Effects of Creep Heat Type and Location on Its Usage by Piglets in Farrowing Crates

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Abstract
Comparative tests were conducted in an environment-controlled farrowing room (21 °C, 70 °F) to determine the choice of mat heat vs. lamp heat by piglets in farrowing crates. Two widened farrowing crates (2.40 × 2.13 m, 8 × 7 ft.) were used, each equipped with two double-size heat mats (0.6 × 1.2 m or 2 × 4 ft, 120 W capacity each). One mat was powered to provide the localized heat, while the other simply served as a floor mat with a 175 W heat lamp suspended 76 cm above it for the localized heat. Both heat sources were placed along one side of the sow; hence one mat was closer to the rear end of the sow than the other. Location of the heat source showed a profound effect on its choice by the piglets, with the one near the rear end being clearly preferred regardless of its type. Lamp heat was used significantly more than mat heat for the first two days after birth. Surface temperatures of piglets and heat sources were quantified. In particular, surface temperature of piglets under the heat lamp decreased linearly with the distance between the piglets and the center of the heat source, ranging from 39.4 to 33.4 °C (103 to 92 °F).

Keywords
Creep heating, Swine farrowing, Heat lamp, Heat mat

Disciplines
Bioresource and Agricultural Engineering

Comments
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ABSTRACT

Comparative tests were conducted in an environment-controlled farrowing room (21°C, 70°F) to determine the choice of mat heat vs. lamp heat by piglets in farrowing crates. Two widened farrowing crates (2.40 × 2.13 m, 8 × 7 ft.) were used, each equipped with two double-size heat mats (0.6 × 1.2 m or 2 × 4 ft, 120 W capacity each). One mat was powered to provide the localized heat, while the other simply served as a floor mat with a 175 W heat lamp suspended 76 cm above it for the localized heat. Both heat sources were placed along one side of the sow, hence one mat was closer to the rear end of the sow than the other. Location of the heat source showed a profound effect on its choice by the piglets, with the one near the rear end being clearly preferred regardless of its type. Lamp heat was used significantly more than mat heat for the first two days after birth. Surface temperatures of piglets and heat sources were quantified. In particular, surface temperature of piglets under the heat lamp decreased linearly with the distance between the piglets and the center of the heat source, ranging from 39.4 to 33.4°C (103 to 92°F).

KEYWORDS: Creep heating, Swine farrowing, Heat lamp, Heat mat

INTRODUCTION

Neonatal pigs require warmer environment than the sow for reasons such as potential chilling caused by evaporation of birth fluid and less developed thermoregulatory systems. To accommodate the different thermal needs of sows and piglets, it is a typical management practice to keep relatively low room temperatures while providing localized creep heating. Heat lamps have been commonly used as creep heat source (Xin et al, 1997), while electrical heat mats are increasingly promoted as an energy-efficient alternative. From the viewpoint of heat transfer, overhead radiant heating with lamps is more effective in providing heat to piglets than underneath conductive heating with mat. This is because heat loss by convection and radiation modes account for the majority of the sensible heat loss of the piglets. However, heating with heat lamps has several drawbacks such as higher energy use and limited area of thermal comfort zone for the piglets, as compared with heating with heat mats. Xin and Zhang (1999) examined the preference of lamp heat vs. mat heat by piglets. They found that the preference of mat or lamp heat for small piglets (< 1.7 kg or 3.7 lb.) was influenced by the original heat source the piglets had been exposed to, except for drafty conditions where lamp heat was preferred. As piglets grew (2.4 to 5.3 kg or 5.3 to 11.7 lb.), they showed a similar preference for lamp and mat heat. Further increase in body size (7.1 kg or 15.6 lb.) shifted the preference to mat heat. The study by Xin and Zhang (1999) used two pigs kept in a small environment-controlled wind tunnel for a relatively short-time period.

