Preference for Lamp or Mat Heat by Piglets at Cool and Warm Ambient Temperatures with Low to High Drafts

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Abstract. *Neonatal piglets (1.7 to 7.1 kg; 3.7 to 15.7 lb body weight) were allowed to choose at will a heat source (lamp or mat) in a wind tunnel at cool (20°C; 68°F) or warm (30°C; 86°F) air temperature coupled with various air velocities (0.05 to 0.45 m/s; 10 to 90 ft/min). The effects of original heat source in the farrowing crates on the choice of the piglets were included. At the cool temperature (20°C), piglets from heat lamp-equipped farrowing crates showed preference for lamp heat at 1.7 kg (3.7 lb) and similar usage of mat and lamp at 2.4 to 5.3 kg (5.3 to 11.7 lb). Piglets up to 5.3 kg from the heat mat-equipped farrowing crates generally did not show distinct preference for lamp or mat heat, except at the high draft condition (0.45 m/s; 90 ft/min) where preference for heat mat was exhibited. Piglets of 7.1 kg (15.6 lb) preferred mat independent of the original heat source type. At the warm temperature (30°C), piglets of 2.6 to 5.3 kg (5.7 to 11.7 lb) showed almost equal usage of mat and lamp independent of the original heat source type. Air temperature affected heat needs of the piglets. At 20°C, total (i.e., lamp + mat) heat usage (THU) by piglets of 1.7 to 2.4 kg (3.7 to 5.3 lb) averaged 98% of the exposure time for all air velocities tested. At 30°C, THU ranged from 24% for 2.6 kg (5.7 lb) piglets to 5% for 4.4 kg (9.7 lb) piglets. THU declined substantially as piglets reached 3.4 kg (7.5 lb), especially at the low air velocities. Piglets were more sensitive to drafts at the cool temperature. Drafts up to 0.45 m/s (90 ft/min) had little effect on THU at the warm temperature.*

***Keywords.** Localized heating, Heat lamp, Heat mat, Energy efficiency, Draft, Swine farrowing.*

Low-wattage heat mats (< 100 W) are being promoted by swine equipment suppliers as an alternative, energy-efficient localized heat source in farrowing crates. Compared with heat lamps (conventional, 250 W or relatively energy-efficient, 175 W lamp), heat mats have the following potential advantages: (a) 40 to 60% energy savings; (b) a larger heated surface area to better meet the space need of the litter (10 to 12 piglets); and (c) reduced or eliminated fire hazard. Assuming a 50% improvement in energy efficiency by adoption of the more energy-efficient heat mats, the annual energy savings amounts to about $0.50 per pig marketed or $48 million for the U.S. pork industry. However, little information is available that compares heat mats with lamps regarding their effects on the performance or behavior of pigs. The lack of fundamental and practical research information is believed to be a main contributing factor to the limited use of heat mats by swine producers. A recent statewide survey revealed that less than 25% of pork producers in Iowa are currently using heat mats, while the majority are still using heat lamps (Xin et al., 1997).

This study was conducted to evaluate the adequacy of a heat mat or a heat lamp as the localized heat source for neonatal pigs under various environmental conditions. We hypothesized that radiant heat provided by heat lamps would be preferred to surface heat provided by heat mats by piglets subjected to high drafts because the radiant heat would be more effective in reducing body heat loss of the animals via the main heat loss pathways of convection and radiation (75% total heat loss). However, compared with heat mats, a lamp provides a much smaller heated surface area to piglets, which may be insufficient for average size litters (10 to 12 piglets). The specific objectives of the study were to (1) to determine the preference for lamp or mat heat by piglets subjected to the selected cool (winter) and warm (summer) ambient temperatures with a range of low to high air drafts; and (2) depict the effects of air temperature and draft on heat requirements of piglets.

