INFRARED THERMOGRAPHIC EVALUATION OF COMMERCIALLY AVAILABLE INCANDESCENT HEAT LAMPS

J. D. Davis, H. Xin, R. D. MacDonald

ABSTRACT. *Infrared thermography is a useful tool in visualizing and quantifying spatial distribution in radiant heat of incandescent heat lamps. Radial temperature profiles of six commercially available heat lamps (100W to 250W) were comparatively characterized. Heat lamps with the same power output do not necessarily produce the same temperature profiles on the heated surface because the shape of the temperature profiles was shown to be greatly affected by the lamp lens prescription. At a lamp height of 45.7 cm (18 in.), the net usable area (NUA) for the piglets was 0.102, 0.155, 0.146, 0.275, 0.139 and 0.113 m^2 (1.10, 1.67, 1.57, 2.96, 1.50, and 1.22 ft^2), respectively, for 100W Retrolite (100CZ20), 125W Hogslat (125HOG), 125W SLI Lighting (125SLI), 175W Retrolite (175CZ20), 175W Phillips (175PLP), and 250W SLI Lighting (250SLI). The 175CZ20 had the largest NUA and was the most efficient lamp on the basis of NUA per rated Watt. Although the 250SLI had the largest lamp heated area, it and the 175PLP were the least efficient lamps due to the large hotspots they produced. Lamp height affects the size of heated area, hotspot area and NUA for most of the lamps tested. These results suggest that in a commercial swine farrowing system, the 175CZ20 has the most potential among the incandescent heat lamps tested for meeting the thermal needs of the piglets and improving energy efficiency of the localized supplemental heating.*

Keywords. *Creep heat, Supplemental heat, Swine farrowing.*

In 2000, 55.5% of all preweaning mortalities by producer-identified cause were classified as "laid-on" by the sow (NAHMS, 2002). Swine producers traditionally place a supplemental heat source in the farrowing creep area to provide localized heat for the piglets to attract them away from the sow and thus decrease pig mortality from crushing. Infrared heat lamps are commonly used as a localized creep heat source, thus meeting the different thermal needs of the newborn piglets [30°C to 32°C (86°F to 90°F)] and the sow [18°C to 21°C (64°F to 70°F)] (Xin et al., 1997).

MacDonald et al. (2000) and Zhang and Xin (2000a) compared heat lamp systems to other creep-heating systems. Zhang and Xin (2000a) found that lamp heat was the preferred heat source for the first two days after birth when compared to a heat mat. Others have studied the effects of heat lamp placement on lying behavior and thermal comfort of sow and piglets (Titterington and Fraser, 1975; Zhou et al., 1996; Hrupka, et al., 1998), energy efficiency and radial temperature distribution of heat lamps (Xin et al., 1997) and variable versus constant heat lamp output and lamp colors (Zhou and Xin, 1999). Zhang and Xin (2000b) measured the maximum contact temperature between piglets and heat mats during a 14-day lactation period. They found that the threshold temperature ranged from 44.5°C to 46.2°C (112.1°F to 115.2°F) and was independent of the piglet age.

The effectiveness of heat lamps as a local heat source depends on the size of the lamp and the spatial distribution of radiant heat. Suspended heat lamps in farrowing crates may cast excess heat over the sow's lying area, which may in turn over-heat the sow. This also encourages the piglets to lie closer to the sow and increase the possibility of crushing (Titterington et al., 1975).

The 250W R40 (gooseneck) lamp has been often used in heat lamp installations. However, as producers become more energy conscious, alternative types of infrared heat lamps have been developed. In warmer climates, the lamp of choice has been the 125W R40 lamp due to the lower heat requirements. In a study by Xin et al. (1997), the traditional 250W lamp was compared with an energy efficient 175W (PAR38) Phillips lamp. They determined that the 175W lamp produced a significant energy savings, 45% lower lamp failure rate, 1.2% reduction in birth-to-weaning mortality and a slightly higher piglet rate of gain.

