Resting Behavior Indexes for Thermal Comfort Assessment of Young Pigs

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Summary and Implications

Nursery pigs (4 to 7 week old, weighing 7 to 15 kg or 16 to 32 lb) were exposed to 20 combinations of five air temperatures (20, 24, 28, 32, and 36°C; 68, 75, 82, 90, and 97°F) by four air velocities (0.1, 0.5, 1.0, and 1.5 m/s; 20, 100, 200, 300 ft/min). An infrared thermal imager (0.06°C or 0.1°F sensitivity) was used to simultaneously quantify resting pattern and surface temperature (T_s) of the pigs. Three postural behavior indexes were examined to represent thermal comfort level of the pigs; namely, the ratio of occupied floor area (A_p) to total surface area of the pigs – index I_a, the ratio of A_p to its maximum theoretical value – index I_f, and A_p per 100 kg body weight – index $A_{p(100kg)}$. The pigs showed a common range of I_a = 0.20 to 0.24, I_f = 0.75 to 0.84, and T_s = 34.5 to 36.3°C (94.1 to 97.3°F) corresponding to their thermal neutral zone (TNZ). By comparison, $A_{p(100kg)}$ of TNZ was largely affected by pig age or body weight. I_a and I_f can serve as quantitative measures for assessment and control of thermal comfort of the pigs. They will be useful in the logic development of a novel controller that assesses and controls the microenvironment based on the resting pattern of the pigs as opposed to air temperature only. For instance, the increment or decrement of temperature setpoint can be determined in proportion to the deviation of the measured behavioral index from its ideal or TN values. The effects of air velocity on the effective environmental temperature of the pigs also were demonstrated with the postural index data.

Introduction

Thermal environment influences swine performance and well-being. For confinement production systems, the thermal environment typically consists of air temperature (T_a), air velocity (V), relative humidity (RH), and floor type and conditions. Most environmental studies on pigs have been focusing on the effects of T_a. Environmental control has also been primarily based on T_a. Such a practice stems from the impracticality of physically measuring all the environmental parameters to produce a comprehensive thermal index quantifying the microenvironment. Consequently, although T_a can be controlled near the seemingly optimum values, health- and behavior-related problems still may occur that frequently suppress the animal performance (7).

Pigs modify their postural behavior to either increase or decrease heat loss from their bodies in relation to the magnitude of thermal deviation from their TNZ (8, 10). They huddle when cold and spread out when hot. The postural behavior integrates all the internal and external environmental factors, and thus is the best indicator for the adequacy of their microenvironment. The use of computer imagery to implement the behavior-based approach of assessing and controlling thermal comfort of group-housed swine has been investigated (6, 12). Shao et al. (9) demonstrated the feasibility of classifying thermal comfort of young pigs with postural images of pigs as input to an artificial neural network (ANN). The same study also revealed the need to establish some quantitative postural indexes or physiological measurements that could enhance the assessment of the thermal comfort level. The same information also would help training the ANN and improving its classification accuracy.

The objectives of this study were 1) to investigate postural behavior indexes and surface temperature (T_s) of group-housed young pigs that may be used to enhance assessment of the thermal comfort of the pigs, and 2) to quantify the effects of T_a and V on the effective environmental temperature (EET) of the animals.

Materials and Methods

Experimental pigs

Twenty young pigs with the same date of birth and an initial age of 3 weeks were used in the study. Before and after exposure to the testing thermal conditions (described below), the pigs were kept in four-pig groups in an environment-controlled room at TNZ. The tests started when the pigs were 4 weeks old, and were performed for two age groups – 4 to 5 weeks of age (6.7 ± 0.28 kg or 14.7 ± 0.6 lb. body mass) and 6 to 7 weeks of age (14.7 ± 1.54 kg; 32.3 ± 3.4 lb.). The pigs were exposed in four-pig groups to the testing thermal conditions for the 4- to 5- week age group, and in three-pig groups for the 6- to 7- week age group. Selection of group sizes was based on the size of floor area inside the wind tunnel.