Materials and Methods

Testing Wind Tunnel and Instrumentation

A wind tunnel (1.0 W × 0.6 H × 4.3 L m; 40 W × 24 H × 170 L in.) was constructed and used for this study (fig. 1a). The tunnel consisted of four removable sections: (A) the air entrance extension (made of plywood with a wooden frame); (B) the main body (made of an aluminum tubing frame and polyboard); (C) the connection between the main body and a variable-speed fan (made of sheet metal); and (D) the variable-speed fan. Within the main body was an animal area measuring 1.0 W × 0.6 H × 0.9 L m (40 W × 24 H × 36 L in.). This area was further divided

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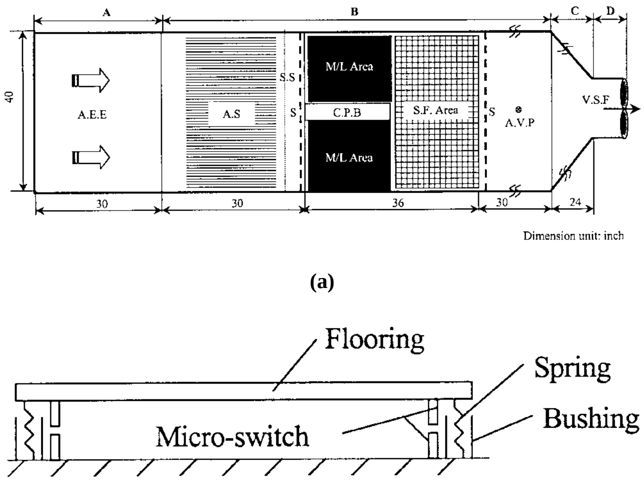

Figure 1–Schematic representation of the portable wind tunnel used in the study (not drawn to scale): (a) top view of the wind tunnel (interior height of the wind tunnel was 24 in.); (b) side view of the floor support in the three subsections of the animal area. A.E.E = air entrance extension; A.S = air straightener (made of 2 × 20 in. PVC tubes); M/L Area = lamp or mat area (18 × 18 in.); C.P.B = clear partition board; S.F. Area = plastic slat floor area (18 × 40 in.); S.S = settling screen; S = wire-mesh screen; A.V.P = air velocity probe; V.S.F = variable speed fan.

into three subsections of two heated areas (0.46 × 0.46 m; 18 × 18 in.) and one slat floor/activity area (0.46 × 1.0 m; 18 × 40 in.). Both heated areas had the identical layout of a heat mat (0.46 × 0.46 m) floor and a 60 W capacity overhead heat lamp. This identical physical layout allowed an easy, randomized alternation of the paired treatment (lamp vs mat) assignment to the heated areas. Below the slat floor was a waste collection pan (0.46 × 0.97 × 0.04 m; 18 × 38 × 1.5 in.) that could be inserted into or removed from the tunnel via a side door (510 × 50 mm; 20 × 2 in.). The floor of each of the three subsections in the animal area was independently supported with four spring-bushing assemblies located at the four corners (fig. 1b). Beneath each area were two normally open micro-switches connected in parallel that would close upon visit or use of the area by a pig(s). The bushings served as the safety stop to protect the micro-switches. The output of the switches was connected to a counter switch (model SDM-SW8A, Campbell Scientific, Inc. Logan, Utah) (CSI) that measured the operational duty cycle of the micro-switches for the specific sampling period. Usage of the mat or lamp heated area was determined from the measured duty cycles as follows:

$$\text{MU or LU} = \frac{DC_{mat} \text{ or } DC_{lamp}}{DC_{mat} + DC_{lamp} + DC_{floor}} \qquad (1)$$

where

MU, LU = mat or lamp usage (%)
DC_{mat} = measured duty cycle of micro-switches for mat area (%)
DC_{lamp} = measured duty cycle of micro-switches for lamp area (%)
DC_{floor} = measured duty cycle of micro-switches for slat floor/activity area (%)

The possible animal distributions in the three areas inside the wind tunnel are depicted in figure 2. Note that the measured duty cycle could not differentiate between the entire pig versus half of the pig occupying the area. Thus, a discrepancy might occur between the actual usage of the area and that calculated from equation 1 for certain specific situations (see table 1). However, the average area usage calculated from equation 1 for all the possible situations is identical to the actual average value (table 1). Hence, use of

Table 1. Comparative determination of mat, lamp or floor usage for the possible spatial distributions of the experimental pigs in the wind tunnel as illustrated in figure 2

	Mat Usage		Lamp Usage		Floor Usage	
Animal Arrangement	Actual (%)	Eq. 1 (%)	Actual (%)	Eq. 1 (%)	Actual (%)	Eq. 1 (%)
1	100	100	0	0	0	0
2	0	0	100	100	0	0
3	0	0	0	0	100	100
4	50	50	50	50	0	0
5	50	50	0	0	50	50
6	0	0	50	50	50	50
7	50	33.3	25	33.3	25	33.3
8	25	33.3	50	33.3	25	33.3
9	25	33.3	25	33.3	50	33.3
10	25	50	0	0	75	50
11	0	0	25	50	75	50
12	75	50	0	0	25	50
13	0	0	75	50	25	50
Average	31	31	31	31	38	38