Zhou et al. (1996) measured the dynamic heat lamp usage rate (HLU) of neonatal pigs exposed to 250W, 175W, and 125W heat lamps. HLU is defined as the percentage of a litter having their bodies within a 45-cm (17.7-in.) radial distance from the projected center of lamp (PCL). HLU was significantly affected by heat lamp size with the 175W lamp producing the best piglet resting pattern. There was a consistent circadian pattern in HLU for all heat lamps. Average HLU was 28%, 31%, 39% for 250W, 175W, and 125W, respectively, during the day and 13%, 24% and 24%, respectively, at night. HLU also declined with increasing pig age. Since HLU is affected by heat level and distribution, updated information on heat distribution as affected by

Submitted for review in December 2007 as manuscript number IET 7290; approved for publication by the Information & Electrical Technologies Division of ASABE in June 2008.

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  ISSN 0883-8542

different lamp sizes and fixture designs and the amount of heated area meeting the thermal comfort of the piglets will enhance swine producers' ability to properly select and operate the heat lamps and their fixtures.

The objectives of this study were: a) to comparatively characterize the radial temperature distribution of six commercially available heat lamps (100W to 250W); b) to determine if there are differences in lamp heated area (HA), hotspot area (HSA), and net useable area (NUA) due to treatments of lamp and height; and c) to determine which lamp(s) provides the best option in commercial farrowing operations.

Materials and Methods

A Retroliter® Hang Straight® plastic heat lamp fixture (RetroLite Corporation of America, Hatboro, Pa.; fig. 1) was suspended at four heights - 45.7, 50.8, 55.9, or 66.0 cm (18, 20, 22, and 26 in.) from a rubber mat [0.91 × 0.91 m (36 × 36 in.)] placed on plastic slat flooring inside an environmentally controlled test room (fig. 2). The suspension height was measured from the mat surface to the lamp face. The range of values was chosen based on the lamp heights encountered in swine farrowing operations. The only recommended lamp height readily supplied by a manufacturer was a 51-cm (20-in.) lamp height to provide a 51-cm (20-in.) diameter comfort zone using a Comfort Zone 20™ (Retrolite Corp. of America, 2008). The room ambient temperature was held at 21+1°C (70±2°F) throughout the tests.

Figure 1. Experimental layout showing the PM250 IR camera above the plastic lamp fixture and flooring.

Figure 2. Lamp surface treatment (l to r) for (a) 125HOG, (b) 125SLI and 250SLI, (c) 100CZ20 and 175CZ20, and (d) 175PLP.

Six commercially available incandescent infrared heat lamps were used in this study. Lamp size, brand and lamp lens prescription are described in table 1 and illustrated in figure 2. Three replications of each type of lamp were individually installed and allowed to stabilize before acquiring the thermographs using an infrared (IR) camera [0.06°C (0.1°F) discernability, model PM250; Inframetrics, Inc., North Billerica, Mass.] positioned 1.6 m (64 in.) directly above the mat. Thermal stabilization of each setting was determined when the change in temperature of a radial spot of the heated mat reached zero. The thermograph of heated mat surface was taken immediately following removal of the heat lamp. The rubber mat was cooled using a fan before the next thermograph was taken.

The thermographs were analyzed using the companion TherMonitor® 95 software (Thermoteknix Systems Ltd., Cambridge, U.K.) for this camera to determine mat surface temperatures and distribution. Two-dimensional mean radial temperature profiles were constructed using eight (45° apart) temperature profiles extending 40.6 cm (16 in.) from the PCL of the heated mat area. These measured profiles represent 0.52 m^2 (5.6 ft^2) of mat area.