Testing thermal conditions

To induce the postural behaviors of the pigs corresponding to their cold- to warm- sensations, a factorial combination of five-level T_a by four-level V was formed. The five levels of T_a were 20, 24, 28, 32, and 36°C (68, 75, 82, 90, and 97°F), and the four levels of V were 0.1, 0.5, 1.0, and 1.5 m/s (20, 100, 200, 300 ft/min). For a given T_a, the series of V was imposed

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successively, from low to high, to the pigs. Each Ta/V exposure lasted for 20 min and the pigs were given 40 to 50 min for acclimation in the wind tunnel before start of the exposure series. It was found that T_s of the pigs became stabilized within 10-min exposure to a new V setting. Hence the last 10-min stable data were used in the analysis. Sequence of the trials was randomized as 28, 32, 36, 20, and 24°C. Four replications were performed for each Ta/V exposure.

Image recording systems

A thermal imaging system and a video imaging system were used in this study (figure 1). Both thermal and video cameras were mounted vertically 2 m (6 ft) above the pigpen floor, viewing the entire floor area. The thermal imaging system consisted of an infrared (IR) imager (ThermaCAM PM250, Inframetrics, Inc., North Billerica, MA), a TV monitor, a PC for remote control of the IR imager operation, and the companion image analysis program (TherMonitor 3.0, Inframetrics). The IR imager had a thermal sensitivity of 0.06°C (0.1°F), and the thermographs simultaneously depict postural behavior (e.g., occupied floor area) and T_s of the pigs. The thermographs were recorded at 2-min intervals onto a PCMCIA data storage card of the imager and then retrieved to a PC for analysis.

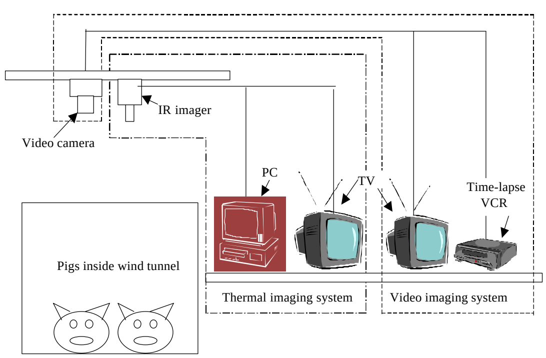

Figure. Schematic setup of the testing facility.

To determine the projected floor area occupied by the pigs, the IR images recorded in pixels needed to be converted to the physical area. Calibration of the floor area with regard to the image pixels was done by creating a rectangle of 86 × 73 cm (34 × 29 in.) on the floor using ice tubes that had different colors from that of the floor in the thermograph. The area calibration factor (CF) was 1.59×10^{-5} m^2/pixel. Because the mounting position of the IR imager was fixed, the CF remained constant during the study.

The video imaging system consisted of a CCD camera (Panasonic, WV-CP410), a TV monitor, and a time-lapse VCR (Panasonic, AG-6730) that recorded the behavioral images at 5-s intervals. The video images served as a supplemental source of reference for the thermal imaging analysis of the postural behavior of the pigs.

Measured and derived variables

The projected occupied floor area (A_p) and T_s of the pigs were determined from the thermographs. More than 800 thermographs were analyzed. Images of the last 10-min for each T_a/V exposure episode and involving the pigs in resting postures were used in the final analysis. Based on the measured A_p, three postural indexes were derived. The intention was to search for a postural index or indexes that could quantitatively describe the thermal comfort level of the pigs for a wide range of age or body weight.

1) Index I_a – the ratio of A_p to the total surface area (A, m^2):

$$I_a = \frac{Ap}{A} \qquad [1]$$

$$A = N*0.0974W^{0.633} \quad (2) \qquad [2]$$

where W is the mean body weight of the pigs (kg) and N is the number of pigs in the group.

2) Index I_f – the ratio of A_p to the maximum occupied floor area (A_{fmax}):

$$I_f = \frac{Ap}{A_{f\,max}} \qquad [3]$$

$$A_{fmax} = N*0.025W^{2/3} \quad (1) \qquad [4]$$

3) Index $A_{p(100kg)}$ – A_p per 100 kg body weight:

$$A_{p(100\,kg)} = \frac{Ap}{N*M}*100 \qquad [5]$$

The thresholds of the postural indexes for TNZ were defined by the respective values of the indexes corresponding to the lower critical temperature (LCT) and the upper critical temperature (UCT) of the pigs. LCT and UCT (Table 1) were determined using the models by Bruce and Clark (3) and CIGR (4). Ye (13) and Ye and Xin (14) provided more detailed descriptions of the experimental facilities and procedures.

