP, LHL, and SHL of the pigs associated with each temperature regimen are graphically shown in figures 2a, 2b, and 2c. A modified cumulative THP obtained by subtracting 120 W/pig from each THP value is presented in figure 3a to provide a comparative inspection of the dynamic profiles of the THP. Subtraction of 120 from each THP value allowed the display of the dynamic changes in THP. The cumulative feed intake and cumulative water usage of the pigs are presented in figures 3b and 3c.

Dynamic responses of the pigs within the 24-h period were partitioned into the time zone with higher than

TABLE 2. Five-day average energetic and performance responses of the pigs to constant and cyclic air temperatures.

						HP						
TRT	ABM	DFI	DWU	ADG	FC	SHL	LHL	THP	ME	RE	K_g	RQ
RPK	38.8	1.78a	9.8a	0.84a	2.1a	3.9a	5.1a	9.0a	16.7a	7.7a	0.72a	1.1a
SEM	1.8	0.07	1.1	0.02	0.1	0.4	0.3	0.4	0.3	0.6	0.04	0.05
CON	39.7	1.71a	9.4a	0.81a	2.1a	3.5a	5.1a	8.6a	15.7ab	7.1ab	0.73a	1.2a
SEM	1.3	0.06	1.4	0.02	0.1	0.5	0.3	0.7	0.3	0.6	0.06	0.04
RNT	37.9	1.56b	8.9a	0.70b	2.2a	3.7a	5.3a	9.0a	14.8b	5.8b	0.66a	1.1a
SEM	1.7	0.06	1.2	0.02	0.1	0.4	0.3	0.5	0.4	0.7	0.06	0.06

Column means followed by different letters are significantly different ($P < 0.01$).

Symbols:

- ABM - Average Body Mass during the last five days of the experiment (kg)
- ADG - Average Daily Gain (kg / day-pig)
- CON - Constant Temperature of 30.8° C
- DFI - Daily Feed Intake (kg / day-pig)
- DWU - Daily Water Usage (kg / day-pig)
- FC - Feed Conversion (kg feed / kg gain)
- HP - Heat Production Rate ($W / kg^{0.75}$)
- Kg - Partial efficiency of ME utilization for gain
- LHL - Latent Heat Loss Rate ($W / kg^{0.75}$)
- ME - Metabolized Energy Intake ($W / kg^{0.75}$)
- RE - Retained Energy ($W / kg^{0.75}$)
- RPK - Reduced Peak Temperature with a diurnal cycle of 26 to 33° C and the mean of 30.8° C
- RNT - Reduced Night Temperature with a diurnal cycle of 23.4° to 40° C and the mean of 30.8° C
- RQ - Respiratory Quotient (1 CO_2 / 1 O_2)
- SEM - Standard Error of the Mean
- SHL - Sensible Heat Loss Rate ($W / kg^{0.75}$)
- THP - Total Heat Production Rate ($W / kg^{0.75}$)
- TRT - Treatment

TABLE 3. Ingestion patterns of swine in constant and cyclic temperatures

	Feeding			Drinking		
TRT	Size*	Dur.†	Freq.‡	Size*	Dur.†	Freq.‡
RPK§	160	14.3	11	275	0.61	36
SEM	20	2.3	1	35	0.08	3
CON§	170	13.3	10	270	0.60	35
SEM	30	1.9	2	30	0.10	5
RNT§	170	13.5	9	250	0.62	36
SEM	15	1.1	1	45	0.15	4

*Size - Feed or water consumed per meal or drink (gram / meal-pig)
†Dur - Duration of each meal or drink (min / meal or drink)
‡Freq - Frequency of feeding and drinking (times / day-pig)
§CON- Constant temperature of 30.8° C
RPK - Reduced Peak Temperature with diurnal cycle of 26 to 33° C and the mean of 30.8° C
RNT - Reduced Night Temperature with a diurnal cycle of 23.4 to 40° C and the mean of 30.8° C
SEM Standard Error of the Mean
TRT - Treatment

average responses and the time zone with lower than average responses (fig. 4). This partitioning displays the relationship among the dynamic responses (e.g., FI vs. THP) for each treatment as well as between treatments. The cumulative hours of standing for the last trial pigs is presented in figure 5.