To determine the usefulness of each lamp type, lamp heated area (HA; m^2), hotspot area (HSA; m^2) and net usable area (NUA; m^2) were determined using the Thermonitor® software. Lamp effective area was defined as the heated area above a minimum temperature that meets the needs of the newborn piglets. The minimum temperature was set to 30°C or 86°F (Xin et al., 1997). Hotspot area was defined as the heated area that exceeded a maximum contact temperature the piglets would tolerate. The maximum temperature was set at the lower maximum contact temperature of 44.5°C

Table 1. Incandescent infrared heat lamps tested in this comparative study.

	Symbol	Brand	Type	Power (W)	Lamp Surface Treatment
1	100CZ20	Retrolite	PAR 38	100	Reticle surface
2	125HOG	Hog slat	R40	125	Clear
3	125SLI	SLI lighting	R40	125	Clear
4	175PLP	Philips	PAR 38	175	Reticle/clear hexagon center
5	175CZ20	Retrolite	PAR 38	175	Reticled surface
6	250SLI	SLI lighting	R40	250	Clear

(112.1°F) tolerated by the piglets, as reported by Zhang and Xin (2000b). Mat surface area within the 30°C to 44.5°C (86°F to 112.1°F) was defined as the net usable area (NUA) for piglet utilization, calculated as:

$$NUA = HA - HSA \quad (1)$$

Statistical Analysis

The six incandescent heat lamps and four lamp heights were arranged in a 6 × 4 factorial treatment regimens, each with three replications. All data were analyzed with PROC MIXED in SAS (SAS v9.1, SAS Institute, Inc., Cary, N.C.) and differences in treatment means were separated using Fisher's LSD. Differences in treatment effects were considered to be significant at $P \leq 0.05$.

Results and Discussion

Example thermographs of each lamp type tested at the 45.7-cm (18-in.) height are presented in figure 3. Each thermograph has a 0.9-m (36-in.), two-dimensional temperature profile through the PCL of the HA to illustrate the surface temperature variations. The 100CZ20 (fig. 3a) and 175CZ20 (fig. 3b) lamps had evenly spaced lenticels