Results and Discussion

Indexes I_a and I_f as affected by T_a and V

The effects of T_a and V on I_a and I_f are shown in Figures 2 – 5. I_a and I_f decreased linearly with increase in V, and the regression parameters are presented in tables 2 (I_a) and 3 (I_f), respectively. The decrease of I_a or I_f with V was greatly influenced by T_a, with greater rates at lower T_a. As expected, for a given V, higher T_a led to higher index values. Index $A_{p(100kg)}$ had a poor regression coefficient with V, and the regression parameters were omitted from the presentation.

Using the LCT and UCT at V = 0.1 m/s (20 ft/min) as the criterion to define TNZ of the pigs, the TN thresholds of the postural indexes were identified and shown in table 4 as well as in the respective figures (2 – 5). The results showed that pigs at 4 to 7 weeks of age (7.6 to 14.7 kg; 16.7 to 32.3 lb) had similar TN thresholds of I_a and I_f. For practical purposes (e.g., development of environmental assessment and control logic), TN range of the indexes may take the values of $I_a = 0.20 \sim 0.24$ and $I_f = 0.75 \sim 0.84$ for this weight range of pigs. The question of which index to use as the postural indicator is an interesting one. Index I_f did have a larger TN range and thus might be more immune to temporary fluctuations in postural behavior. This speculation, however, remains to be further tested during real-time evaluation of the behavior-based thermal comfort assessment and control system. By comparison, a large difference in $A_{p(100kg)}$ of TNZ existed between 4-week-old pigs and 6-week-old pigs. Specifically, $A_{p(100kg)}$ range of TNZ was about 0.95 to 1.11 for 4-week-old pigs but 0.70 to 0.90 for 6-week-old pigs. The higher $A_{p(100kg)}$ values for the smaller (4-week-old) pigs arose from the fact that $A_{p(100kg)}$ was inversely proportional to the body weight (W) instead of $0.097W^{0.667}$ (for I_a) or 0.025W0.667 (for I_f). Hence, from the practical standpoint of control logic development, $A_{p(100kg)}$ would not be as effective as I_a or I_f because of its strong dependence on pig age or weight.

Effects of V on EET at different T_a

If index I_f is used as a behavioral indicator for the pigs' sensation to thermal conditions, the effects of V on EET may be delineated. For instance, the following T_a/V (°C, m/s) (°F, ft/min) combinations would yield a similar EET for 4-week-old pigs: 20/0.1 (68/20), 24/0.3 (75/60), and 28/0.7 (82/140). Similarly, the following T_a/V combinations would yield a similar EET for 6-week-old pigs: 20/0.1(68/20), 24/0.45 (75/90), and 28 and 0.9 (82/180). The EET results show that the 6-week-old pigs are slightly more tolerant to V as compared with the 4-week-old pigs. The LCT and UCT for V greater than 0.1 m/s (20 ft/min) obtained using I_f as the guide (figures 4 and 5) were reasonably similar to those simulated from the models of Bruce and Clark (1979) and CIGR (1992). Some differences that did exist between the two methods could have attributed to the numerous assumptions involved in the simulation models which might not completely represent the actual conditions.

Effects of T_a and V on T_s

The effects of T_a and V on T_s for the 4-week-old and 6-week-old pigs are shown in figures 6 and 7, respectively. As observed with I_a and I_f, T_s also decreased linearly with increase in V, and the regression parameters are presented in Table 5. The rate of T_s decrease with V was greatly influenced by T_a, with greater rates at lower T_a. For a given V, higher T_a produced higher T_s, a result of vasodilatation to facilitate blood flow to the surface and thus body heat loss. Delamo and Heath (5) had reported a similar result. The slope data also revealed that T_s decreased with V faster for the 4-week-old pigs than for the 6-week-old pigs. This result was consistent with the biological structure of the pigs in that younger pigs have a lesser tissue thermal insulation. As T_a further increased, the effect of increasing V on T_s reduction became less significant. This result paralleled the report by Vergel and Hazen (11) that V alone would not suffice to relieve heat stress of pigs as T_a approaches the body core level.