DISCUSSION

The average daily feed intake was similar for the CON and RPK treatments, which was consistent with the findings of Feddes and DeShazer (1988) for 35-kg pigs at 33° C and 33 ± 7° C. However, the RNT pigs had 14% and 10% less feed intake compared to the RPK pigs and CON pigs respectively. The relationships of daily feed intake among the experimental pigs in this study (39 ± 2 kg) exposed to mean air temperatures of 30.8° C with a cycle range of 0°, 7°, or 16.6° C agreed with those reported by Morrison et al. (1975) for 63-kg pigs exposed to temperatures of 29° C with a cycle range of 0°, 10°, or 20° C. Apparently, an increase in the magnitude of temperature fluctuation or degree hours of stress impairs

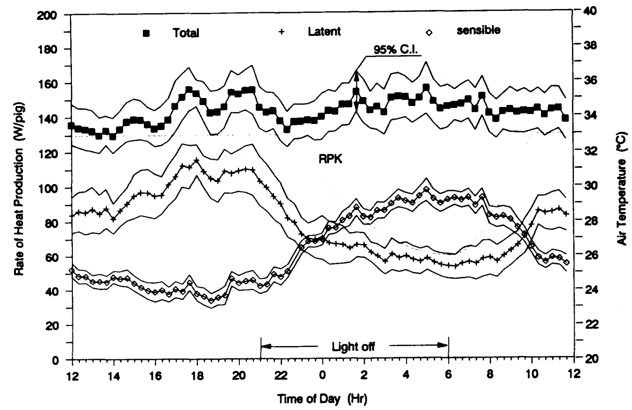

Figure 2b–Twenty-min total heat production, latent heat loss and calculated sensible heat loss for the reduced peak temperature of 26° to 33° C (RPK).

short-term performance responses of growing swine under the hot environmental conditions. In summarizing the influences of air temperature on swine performance and behavior, Hahn et al. (1987) concluded that within the nominal performance loss ranges, daily cycles of up to ± 5° to 8° C will not cause adverse consequences on healthy animals. Our finding partly verified the conclusion. Further, based on the combined results, the critical cycle range for growing pigs may be narrowed to between 14° C (Feddes and DeShazer, 1988) and 16.6° C under hot temperature conditions (current study).

The incidence of significantly lower feed intake for the RNT pigs is examined more closely from the cumulative feed intake curve of the pigs (fig. 3b). There was minimal feed intake for the RNT pigs between 0900 and 1700 h. This depression in feed intake was presumably caused by the hot ambient temperature occurring during this period. The cumulative feed intake curve showed a higher than average hourly feed intake of 135 g/h-pig occurring from 1500 to 2100 h for the CON pigs; 100 g/h-pig from 1600 to 0800 h for the RPK pigs; and 130 g/h-pig from 2100 to 0900 h for the RNT pigs. The dynamic feed intake patterns for the CON and RNT pigs were somewhat similar to those found by Feddes and DeShazer (1988) and Hahn et al. (1987) based on Feddes data. Despite the compensatory

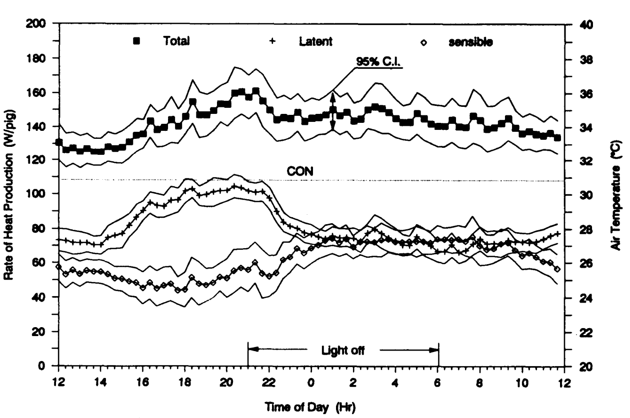

Figure 2a–Twenty-min total heat production, latent heat loss and calculated sensible heat loss for the 30.8° C constant temperature (CON).

