

EFFECTS OF FLUCTUATING TEMPERATURES ON ISOWEAN PIGS

H. Xin, Q. Zhang, M. C. Puma, J. D. Harmon, D. L. Harris, M. L. Gramer

ABSTRACT. *This study quantifies responses of isowean pigs (10 to 12 days of age, PIC breed) to potential in-transit temperature fluctuations for 54 h, followed by a 14-day growth period under thermoneutrality. The 54-h temperature regimens included a constant air temperature of 26.7°C (as control) and three cyclic air temperatures of $26.7 \pm 2.8^\circ\text{C}$, $26.7 \pm 5.6^\circ\text{C}$ and $26.7 \pm 8.3^\circ\text{C}$, all using woodshavings bedding atop rigid board insulation. The pigs received an average dosage of 0.91 kg/pig water replacement supply during the 54-h treatment period, and ad-libitum feeding and watering during the growth period. Pigs in all three treatments and the control had similar growth performance, physiological, and energetic responses during both treatment and growth periods. At the end of the treatment period, the pigs had elevated concentrations of hematocrit, plasma protein, blood urea nitrogen, sodium and chloride, but declined concentration of glucose ($P < 0.05$). Potassium and bicarbonate levels remained relatively constant ($P > 0.05$). Concentrations of the blood constituents returned to normal during the growth period. The results suggest that the isowean pigs respond well to air temperature fluctuations of up to $\pm 8.3^\circ\text{C}$ around the thermoneutral condition of 26.7°C air temperature coupled with woodshavings bedding.*

Keywords. *Transportation, Cyclic temperature, Isowean pigs, Physiological responses, Bioenergetics.*

A previous study conducted in our laboratory revealed that isowean PIC pigs cope well with postweaning nutritional conditions that may be encountered during extended overseas shipment journeys (Xin et al., 1999). In-transit supply of water replacement was beneficial in alleviating dehydration of the animals. The study was performed at the constant thermoneutral (TN) condition of 26.7°C air temperature and floor bedding of woodshavings to avoid possible interference of thermal factors and the nutritional regimens.

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The authors are **Hongwei Xin, ASAE Member Engineer**, Associate Professor, Agricultural and Biosystems Engineering Dept., Iowa State University; **Qiang Zhang, ASAE Member Engineer**, Associate Professor, Biosystems Engineering Dept., University of Manitoba, Canada (former visiting Associate Professor at Iowa State University); **Jay D. Harmon, ASAE Member Engineer**, Associate Professor, **Manuel C. Puma, ASAE Member Engineer**, Post-doctoral Research Associate, Agricultural and Biosystems Engineering Dept., **D. L. Hank Harris**, Professor, Microbiology Dept. and Veterinary Diagnostic and Production Animal Medicine Dept., Iowa State University; and **Marie L. Gramer**, PIC-USA, Franklin, Ky. **Corresponding author:** Hongwei Xin, Iowa State University, 203 Davidson Hall, Ames, IA 50011-3080, phone: 515.294.9778, fax: 515.294.9973, e-mail: <hxin@iastate.edu>.

Aqua-Jel® is a commercial, jelly-type water supplement designed for use in transport of certain animals (Transport Container Corporation, Columbus, Ohio). It contains more than 93% water, hydrocolloid, phosphoric acid, and potassium sorbate with a pH of 3.2. The product has been used as an effective water replacement for transport of breeder chicks (Xin and Lee, 1996). It was also used in our previous study on nutritional feasibility of transporting isowean pigs (Xin et al., 1999).

Having investigated the effects of the nutritional regimens on the ability of the pigs to cope with the potential long journeys, the next logical step would be to quantify the responses of the pigs to possible in-transit thermal fluctuations as seen for air shipment of day-old breeder chicks (Xin and Rieger, 1995). These unique, in-transit thermal fluctuations seldom occur in typical production facilities for young animals. Literature reports on the effects of fluctuating temperatures on pigs have dealt with pigs older than four weeks of age (Bond et al., 1963; Bond et al., 1967; Morrison et al., 1975; Brumm and Shelton, 1988; Feddes and DeShazer, 1988; Giles et al., 1988; Minton et al., 1988; Nienaber et al., 1989; Lopez et al., 1991a,b; Xin and DeShazer, 1991). An animal's ability of thermoregulation largely depends on its age, and directly referring to the literature data for this unique situation may lead to erroneous conclusions. Moreover, the magnitude and temporal patterns of the thermal fluctuations examined in this study differ considerably from those reported in the literature.