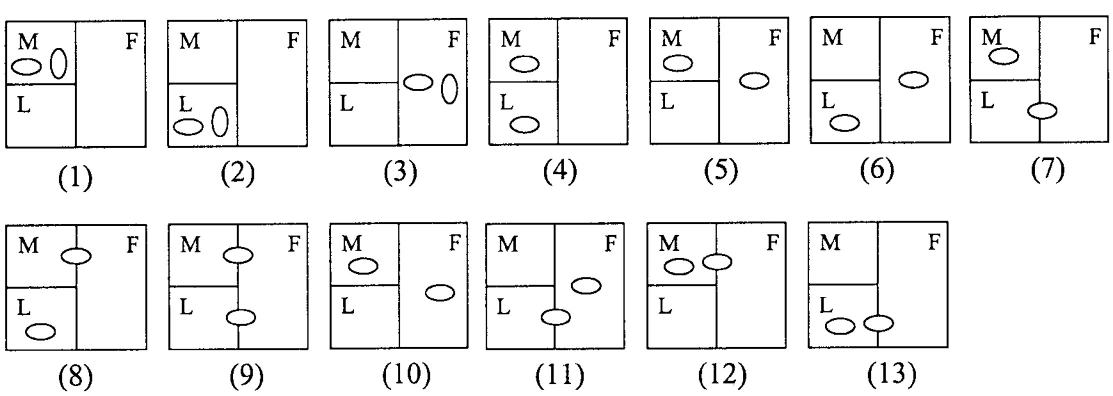

Figure 2–Schematic illustrations of possible spatial distributions of two experimental piglets in the wind tunnel (M = mat; L = lamp; F = floor).

equation 1 to determine the area usage should reflect the true values reasonably well. Furthermore, the supporting springs for each area were adjusted such that the micro-switches would not be triggered by a small fraction of the piglet (e.g., limbs) that might be extended to the area. This was especially true for smaller piglets.

An omindirectional air velocity transducer (model 8475 Davis Instruments, Baltimore, Md.) was placed in the downstream of the wind tunnel for continuous measurement and recording of the air velocity (±3% reading). Air temperature near the pig level was continuously measured with a type-T thermocouple (±0.1°C; 0.2°F). Each heat mat surface was fixed with a 25-point thermocouple grid covered by adhesive (duct) tape. Air temperature and relative humidity (RH) of the environmentally controlled room housing the wind tunnel was measured with a T/RH sensor (model HMP35, CSI). The automatic data acquisition system included a measurement and control module (CR10, CSI), a multiplexer (AM416, CSI), a counter switch (SDM-SW8A, CSI), and a desktop PC that sampled the variables every 2 s and stored the measured data as 5-min averages.

Before each experiment, temperature distribution of the heated areas for both the lamp and mat treatments was evaluated and adjusted to the specified level. This was achieved by controlling the power input to the mat or lamp with rheostat controllers (Model F911, Osborne Industries, Osborne, Kans.). The uniformity of the air velocity distribution across the wind tunnel was also examined using a 3 (vertical) × 7 (horizontal) equally spaced velocity array in the animal area. Within the air-stream space of 150 mm (6 in.) from the sidewalls and 100 mm (4 in.) from the floor or ceiling, the air velocity distribution had a coefficient of variation of 5% for high velocity (1.45 m/s; 286 ft/min) and 8% for low velocity (0.19 m/s; 37 ft/min).