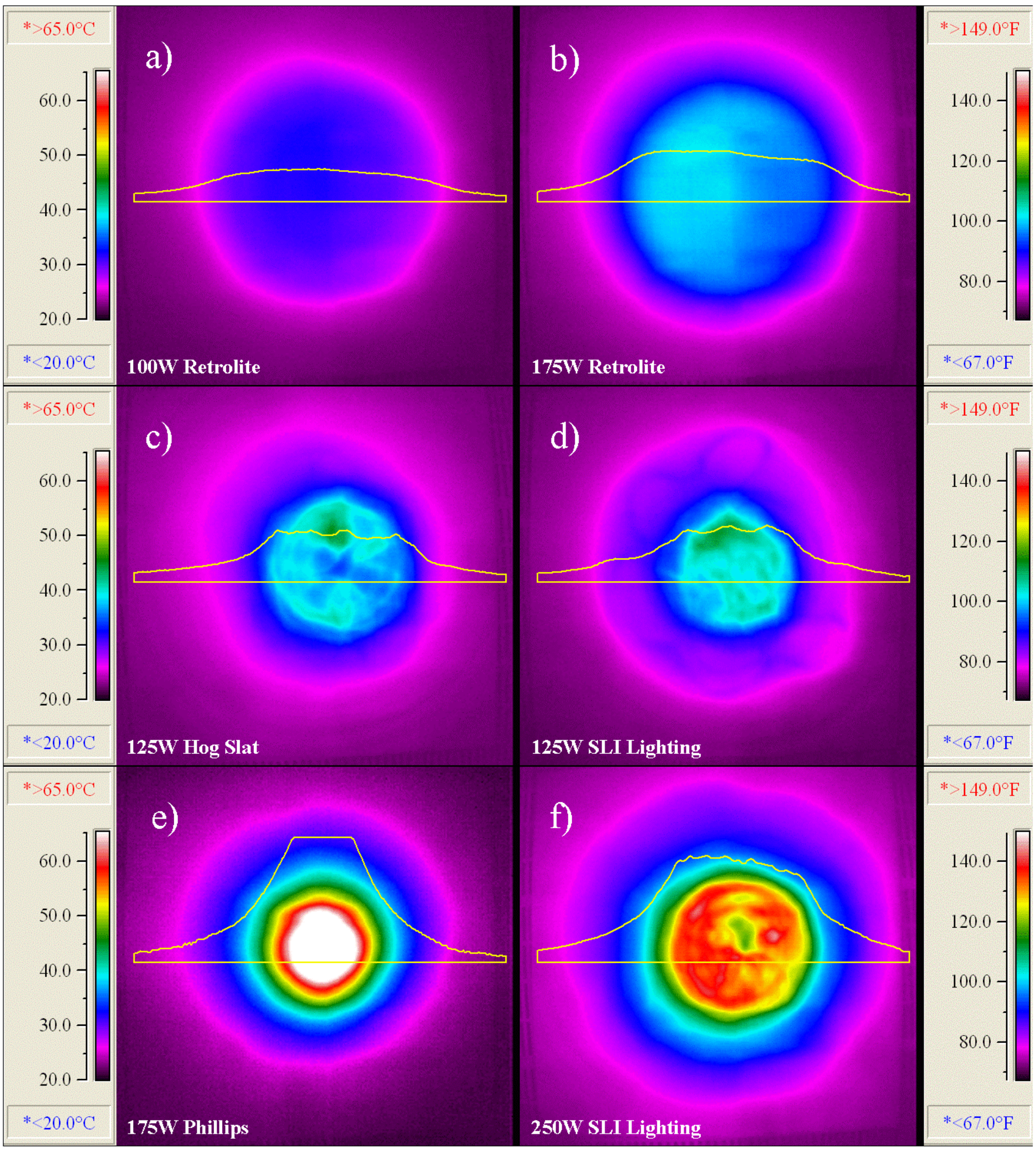

Figure 3. Infrared thermographs of each lamp type at the 45.7-cm (18-in.) height. Note: Thermograph (e) has been clipped due to the thermal range needed to capture to smaller lamp thermographs. The actual profile peaks to a point as shown in figure 4.

along the inner surface, thus demonstrating the most uniform HA. The clear lens lamps 125HOG, 125SLI, and 250SLI displayed spatial variations near the center due to the heating elements (fig. 3c, d, f, respectively). The 175PLP lamp (fig. 3e) had a clear hexagonal center surrounded by evenly spaced lenticels and exhibited the largest radial temperature gradient of the HA.

RADIAL TEMPERATURE DISTRIBUTION

The thermographs were compiled into two-dimensional radial temperature profiles (fig. 4) for each lamp to illustrate the radial variation in heat distribution at the 45.7-cm (18-in.) height. The minimum and maximum temperatures within the 40.6-cm (16-in.) radial span are shown in table 2. The 100CZ20 and 175CZ20 lamps demonstrated a relatively constant radial temperature profile with maximum