The objective of this study was to examine the effects of potential in-transit fluctuating air temperatures on the performance, physiology, and energetics of isowean pigs.

MATERIALS AND METHODS

AIR TEMPERATURE REGIMENS AND HANDLING OF THE EXPERIMENTAL PIGS

Four pig-level temperature regimens were examined: constant temperature of 26.7°C and three cyclic temperatures of $26.7 \pm 2.8^\circ\text{C}$ (time weighted average, TWA, of 26.3°C), $26.7 \pm 5.6^\circ\text{C}$ (TWA of 26.0°C), and $26.7 \pm 8.3^\circ\text{C}$ (TWA of 25.6°C). Relative humidity (RH) at 26.7°C averaged 35% and was allowed to vary as temperature cycled. The actual temperature profiles achieved were somewhat different from the target values

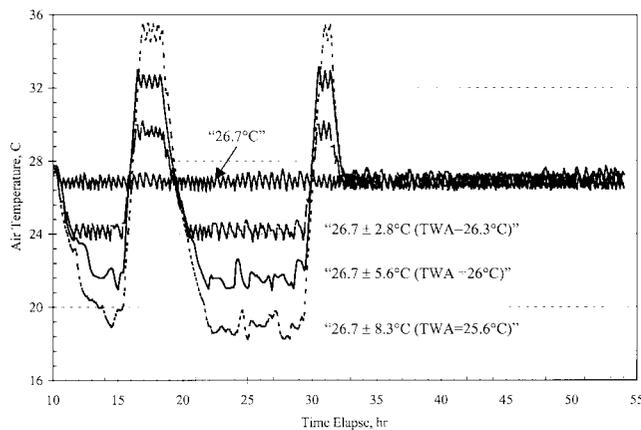


Figure 1—Example air temperature profiles achieved inside the calorimeter chambers (TWA = time weighted average).

(fig. 1). Air draft at the pig level was less than 0.15 m/s. Floor bedding as used in the previous study (Xin et al., 1999) was used during the treatment period, and was formed with woodshavings (5 to 7.5 cm thick) atop rigid insulation board (2.5 cm thick, $R = 0.88 \text{ m}^2 \cdot \text{C} \cdot \text{W}^{-1}$).

Three trials were conducted during the period of January to April 1999. Each trial used 60 isowean barrows (10 to 12 days of age, PIC breed) that were transported by a nursery truck from a PIC breeder farm in Minnesota to the Livestock Environmental and Animal Physiology (LEAP) Research Laboratory of Iowa State University in Ames, Iowa. Upon arrival, the pigs were individually weighed and randomly assigned to four environment-controlled indirect calorimeter chambers, 15 pigs per chamber. The average initial body mass (IBM) was equalized among the chambers. Each chamber had a specific temperature regimen that lasted for 54 h (including the ground transport time of 6.5 to 7 h). During the treatment period, each chamber was provided with 13.6 kg of Aqua-Jel (AJ) water replacement that was placed in a wooden trough along a sidewall of the chamber (fig. 2). The amount of AJ supply provided was based on its consumption during the previous study on nutritional

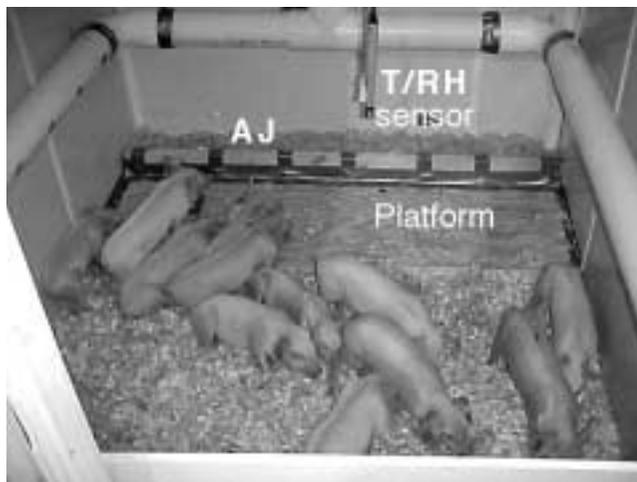


Figure 2—An interior view of the calorimeter chamber during the treatment period, showing the Aqua-Jel (AJ) placement, the platform for AJ supply, and floor bedding.

feasibility with the same type of isowean pigs (Xin et al., 1999). A wooden platform for accessing the AJ supply was used to minimize the bedding materials from being mixed into the AJ. Darkness was used during the treatment period to reflect commercial transport situations, except that a 15-W red light was used for visual observation of the pigs during this period.