Experimental Conditions and Procedures

Neonatal pigs (Yorkshire × Landrace), weighing 1.7 to 7.1 kg (3.7 to 15.6 lb) (3 to 18 days old), were used in this study. The experimental pigs, in groups of two litter mates (to reduce potential isolation stress), were brought into the wind tunnel from the farrowing crates. The two piglets were first subjected to a “calm” condition (air velocity of 0.05 m/s or 10 ft/min) for 1 h, and then the air velocity was increased in steps to 0.15, 0.30, and 0.45 m/s (30, 60 and 90 ft/min). An air velocity of 0.15 m/s (30 ft/min) is generally considered the threshold of cold drafts for young pigs (Harmon and Xin, 1995). The relatively high drafts were of interest because they could occur in some housing conditions such as tunnel-ventilated farrowing barns with limited draft barriers. The piglets were subjected to each of these draft conditions for 45 min. This duration was selected to maximize data collection time while minimizing potential nutritional stress of the piglets (Zimmerman, 1997). During each 45-min test period, the lamp and mat usage data were taken every 2 s and stored as 5-min averages. Data in the last 30 min were used in the analysis while the first 15 min were considered as the period of acclimation to the new air velocity. The pigs were individually weighed before the onset of each test. After the 180-min test, the piglets were returned to the original farrowing crates.

Table 2. Experimental factors for testing piglets’ preference of heat mat or heat lamp at air temperature of 20°C (68°F) or 30°C (86°F)

Factors	Levels
Original heat source	Lamp or mat
Body weight, kg (lb)	1.7 (3.7), 2.4 (5.3), 3.4 (7.5), 5.3 (11.7), and 7.1 (15.6) (for 20°C)
	2.6 (5.7), 3.4 (7.5), 4.4 (9.7), and 5.3 (11.7) (for 30°C)
Air velocity, m/s (ft/min)	0.05 (10), 0.15 (30), 0.30 (60), and 0.45 (90)

Two ambient temperatures of 20°C (68°F) and 30°C (86°F) were tested to be reflective of winter and summer climatic conditions in farrowing facilities. The corresponding RH was 45% to 50% for 20°C (68°F) and 35% to 40% for 30°C (86°F). The surface temperature of the heated areas in the wind tunnel was set as follows: for the mat treatment, 33.9°C (93°F) for piglets up to one week old, lowered to 32.2°C (90°F) during the second week, and to 30.6°C (87°F) during the third week; for the lamp treatment, it varied from 37.8°C (100°F) (under the lamp) to the ambient temperature level (at the edge) for all the age groups. Selection of the mat surface temperatures for different ages was based on behavioral observations of piglets in a preliminary trial. Since the heat source in the farrowing crate might influence the piglets’ choice of heat source in the wind tunnel treatments, two types of farrowing crates, one equipped with heat lamps and one with heat mats, were used to keep the piglets when they were not used in the wind tunnel treatments. The experimental factors (original crate heat source, ambient temperature, body weight, and air velocity) are summarized in table 2. Note that only four levels of body weight were considered for the ambient temperature of 30°C (86°F) because piglets showed little usage of the heated areas at this elevated temperature. Each test condition was replicated four times. Analyses of variance were performed to compare the mat usage (MU) and the lamp usage (LU) by the piglets under the environmental conditions.

Results and Discussion

Preferred Heat Sources by Piglets

Table 3 summarizes the preference of heat mat or lamp by the piglets at the cool temperature of 20°C (68°F). Figures 3 and 4 provide further quantitative representation of the heat source preference using the ratio of MU to total heat (mat plus lamp) usage (THU). The result indicated that smaller piglets of 1.7 kg (3.7 lb) preferred heat lamp in the wind tunnel after they had previously been exposed to heat lamp in the farrowing crate (table 3 and fig. 3).

Table 3. Comparison of heat lamp or heat mat preference by piglets subjected to 20°C (68°F) air temperature and four air velocities in a wind tunnel

Body Weight kg (lb)	Previous Exposure to Heat Lamp				Previous Exposure to Heat Mat			
	0.05 m/s 10 ft/min	0.15 m/s 30 ft/min	0.30 m/s 60 ft/min	0.45 m/s 90 ft/min	0.05 m/s 10 ft/min	0.15 m/s 30 ft/min	0.30 m/s 60 ft/min	0.45 m/s 90 ft/min
1.7 (3.7)	M < L	M < L	M < L	M < L	M ≈ L	M ≈ L	M > L	M ≈ L
2.4 (5.3)	M ≈ L	M ≈ L	M ≈ L	M < L	M ≈ L	M ≈ L	M ≈ L	M ≈ L
3.4 (7.5)	M > L	M ≈ L	M ≈ L	M < L	M ≈ L	M ≈ L	M ≈ L	M > L
5.3 (11.7)	M ≈ L	M ≈ L	M ≈ L	M > L	M ≈ L	M ≈ L	M ≈ L	M > L
7.1 (15.6)	M ≈ L	M > L	M > L	M > L	M > L	M > L	M ≈ L	M > L

M < L: Mat usage was significantly less than lamp usage ($P < 0.05$).
M > L: Mat usage was significantly greater than lamp usage ($P < 0.05$).
M ≈ L: There was no significant difference between mat usage and lamp usage ($P > 0.05$).