Relationships between I_f and T_s

Index I_f as a function of T_s for 4- and 6-week-old pigs are plotted in Figures 8 and 9, respectively. Linear relationship between I_f and T_s was found for 4-week-old pigs, whereas a quadratic relationship was found for 6-week-old pigs. Based on the respective TN ranges of I_f for 4-week-old and 6-week-old pigs, T_s range of TNZ could be defined (Figures 8 and 9; Table 4). Specifically, T_s range of TNZ was 34.5~36.7°C (94~98°F) for 4-week-old pigs and 34.4 ~36.3°C (94~97.3°F) for 6-week-old pigs. Thus, for practical purposes, T_s range of 34.5 to 36.3°C (94~97.3°F) would indicate TN conditions for 4- to 7-week-old (7.6 to 14.7 kg, 16.7 to 32.4 lb) pigs.

Acknowledgement

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Table 1. Calculated lower critical temperature (LCT, °C) and upper critical temperature (UCT, °C) of 4- and 6-week-old pigs exposed to different air velocities (group size = four for 4-week-old pigs and three for 6-week-old pigs. Floor type: plastic slat).

Age (week)	Body weight (kg)		Air velocity (m/s) 0.1	0.5	1.0	1.5
4	7.6	LCT	21.0	25.3	27.2	28.1
		UCT	30.0	32.2	33.3	33.9
6	14.7	LCT	19.3	23.7	25.5	26.5
		UCT	29.2	31.5	32.6	33.2

Unit conversion factors: lb = kg × 2.2; °F = °C × 1.8 + 32; ft/min = m/s × 197.

Table 2. Effects of air velocity on index I_a (ratio of occupied floor area to the total surface area of the pigs) at different air temperatures.

Air temperature	Age = 4 week (W = 7.6 kg)			Age = 6 week (W = 14.7 kg)		
(°C)	Intercept (%)	Slope	R^2	Intercept (%)	Slope	R^2
20	20.9	-4.24[a]	0.98	22.0	-4.11[a]	0.98
24	21.8	-3.50[b]	0.96	22.9	-3.37[b]	0.96
28	22.8	-2.85[c]	0.96	23.9	-2.75[c]	0.96
32	24.4	-1.78[d]	0.90	25.2	-1.86[d]	0.92
36	25.8	-1.33[d]	0.89	26.8	-1.41[d]	0.86

Column slopes with different superscript letters were significantly different ($P < 0.05$).

Table 3. Effects of air velocity on index I_f (ratio of occupied floor area to its maximum theoretical value) at different air temperatures.

Air temperature	Age = 4 week (W = 7.6 kg)			Age = 6 week (W = 14.7 kg)		
(°C)	Intercept	Slope	R^2	Intercept	Slope	R^2
20	0.76	-0.15[a]	0.98	0.78	-0.15[a]	0.98
24	0.79	-0.13[b]	0.96	0.82	-0.12[b]	0.96
28	0.83	-0.10[c]	0.98	0.85	-0.10[c]	0.96
32	0.89	-0.06[d]	0.90	0.90	-0.07[d]	0.92
36	0.94	-0.05[d]	0.91	0.95	-0.05[d]	0.89

Column slopes with different superscript letters were significantly different ($P < 0.05$).

Table 4. Thermoneutral thresholds of postural indexes and surface temperature (°C) of the experimental pigs.

Index	Pig age (Body weight)		Common
or T_s	4 – 5 week (7.6 kg)	6 – 7 week (14.7 kg)	Range
I_f	0.75 - 0.85	0.74 - 0.84	0.75 - 0.84
I_a	0.20 - 0.24	0.20 - 0.24	0.20 - 0.24
A_p	0.95 - 1.11	0.70 - 0.90	N/A
T_s	34.5 - 36.7	34.4 - 36.3	34.5 - 36.3

Table 5. Effects of air velocity (0.1 to 1.5 m/s) on mean surface temperature of the experimental pigs at different air temperatures.