Following the temperature treatments was a 14-day subsequent growth period, during which the pigs were reared on plastic-coated expanded wire floor with free access to feed and water. Below the floor was a pull-plug manure pit, as commonly used in commercial nursery facilities. Air temperature near the pig level was maintained constant at $28.9 \pm 0.5^\circ\text{C}$ during the first week of growth period and $27.8 \pm 0.5^\circ\text{C}$ during the second week. RH during the growth period ranged from 35 to 55%. Lighting (27 lux) was continuous for the first two days of the growth period and 12L:12D thereafter. The chambers were cleaned weekly (i.e., the manure pit emptied and refilled with clean water) to maintain adequate air quality inside the chambers.

Upon switching from treatment to growth phase, the pigs were allowed about one hour to access drinking water, and then feed was introduced. To prevent excessive eating, limited amount of feed (1.0 kg/chamber) was provided initially. Thereafter, feed was added every four hours during the first two days (except for nighttime), followed by less frequent but larger quantities of feed addition. Two types of commercial isowean diets, similar to those used in the previous study (Xin et al., 1999), were used. The first diet, averaging 1.14 kg of feed per pig, had a metabolizable energy (ME) content of 14.8 MJ/kg and a protein content of 22.1%. The second diet, used for the remaining growth period, had a ME content of 14.9 MJ/kg and a protein content of 21.6%.

RESPONSE VARIABLES MEASURED OR DERIVED

Body mass (BM) of the pigs was measured with an electronic weighing scale ($\pm 20 \text{ g}$ resolution) individually before the treatment, at end of the treatment, and at end of the first and second week of growth period. BM loss or gain during the respective periods then was derived. Analyses of hematology and blood chemistry performed included hematocrit, plasma protein, blood urea nitrogen (BUN), glucose, and Na^+ , K^+ , Cl^- , and HCO_2^- contents. Samples of whole blood (i.e., blood not allowed to clot) and serum (i.e., blood allowed to clot and serum removed) were obtained from five randomly selected pigs in each regimen just before the treatment, at end of the treatment, and at end of the two-week growth period (see Xin et al., 1999, for blood sampling procedure). The collected samples were immediately delivered to the Iowa State University Animal Pathology Laboratory for analysis. Weekly feed intake and feed conversion (FC) during the growth period were determined on the group basis. Total heat production rate (THP, W/kg), moisture production rate (MP, g $\text{H}_2\text{O}/\text{kg}\cdot\text{h}$), sensible heat production rate (SHP, W/kg), and respiratory quotient (RQ) were determined at 30-min intervals throughout the trial period using indirect calorimetry (see Xin and Harmon, 1996, for description of the ISU indirect calorimeter system and the calculation equations). Resting behaviors of the pigs during the treatment periods were recorded at one-hour intervals with

programmable 35 mm cameras (Canon model T70 with command back) viewing the entire floor area. Mortality and morbidity (such as pigs with deteriorating BM or unhealthy appearance) also were monitored.

The response variables were subjected to analysis of variance (ANOVA) and multiple means comparisons following an arrangement of complete randomized block design.

