Surface Temperature of Creep Heat Mat as Affected by Piglet Use

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ASL – R 1690

Summary and Implications

In a previous study (3), the temperature (T_{mat}) distribution of commercial creep heat mats had been examined under static laboratory conditions. This follow-up study evaluated T_{mat} of a selected heat mat as influenced by the activities of piglets in experimental farrowing crates. The heat mat was operated either with regulated power input by embedded temperature sensors or with constant power input. Embedded temperature sensors were found to facilitate the controllability of T_{mat}, and thus were recommended. When piglets rested on sensor-regulated heat mat, T_{mat} rose in the occupied region and declined in the unoccupied region, with temperature differences between the two regions ranging from 7 to 12°C (13 to 22°F). The temperature feedback control generally allowed for the maintenance of thermal comfort of piglets. In comparison, mats without temperature feedback control could become undesirably warm (>43°C; 109°F) for the piglets.

Introduction

The microenvironment in swine farrowing crates plays a critical role for the well-being of the piglets. To meet the different thermal requirements by 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 and localized heat provided in farrowing barns. Traditionally, heat (infrared) lamps have been used as the localized heat source (2). However, several potential drawbacks exist with heat lamps, including relatively high power consumption, limited thermal comfort zone to accommodate the whole litter, and potential fire hazards. A uniform floor heating system would result in less crowding, which may in turn lead to improved weight gain and better livability than would the radiant heating systems. Heat mats have been considered by the swine industry in North America and Europe as an energy-efficient localized creep heat source. However, little information was available about the operational performance of heat mats. This led to a study that examined uniformity and controllability of T_{mat} for several commercial heat mats (3). The study, conducted under static laboratory conditions (no pigs involved), revealed that considerable variations existed in the performance among the heat mats tested. For those mats that showed good static performance, its performance under dynamic conditions involving use by piglets remained to be determined. This is because the mat use by piglets may change the heat balance between the mat and the surroundings. Consequently, T_{mat} will change with the pig-resting behavior. The objective of this study was to evaluate the operational characteristics of a heat mat in farrowing crates. The mat used in the current study had the best performance under the static conditions, as determined in the previous study.

Materials and methods

One of the four types of heat mats used in the static test (3) was chosen for this dynamic test. The mat had the most uniform T_{mat} distribution. It had a double-side dimension of 0.61 × 1.22 m (24 × 48 in.) and a rated power capacity of 120 W. Actual power input to the mat was regulated either through four temperature sensors embedded along the lengthwise centerline of the mat or through direct voltage control (Figure 1). Sensor regulated power input would vary according to the T_{mat} setpoint and the instantaneous value of T_{mat} sensed by embedded sensors, whereas the voltage regulated power input would remain constant once set. For the sensor regulated power input, a minimum input of 10% of the full power was maintained even after T_{mat} setpoint had been reached.

The tests were conducted in an environmentally controlled farrowing room that was maintained at 21°C (70°F) to reflect typical winter room conditions. Relative humidity in the room was about 40% during the tests. Two enlarged crates (1.94 × 2.13 m or 6.4 × 7 ft) were used in the tests, both having woven-wire flooring for the sow and plastic slats for the creep area. One double 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). For each trial, sows were brought into the farrowing crates two days prior to the expected farrowing date.

T_{mat} was measured with an infrared (IR) imager (Inframetrics PM250) and type T (copper-constantan) thermocouples (TCs) (resolution of 0.1°C or 0.2°F). A series of thermal images was taken every second day during a 14-d 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 with the companion software package (TherMonitor®) of the imager to determine T_{mat} distribution. Although the IR images provided instant measurement or snapshots of T_{mat} of the entire mat, TCs continuously measured T_{mat} of selected locations during the entire lactation period. Six

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TCs (T_1 – T_6) were fixed with silicon onto each mat surface in two rows. Row 1 (T_1, T_2, and T_3, equally spaced) was along the centerline across the width of the mat, and row 2 (T_4, T_5, and T_6, equally spaced) was ¼ into lengthwise centerline from the width side. 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. T_{mat} signals from the TCs were recorded with a data measurement module (CR10 and AM416, Campbell Scientific, Inc., Logan, UT) and a PC. The data were sampled every 3 s and stored as 10-min averages.

A video camera (Panasonic, WV-CP410) was mounted directly above each crate and used in conjunction with a time-lapse VCR (Panasonic, AG-6730) to record the mat use by piglets. The tapes were subsequently played back to determine the mat use by counting the number of piglets lying on the mat at 15-min sampling intervals.