Air temperature	Age = 4 week (W = 7.6 kg)			Age = 6 week (W =14.7 kg)		
(°C)	Intercept	Slope	R^2	Intercept	Slope	R^2
20	32.9	-1.95[a]	0.92	33.2	-1.93[a]	0.93
24	34.6	-1.55[b]	0.93	35.4	-1.33[b]	0.92
28	36.0	-1.44[b]	0.94	36.3	-1.26[b]	0.93
32	37.6	-1.15[c]	0.95	37.1	-1.02[c]	0.96
36	38.9	-0.82[d]	0.92	38.2	-0.77[d]	0.92

Column slopes with different superscript letters were significantly different ($P < 0.05$).

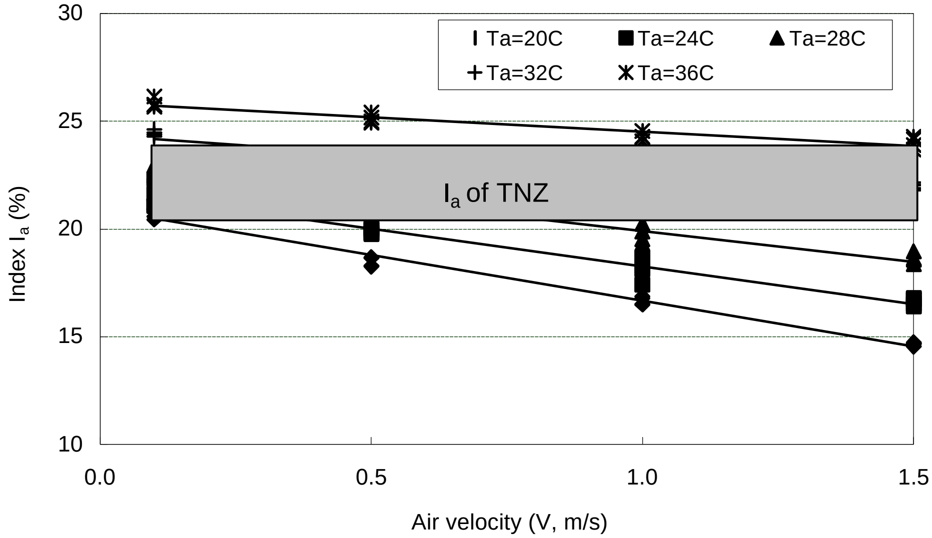

Figure 2. Postural index I_a (ratio of occupied floor area to the total surface area) for 4-week-old pigs (7.6 kg) subjected to different V and air temperature (T_a). ***LCT = 21°C and UCT = 30°C at V = 0.1 m/s.***

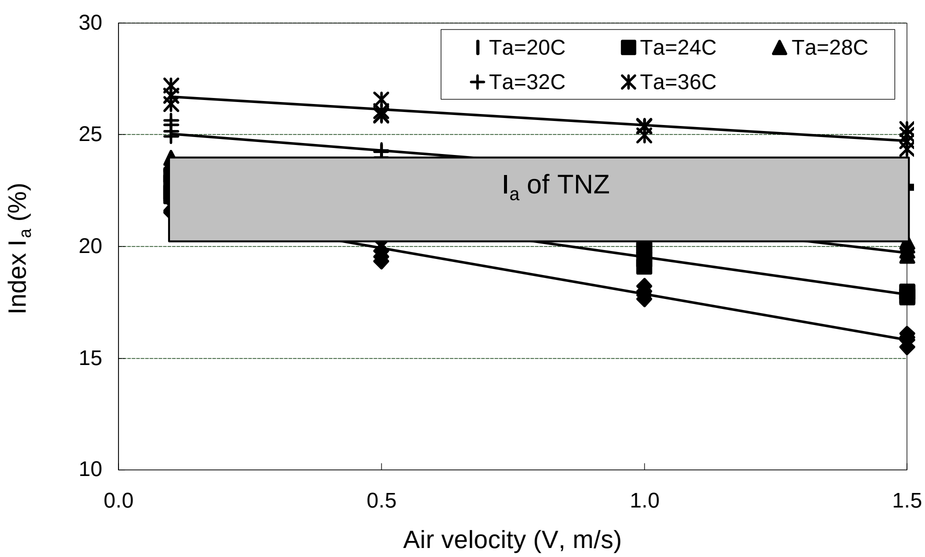

Figure 3. Postural index I_a (ratio of occupied floor area to the total surface area) for 6-week-old pigs (14.7 kg) subjected to different V and air temperature (T_a). ***LCT = 19°C and UCT = 29°C at V = 0.1 m/s.***