The study reported in this paper was conducted to elucidate thermoregulation behavior of piglets, particularly during the initial period of afterbirth, with regard to their choices of lamp or mat heat source in actual farrowing crates. The specific objectives were 1) to determine the choice of lamp
heat or mat heat by piglets; and 2) to delineate dynamic behavior of heat usage and skin temperature of the piglets.

**MATERIALS AND METHODS**

The tests were conducted in an environment-controlled farrowing room as described by Zhou and Xin (1999). The room temperature was kept at 21°C to reflect room conditions of farrowing barns in winter, with a concomitant RH of 40 ± 5%. Two widened farrowing crates (2.4 × 2.13 m or 8 × 7 ft) were used in the tests (fig. 1), both having woven-wire flooring for the sow and plastic slats for the creep area. A sow was brought into each crate about two days before the expected farrowing date for each trial.

Two commercial heat mats of double size (0.6 × 1.2 m, or 2 × 4 ft) were placed in each crate, with M1 and M2 in one crate and M3 and M4 in another (fig. 1). Mats M1 and M4 were each located near the rear end of the sow in its respective crate (noted as Back location), and mats M2 and M3 were each near the head end of the sow (noted as Front location). The mats contained embedded electrical heating elements rated at 120 W – a power density of 188 W/m² and four embedded temperature sensors evenly spaced along the centerline of the mat for mat temperature sensing and feedback control (Zhang and Xin, 1999a). There was a 12-mm layer of insulation (R = 0.6 m²K/W) underneath the mat surface to reduce heat loss to the floor. In each test, one of the two mats in a crate was connected to a power controller as a regular heat mat and the other one was not powered and used simply as a floor mat above which a 175 W heat lamp was suspended. The assignment of mat location and functions (as a heat mat or floor mat) are summarized in table 1 for the four tests conducted. When used as a powered heat mat, its surface temperature was set at 37°C on the power controller. When used as a unpowered floor mat, its surface temperature varied from 50°C to nearly ambient level achieved by suspending the 175 W heat lamp 76 cm (30 in) above the mat.

Mat surface temperature was measured using an infrared (IR) imager (0.06°C or 0.1°F sensitivity, model PM250, Inframetrics, Inc., North Billerica, MA). A series of thermal images were taken daily or every second day during the 2-week lactation period. 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 to determine the pig and mat surface temperatures. In addition, thermocouples (TC) (0.1°C or 0.2°F resolution) were used to continuously measure mat surface temperature at selected locations. Specifically, three TC were fixed with silicon onto each mat surface along the centerline, equally spaced, with the first one at the center of the mat and the third one 12 mm from the mat edge. Two layers of adhesive (duct) tape were used to protect the TC from being damaged by the piglets. Output signals of the TC were recorded with an environmental measurement system (Model CR10 and AM416, Campbell Scientific, Inc., Logan, UT) and a PC. Data were sampled every 3 seconds and stored as 15-minute averages.

Behavior of the piglets was continuously monitored and recorded throughout the test period with a video imaging system which consisted of CCD video cameras (Panasonic, WV-CP410) mounted above each crate, a time-lapse VCR (Panasonic, AG-6730), and a TV monitor. The data tapes were subsequently viewed to determine the resting patterns of piglets on the mat and mat usage (MU). MU was calculated as the ratio of number of pigs lying on the mat (n) sampled every 15 minutes to the total number of pigs in the litter (N): MU = n/N. The video images were also digitized using a video board (All-In Wonder, ATI Technologies Inc., Thornhill, ON, Canada) installed in the host PC. Adobe Photoshop program (Adobe Systems Inc., San Jose, CA) was then

<table>
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<tr>
<th>ID</th>
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<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
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<td>UL</td>
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<td>Back</td>
<td>P</td>
<td>UL</td>
<td>UL</td>
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P = powered; UL = under heat lamp as a floor mat.
used to analyze the images to determine the mat surface area occupied by piglets. Area (or
distance) measurements were based on calibrations of pixels on the images against the known
dimensions of the mat (60 x 120 cm). More details on area and distance measurements are
discussed in the next section.