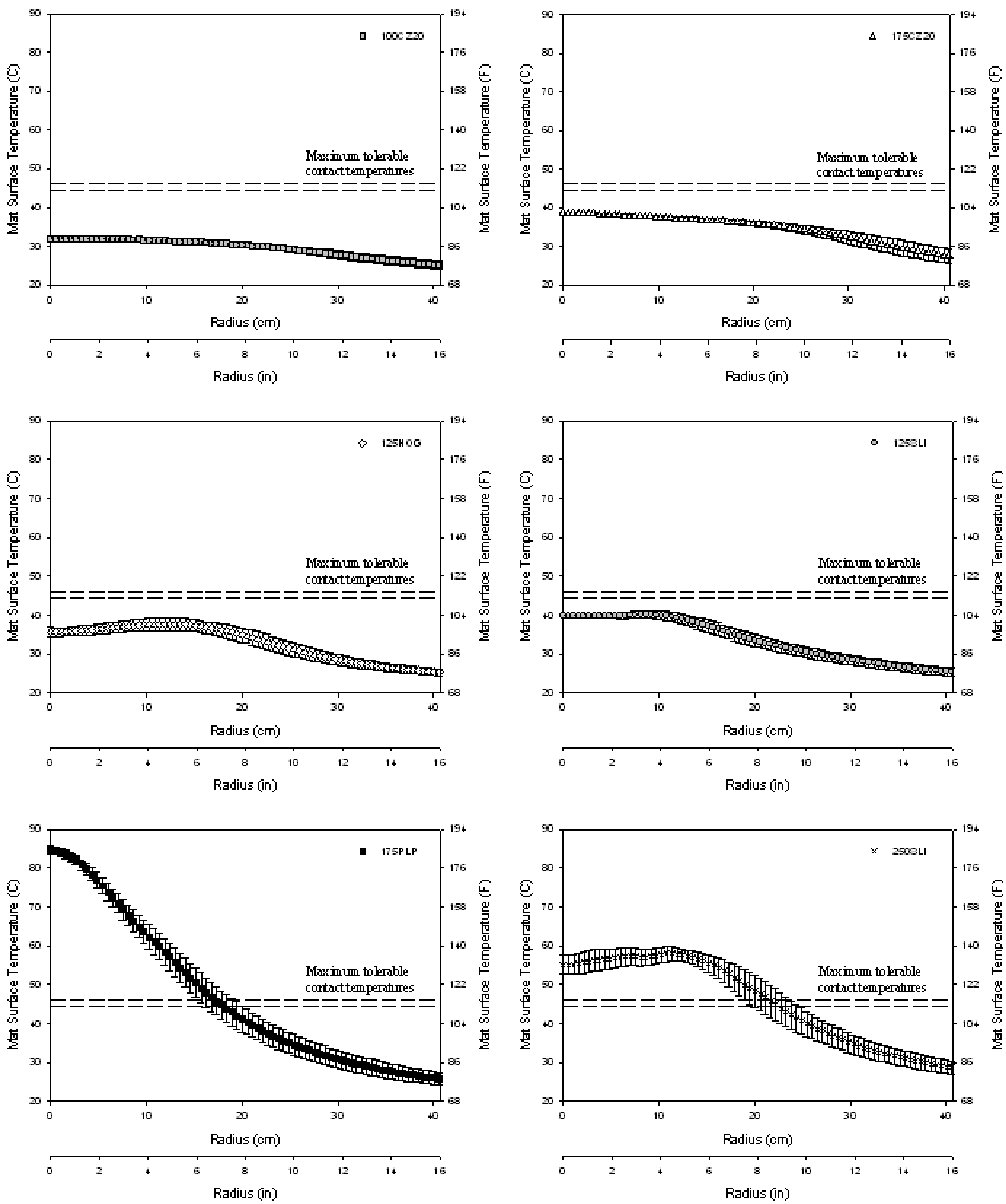

Figure 4. Radial temperature profiles of each lamp type in plastic fixture at 45-cm (18-in) height.

temperatures of 32.3°C (90.1°F) and 39.2°C (102.6°F), respectively. The clear surfaced 125HOG, 125SLI, and 250SLI had maximum temperatures [43.0°C, 44.1°C, and 64.0°C (109.4°F, 111.4°F and 147.2°F, respectively)] between 10 and 15 cm (4 and 6 in.) radius, corresponding to the radiant projection from the heating element. The 175PLP had the highest mat temperature gradient, with mat surface temperature reaching 85.1°C (185.2°F), resulting in rippling of the mat. The two horizontal dashed lines represent the maximum tolerated contact temperature range [44.5°C to 46.2°C (112.1°F to 115.2°F)] between piglets and heat mats, as measured by Zhang and Xin (2000b). The area within 17- and 20-cm (6.7- and 7.9-in.) radius would be used only in short durations if applying the maximum contact temperature threshold for 175PLP and 250SLI at the 45.7-cm (18-in.) height, respectively. These results demonstrate that heat lamps with the same power output do not necessarily produce the same temperature profiles on the heated surface.