RESULTS AND DISCUSSION

TREATMENT EFFECTS ON BM AND FC

BM at different stages of the trial, BM gain or loss, and FC of the pigs are summarized in table 1. Pigs in all the temperature regimens had the similar BM loss of 0.34 to 0.36 kg/pig or 8.4 to 8.9% of IBM during the treatment period. BM gain during the first-week growth period also was similar, averaging between 1.43 and 1.51 kg/pig or 39 and 41% of the weekly beginning BM (WBBM). Differences in BM gain were noticed during the second-week growth. Pigs previously exposed to the 26.7°C or 26.7 ± 5.6°C regimen showed higher BM gain (2.64 kg/wk; 51~52% WBBM) than pigs previously exposed to 26.7 ± 2.8°C or 26.7 ± 8.3°C regimen (2.30 to 2.44 kg/wk; 45~47% WBBM) ($P < 0.05$). Overall, pigs previously exposed to 26.7 ± 8.3°C showed slower gain (3.78 kg; 103% IBM) than those previously exposed to 26.7 ± 5.6°C (4.15 kg; 113% IBM) ($P < 0.05$). However, there was no significant difference in overall BM gain among the regimens of 26.7°C, 26.7 ± 2.8°C and 26.7 ± 8.3°C or among 26.7°C, 26.7 ± 2.8°C, and 26.7 ± 5.6°C ($P > 0.05$). There also were no significant differences in FC among the regimens for the overall 14-day growth period ($P > 0.05$). The reason for the BM gain difference between 26.7 ± 5.6°C and 26.7 ± 8.3°C regimens was not directly apparent to the authors. This difference might have disappeared with longer growth time. BM gain and FC in

the present study were similar to those found in the previous study (Xin et al., 1999).

TREATMENT EFFECTS ON PHYSIOLOGICAL RESPONSES OF THE PIGS

The results of blood analyses for various experimental stages are summarized in table 2. There were no significant treatment effects on any of the response variables ($P > 0.05$) during both the treatment period and the growth period. However, exposure to the treatment duration (54 h) led to elevated concentrations of hematocrit, plasma protein, BUN, sodium, and chloride ($P < 0.05$), but declined concentration of glucose ($P < 0.05$). Concentrations of potassium and bicarbonate remained relatively constant ($P > 0.05$). The slight elevation of hematocrit, sodium, and chloride concentrations during the treatment period was presumably an effect of dehydration. The marked increase in BUN concentration is an indication that the pigs were degrading protein to supply energy to meet their energy needs and offset the decline in glucose concentration. The glucose content measured in the current study (104 mg/dl) was considerably higher than the generally recognized hypoglycemic level of 75 mg/dl (Swiatek et al., 1968). The blood concentrations returned to normal during the growth period. These results agreed well with those of the previous study (Xin et al., 1999).

TREATMENT EFFECTS ON ENERGETICS OF THE PIGS

The average THP (W/kg), MP (g/kg-h), SHP (W/kg), and RQ (VCO_2/VO_2) of the pigs for the treatment and growth periods are shown in table 3. Daily mean THP and MP are plotted in figure 3. As found with the physiological responses, there were no significant treatment effects on any of the energetic responses ($P > 0.05$) during both the treatment and the subsequent growth period. The lower THP during the treatment period presumably resulted from

Table 1. Body mass (BM) and feed conversion (FC) of isowean PIC pigs during and subsequent to simulated in-transit air temperature regimens*†

Period	54 h Temp. Regimen	BM (kg)		BM Gain (kg)				FC (Feed/Gain)	
		Mean	S.D.	Mean	S.D.	Pct	S.D.	Mean	S.D.
Initial	26.7°C	4.03	0.47						
	26.7 ± 2.8°C	4.03	0.55						
	26.7 ± 5.6°C	4.02	0.52						
	6.7 ± 8.3°C	4.03	0.54						
54 h (Treatment)	26.7°C	3.68	0.47	-0.34	-0.11	-8.6%	-2.9%		
	26.7 ± 2.8°C	3.69	0.52	-0.34	-0.09	-8.4%	-2.2%		
	26.7 ± 5.6°C	3.67	0.47	-0.35	-0.11	-8.7%	-2.9%		
	26.7 ± 8.3°C	3.67	0.52	-0.36	-0.09	-8.9%	-2.3%		
1st week (Growth)	26.7°C	5.11	0.68	1.43	0.36	39%	9%	0.91	0.12
	26.7 ± 2.8°C	5.19	0.74	1.48	0.43	40%	10%	0.91	0.02
	26.7 ± 5.6°C	5.18	0.72	1.51	0.43	41%	11%	0.84	0.05
	26.7 ± 8.3°C	5.15	0.81	1.48	0.37	41%	9%	0.87	0.04
2nd week (Growth)	26.7°C	7.76	1.03	2.64 ^a	0.44	52% ^a	6%	1.11 ^a	0.08
	26.7 ± 2.8°C	7.64	1.08	2.44 ^b	0.47	47% ^b	8%	1.26 ^b	0.03
	26.7 ± 5.6°C	7.84	1.21	2.64 ^a	0.63	51% ^a	11%	1.18 ^{a,b}	0.07
	26.7 ± 8.3°C	7.45	1.20	2.30 ^b	0.54	45% ^b	8%	1.22 ^{a,b}	0.07
Overall	26.7°C			4.07 ^{a,b}	0.72	111% ^{a,b}	18%	1.02	0.07
	26.7 ± 2.8°C			3.92 ^{a,b}	0.82	107% ^{a,b}	22%	1.10	0.03
	26.7 ± 5.6°C			4.15 ^a	0.89	113% ^a	22%	1.05	0.06
	26.7 ± 8.3°C			3.78 ^b	0.83	103% ^b	19%	1.08	0.02