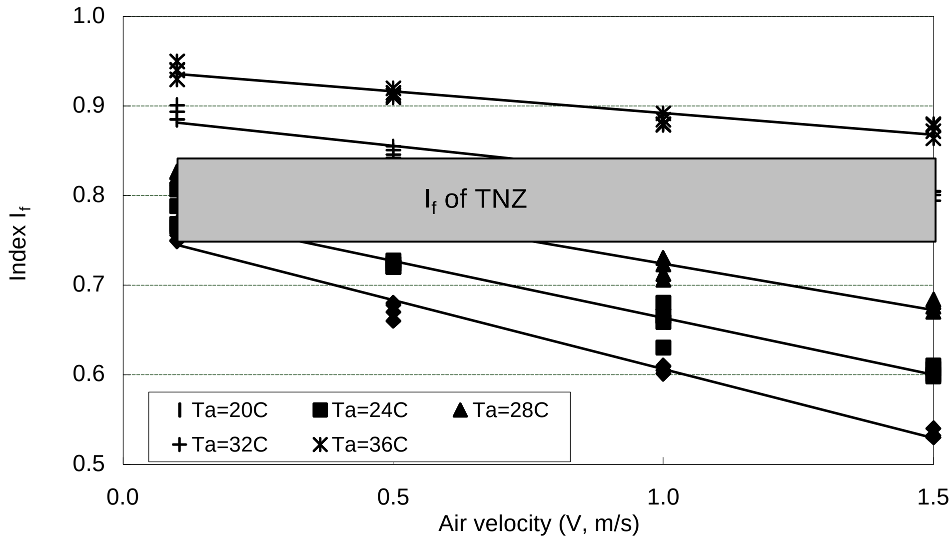

Figure 4. Postural index I_f (ratio of occupied floor area to its max theoretical value) for 4-week-old pigs (7.6 kg) subjected to different V and air temperature (T_a). ***LCT = 21°C and UCT = 30°C at V = 0.1 m/s.***

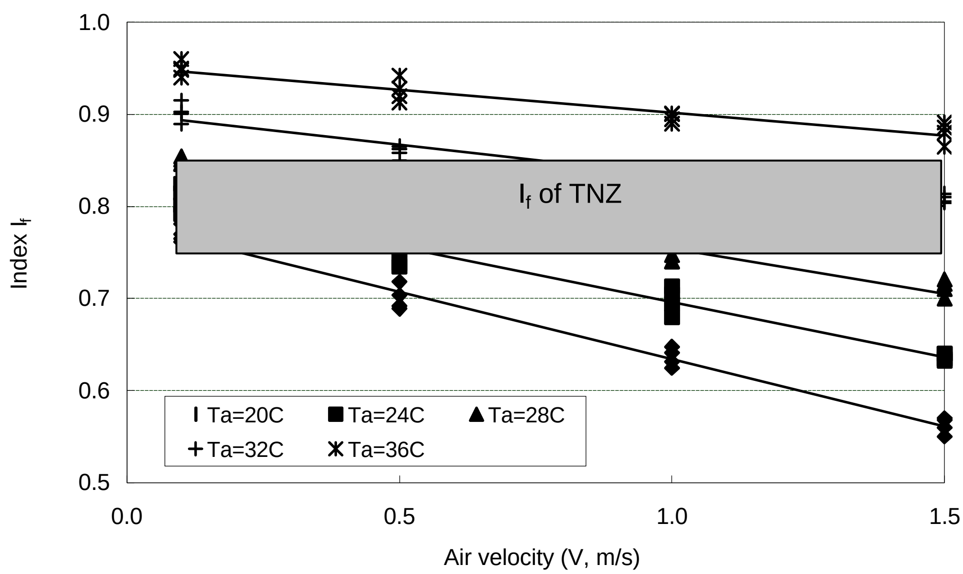

Figure 5. Postural index I_f (ratio of occupied floor area to its max theoretical value) for 6-week-old pigs (14.7 kg) subjected to different V and air temperature (T_a). ***LCT = 19°C and UCT = 29°C at V = 0.1 m/s.***