Lamp Areas

The lamp areas of interest for each lamp type were obtained by setting the minimum [30°C (86°F)] and maximum [44.5°C (112.1°F)] temperature thresholds for each thermograph. The lamp matrices in figure 5 illustrate the variations in NUA for each lamp at the four heights using these thresholds. The blue shaded regions illustrate the areas that stabilize below the 30°C (86°F) minimum temperature. The circular region above the minimum temperature threshold comprised the lamp HA. Any HA that exceeded the maximum temperature was shaded in red and represented the HSA. The NUA was illustrated by the gray shading between the blue and red regions.

Lamp Heated Area (HA)

At the 45.7-cm (18-in.) height, lamp HA was smallest in 100CZ20 and largest in 250SLI (fig. 5). There was no difference in HA between 250SLI and 175CZ20 or between 125HOG and 125SLI (table 2). Increasing lamp height greatly affected HA. By raising the lamp height greater than 45.7 cm (18 in.), the HA of 100CZ20 was reduced to zero. Heated areas for 125HOG and 125SLI were similar for heights between 45.7 and 55.9 cm (18 and 22 in.). The HA of 125HOG, 125SLI, and 175CZ20 diminished when lamp height was 66 cm (26 in.) (table 2). In comparison, lamp height did not affect HA of the 175PLP.

Hotspot Area (HSA)

The 100CZ20 and 175CZ20 lamps did not produce any HSA. The 125HOG and 125SLI only produced one small

Table 2. Minimum and maximum temperatures and least square means for lamp heated area, hotspot area, and net usable area at varying lamp suspension heights.