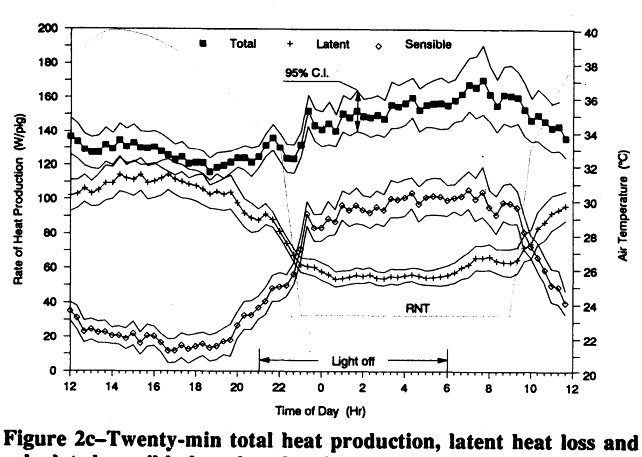

Figure 2c–Twenty-min total heat production, latent heat loss and calculated sensible heat loss for the reduced night temperature of 23.4° to 40°C (RNT).

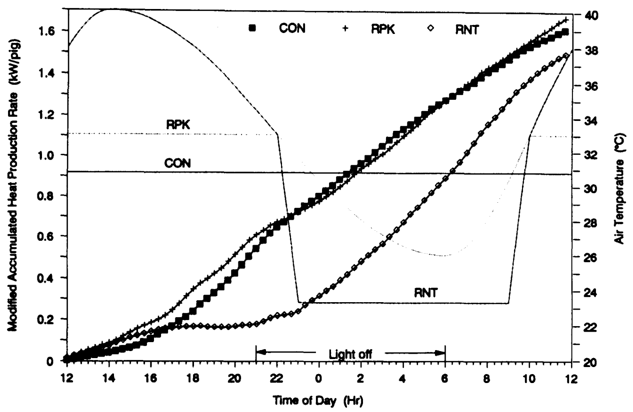

Figure 3a–Accumulated total heat production above a baseline of 120 W/pig for the constant and cyclic temperature treatments.

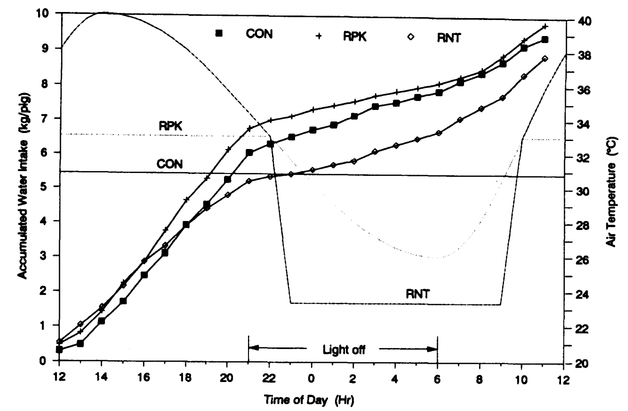

Figure 3c–Accumulated water usage for the constant and cyclic temperature treatments.

higher feed intake rate of the RNT pigs during the cooler hours of 2100 to 0900 h, it did not overcome the decreased feed intake of the pigs during the high temperature period. Scott et al. (1983) indicated that increasing diurnal cycle range for mean temperatures above the thermoneutral zone allowed non-lactating Holstein cows to more easily dissipate excess body heat accumulated during the day and minimize the thermal inhibition on feed intake. Hahn et al. (1975) reported compensatory feed intake and growth of growing pigs within 20 days after removal from moderate heat stress (30° to 33° C). However, feed intake data of the present study implied that 130-135 g/h-pig appeared to be the limit of hourly feed intake of 40-kg pigs. Thus the pigs were not able to compensate for the depressed feed intake and consequently failed to meet the daily energy intake requirement for maximum growth.