* The pigs were provided with Aqua-Jel water replacement during treatment period and fed *ad libitum* during growth period. Air temperature was 28.9°C and 27.8°C, respectively, during the first and second week of growth.

† For the specific treatment or growth period, column means with different superscript letters were significantly different ($P < 0.05$); unlabeled means were not significantly different ($P > 0.05$).

Table 2. Serological responses of isowean pigs (PIC breed) during and subsequent to simulated in-transit air temperature regimens*†

Serological Variable	Initial		54 h		2nd week	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Hematocrit (%)	34.2 ^b	2.2	38.5 ^a	2.0	32.5 ^c	2.7
Plasma protein (g/dl)	6.3 ^b	0.4	7.0 ^a	0.5	5.1 ^c	0.4
BUN (mg/dl)	8.8 ^b	2.8	29.8 ^a	7.5	8.2 ^b	1.7
Glucose (mg/dl)	121.8 ^a	9.9	103.9 ^b	16.5	122.7 ^a	11.5
Sodium (mEq/l)	141.3 ^b	2.6	146.5 ^a	5.0	140.2 ^b	1.8
Potassium (mEq/l)	5.0 ^b	0.5	5.0 ^b	0.5	5.7 ^a	0.6
Chloride (mEq/l)	104.9 ^b	2.1	108.6 ^a	4.5	101.2 ^c	2.9
Bicarbonate (mEq/l)	21.4 ^b	1.8	22.0 ^b	2.4	23.8 ^a	2.0

* There was no significant difference among the groups ($P > 0.05$) within the treatment or growth period. Thus, only means were presented.

† For each response variable, row means with different superscript letters were significantly different between the trial stages ($P < 0.05$).

Table 3. Energetic responses of isowean pigs (PIC breed) during simulated in-transit air temperature regimens and subsequent growth under thermoneutrality*

Trial Period	BM (kg)		THP (W/kg)		MP (g/h·kg)		SHP (W/kg)		RQ	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
54 h	3.85	0.51	4.2	1.4	4.3	1.8	1.3	0.9	0.82	0.12
1st week	4.42	0.62	4.8	1.7	3.8	1.4	2.3	0.9	0.89	0.12
2nd week	6.41	0.93	4.8	1.3	3.5	1.2	2.4	0.7	0.98	0.12

* There was no significant difference among the groups ($P > 0.05$) within the treatment or growth period. Thus, only means were presented.