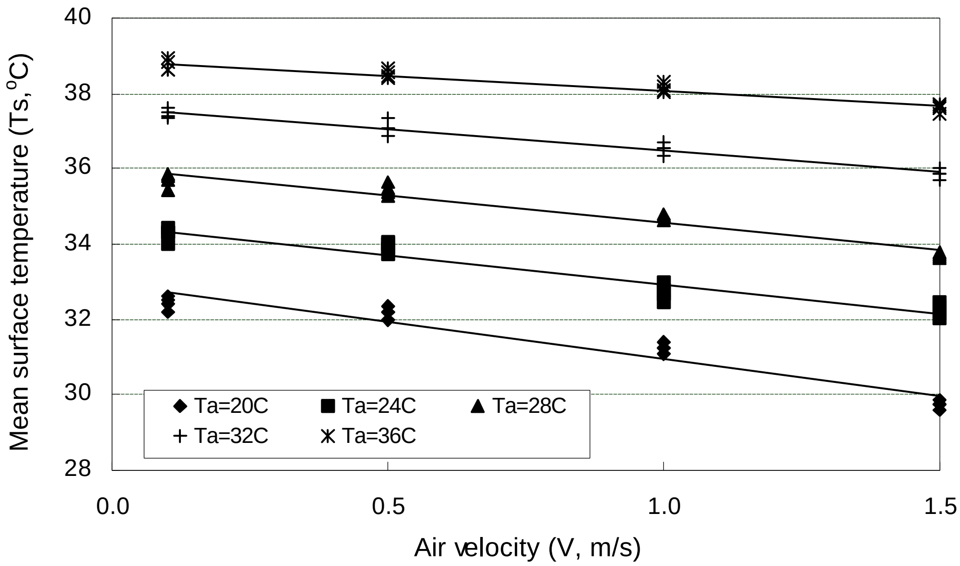

Figure 6. Mean surface temperature of 4-week-old (7.6 kg) pigs in relation to air velocity and air temperature (T_a).

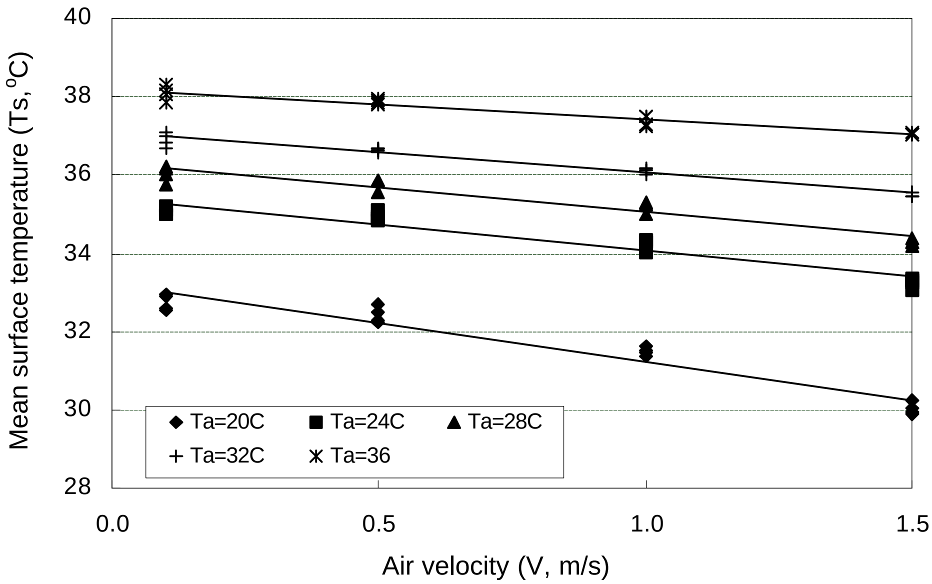

Figure 7. Mean surface temperature of 6-week-old (14.7 kg) pigs in relation to air velocity and air temperature (T_a).