It seemed that if the accumulated feed intake curve of the RNT pigs could be extended about two more hours into the afternoon, allowing for a total of 14 hours (vs. 12 hours) of high feed intake, the RNT pigs might have been able to compensate for their feed intake loss. Increasing energy content of the diet for the RNT pigs might also lead to improved energy retention for the pigs.

All pigs showed a decline in feed intake when lights were off (fig. 3b). The decrease in feed intake continued until the lights were switched on the next morning for the CON pigs. But for the RPK and RNT pigs, this trend lasted only approximately one hour. This incidence indicated that darkness reduced eating in all, but that other stimuli associated with need to eat may have overridden the normal sleeping or reduced feed intake for the RPK and RNT pigs. In fact, it would be of interest to study the eating behavior under continuous lighting.

The CON and RPK pigs had similar cumulative feed intake (CFI) for the first hour (fig. 3b). However, after 1200 h the CON pigs continued to have a higher CFI than the RPK pigs until the next day at about 300 h, at which both CON and RPK pigs reached similar CFI. The RPK pigs had a slightly greater daily feed intake. The rate of feed intake for the RPK pigs became higher than the CON pigs at about 2200 h, when the air temperature started to decline for the RPK treatment. Thus the slightly higher daily feed intake of the RPK pigs was believed to be the result of the lower air temperature during the period from 2200 to 0900 h. Figure 4 shows that the period of higher than average feed intake for the RPK pigs almost equaled the combined periods of higher feed intake for the CON and RNT pigs. This extended period of higher than average feed intake indicates a more consistent feeding over time for the RPK treatment than for the CON and RNT treatments. This may have the advantage of having a more

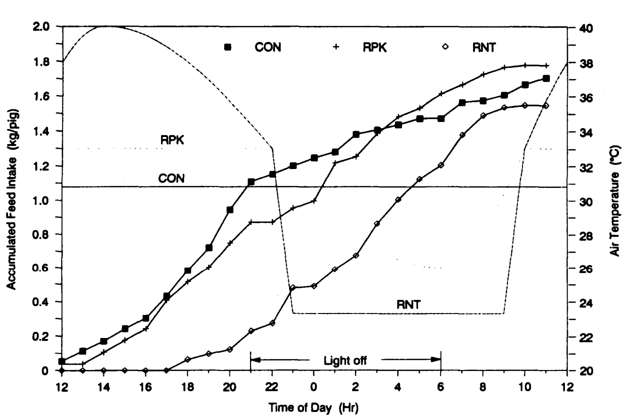

Figure 3b–Accumulated feed intake for the constant and cyclic temperature treatments.

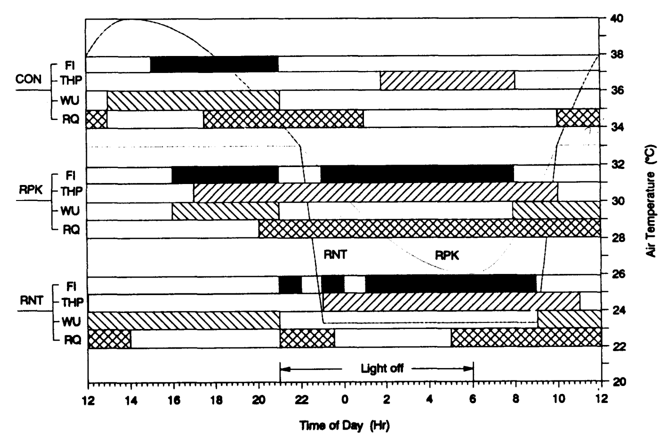

Figure 4–Daily time zones of higher than average (shade) and lower than average (open) responses for the constant and cyclic temperature treatments. (FI – feed intake; THP – total heat production rate; WU – water usage; RQ – respiratory quotient).