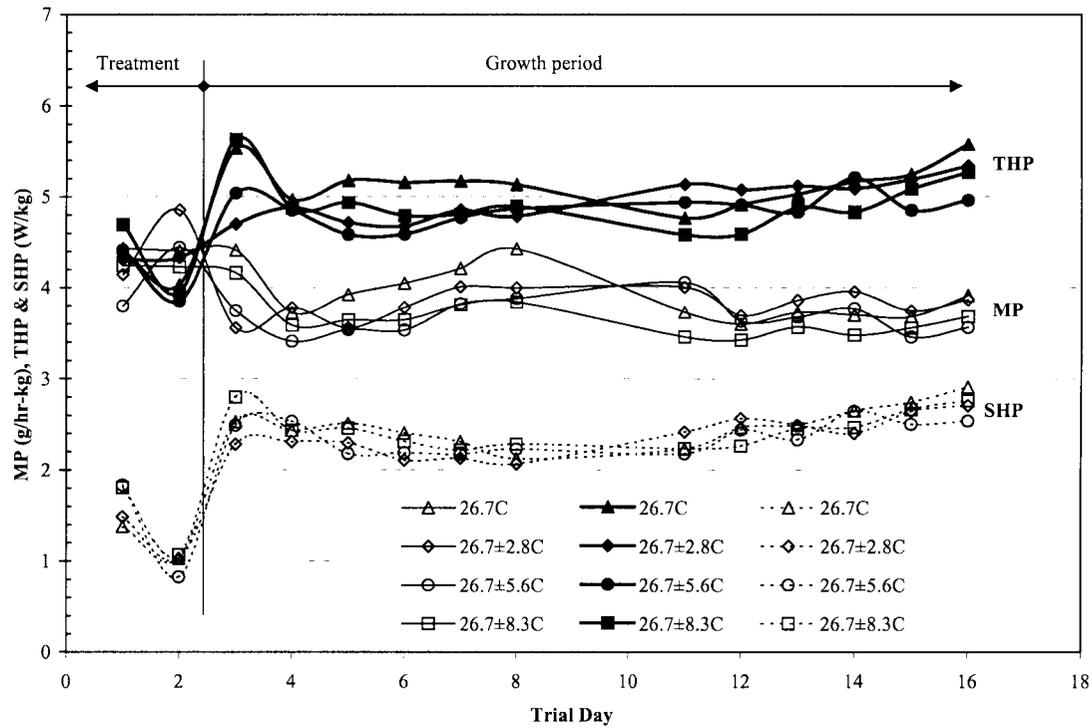


Figure 3—Daily mean moisture productions rate (MP), total heat production rate (THP), and sensible heat production rate (SHP) of isowean pigs during the 54-h temperature treatment period with water supply only and the subsequent growth period under thermoneutrality with *ad-libitum* feeding.

the absence of external energy supply and a relatively undeveloped metabolic system of the pigs. Results of the isowean pig energetics obtained from the current study compared favorably with those obtained in the previous studies from this laboratory (Harmon et al., 1997; Xin et

al., 1999). Dynamic responses of THP and SHP to the temperature variation are illustrated in figure 4 for pigs exposed to the $26.7 \pm 8.3^{\circ}\text{C}$ regimen. Note that THP during the cooler (18°C) period of the cycle was maintained nearly at the same level as that during the constant TN