Two controller settings of 34 and 37°C (93 and 99°F) were tested. Note that these two setpoints on the controller dial were different from the actual measured T_{mat}. The 37°C (99°F) setting was the highest power setting on the controller, and the 34°C (94°F) setting corresponded to 90% of the full power input. The two controller settings resulted in mean T_{mat} of 33 and 35°C (91 and 95°F), respectively. For the 34°C (93°F) setting, 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 was performed and they were identified as: 1) C34, i.e., 34°C (93°F) setting with temperature feedback control; 2) C37, i.e., 37°C (99°F) setting with temperature feedback control; and 3) NC37, i.e., 37°C (99°F) setting without temperature feedback control. Each test had three replications. A more detailed description of the experimental setup was given by Zhang and Xin (4).

Results and Discussion

T_{mat} distribution

The pattern of T_{mat} distribution with piglets on the mat was dramatically different from that observed in the static laboratory test. In tests C34 and C37 (i.e., with temperature feedback control), the piglets-occupied region (OR) became warmer and the unoccupied region (UR) became cooler than the initial T_{mat} (Figure 2). The elevated T_{mat} in OR was a result of the reduced heat loss from the mat to the ambient by piglets occupying the mat. Because T_{mat} was controlled via the embedded sensors, the rising T_{mat} caused reduction of power input to the mat. This in turn caused T_{mat} to drop in UR. The magnitude of T_{mat} increase or decrease depended on the lying pattern of the piglets.

Figure 3 shows example snapshots of two typical mat use patterns by the piglets: a low area occupation (LAO), where OR did not cover all the embedded sensors, and a high area occupation (HAO), where OR covered all the embedded sensors. With no piglets resting on the mat, T_{mat} distribution curve had a single peak that occurred near the setpoint. When the mat was used by piglets, two peaks generally occurred (Figure 4), with the high T_{mat} peak indicating T_{mat} in OR and the low T_{mat} peak showing T_{mat} of UR. The low T_{mat} peak for HAO was not as apparent as that for LAO because of the relatively small UR when the piglets occupied most of the mat. T_{mat} in OR, as indicated by the high T_{mat} peak, was close to the setpoint for HAO and was higher than the setpoint for LAO. This was attributed to the temperature feedback control. Power input to the mat was based on the average T_{mat} sensed by the four embedded sensors. This average T_{mat} 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 T_{mat} distribution is numerically shown in Table 1, which summarizes the measured T_{mat} in OR and UR for piglets 2 – 3 and 8 – 9 days old. These two age groups were selected to represent LAO and HAO conditions, respectively. T_{mat} 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 T_{mat} difference between OR and UR ranged from 7 to 12°C (12.6 to 21.6°F). The T_{mat} of OR was 41.0°C (105.8°F) for the LAO condition and 37.5°C (99.5°F) for HAO. At the same controller setting, T_{mat} was 34.7°C (94.5°F) under the constant static environment. Namely, resting of piglets on the mat caused 6.3°C (11.3°F) and a 2.8°C (5.0°F) T_{mat} rise for LAO and HAO, respectively.

The temperature differences between OR and UR could have some adverse effects on the comfort of piglets on the mat. When only small portion of the mat is used by part of the litter, the rest of could become undesirably cool for the remaining litter. 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 the constant power input (Test NC37), T_{mat} increased considerably in OR and slightly in UR (Table 1). The T_{mat} distribution curve had two distinct peaks for LAO, with the high T_{mat} peak for OR and the low T_{mat} peak for UR (Figure 5). The low T_{mat} peak occurred at almost the same level as that of mat with no piglets on it, indicating that piglets had little effect on the T_{mat} of UR when temperature feedback control was not used.

