Static and Dynamic Temperature Distribution of Heat Mats for Swine Farrowing Creep Heating

Q. Zhang, H. Xin

Abstract. *Laboratory and in-barn tests were conducted to study the thermal characteristics of electrical heat mats for creep heating in swine farrowing crates. An infrared imager was used to evaluate the surface temperature distribution and controllability of four commercial heat mats under constant environmental conditions. The effects of pig resting behavior on surface temperature distribution of the heat mat were elucidated by in-barn tests. Embedded temperature sensors facilitated the controllability of mat surface temperature. If either designed or operated improperly, electrical heat mats could contain hot spots (> 43°C or 109°F), which would greatly reduce the effective usable mat area for piglets. When piglets were lying on the mat with embedded temperature sensors, mat surface temperature rose in the occupied region and declined in the unoccupied region. The temperature difference between the two regions ranged from 7 to 12°C (13 to 22°F). Temperature feedback control maintained the mat temperature in a comfortable range for piglets. By comparison, a mat without temperature feedback control could become excessively hot (> 43°C or 109°F) for piglets.*
Keywords. *Piglets, Localized heating, Heat mat, Swine farrowing.*

The microenvironment in swine farrowing crates plays a critical role for the wellbeing of the piglets. Because of the different temperature requirements of sows (18 to 21°C; 65 to 70°F) and piglets (32 to 35°C; 90 to 95°F), relatively low room temperature is usually maintained in farrowing barns for the comfort of the sows, while localized heating is used to meet the thermal needs of the piglets. Traditionally, heat (infrared) lamps have been used as the localized heat source in farrowing facilities (Xin et al., 1997; Zhou and Xin, 1999). However, there are several potential problems associated with heat lamps, including relatively high power consumption, limited thermal comfort zone to accommodate the litter, and potential fire hazards. Based on test results on 10 different localized heating systems, de Baey-Ernsten et al. (1995) reported that surface (floor) heating provided more uniform temperature in the pig rest area than overhead (radiant) heating. A uniform floor heating system resulted in less crowding and greater weight gain than did radiant heating systems. Heat mats, i.e., solid or flexible boards with embedded heating elements, have been considered by the swine industry in North America and Europe as a means of localized surface heating. Xin and Zhang (1999) examined the preference of heat lamp or heat mat by piglets (birth to weaning) under various environmental conditions and revealed that heat mat was generally preferred by larger piglets. The thermal performance of heat mats, as measured by uniformity and controllability of the mat temperature, can vary considerably depending on the mat design. When operated without adequate temperature controllers, mats may produce excessively hot regions around the heating elements that prevent piglets from using the mats. Furthermore, when piglets are resting on a mat, heat balance between the mat and the ambient environment changes. Consequently, mat temperature changes with the pig-resting behavior. These dynamic characteristics of heat mats have not been considered in the design of most, if not all, commercial mats because of the lack of information in the literature.

The objectives of this study were to (1) evaluate the static thermal performance of four types of commercial heat mats at steady laboratory conditions, and (2) investigate the dynamic thermal characteristics of one heat mat chosen from objective 1 when used in farrowing crates.

Materials and Methods

Heat Mats

Four commercially available heat mats, representing four manufacturers, were evaluated in this study. These were designated as Mat A, B, C, and D. Mats A, B, and C were double-size mats and each measured 610 × 1219 mm (24 × 48 in.). Mat D was a single-size mat and measured 381 × 1219 mm (15 × 48 in.). All mats were electrically heated with either one bank of heating elements (Mats C and D), or two banks, one for each side of the double mat

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(Mats A and B). The wattage ratings of the heating elements were 240, 200, 120, and 125 W for Mats A, B, C, and D, respectively. Hence, the rated power capacities per crate (single mat) were 120, 100, 60, and 125 W for the four mats, respectively. The actual power input to a mat was regulated through a power controller, either with temperature feedback control or direct voltage control. For the temperature feedback control, mat temperature was sensed by embedded thermistors and power input to the mat was regulated based on the sensed temperature and the setpoint (path 1, fig. 1). For direct voltage control, the power input was adjusted through a voltage controller to set the initial temperature, and this power input remained constant thereafter (path 2, fig. 1). Another control method that is also used by some mat manufacturers is to use ambient air temperature as the control variable. This method is equivalent to the direct voltage control if the ambient temperature stays constant. Among the four mats tested, A, C, and D had embedded temperature sensors and B had an air temperature sensor. The location of embedded sensors was also different among the three mats. Mat A had a single sensor placed on the edge of the short side. Mat C had four embedded sensors evenly spaced along the centerline of the mat. The exact sensor location was not clear for Mat D. Mats A, B, and D used an on-off control scheme, i.e., full power was directed to the heating elements when temperature was below the setpoint and power was turned off when temperature exceeded the setpoint. For Mat C, a minimum input of 10% of the full power was maintained when the mat temperature reached the setpoint.