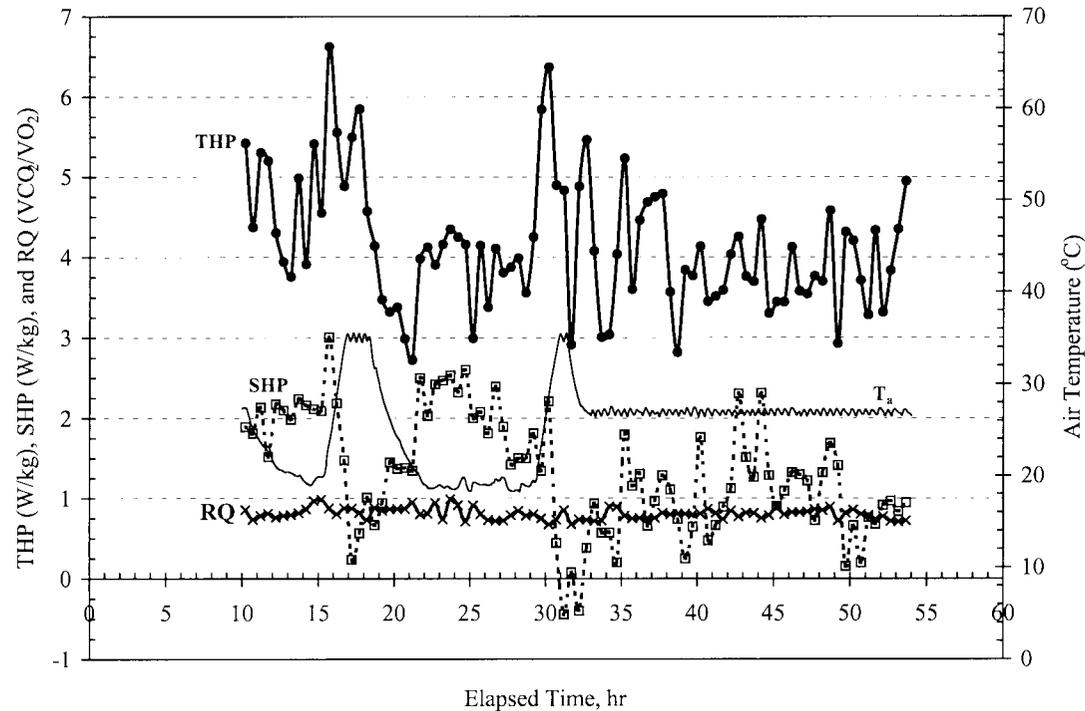


Figure 4—Dynamic total heat production rate (THP), sensible heat production rate (SHP), and respiratory quotient (RQ) of isowean pigs during exposure to cyclic temperature (T_a) of $26.7 \pm 8.3^{\circ}\text{C}$.

(27°C) period. This outcome was presumably attributed to the huddling behavior of the pigs under the cooler conditions (as shown in the next section). The elevated THP of these fasting pigs during the warm/hot period of the cycle was consistent with the phenomenon of increased metabolic rate for fasting animals subjected to hot conditions (DeShazer and Overhults, 1982). SHP was negatively related to air temperature, as expected. Note that SHP of the present study accounted for both SHP by the pigs and the heat needed to evaporate water, and consequently its magnitude was reduced during the high

temperature periods when more evaporation occurred. SHP obtained as such more truly reflects production conditions, thereby providing more realistic data for ventilation design of shipment facilities.

BEHAVIORAL RESPONSES TO TREATMENT TEMPERATURES

A series of representative images depicting postural patterns of the pigs at selected temperatures and times of the treatment period, captured using the programmable cameras, are shown in figure 5. Pigs generally take the posture of nearly touching one another on the side when