Lamp Type	Lamp Height (cm)	Minimum Temperature (°C)	Maximum Temperature (°C)	Lamp Heated[a] Area (m^2)	Hotspot[b] Area (m^2)	Net Usable[c] Area (m^2)
100SYL	45.7	23.1 ± 0.1	32.3 ± 0.2	0.102 ± 0.006[g]	0.001 ± 0.000[e]	0.102 ± 0.002[j]
	50.8	22.5 ± 0.2	29.1 ± 0.1	0.000 ± 0.000[h]	0.001 ± 0.000[e]	0.000 ± 0.000[k]
	55.9	23.6 ± 0.1	29.2 ± 0.2	0.000 ± 0.000[h]	0.001 ± 0.000[e]	0.000 ± 0.000[k]
	66.0	23.2 ± 0.1	27.0 ± 0.5	0.000 ± 0.000[h]	0.001 ± 0.000[e]	0.000 ± 0.000[k]
125HOG	45.7	23.0 ± 0.1	43.0 ± 2.2	0.156 ± 0.002[e]	0.001 ± 0.000[e]	0.155 ± 0.002[f,g]
	50.8	22.5 ± 0.3	37.3 ± 1.0	0.129 ± 0.002[f]	0.001 ± 0.000[e]	0.129 ± 0.002[h,i]
	55.9	23.1 ± 0.2	37.1 ± 1.1	0.141 ± 0.006[e,f]	0.001 ± 0.000[e]	0.141 ± 0.006[g,h,i]
	66.0	22.8 ± 0.2	31.7 ± 0.7	0.007 ± 0.004[h]	0.001 ± 0.000[e]	0.007 ± 0.004[k]
125SLI	45.7	22.9 ± 0.2	44.1 ± 0.9	0.147 ± 0.010[e,f]	0.001 ± 0.000[e]	0.146 ± 0.010[g,h,i]
	50.8	22.9 ± 0.3	39.9 ± 1.1	0.139 ± 0.010[e,f]	0.001 ± 0.000[e]	0.139 ± 0.010[g,h,i]
	55.9	23.2 ± 0.1	38.4 ± 1.1	0.136 ± 0.003[e,f]	0.001 ± 0.000[e]	0.136 ± 0.003[g,h,i]
	66.0	23.4 ± 0.1	32.3 ± 0.1	0.021 ± 0.009[h]	0.001 ± 0.000[e]	0.021 ± 0.009[k]
175SYL	45.7	23.4 ± 0.5	39.2 ± 0.3	0.275 ± 0.008[b]	0.001 ± 0.000[e]	0.275 ± 0.008[a]
	50.8	24.3 ± 0.6	34.6 ± 0.4	0.244 ± 0.020[c]	0.001 ± 0.000[e]	0.244 ± 0.020[b]
	55.9	24.9 ± 0.0	33.3 ± 0.3	0.211 ± 0.031[d]	0.001 ± 0.000[e]	0.211 ± 0.031[c,d]
	66.0	25.2 ± 0.1	29.9 ± 0.1	0.000 ± 0.000 [h]	0.001 ± 0.000[e]	0.000 ± 0.000[k]
175PLP	45.7	22.1 ± 0.2	85.1 ± 1.3	0.217 ± 0.001[d]	0.079 ± 0.001[b]	0.139 ± 0.001[g,h,i]
	50.8	22.0 ± 0.1	74.3 ± 1.1	0.205 ± 0.004[d]	0.071 ± 0.001[c]	0.134 ± 0.003[g,h,i]
	55.9	21.5 ± 0.2	72.3 ± 1.3	0.192 ± 0.002[d]	0.068 ± 0.001[c]	0.125 ± 0.002[i,j]
	66.0	23.5 ± 0.2	56.4 ± 1.0	0.202 ± 0.005[d]	0.050 ± 0.004[d]	0.153 ± 0.003[g,h]
250SLI	45.7	24.7 ± 0.2	64.0 ± 1.0	0.298 ± 0.008[a,b]	0.113 ± 0.004[a]	0.186 ± 0.007[d,e]
	50.8	25.0 ± 0.1	57.0 ± 0.8	0.291 ± 0.005[b]	0.114 ± 0.004[a]	0.178 ± 0.002[e,f]
	55.9	25.1 ± 0.4	53.7 ± 0.7	0.321 ± 0.010[a]	0.110 ± 0.003[a]	0.212 ± 0.007[c]
	66.0	24.5 ± 0.1	44.4 ± 0.6	0.280 ± 0.007[b]	0.001 ± 0.001[e]	0.280 ± 0.007[a]

Column values represent means ± standard error of the mean.
[a] Means are separated using pooled standard error of 0.00920. Significance was considered at $P \leq 0.05$.
[b] Means are separated using pooled standard error of 0.00165. Significance was considered at $P \leq 0.05$.
[c] Means are separated using pooled standard error of 0.00897. Significance was considered at $P \leq 0.05$.

Unit conversion: 1 cm = 0.3937 in.; °C = (°F-32)/1.8; 1 m^2 = 10.76 ft^2.