Laboratory Test

The purpose of the laboratory test was to evaluate the uniformity and controllability of the mat surface temperature under constant environmental conditions. The mats were tested at low, medium, and high power settings. The low and medium power settings were selected to achieve targeted mat temperatures of 29 (84°F) and 35°C (95°F), respectively. The high power level was the highest setting on the controller for each mat. For Mat A, the low power level resulted in a mat temperature of 29°C (84°F), but mat temperature was not responsive to controller setting at the medium or high settings. In other words, higher temperatures could not be achieved through adjusting the dial on the controller. Therefore, a test was performed by supplying power directly to the heating elements (bypassing the controller). Because of differences in the controller design, the four mats could not be tested at exactly the same temperatures for the high power setting.

The test was conducted in a well-insulated room under a draft-free ambient temperature of 21°C (70°F). The mats were supported with wooden blocks 100 mm (4 in.) off a concrete floor. For each controller setting, the mats were given at least 40 min for the surface temperature to stabilize. Once stabilized, thermal images or thermographs of the heat mats were recorded with an infrared (IR) imager (discernability of 0.06°C or 0.11°F) (Inframetrics Model PM250, Inframetrics, N. Billerica, Massachusetts). The images were later retrieved to a PC for analysis with the companion software (TherMonitor®).

Variables used to characterize the operational performance of the mats included average surface temperature (t_{avg}), maximum surface temperature (t_{max}), lowest 5% ($t_{5\%L}$), and highest 5% ($t_{5\%H}$) surface temperatures. Specifically, $t_{5\%L}$ was the average temperature of 5% coolest surface area of the mat, while $t_{5\%H}$ was the average temperature of 5% warmest surface area of the mat. In other words, 90% of the mat surface area had temperatures between $t_{5\%L}$ and $t_{5\%H}$. To determine if the mat temperature meets the thermal needs of the piglets, it is necessary to define a range of thermoneutrality (TN) for piglets on heated mats. Newborn piglets require relatively high mat surface temperature to prevent excessive body heat loss. However, too high mat temperature may also cause discomfort to the piglets. Little information is available in the literature concerning TN of piglets on heat mats. de Baey-Ernsten et al. (1995) suggested a tolerable temperature range of 37 to 43°C (99 to 109°F) for surface heating in farrowing crates. However, even if the set temperature is lower than 37°C (99°F), the actual mat temperature may still exceed 37°C (99°F) when piglets rest on the mat (details in the Results and Discussion section). Therefore, we suggested that the lower limit of the initial mat temperature be defined as the pig surface (skin) temperature. A piglet would not feel "cold" when the contacting surface temperature is equal to or higher than its skin temperature. Under the practically draft-free conditions (i.e., air velocity < 0.15 m/s or 30 ft/min) and 21°C (70°F) ambient temperature, the surface temperature of 2- to 9-day-old piglets, as measured with the IR imager, was found to be 34.6°C (94°F) (standard deviation or SD = 0.9°C or 1.6°F). Ye and Xin (1999) reported a surface temperature of 32.8°C (91°F) for 4-week-old pigs at an air temperature of 20°C (68°F) and air velocity of 0.15 m/s (30 ft/min). Therefore, an acceptable mat surface temperature range (noted as T_{mat_ok}) of 34 to 43°C (93 to 109°F) was adopted in this study. Note that T_{mat_ok} does not necessarily represent the thermal comfort temperature range because surface heating alone may not suffice for piglets to maintain TN at low ambient temperatures (de Baey-Ernsten et al., 1995; Zhang and Xin, 1999).

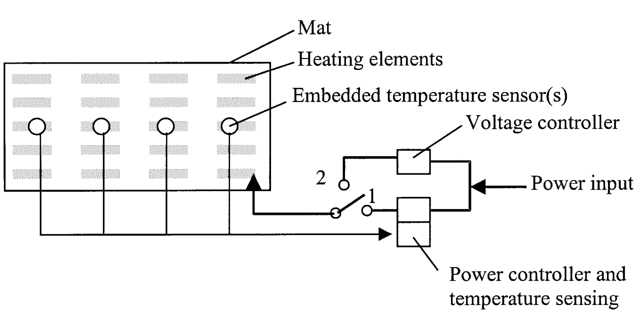

Figure 1–Schematic representation of heat mat layout and power input control.