RESULTS AND DISCUSSION

Usage of Mat or Lamp Heat

The daily average MU values for the four mat, lamp, and location cases are shown in figure 2.
Although it was not our original intent of the study, location of the heat source was found to have a
very strong effect on the choice of the heat source by the piglets. Specifically, the piglets
consistently chose the Back heat source regardless of its type (fig. 2). This remained the case for
the first eight days. Despite the interactive effects of location, lamp heat was clearly preferred over
the mat heat for the first two days of afterbirth (P<0.05). This outcome would be expected when
considering the likelihood that overhead radiant heat would benefit piglets more than conductive
floor heat in drying off the birth fluid. The sooner the birth fluid is dried off, the better the piglets
may maintain their thermal comfort. A recent study by our group (unpublished) involving
thermographical measurements of wet vs. dried newborn piglets revealed that the skin temperature
of dried piglets was 3 to 4 °C higher than that of wet piglets. The thermographs further showed a
more extended gesture of body limbs at rest for the dried newborns as compared with their wet
littermates. The other possible but less likely reason for the piglets to prefer the lamp heat for the
first two days was attraction of the light associated with heat lamp. However, data from the current
study did not allow for further explanation in this aspect. Usage of the Back heat source, powered
or under lamp, increased sharply in the first two or three days (fig. 2). The peak usage for both
heat sources was about 50%. It seems that the piglets started to use lamp heat about one day earlier
than mat heat. For example, the first-day usage of mat heat was only 4%, increased to 19% for the
second day, which was close to the magnitude of the first-day lamp heat usage.

From 3 to 8 days of age, the piglets exhibited no clear preference of one heat type over the other
for the Back heat source. Beyond 8 days of age, the piglets seemed to use the lamp heat source
more, as shown in figure 2. However, caution must be exercised in concluding that piglets
preferred lamp heat to mat heat for this growth period because of two underlying reasons. First,
the set-point temperature of heat mat (37°C) was not adjusted as the piglets grew, which could
have become warmer than desired and thus repelled the piglets from its use (more discussion
below). Second, the floor mat under the heat lamp was well insulated and relatively large in size
(0.6 x 1.2 m, or 2 x 4 ft), which might have provided a more comfortable resting surface than the
bare plastic flooring in the creep area. Viewing of the video images revealed that piglets resting on
the floor mat were not necessarily occupying the area influenced by the heat lamp. Nevertheless,
the results did indicate that placing large insulated mats under the lamp would provide a better
thermal environment to piglets.

Heat usage started to decrease after the fourth and fifth day (2.7 and 2.9 kg in body mass or BM)
for lamp and heat mat, respectively, and remained relatively constant after day 11 (4.4 kg in BM).
This was in agreement with the observation made by Xin and Zhang (1999). They reported that
under a calm (air velocity less than 0.15 m/s) environmental condition of 20°C, the usage of
localized heating decreased significantly when piglets grew from 2.4 kg to 3.4 kg, whereas no
changes in heat usage were observed when piglets grew from 1.7 to 2.4 kg.

The rate of decrease in mat heat usage was higher than that for lamp heat usage. The difference
between the usage of the two heat sources was negligible on day 7, but lamp usage was about
twice as high as the mat usage (32% vs. 15%) on day 8. The low usage of mat heat for large
piglets was speculated to arise from the high contact temperature between pigs and the mat. Zhang
and Xin (1999b) presented an equation for predicting the contact temperature between piglets and
heat mat:

\[ t_{cont} = t_{core} + q_m R_t \]  \hspace{1cm} (1)
\[ R_t = 0.02M^{0.33} \]  \hspace{1cm} (2)
where:

- $t_{\text{cont}}$ = contact temperature between pig and mat, °C
- $t_{\text{core}}$ = core body temperature of piglets, 39.5°C
- $q_m$ = power input to heat mat, W
- $R_t$ = tissue thermal resistance of piglet, m$^2$ K/W
- $M$ = body mass of individual pigs, kg

For 8-day old piglets averaging 3.7 kg in body mass, the predicted contact temperature was 45.6°C when the power input density to the mat was 188 W/m$^2$. This temperature might cause discomfort to the piglets and thus discourage them from using the mat. This suggests that mat temperature should be reduced as piglets grew to better meet the thermal needs of the piglets. In comparison, the inherent temperature gradient under the heat lamp always provides a small zone of thermal comfort for piglets of different ages, although this area is generally not large enough to accommodate the entire litter at one time.