T_{mat} variation with time

T_{mat} was fairly constant before farrowing and fluctuated considerably as piglets started to use the mat (Figure 6). The magnitude of T_{mat} fluctuation was closely related to the mat use by piglets; the more frequently the mat was used, the more T_{mat} fluctuated. Table 2 summarizes the T_{mat} ranges measured for the 14-d lactation period in the three test series. With temperature feedback control (tests C34 and C37), the maximum and minimum T_{mat} were about 5°C (9°F) higher and 10°C (18°F) lower, respectively, than the initial T_{mat}. Without temperature feedback control (test NC37), the highest T_{mat} was 46.6°C (115.9°F), or 7.8°C (14.0°F) higher than the initial T_{mat} and the minimum T_{mat} was 7.9°C (14.2°F) lower. If only sensible heat exchange is considered, T_{mat} should not fall below the setpoint for test NC37 because power input to the mat was constant during the test. The declined T_{mat} was speculated to result from evaporation of wet mat surface caused by the piglets. In all three tests, the time – averaged T_{mat} over the 14-d period was within 2°C (3.6°F) of the initial value. The minimum T_{mat} for all three test conditions was lower than the lower threshold of the TN T_{mat} range (34°C or 93°F, [1]). However, the minimum T_{mat} occurred in UR, which would not be a major concern because UR is the area not used by the piglets. The maximum T_{mat}, the temperature felt by the piglets while lying on the mat, was within the tolerable range (<43°C or 109°F) for test C34, slightly higher than the upper limit for C37, and considerably higher than the upper limit for NC37 (>43°C or 109°F).

Note that the magnitude of T_{mat} alone would not fully represent thermal comfort needs of piglets on mat. Duration or frequency of certain T_{mat} occurrence must be considered along with magnitude. Without temperature feedback control (NC37), the frequency of T_{mat} exceeding the upper limit (43°C; 109°F) was 18% (Figure 7). This implies that on average for 11 min out of each hour the mat would be undesirably warm for piglets in OR. At the same setpoint (37°C; 99°F), but with temperature feedback control (C37), the frequency of T_{mat} exceeding 43°C (109°F) was less than 1% (Figure 7). For test C34, T_{mat} never exceeded 43°C (109°F). Hence, the results showed the merit of regulating the power input to the mat and thus T_{mat} using the embedded temperature sensors.

Acknowledgements

Funding for this study was provided in part by the Agri-Food Research and Development Initiative (ARDI) of Manitoba and the Iowa Energy Center, and was acknowledged with gratitude.

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Table 1. Mat surface temperature (°C) in regions occupied and unoccupied by piglets.

Test[a]	LAO (day 2 – 3)		HAO (day 8 – 9)	
	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)

[a] C34: Temperature – feedback controlled with controller setpoint = 34°C.
C37: Temperature – feedback controlled with controller setpoint = 37°C.
NC37: No temperature – feedback control with controller setpoint = 37°C.
Numbers in parentheses were standard deviations.
LAO, low area occupation; HAO, high area occupation.
Temperature conversion: °F = °C × 1.8 + 32; Δ°F = 1.8Δ°C

Table 2. Ranges of mat surface temperature measured by six thermocouples during a 14-day lactation period.

Test [a]	Temperature, °C			
	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)

[a] C34: Temperature – feedback controlled with controller setpoint = 34°C.
C37: Temperature – feedback controlled with controller setpoint = 37°C.
NC37: No temperature – feedback control with controller setpoint = 37°C.
Numbers in parentheses were standard deviations.
Temperature conversion: °F = °C × 1.8 + 32; Δ°F = 1.8Δ°C

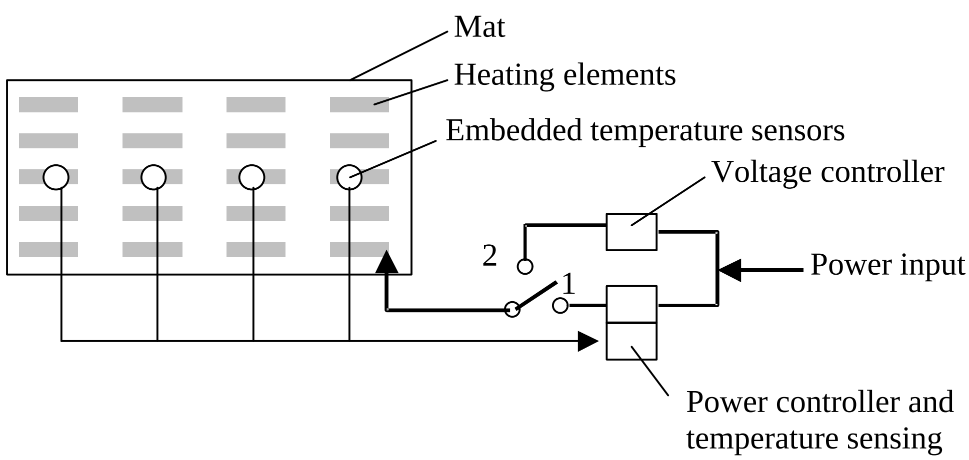

Figure 1. Schematic representation of heat mat layout and power input control.