In-barn Tests

Among the four mats tested in the laboratory, Mat C showed the most uniform surface temperature distribution under the constant environment and was therefore selected for in-barn tests. The tests were conducted in an environmentally controlled farrowing room. Fresh air was heated or cooled before entering the room and distributed to the room through a perforated PVC duct suspended about 1.8 m (6 ft) above the crate floor. The room air was exhausted through another perforated PVC duct located underneath the floor (i.e., pit ventilation). The room temperature was set at 21°C (70°F) to simulate typical winter conditions in farrowing barns. Relative humidity (RH) was about 40% in the room during tests. Two enlarged crates (1.94 × 2.13 m or 6.4 × 7 ft.) used in the tests (fig. 2) had woven-wire flooring for the sows and plastic slats for the creep area. One double size mat was placed in each crate on the right (crate 1) or left (crate 2) side of the sow. The total creep area of each crate was 2.85 m^2 (30.7 ft^2), including the mat area of 0.74 m^2 (8.0 ft^2). A sow was brought into each crate about two days before the expected farrowing date for each trial.

Mat surface temperature was measured using the IR imager and type T (copper-constantan) thermocouples (TCs) at the resolution of 0.1°C (0.2°F) (Omega Engineering, Inc., Stamford, Connecticut). A series of thermal images was taken every second day from farrowing to weaning (two weeks). Each series of images contained a complete "resting" cycle of piglets, i.e., piglets getting on the mat, resting on the mat, and leaving the mat. The thermal images were analyzed using the companion TherMonitor software of the imager for mat surface temperature distribution. Although IR images provided measurements of the true surface temperature of the entire mat, it was not practical to use the IR imager for continuous temperature measurement for the 14-day lactation period. Therefore, TCs were used to continuously measure the surface temperature at selected locations. Six TCs ($T_1 - T_6$) were fixed with silicon onto each mat surface in two rows, as shown in figure 2. Row 1 consisted of T_1, T_2, and T_3 that were equally spaced at the centerline across the width of the mat. Row 2 consisted of T_4, T_5, and T_6 at one-quarter length line across the width of the mat. This arrangement of TCs was expected to cover the mat surface that was most likely to be used by the piglets. Two layers of adhesive (duct) tape were used to protect the TCs from being damaged by the piglets. Temperature signals from the TCs were recorded with a data acquisition system (CR10 and AM416, Campbell Scientific, Inc., Logan, Utah) and a PC. Data were sampled every 3 s and stored as 10 min averages for TC sensor.

A video camera (Panasonic, WV-CP410) was mounted directly above the heat mat in each crate to monitor the mat usage by piglets, and the video images were recorded using a time-lapse VCR (Panasonic, AG-6730). The tapes were then played back to determine the mat usage by counting the number of piglets lying on the mat at a 15-min sampling interval.

Two surface temperature settings of 34 and 37°C (93 and 99°F) were tested for the in-barn experiments. It should be noted that these two setpoints on the controller dial were different from the actual measured temperatures. The 37°C (99°F) setting was the highest power setting on the controller, and the 34°C (94°F) setting corresponded to about 90% of the full power input. The two settings resulted in mean mat surface temperatures of 33 and 35°C (91 and 95°F), respectively. For the 34°C (93°F) setting, the temperature feedback control method was tested. For the 37°C (99°F) setting, both the temperature feedback and direct voltage control methods were tested. Hence, a total of three series of tests were performed: (1) C34: 34°C (93°F) setting with temperature feedback control; (2) C37: 37°C (99°F) setting with temperature feedback control; and (3) NC37: 37°C (99°F) setting without temperature feedback control. Each test was replicated three times from consecutive farrowings. A 175 W heat lamp was suspended 76 cm (30 in.) above the floor in the back of each farrowing crate, and was used during the first 24 h of parturition.

Results and Discussion

Laboratory Test

All four mats were responsive to the low controller setting of 29°C (94°F) (table 1). The differences between the measured mean temperature and the targeted setting were 0.1, 0.1, 0.8, and 1.1°C (0.2, 0.2, 1.4, and 2.0°F) for Mats A, B, C, and D, respectively. Mats B, C and D responded well to the controller setting at medium and high power levels; whereas, temperature of Mat A increased only 0.6°C (1.1°F) when the dial setting was changed from