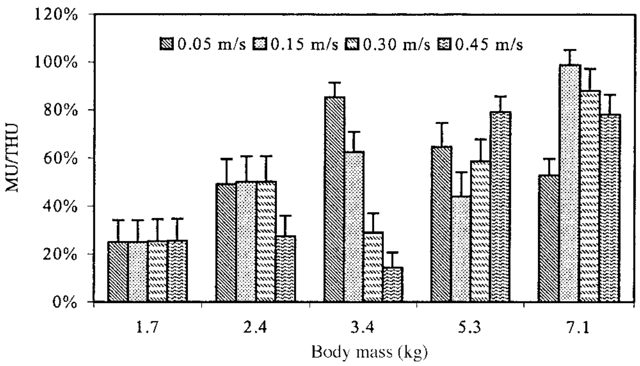

Figure 3–Mat usage (MU) as percentage of total heat usage (THU) of piglets inside the wind tunnel at ambient temperature of 20°C (68°F) and four air velocities. The piglets had previously been exposed to *heat lamp* in farrowing crates [⊤ : standard error].

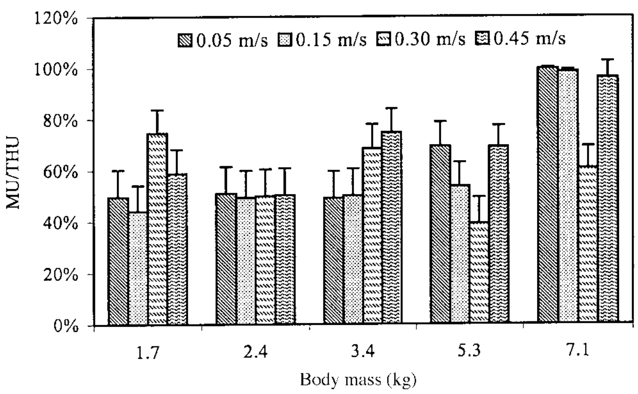

Figure 4–Mat usage (MU) as percentage of total heat usage (THU) of piglets inside the wind tunnel at ambient temperature of 20°C (68°F) and four air velocities. The piglets had previously been exposed to *heat mat* in farrowing crates [⊤ : standard error].

However, the same size piglets showed similar mat and lamp usage after they had previously been exposed to heat mat in the farrowing crate (table 3 and fig. 4), except at the air velocity of 0.30 m/s (60 ft/min) where MU was significantly higher ($P < 0.05$) than LU. For bigger piglets (2.4 to 7.1 kg; 5.3 to 15.6 lb) previous heat source type had little effect on their heat preference in the wind tunnel. It can also be noticed that these piglets showed an increasing tendency of preferring heat mat with increasing body weight/age. Moreover, the increased preference of mat heat with age was more apparent for piglets previously exposed to heat lamp in the farrowing crates. The effects of air velocity on the piglets' preference for the heat source were somewhat mixed. Specifically, the lighter piglets (< 3.4 kg or 7.5 lb) previously exposed to heat lamp tended to use lamp heat more as air in the wind tunnel became drafty (0.45 m/s; 90 ft/min); whereas the heavier piglets (> 5.3 kg or 11.7 lb) exposed to the same original heat source tended to use mat heat more for the same drafty condition. This outcome presumably arose from insufficient comfort surface area for the bigger piglets provided by the lamp. Piglets previously exposed to heat mat generally remained to be attracted to mat heat in the wind tunnel.