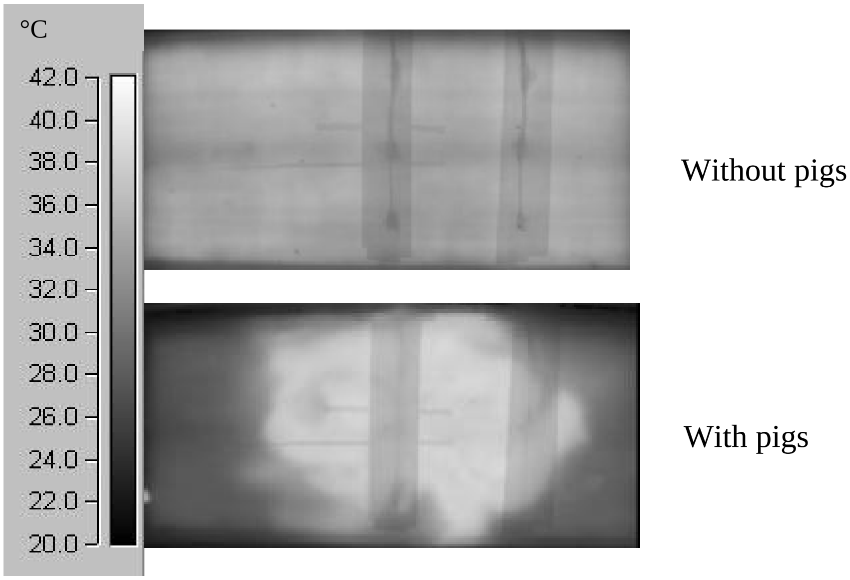

Figure 2. Comparison of mat temperature distribution without vs. with pigs.

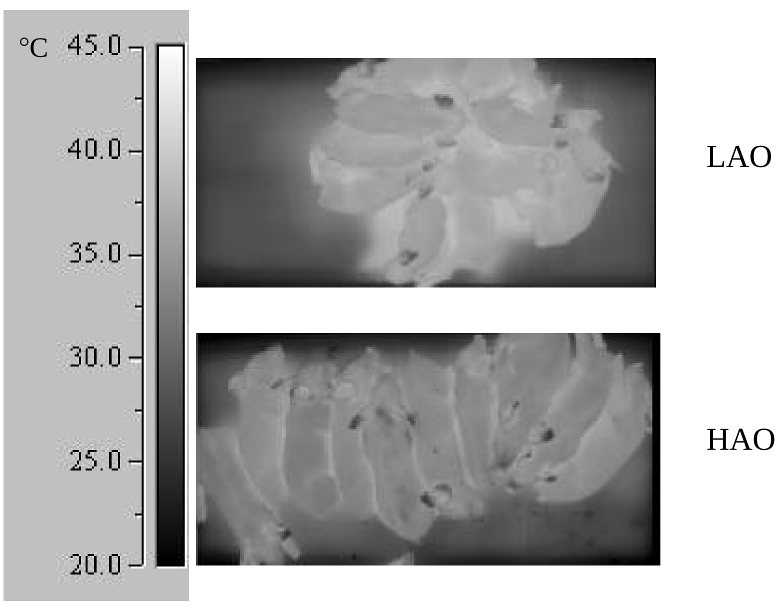

Figure 3. Typical lying patterns of piglets on heat mats (LAO, low area occupation; HAO, high area occupation).