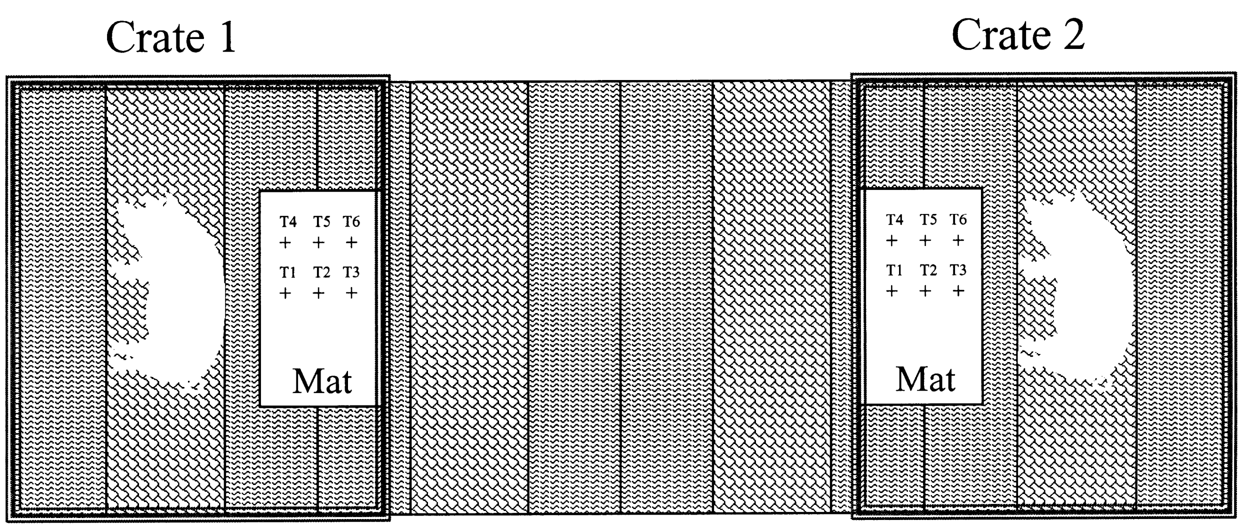

Figure 2–Schematic layout of the experimental farrowing crates for in-barn test. Measurement locations of the thermocouple sensors are indicated by "+".

Table 1. Summary of measured mat surface temperatures under constant air temperature of 21°C (70°F) and draft-free condition in the laboratory test

Mat ID	Power Setting	Surface Temperature, t (°C)				
		t_{avg}	t_{max}	$t_{5\%L}$*	$t_{5\%H}$*	$t_{5\%H}$-$t_{5\%L}$
A	Low (29°C)	28.9	33.8	26.0	30.5	4.5
	High	29.5	34.4	26.5	31.5	5.0
	Direct†	38.3	50.2	31.0	44.5	13.5
B	Low (29°C)	28.9	32.7	23.5	31.5	8.0
	Medium	33.1	39.2	24.5	37.5	13.0
	High	37.6	45.9	25.5	44.0	18.5
C	Low (29°C)	28.2	32.5	25.0	28.0	3.0
	Medium	32.2	37.3	27.0	34.0	7.0
	High	34.7	39.1	29.5	36.5	7.0
D	Low (29°C)	27.9	32.2	24.5	29.0	4.5
	Medium	32.2	36.5	27.5	34.0	6.5
	High	38.0	43.3	29.0	42.5	13.5

* Mat temperature than which 5% of the surface area was lower ($t_{5\%L}$) or higher ($t_{5\%H}$).

† Direct: bypassed the controller.

NOTE: Temperature conversion: °F = °C × 1.8 + 32.

the lowest to the highest level on the controller. At the high-level power input (bypassing the controller for Mat A), the mean temperature of Mats A, B, and D exceeded 37°C (99°F), the suggested lower limit of tolerable temperature by de Baey-Ernsten et al. (1995), and the mean temperature of Mat C was slightly higher than the lower limit of the proposed T_{mat_ok} (34.7 vs 34°C; 94.5 vs 93.2°F). This result indicates that all four mats were able to provide an initial temperature warm enough for the piglets. However, the maximum temperature of Mats A, B, and D exceeded 43°C (109°F) (table 1), meaning that there were some hot spots on these three mats that would be intolerable to the piglets. At the high power setting (bypassing controller for Mat A), the percentage of mat surface within the acceptable surface temperature range

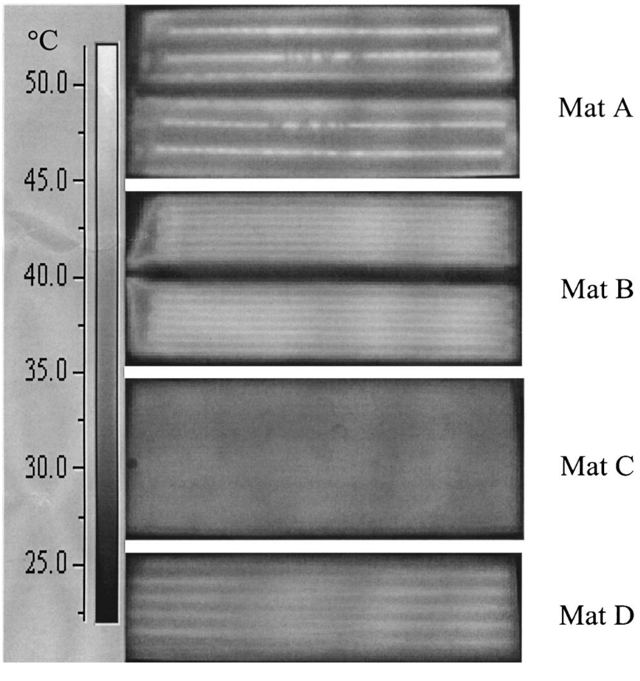

Figure 3–Thermographs of heat mats at high power setting under constant ambient temperature of 21°C (70°F).