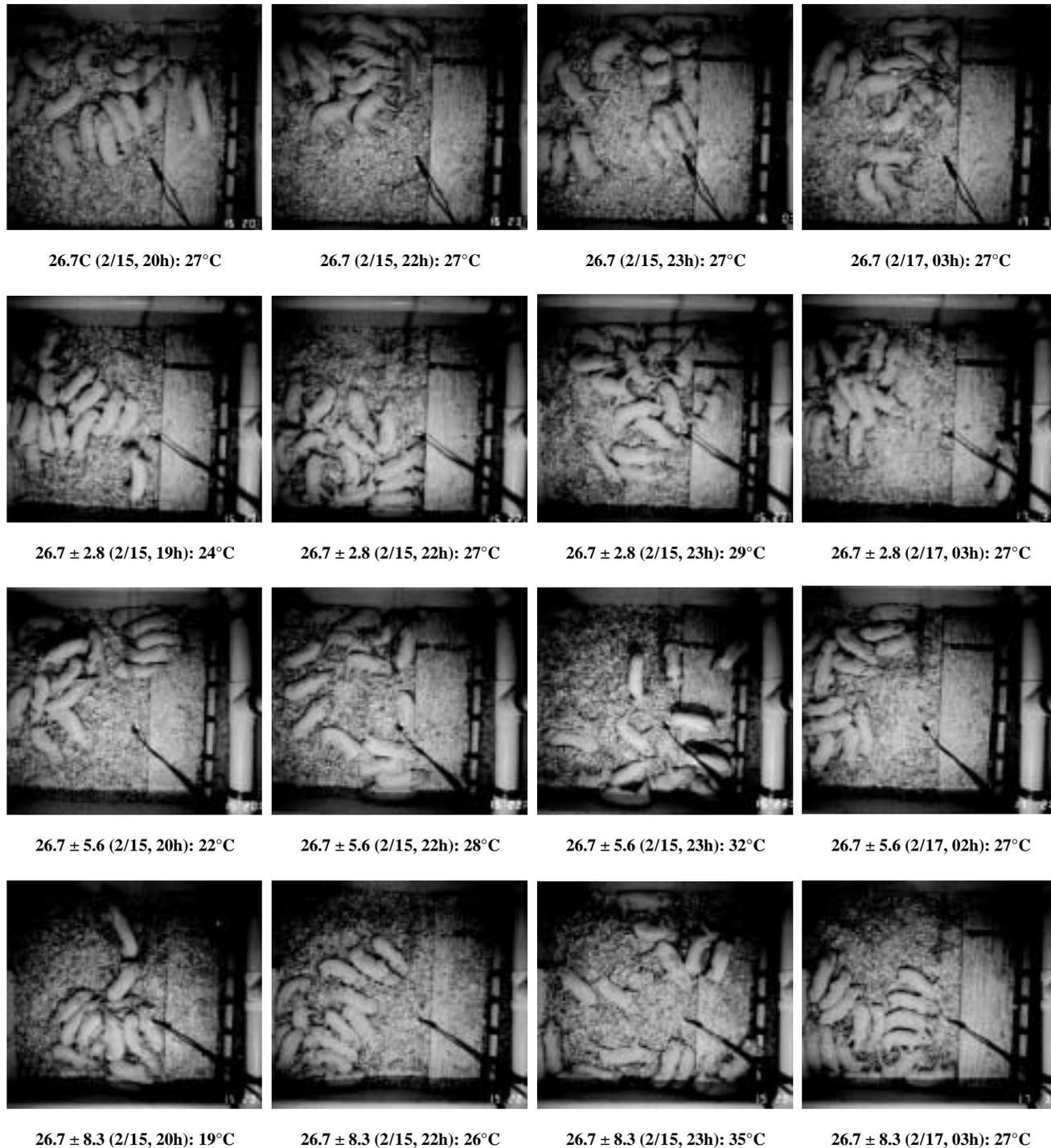


Figure 5—Resting patterns of isowean pigs at various times of the constant (26.7°C) and cyclic (26.7 ± 2.8, 5.6, or 8.3°C) temperature regimens. The exposure started at 15h on 15/2/99.

comfortable, huddling when cold, and spreading out when too warm or too hot (Mount, 1968). Using these comfort behavior criteria, it can be seen that with the bedded flooring of the present study, air temperatures of 24 to 29°C seem to be within the zone of thermoneutrality for these pigs. By comparison, air temperatures of 21°C or lower would be cool or cold, and air temperatures of 32°C or higher would be warm or hot. However, the physiological, energetic, and performance responses of the pigs suggest that the pigs coped well with the intensity (i.e., magnitude and duration) of the thermal fluctuations. The huddling behavior could have contributed to the maintenance of relatively constant THP at the lower air temperatures as compared with that at the TN conditions (fig. 4).

BELLY NOSING (BN) BEHAVIOR

Occasional, visual observations of the pigs revealed the existence of BN behavior, as had been seen in the previous study (Xin et al., 1999). Also as previously observed, this behavior generally started within two days into the growth period. The intensity of BN behavior tended to increase with time initially and then gradually diminished (by 2 weeks of time). There was no clear indication that the BN was treatment specific. The behavior did not seem to adversely affect performance of the pigs, which agreed with the report by Borgman et al. (1998) and our previous experience (Xin et al., 1999).

MORTALITY AND MORBIDITY

There was no mortality for all the trials. One morbid pig in the 26.7 ± 2.8°C regimen (trial no. 1, IBM of 2.88 kg) and two morbid pigs in the 26.7 ± 8.3°C regimen (trials no. 1 and no. 3) were culled during the first-week growth period. Diagnosis by the ISU Veterinary Diagnostic Lab revealed that the two pigs from trial no. 1 had moderate bacterial pneumonia and the pig from trial no. 3 had septicemia due to *Streptococcus equisimilis*.

CONCLUSIONS

Isowean pigs (10 to 12 d of age, PIC breed) responded well to simulated, potential in-transit air temperature fluctuations of up to ±8.3°C around a baseline temperature of 26.7°C on insulated, bedded floor. Although pigs previously exposed to the 26.7 ± 8.3°C regimen showed a somewhat lower body mass gain during the 14-day subsequent growth period under constant thermoneutral conditions, physiological and energetic measurements all indicated no adverse effects of the treatment. Postural thermoregulation and energetic reactions of the pigs to the thermal condition changes were apparent.

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