To further examine the heat usage by piglets in the first two days after farrowing, cumulative heat usage (CHU) was plotted for the first 48 hours (fig. 3). CHU has the unit of hr with a physical meaning of the equivalent number of hours that the entire litter utilized the heat source during the 48-hr period. CHU was calculated as:

$$\text{CHU} = \frac{\theta}{N} \sum n_i$$

where:

- $n_i$ = number of pigs using the heat source (on mat) at $i^{th}$ sampling or observation time
- $N$ = total number of pigs in the litter
- $\theta$ = sampling or observation interval, 0.25 hr for the entire period
- $i$ = order of sampling, $i = 1, 2, 3, \ldots 192$ (i.e., 4 samples/hr $\times$ 48 hrs)

Note that the premise for the CHU calculation (Eq. 3) was that the pigs remained in the same resting status between the adjacent observation times (Heitman et al., 1962; Zhou et al., 1996). The piglets started to use the heat mat and heat lamp about 4 and 6 hours after birth, respectively (fig. 3). CHU increased rapidly at about 13 hours for heat lamp usage and changed very little until 26 hours for heat mat usage.

Mat surface temperature

Heat mats usually provide uniform heated areas to piglets (Zhang and Xin, 1999a). As shown in figure 4, the mat surface temperature remained almost constant across the mat, except at mat edges (58 cm away from the mat center). In contrast, the surface temperature on floor mats under heat lamps varied dramatically (fig. 4). A small, high temperature zone existed directly under the lamp. The highest temperature in this zone was about 49°C. A similar surface temperature profile of lamp heating also had been reported by Xin et al. (1997). Zhang and Xin (1999a) proposed an acceptable temperature rage of 34 to 43°C for mat heating. A surface temperature of 49°C would discourage the piglets for using the area (Xin, 1998). The surface temperature dropped to 34°C at a distance 19 cm from the projected lamp center on the mat (PLC) (fig. 4). Because the mat was well insulated, temperature at the edges of the mat (60 cm from PLC) was slightly (1°C) higher than that of the ambient air.

Pig skin temperature

Zhang and Xin (1999a) reported that the skin (surface) temperature of 2- to 9-day old piglets lying on heat mats was 34.6°C ($\pm$ 0.9°C S.D.). For the similar age group under the same environmental conditions, the skin temperature was as high as 39.5°C when piglets were lying directly under the lamp and 33.4°C when lying 60 cm away from PLC (fig. 5). The pig skin temperature decreased
with the distance to PLC rapidly in the first 28 cm or so, and changed slightly afterward. A bilinear model was developed to describe the variation of skin temperature under heat lamps:

\[
\begin{align*}
\text{\( t_{\text{skin}} \)} &= \begin{cases} 
38.9 - 0.15x & \text{if } 0 \leq x \leq 28 \\
35.4 - 0.029x & \text{if } 28 < x \leq 60
\end{cases}
\end{align*}
\]

where:

\( t_{\text{skin}} \) = skin temperature of piglets using the heat lamp (175 W, 76 cm above mat), °C
\( x \) = distance between pig and projected lamp center (PLC) on mat, cm