(T_{mat_ok}) was 76%, 54%, 77%, and 79% for Mats A, B, C, and D, respectively. Although the percentage comfort area provided by Mats A (bypassing controller), C, and D were similar, surface temperature distribution of Mat C was noticeably more uniform than the other two mats (fig. 3). Distinct hot strips were observed near the heating elements in Mats A, B, and D, which could reduce the actual usable mat area for piglets because piglets would avoid contacting these hot spots. The uniformity of mat surface temperature was numerically described by $t_{5\%L}$ and $t_{5\%H}$ in table 1. A smaller difference between $t_{5\%L}$ and $t_{5\%H}$ represents more uniform surface temperature. Temperature was fairly uniform for all mats at the low power setting, and Mat C had the most uniform temperature distribution at the high power setting.

In-barn Tests

Mat surface temperature measured by TCs was slightly higher than that measured by the IR imager when there were no piglets on the mat. Temperatures measured by the two methods were compared for the effectively heated mat surface (surface excluding the cooler edges). In test C34, the IR imager measured a mat surface temperature of 34.1°C (93.4°F) (SD = 1.0°C, 1.8°F), while the corresponding TC reading was either 35.9°C (96.6°F) (SD = 1.4°C; 2.5°F) or 1.8°C (3.2°F) higher. In test C37, temperature readings were 36.3°C (97.3°F) (SD = 1.9°C; 3.4°F) and 38.2°C (100.8°F) (SD = 1.9°C; 3.4°F) for the IR and TC methods, respectively, or a difference of 1.9°C (3.4°F). These differences between the IR and TC measurements were attributed to: (1) the adhesive tape covering the TCs; and (2) the fact that the IR imager measured the temperature of the large surface while the TCs measured only discrete points on the surface. The two layers of adhesive tape (to protect TCs) acted as thermal insulation between the mat surface and the ambient air, resulting in higher temperature readings by the TCs. Because of the manufacture limitation, the mat edges were cooler than the central region. Temperature near the mat edges typically was 31°C (88°F) while the central area was 36°C (97°F) (fig. 3). The surface temperature measured by the IR imager included part of the cooler edge area, while all the TCs were placed in the warmer central region. Therefore, IR temperature readings were lower than those by the TCs. Although the IR imager was capable of measuring the true mat surface temperature, it could not measure the mat surface temperature directly while piglets were lying on the mat. In comparison, TCs could measure the temperature that was felt by the piglets when lying in the sensor area. For analyzing results, the IR measurements were used in describing the temperature variation across the surface; whereas, TC readings were used in describing the variation of the mat temperature with time.

Surface Temperature Distribution. The pattern of mat temperature distribution with piglets on the mat was dramatically different from that observed in the laboratory test. In tests C34 and C37 (with temperature feedback control), the area occupied by piglets in the occupied region (OR) became warmer and in the unoccupied region (UR) became cooler than the initial mat temperature (fig. 4). Since heat loss from the mat to the ambient was reduced by piglets lying on the mat, the temperature in OR rose. Since mat temperature was controlled by the embedded

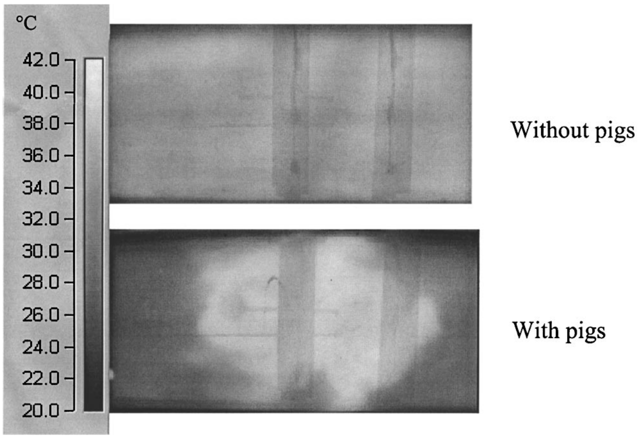

Figure 4–Comparison of mat temperature distribution between pig-free and pig-laden conditions.