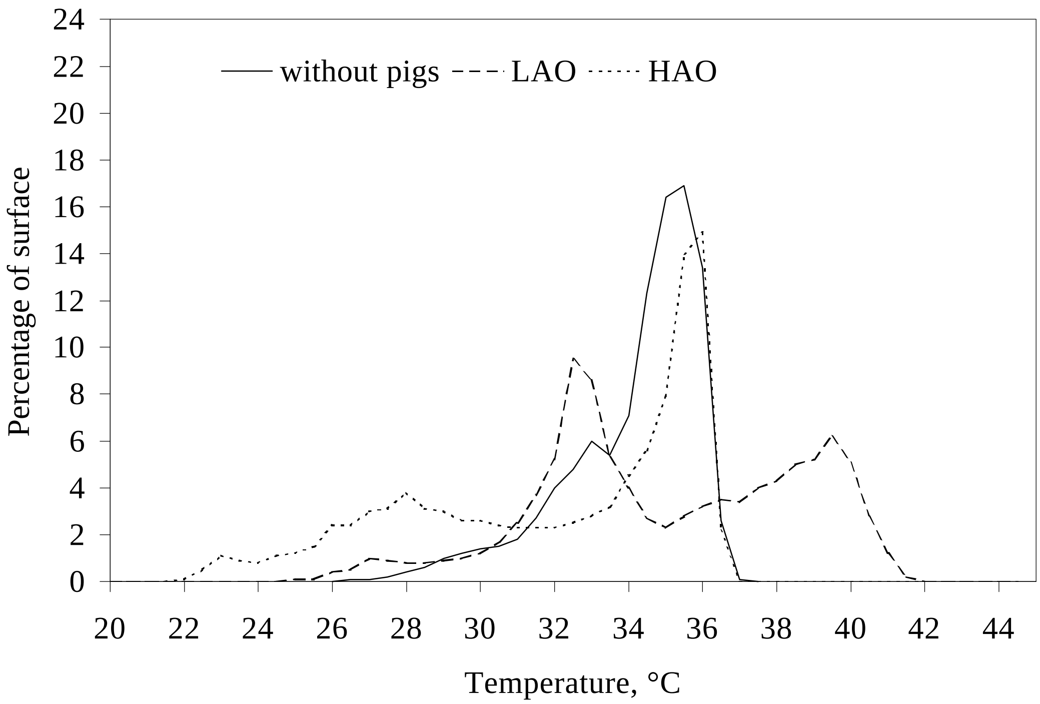

Figure 4. Surface temperature distribution of heat mat with temperature feedback control and at set temperature of 37°C (99°F) (C37). °F = °C × 1.8 + 32.

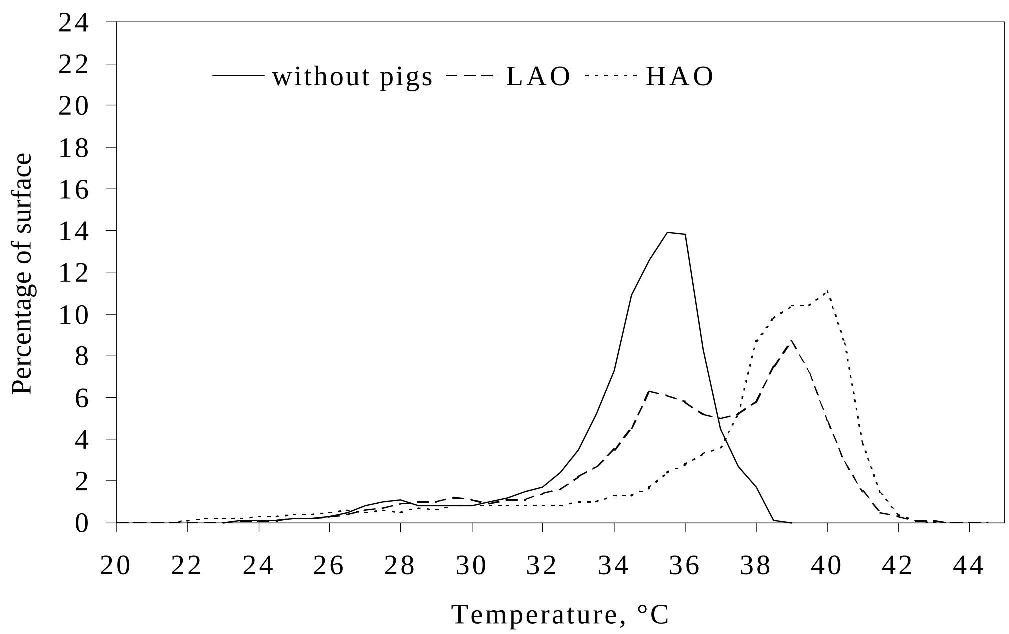

Figure 5. Surface temperature distribution of heat mat without temperature feedback control and at set temperature of 37°C (99°F) (NC37). °F = °C × 1.8 + 32.