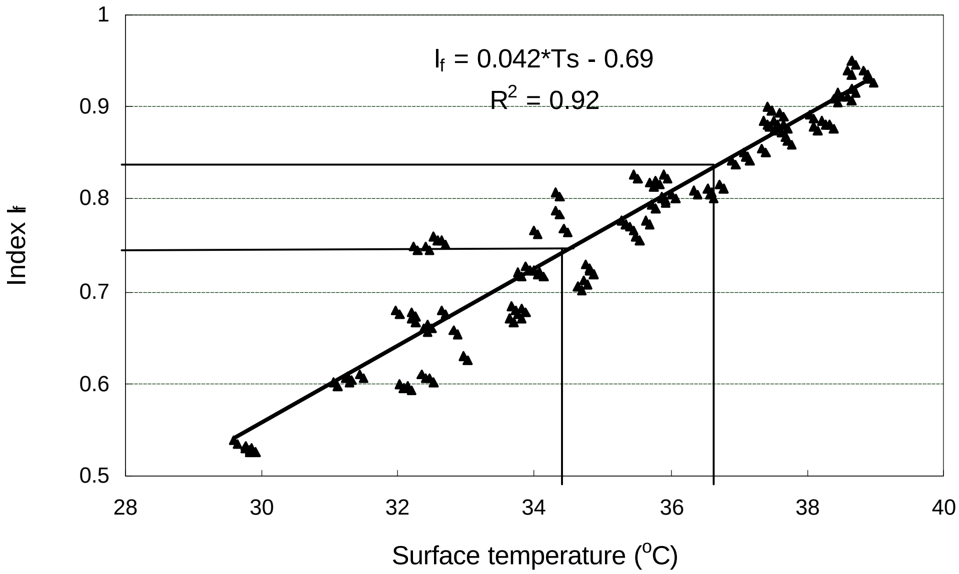

Figure 8. Relationship between postural index I_f (ratio of occupied floor area to its max theoretical value) and the mean surface temperature (T_s) for 4-week-old pigs (7.6 kg). The T_s band between the vertical lines corresponded to the TN I_f range.

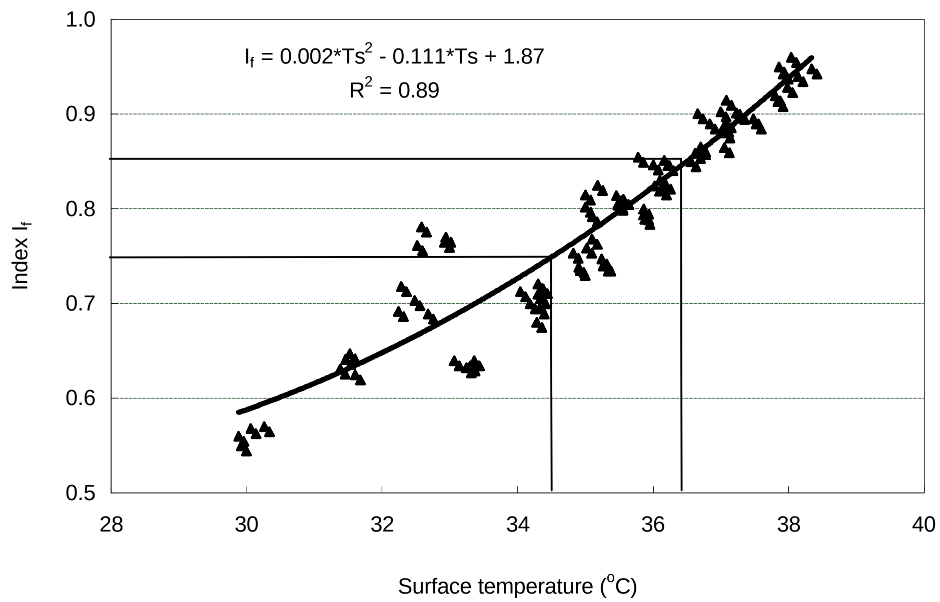

Figure 9. Relationship between postural index I_f (ratio of occupied floor area to its max theoretical value) and the mean surface temperature (T_s) for 6-week-old pigs (14.7 kg). The T_s band between the vertical lines corresponded to the TN I_f range.