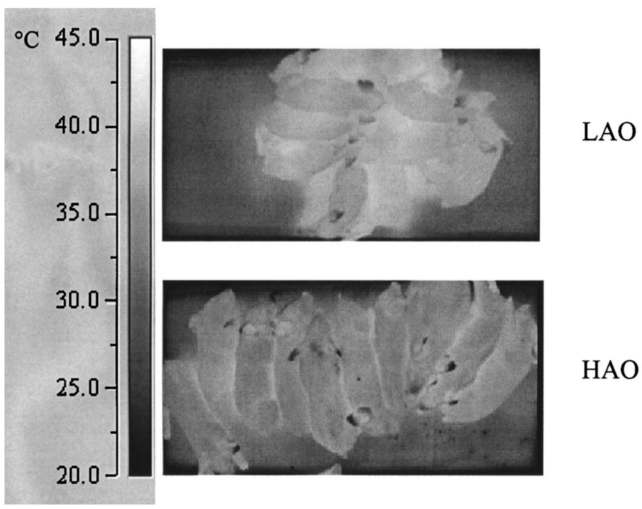

Figure 5–Typical lying patterns of piglets on heat mats (LAO = low area occupation; HAO = high area occupation).

sensors, the rising temperature caused reduction of power input to the mat. This in turn caused temperature to drop in UR. The magnitude of mat temperature increase or decrease depended on the resting behavior of the piglets. Figure 5 shows example snapshots of two typical mat usage patterns by the piglets: (a) low area occupation (LAO), where not all the embedded sensors were in OR, and (b) high area occupation (HAO), where all the embedded sensors were covered by the piglets. The surface temperature distribution curve had a single peak that occurred near the setpoint when no piglets were on the mat; whereas, two peaks generally occurred when the mat was used by piglets (fig. 6), with the high temperature peak indicating the temperature in OR and the low temperature peak showing the temperature of UR. The low temperature peak for HAO was not as apparent as that for LAO because of the relatively small UR when the mat was mostly used by the piglets. Temperature in OR, as indicated by the high temperature peak, was close to the set temperature for HAO and was higher than the set temperature for LAO. This result was attributed to the temperature feedback control. Power input to the mat was based on the average temperature sensed by the four embedded sensors. This

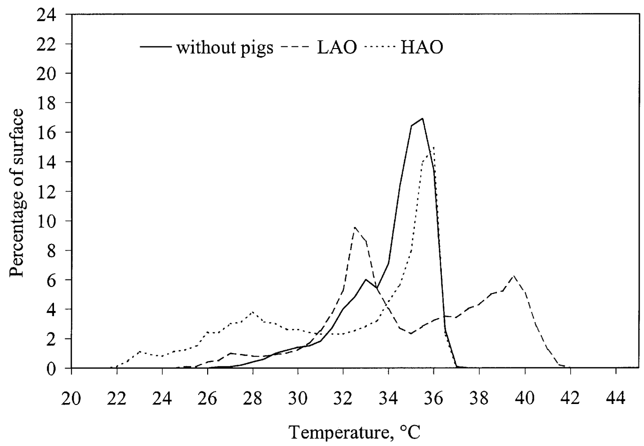

Figure 6–Surface temperature distribution of heat mat with temperature feedback control (test C37) and at set temperature of 37°C (99°F); °F = °C × 1.8 + 32).

Table 2. Mat surface temperature (°C)* in regions occupied and unoccupied by piglets

	LAO (Day 2-3)†		HAO (Day 8-9)†	
Test‡	Occupied	Unoccupied	Occupied	Unoccupied
C34	38.6 (0.4)	27.8 (0.3)	36.4 (0.3)	24.8 (1.7)
C37	41.0 (0.7)	34.2 (1.5)	37.5 (0.3)	29.7 (0.9)
NC37	42.9 (0.9)	37.6 (1.6)	40.0 (0.8)	35.1 (0.9)

* Temperature conversion: °F = °C × 1.8 + 32; Δ°F = 1.8Δ°C.
† LAO: low area occupation; HAO: high area occupation.
† C34: 34°C setpoint with feedback control; C37: 37°C setpoint with feedback control; NC37: 37°C setpoint without feedback control. Numbers in ( ) are standard deviations.

average temperature increased faster when more mat surface (sensors) was (were) covered by piglets (HAO), thus power input was reduced at a faster rate, resulting in lower temperature in OR for HAO than for LAO. This effect of mat occupancy on the temperature distribution is numerically shown in table 2, which summarizes the measured temperatures in OR and UR for piglets two to three and eight to nine days old. These two age groups were selected to represent LAO and HAO conditions, respectively. The average IR temperature of the entire OR could not be accurately measured because of piglets on the mat. Thus, temperatures shown in table 2 for OR were temperatures of small areas of the mat surface exposed between lying piglets. These temperatures might be slightly lower than the true temperature of the contact between the piglets and the mat. Temperature for 2- to 3-day-old piglets (LAO) was about 3°C (5.4°F) higher than that for 8- to 9-day old piglets (HAO) in OR, and 4°C (7.2°F) higher in UR. The temperature difference between OR and UR ranged from 7 to 12°C (12.6 to 21.6°F). The mat temperature of OR was 41.0°C (105.8°F) for the LAO condition and 37.5°C (99.5°F) for HAO when piglets were lying on the mat. At the same controller setting, the mat surface temperature was measured to be 34.7°C (94.5°F) under the constant laboratory environment. In other words, piglets resting on the mat caused 6.3°C (11.3°F) and 2.8°C (5.0°F) temperature rises in the case of LAO and HAO, respectively.