At the warm air temperature of 30°C (86°F), piglets of all ages showed similar or higher usage of heat mat for all air velocities (table 4). Neither body weight nor air velocity

Table 4. Comparison of heat lamp or heat mat preference by piglets subjected to 30°C (86°F) air temperature and four air velocities in a wind tunnel

Body Weight kg (lb)	Previous Exposure to Heat Lamp				Previous Exposure to Heat Mat			
	0.05 m/s 10 ft/min	0.15 m/s 30 ft/min	0.30 m/s 60 ft/min	0.45 m/s 90 ft/min	0.05 m/s 10 ft/min	0.15 m/s 30 ft/min	0.30 m/s 60 ft/min	0.45 m/s 90 ft/min
2.6 (5.7)	M > L	M > L	M ≈ L	M ≈ L	M ≈ L	M ≈ L	M ≈ L	M ≈ L
3.4 (7.5)	M ≈ L	M ≈ L	M ≈ L	M ≈ L	M ≈ L	M ≈ L	M ≈ L	M ≈ L
4.4 (9.7)	M ≈ L	M ≈ L	M ≈ L	M ≈ L	M ≈ L	M ≈ L	M ≈ L	M ≈ L
5.3 (11.7)	M > L	M > L	M ≈ L	M ≈ L	M ≈ L	M ≈ L	M ≈ L	M > L

M < L: Mat usage was significantly less than lamp usage ($P < 0.05$).
M > L: Mat usage was significantly greater than lamp usage ($P < 0.05$).
M ≈ L: There was no significant difference between mat usage and lamp usage ($P > 0.05$).

had much effect on the preference of heat source by the piglets. Note that both MU and LU was low at this temperature, consequently, differences in preference between the two heat sources were small.

NEEDS FOR LOCALIZED HEATING BY PIGLETS

Analysis of variance showed that previous exposure to heat lamp or heat mat in the farrowing crates had no significant ($P > 0.05$) effects on THU. Thus, THU data for piglets from both previous heat sources in the farrowing crates were pooled, and shown in figure 5 for 20°C (68°F) temperature and in figure 6 for 30°C (86°F) temperature.

At 20°C (68°F), THU was nearly 100% of the exposure time for piglets less than 2.4 kg (5.3 lb) at all air velocities (fig. 5). While the high THU at all air velocities inevitably would have masked the additional heat needs by the piglets

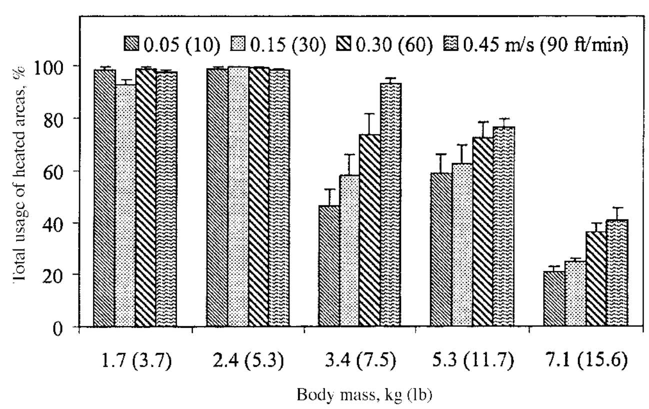

Figure 5–Total usage of heated areas (sum of lamp and mat usage) by piglets subjected to an air temperature of 20°C (68°F) and four air velocities [⊤ : standard error].

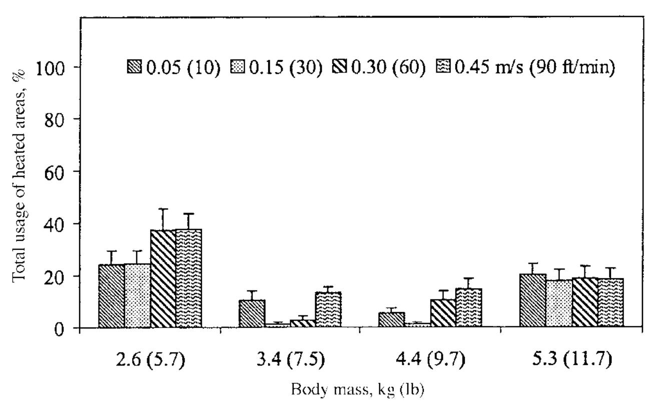

Figure 6–Total usage of heated areas (sum of lamp and mat usage) by piglets subjected to an air temperature of 30°C (86°F) and four air velocities [⊤ : standard error].