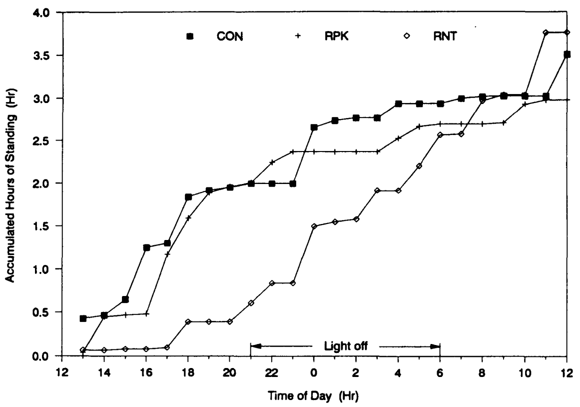

Figure 5–Accumulated standing hours during the 24-h exposure for the *6th* trial pigs.

constant calorigenic effect of feed assimilation, thus reducing peak heat production and therefore heat stress.

There were no significant differences (P > 0.10) in daily water usage for all treatments, although the RPK and CON pigs had slightly greater usage compared to the RNT pigs (Table 3). Some water was wasted during each drink due to playing. Therefore, water consumption was difficult to measure and the values represent water disappearance.

Darkness decreased water usage, as was the case with feed intake. However, in contrast to the increase in feed intake by the RPK and RNT pigs shortly after darkness, water usage remained relatively low during the dark periods. The lower water usage of the RPK and RNT pigs was believed to be driven by the lower ambient temperature during this period. The CON pigs during this period had a lower water usage and feed intake. Hence, it appeared that water usage by the CON pigs was more light dependent, while water usage by the RPK and RNT pigs was more temperature dependent.

Pigs for all three temperature regimens had almost identical average THP, LHL and SHL (Table 2). However, differences in the dynamic heat losses existed among the treatments (fig. 2). SHL and LHL by the RNT pigs fluctuated the most, while SHL and LHL by the CON pigs fluctuated the least within the 24-h cycle. Fluctuation in SHL and LHL was associated with variation in the air temperature for the RPK and RNT treatments. In the case of the CON treatment, SHL was higher during the dark period than during the light period. The lower SHL and higher LHL of the CON pigs during the daytime may reflect the vaporization of water wasted on the floor during drinking activities. It was also hypothesized that the shell conductance of the pigs decreases during the daytime because of an adjustment in the distribution of blood. Such adjustment results in less circulation to the peripheral region and more blood flowing to the respiratory muscles and pathways, as stated by DeShazer et al. (1970) in delineating heat loss responses of the laying hen acclimated at 24° C and subjected to 35° C. The adjustment in blood distribution for the CON pigs would be caused by more daytime activity of the pigs.

The RNT pigs dissipated more heat during the cooler hours, when more feed was consumed. This dynamic heat production pattern was different from the pattern reported by Feddes and DeShazer (1988) for the 33 ± 7° C treatment which showed high heat loss during high temperature period and low heat loss during the low temperature period. However, the RNT treatment in this study had a wider temperature variation, lower average temperature and lower minimum temperature. The CON pigs dissipated more heat between evening and early morning, which agreed with the results of Feddes and DeShazer (1988) and van der Hel et al. (1983). The RPK pigs had the most consistent THP during the 24-h period. The dynamic patterns in THP were correlated with the feed intake patterns of the pigs. An increase in THP followed feed intake elevation with a time lag of two to three hours.

The RPK pigs had significantly higher metabolizable energy intake (ME) and calculated retained energy (RE) than the RNT pigs. ME and RE of the CON pigs were between those of the RPK and RNT pigs (Table 2) . The significantly higher ME and RE of the RPK pigs compared to the RNT pigs was due to the significantly higher feed intake and yet similar THP of the RPK pigs.