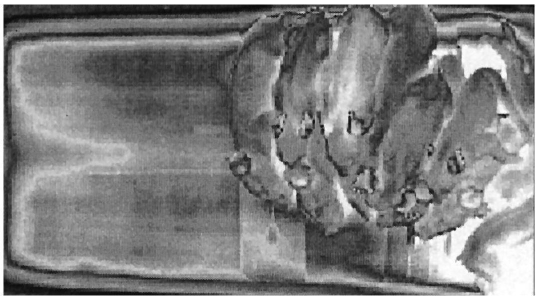

Figure 7–An example of partial usage of heat mat by piglets.

The double-peak temperature distribution could have some adverse effects on the comfort of piglets on the mat, especially when only a small portion of the mat is used by part of the litter. Figure 7 (test C37, LAO) illustrates a condition where about one-half of the mat was used by part of the litter and the other half of the mat became undesirably cool for the remaining litter, at least at the initial contact. Furthermore, when several slave mats are controlled based on the temperature of a master mat (a common arrangement of heat mats in practice), the temperature of the entire slave mats would be as low as that in UR if no piglets are resting on the slave mats while the master mat is fully occupied.

For direct voltage (no temperature feedback) control (test NC37), mat temperature increased considerably in OR and slightly in UR (table 2). The temperature distribution curve had two distinct peaks for LAO, with the high temperature peak for OR and the low temperature peak for UR (fig. 8). The low temperature peak occurred at almost the same temperature as that of mat without piglets, indicating that piglets had little effect on the temperature of UR when temperature feedback control was not used.

Temperature Variation with Time. Mat temperature was fairly constant before farrowing, and fluctuated considerably as piglets started to use the mat (fig. 9). The magnitude of temperature fluctuation was closely related to the mat usage by piglets; the more frequently the mat was used, the more the mat temperature fluctuated. Table 3 summarizes the temperature ranges measured for a 14-day period (from farrowing to weaning) in the three test series.

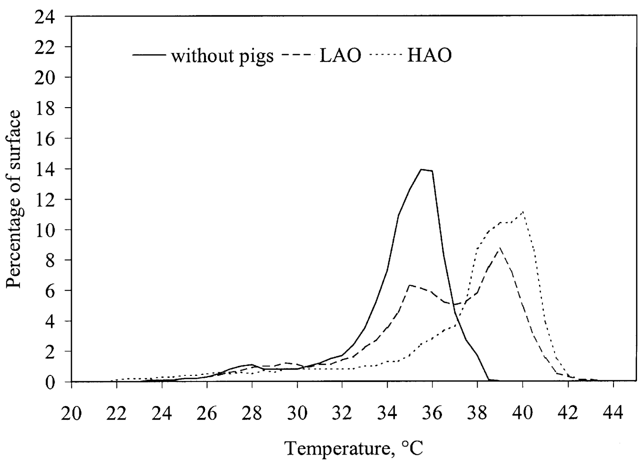

Figure 8–Surface temperature distribution of heat mat without temperature feedback control (test NC37) and at set temperature of 37°C (99°F); °F = °C × 1.8 + 32).

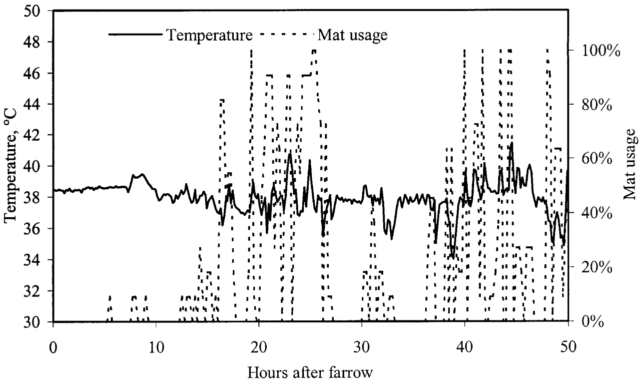

Figure 9–Typical pattern of mat temperature variation with time and mat usage by pigs (test C37). (Note: A heat lamp was available in the back of the crate for the first 48 h.)