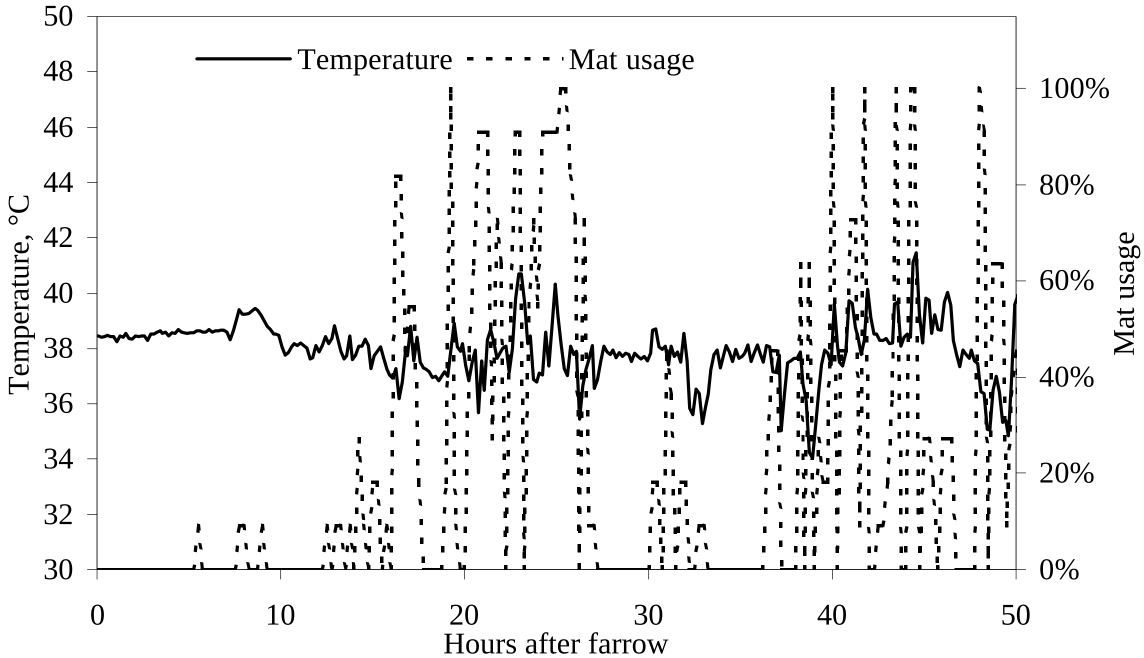

Figure 6. Typical pattern of mat temperature variation with time and mat use by pigs (Test C37) (Note: A heat lamp was available in the back of the crate for the first 48 h).

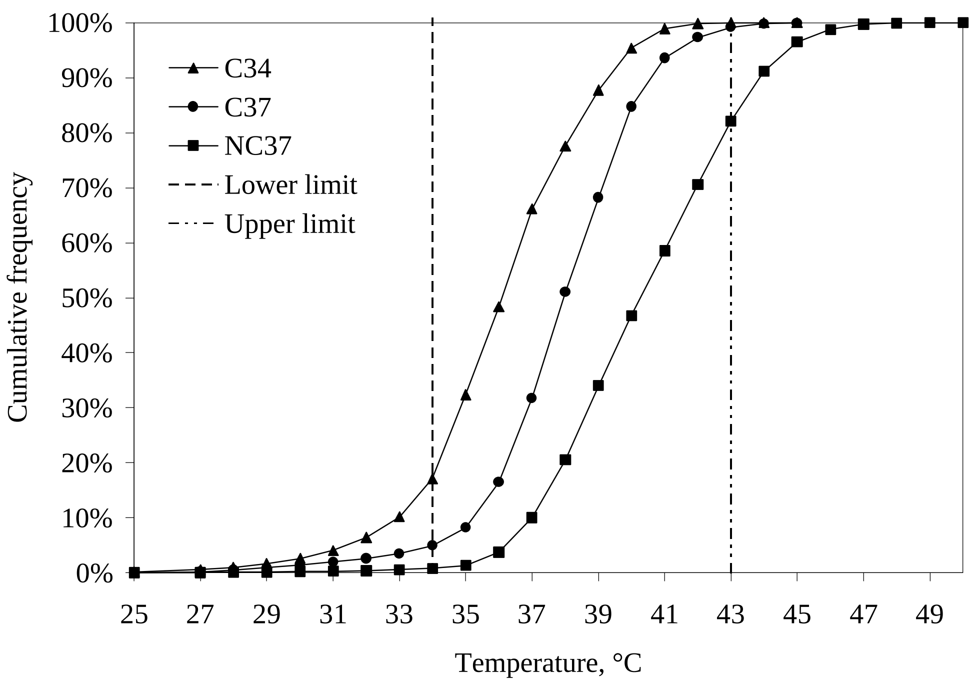

Figure 7. Frequency distribution of mat temperature measured by thermocouples. °F = °C × 1.8 + 32.