The RPK and CON pigs had significantly higher (P < 0.01) average daily gain (ADG) than the RNT pigs (Table 2). There was no significant difference in ADG between the RPK and CON pigs (P > 0.10). These relationships were consistent with the findings of Morrison et al. (1975) and Feddes and DeShazer (1988). The RPK pigs and the CON pigs had 20% and 16% respectively higher growth rate than the RNT pigs. The ADG relationships among the pigs coincided with those on daily feed intake, indicating that feed intake was the driving force to pig performance. Although the CON pigs showed a slightly higher average respiratory quotient (RQ), 1.2, than the RPK and RNT pigs, 1.1, no significant difference in RQ was detected (P > 0.10). However, if higher RQ is a reflection of faster growth, pigs under these treatments would have following dynamic faster growth period within the day (fig. 4): from 1700 h to midnight and 0930 to 1300 h for the CON treatment; from 1900 to 1200 h for the RPK treatment; from 2100 to 2330 h and from 0500 to 1400 h for the RNT treatment.

Feed conversion, averaging 2.1 to 2.2, was not affected by the treatments (Table 2). Partial efficiency of ME utilization for growth (K_g) was similar for the CON and RPK pigs (0.72 and 0.73). The RNT pigs had lower but not significantly different (P > 0.1) K_g of 0.66.

Although a significant difference (P < 0.01) in daily feed intake existed between the RNT pigs and the RPK or CON pigs, there were no significant differences (P > 0.1) detected in meal or drink size, duration, and frequency among the pigs (Table 3). However, the RPK and CON pigs tended to have smaller and more frequent meals (11 and 10) than the RNT pigs (9). Since the RPK and CON pigs had better performance than the RNT pigs, smaller and more frequent meals might enhance the daily feed intake and thus growth rate of the pigs. The enhancement of pig performance by smaller and more frequent meals in warm environments was also implied by Feddes (1986).

The feeding characteristics found in this study, i.e., meal size of 160-170 g/meal, meal duration of 13.3-14.3 min/meal and meal frequency of 9-11 meals/day, were similar to those reported by Bigelow and Houpt (1988) for 30-40 kg female pigs at air temperatures of 22 to 23° C (meal size of 166 g/meal; meal duration of 17.7 min/meal and meal frequency of 10.2 meals/day). These results also coincided with the eating behavior characterized by

Nienaber et al. (1988) for pigs of similar mass at air temperatures 4° C above the lower critical temperature. Thus, meal parameters of the growing pig appear not to be affected by air temperature levels.

The cumulative standing hours in the 24-h period for the last replicate (fig. 5) showed that the CON and RPK pigs tended to rest or lie more at night and in the morning. The RNT pig was rather active during these periods. This observation supported the general feeding behavior of the pigs.

Conclusions

Energetic and behavioral responses of *ad libitum* fed growing pigs (39 ± 2 kg crossbred gilts) were compared under constant temperature of 30.8° C (CON), reduced daytime peak temperature cycling from 26° to 33° C with mean of 30.8° C (RPK), and reduced nocturnal temperature cycling from 23.4° to 40° C with mean of 30.8° C (RNT). The following conclusions were drawn.

- Daily average feed conversion, heat production rates, and respiratory quotient of the CON pig can be used to predict those of the RPK and RNT pigs.
- Feeding and drinking behavioral characteristics of meal and drink size and duration of pigs under the constant mean temperature can be used to predict those of pigs under the cyclic temperatures. However, feeding frequency of the RNT pigs tended to be less than that of the CON or RPK pigs.
- A cycle range of 16.6° C depresses feed intake and growth of 39 (± 2) kg pigs when the mean temperature is 31° C. Thus cycle range of this magnitude or greater should be avoided when planning summer cooling schemes.
- Dynamic feed intake and heat production distributions are influenced by cycle ranges. The cycle range of 16.6° C resulted in the most fluctuating temporal distributions in the energy exchange rates.

Potential Practical Impact of the Findings

Exposure of growing pigs to continuously elevated air temperature for 12 to 15 hours per day may impair feed intake and growth. Compensation in feed intake during 9 to 12 hours at thermal neutral conditions may be inadequate for a total heat stress recovery. Reducing daytime peak temperature and thus narrowing the cycle range is more conducive to pig growth than lowering nighttime temperature. Although not tested, intermittent cooling during high temperatures may be beneficial.