The \( R^2 \) values for the two ranges (0-28; 28-60 cm) were 0.89 and 0.16, respectively. This indicated that correlation between the skin temperature and the distance to PLC was week in the range of 28 to 60 cm. Further statistical analysis showed that the slope of the regression line for the 28-60 cm range was not significantly (\( P>0.05 \)) different from zero. In other words, the skin temperature did not change significantly with the distance to PLC outside the 28-cm ring. The average value of the skin temperature for the 28-60 cm range was 34.1 (± 0.6°C S.D.), which was slightly lower (0.5°C) than that of piglets on powered mat. This further indicated that that lamp heating was most effective approximately within a 28-cm radius around PLC. This radius translates to a surface area of 0.25 m². Analysis of the digitized video images showed that the floor area occupied by a seemingly comfortable piglet averaged 0.044 m² at 1 day of age and 0.074 m² at 14 days of age. This means that area effectively heated by a lamp could accommodate only six 1-day-old piglets or three 14-day-old piglets. Furthermore, not the whole lamp-heated area was thermally comfortable to piglets. As discussed earlier, the surface directly under the lamp was too hot (49°C) for the piglets. IR and video images indicated that the piglets did avoid using a small area under the lamp (fig. 6). To quantify this “uncomfortably hot area”, video images were digitized for days 1, 3, 5, 7, 9, and 13, and Adobe Photoshop program was used to determine the size of the unused mat surface under the lamp. For each image, the x- and y-coordinates of PLC was first determined. These coordinates were measured in pixels in Adobe Photoshop and they were converted to centimeters based on the known dimensions of the mat (60 x 120 cm). Once PLC was located, the minimum and maximum distances between the lying piglets and the PLC were measured. It was found that the pig age had no significant (\( P>0.05 \)) effect on these distances (fig. 7). If the minimum distance is considered the lower limit of the uncomfortably hot zone for piglets under the heat lamp, the average value was 6 cm for a 13-day period. It is interesting to note that the mat surface temperature 6 cm from the PLC was 46.8°C (fig. 4), which was almost the same as the maximum tolerable surface temperature (46.2°C) reported by Zhang and Xin (1999b), but 3.8 °C higher than the tolerable temperature limit (43°C) suggested by de Baey-Ernsten et al. (1995) for surface heating in farrowing crates.

The unused mat area under the lamp was also measured from digitized images and the results are summarized in figure 8. There were no significant differences (\( P>0.05 \)) in unused area among days 1, 3 and 5, nor was among days 3 to 13. The unused area on day 1 was significantly (\( P<0.05 \)) greater than days 7, 9, 11 and 13. It was speculated that 1-day-old piglets left larger unused area under the lamp because their smaller body size allowed the whole litter to rest on the mat without needing to use the hot zone. The overall average of the unused area was 0.10 m². This area is equivalent to that of a circle with a radius of 18 cm, which is close to the average of the minimum (6 cm) and maximum (24 cm) distances between the pigs and PLC.

**CONCLUSIONS**

The following conclusions were drawn from the study.

- Location of the heat source had a profound effect on its choice by the piglets, with the one near the rear end of sow being clearly preferred regardless of its type.
- Lamp heat was used significantly more than mat heat for the first two days after birth.
Surface temperature of piglets resting under heat lamp decreased linearly with the distance between the piglets and the center of the heat source (< 28 cm radius), ranging from 39.5°C to 33.4°C.

REFERENCES

FIGURES

Figure 1 – Schematic of the experimental, widened farrowing crates.
Figure 2 – Daily usage of mat heat and lamp heat by piglets at a calm environmental condition of 21°C

Figure 3 – Cumulative heat usage (CHU, hr) for the first two days after birth.
Figure 4 – Temperature variation on mat surface under heat lamp (175 W, 76 cm above mat).

Figure 5 – Variation of pig skin temperature with the distance from the projected center of 1 175 W heat lamp suspended 76 cm above the floor mat.
Figure 6 – Infrared image of piglets resting on a floor mat under heat lamp (175 W, 76 cm above mat).
Figure 7 – Maximum and minimum distances between lying piglets and the projected lamp center (PLC) (T: standard deviation).

Figure 8 - Unused mat surface area directly under heat lamp (175 W, 76 cm above mat) (T: standard deviation).