at the higher air velocities (more heat loss by convection), increased huddling of these piglets was observed as air velocity increased. THU started to decrease when the piglets reached 3.4 kg (7.5 lb), and the rate of decrease with body weight was greater for lower air velocities. For instance, the decrease in THU between 2.4 (5.3) and 7.1 kg (15.6 lb) piglets was 78% (from 99% to 21%) at 0.05 m/s (10 ft/min) but 58% (from 98% to 40%) at 0.45 m/s (90 ft/min). The increased THU with air velocity was more noticeable for piglets of 3.4 (7.5) to 7.1 kg (15.6 lb). The statistical significance rankings of THU were as follows. For 3.4 kg (7.5 lb) piglets, THU was greater ($P < 0.05$) at 0.45 m/s (90 ft/min) than at the other three air velocities; THU was greater at 0.30 m/s (60 ft/min) than at 0.05 m/s (10 ft/min); but there was no significant difference ($P > 0.05$) between 0.05 (10) and 0.15 m/s (30 ft/min), or between 0.15 (30) and 0.30 m/s (60 ft/min). For 5.3 kg (11.7 lb) piglets, THU was greater ($P < 0.05$) at 0.45 m/s (90 ft/min) than at 0.05 m/s (10 ft/min). For 7.1 kg (15.6 lb) piglets, THU was greater ($P < 0.05$) at 0.30 (60) and 0.45 m/s (90 ft/min) than at 0.05 (10) or 0.15 m/s (30 ft/min), but there was no significant difference ($P > 0.05$) between 0.30 (60) and 0.45 m/s (90 ft/min), or between 0.05 (10) and 0.15 m/s (30 ft/min).

At 30°C (86°F), THU was much lower compared with that at 20°C (68°F), especially for the smaller piglets (figs. 5 and 6). For instance, the average THU by 2.6 kg (5.7 lb) piglets was 31% at 30°C (86°F), as compared with 99% for 2.4 kg (5.3 lb) piglets at 20°C (68°F). The overall THU for the body weight range tested in this study at low air velocities (0.05 and 0.15 m/s; 10 and 30 ft/min) was 66 ± 4% for 20°C (68°F) and 13 ± 3% for 30°C (86°F). These values agreed fairly well with the results reported by Zhou and Xin (1999) who measured the average localized heat usage by piglets in farrowing crates to be 57 ± 2% at 18°C (65°F) and 10 ± 1% at 27°C (80°F) during a 21-day lactation period. The somewhat higher THU values for the present study presumably attributed to its shorter duration of the treatment exposure (no nursing activities). Air velocity had rather small effects on THU at 30°C (86°F). For piglets of 2.6 kg (5.7 lb), THU at 0.30 (60) and 0.45 m/s (90 ft/min) was slightly greater than that at 0.05 (10) and 0.15 m/s (30 ft/min) (fig. 6) ($P > 0.05$). Body weight affected THU ($P < 0.05$), but the patterns were somewhat mixed. At the air velocity of 0.05 m/s (10 ft/min), THU by 2.6 kg (5.7 lb) piglets was significantly ($P < 0.05$) greater than that by 4.4 kg (9.7 lb) piglets. At the other three air velocities, THU by 2.6 kg (5.7 lb) piglets was significantly greater than that by 3.4 (7.3) and 4.4 kg (9.7 lb) piglets, but was no significantly different ($P > 0.05$) from that of 5.3 kg (11.7 lb) piglets.

Conclusions

The following conclusions were drawn from the present study on preference of heat source by neonatal piglets under different environmental conditions:

1. The type of heat source (mat or lamp) to which smaller piglets (1.7 kg or 3.7 lb BW) are originally exposed tends to dictate their preference to that heat source at low air temperature (20°C; 68°F). As piglets grew (2.4 to 5.3 kg; 5.3 to 11.7 lb), they showed a similar preference for lamp and mat heat. Further increase in body weight (7.1 kg; 15.6 lb) shifted the preference toward mat heat regardless of the original heat source type.
2. Heat needs of smaller piglets (1.7 kg; 3.7 lb) remained high for air draft from 0.05 to 0.45 m/s (10 to 90 ft/min) at the cool air temperature (20°C; 68°F); whereas, heat needs of larger piglets (> 3.4 kg or 7.5 lb) decreased with lesser draft. Draft affected the heat needs of piglets more under the cool ambient condition than under the warm condition. Air drafts up to 0.45 m/s (90 ft/min) had little effects on the much reduced heat needs of piglets greater than 3.4 kg (7.5 lb) at the warm air temperature (30°C; 86°F).

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