During cooler periods the RNT pigs will eat a meal of 170 g for 13.5 minutes approximately every 60 minutes. Therefore, a maximum of four pigs could be accommodated for each feeder hole to assure that the pigs will have adequate feeder access time, assuming they eat in "shifts". Further study of alternative modifications of the RNT pattern, e.g., extending cooling period into the hot afternoon, is needed as well as the use of different lighting patterns and high energy content diet to increase ME and thus RE of the RNT pigs. Average energetic responses of heat loss rates, partial efficiency of ME utilization, RQ, and feed conversion for growing pigs under cyclic temperatures may be simulated by those under the mean temperature of the cycle. However, daily feed intake and growth rate of the pigs depend on the particular pattern of the cyclic temperature, e.g., the range of the cycle.

References

AGNET. 1984. Nebraska automated weather data network. Center for Agricultural Meteorology and Climatology, University of Nebraska, Lincoln.

Bigelow, J. A. and T. R. Houpt. 1988. Feeding and drinking patterns in young pigs. *Physiology and Behavior* 43:99-109.

Bond T. E., C. F. Kelly and H. Heitman, Jr. 1963. Effect of diurnal temperature on heat loss of swine. *Transactions of the ASAE* 6(3):132-135.

Brumm, M. C. and D. P. Shelton. 1988. A modified reduced nocturnal temperature regimen for early weaned pigs. *J. Anim. Sci.* 66:1067-1072.

DeShazer, J. A., K. A. Jordan and C. W. Suggs. 1970. Effect of acclimation on partitioning of heat loss by the laying hen. *Transactions of the ASAE* 13(1):82-84.

Feddes, J. J. R. 1986. The response of growing pigs to high cyclic and constant temperatures. Unpublished Ph.D. diss., University of Nebraska, Lincoln.

Feddes, J. J. R. and J. A. DeShazer. 1988. Energetic responses of growing and constant temperatures. *Transactions of the ASAE* 31(4):1203-1210.

Hahn, G. L., J. A. Nienaber and J. A. DeShazer. 1987. Air temperature influences on swine performance and behavior. *Transactions of the ASAE* 3(2):295-302.

Hahn, G. L., N. R. Meador, D. G. Stevens, M. D. Shanklin and H. D. Johnson. 1975. Compensatory growth in livestock subjected to heat stress. ASAE Paper No. 75-4008. St. Joseph, MI: ASAE.

Morrison, S. R., H. Heitman, Jr. and R. L. Givens. 1975. Effect of diurnal air temperature cycles on growth and feed conversion in pigs. *Anim. Prod.* 20:287-291.

Nienaber, J. A. 1988. Personal Communication.

Nienaber, J. A., G. L. Hahn, H. G. Klemcke, B. A. Becker and F. Blecha. 1989. Cyclic temperature effects on growing-finishing swine. *J. Therm. Biol.* 14(4):233-237.

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

Scott, I. M., H. D. Johnson and G. L. Hahn. 1983. Effect of programmed diurnal temperature cycles on plasma thyroxine level, body temperature, and feed intake of Holstein dairy cows. *Int. J. Biometeor.* 27(1):47-62.

Thorbek, G., A. Chwalibog and S. Henckel. 1984. Nitrogen and energy metabolism in pigs of Danish landrace from 20 till 120 kg live weight norm for protein and energy requirement for maintenance and growth. Report No. 563. The National Institute of Animal Science, Denmark.

van der Hel, W., M. W. A. Verstegen and W. Baltussen. 1984. The effect of ambient temperature on diurnal rhythm in heat production and activity in pigs kept in groups. *Int. J. Biometeorol.* 28(4):303-315.

Xin, H. 1989. Energetics, behavior and performance of growing swine at constant and cyclic high temperatures. Unpublished Ph.D diss., University of Nebraska, Lincoln.