Table 3. Ranges of mat surface temperature measured by six thermocouples during a 14-day lactation period

	Temperature (°C)*			
Test†	Initial	Average	Maximum	Minimum
C34	37.2 (1.8)	36.0 (0.9)	42.4 (0.8)	26.9 (3.0)
C37	38.9 (2.1)	37.8 (1.4)	43.9 (1.3)	29.6 (2.1)
NC37	38.8 (1.4)	40.8 (1.3)	46.6 (1.3)	30.9 (2.9)

* Temperature conversion: °F = °C × 1.8 + 32; Δ°F = 1.8Δ°C.

† C34: 34°C setpoint with feedback control; C37: 37°C setpoint with feedback control; NC37: 37°C setpoint without feedback control. Numbers in ( ) are standard deviations.

With temperature feedback control (tests C34 and C37), the maximum and minimum mat surface temperatures were about 5°C (9°F) higher and 10°C (18°F) lower, respectively, than the initial temperature. When no temperature feedback control was used (test NC37), the highest mat temperature was 46.6°C (115.9°F), or 7.8°C (14.0°F) higher than the initial temperature and the minimum temperature was 7.9°C (14.2°F) lower. If only sensible heat exchange is considered, mat temperature should not fall below the set temperature for test NC37 because power input to the mat was constant during the test. The declined temperature was speculated to result from evaporation of moisture caused by the piglets from the mat surface. In all three tests, the time-averaged mat temperature over the 14-day period was within 2°C (3.6°F) of the initial temperature. The minimum temperatures for all three-test conditions were lower than the lower limit of T_{mat_ok}. However, the minimum temperature occurred in UR, which would not be a major concern because UR is the area not used by piglets. The maximum temperature, which was the temperature felt by the piglets while lying on the mat, was within the tolerable range (< 43°C; 109°F) for test C34, slightly higher than the upper limit for test C37 and considerably higher than the tolerable limit for test NC37.

The magnitude of mat temperature alone did not fully describe thermal comfort status of the pigs on the mat. The duration or frequency of certain temperature occurrence should be considered along with the magnitude. Without temperature feedback control (test NC37), the frequency of mat temperature exceeding the upper tolerable limit (43°C; 109°F) averaged 18% (fig. 10) for all three replicates. This result implies that for 11 min out of each hour the mat

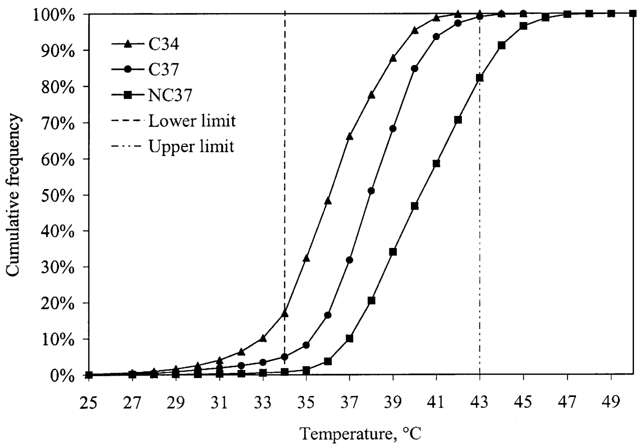

Figure 10–Frequency distribution of mat temperature (°F = °C × 1.8 + 32) measured by thermocouples (pooled data of three replicates during 14-day lactation period).

would be too hot for piglets in OR. At the same setpoint (37°C; 99°F), but with temperature feedback control (test C37), the frequency of mat temperature exceeding 43°C (109°F) averaged less than 1% (fig. 10). For test C34, mat temperature never exceeded 43°C (109°F).

CONCLUSIONS

The following conclusions were drawn from the present studies:

1. Electrical heat mats may contain hot spots (> 43°C; 109°F) if not designed or operated properly, which would reduce the effective usable mat area for the piglets. The mat surface which was in the acceptable temperature range (34-43°C; 93-109°F) accounted for 54% to 79% of the total mat area for the four mats tested.
2. Temperature settings on controllers may not be indicative of the true mat surface temperature. Use of embedded temperature sensors improves controllability of the mat temperature.
3. The temperature of the occupied mat region can be considerably higher than that measured under constant laboratory, free-of-pigs environment. The difference was 6.3°C (11.3°F) (41.0 vs 34.7°C; 105.8 vs 94.5°F) when some of the embedded temperature sensors were in the occupied region and 2.8°C (5.0°F) (37.5 vs 34.7°C; 99.5 vs 94.5°F) if all the temperature sensors were covered.
4. The occupied mat region is much warmer than the unoccupied region. The temperature difference between the two regions ranged from 7 to 12°C (12.6 to 21.6°F).
5. Without temperature feedback control, mats can become excessively hot (> 43°C; 109°F) for piglets in the occupied region although the initial, unoccupied mat temperature is adequate. Thus, feedback control should be used to maintain mat temperature in the occupied region within the acceptable range (34 to 43°C; 93 to 109°F).

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