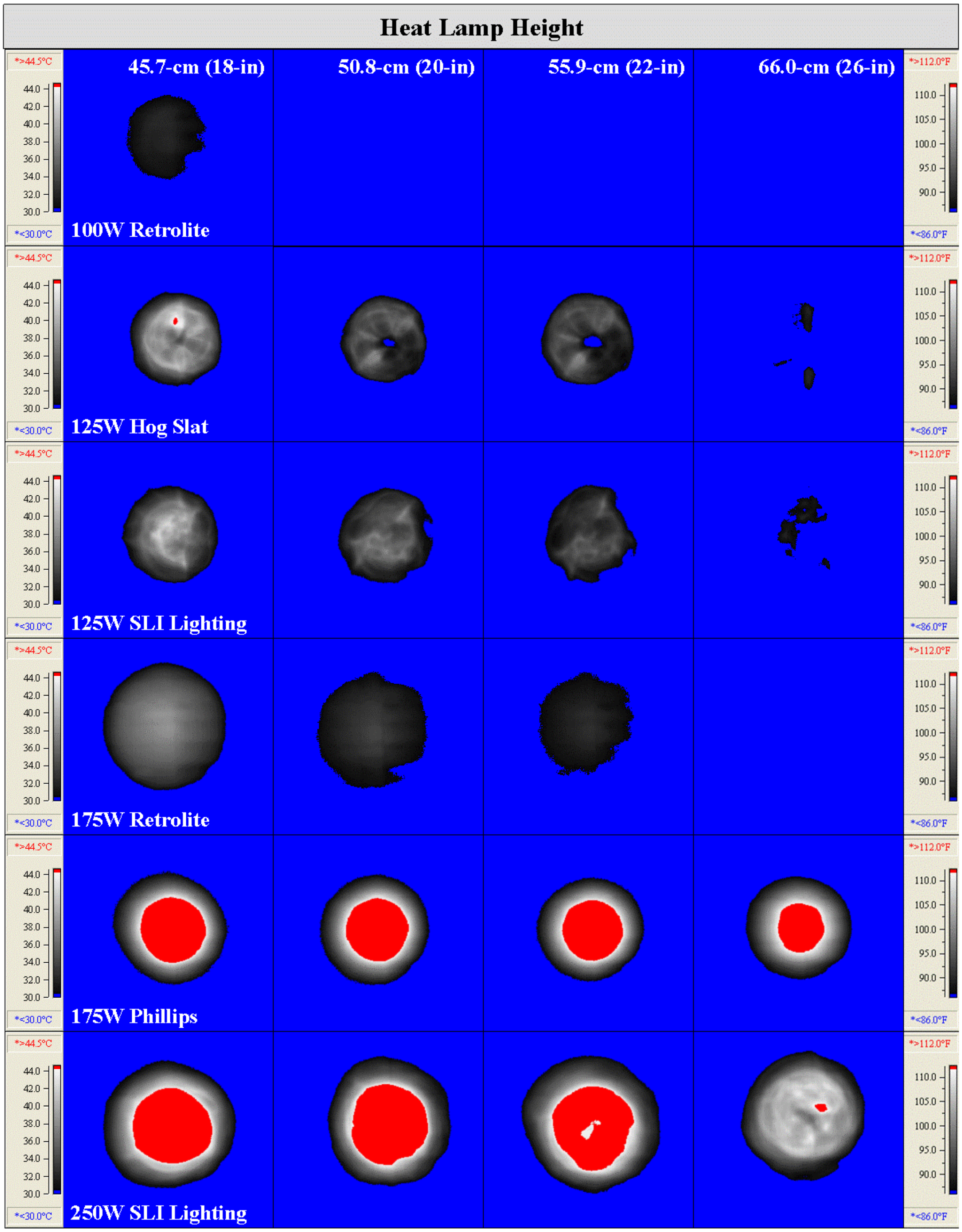

Figure 5. Infrared thermographs of each lamp type illustrating the unheated mat area (blue), net usable area (gray-scale shading), and hotspot area (red) at four lamp heights. Each thermograph square has a width of 99 cm (39 in.) and a depth of 91 cm (36 in.).

HSA region along the heating element projection. The HSA for 175PLP [0.079 m^2 (0.85 ft^2)] and 250SLI [0.113 m^2 (1.22 ft^2)] were significantly different ($P < 0.05$) at the 45.7-cm (18-in.) height (table 2). Hotspot areas of 250SLI were not different between 45.7- and 55.9-cm (18- and 22-in.) heights. Raising 250SLI to 66-cm (26-in.) height reduced the HSA to zero. Increasing lamp height of 175PLP from 45.7 to 66 cm (18 to 26 in.) resulted in a 37% reduction in HSA.

Net Usable Area (NUA)

The NUA was largest for 175CZ20 [0.275 m^2 (2.96 ft^2)] and smallest for 100CZ20 [0.102 m^2 (1.10 ft^2)] at 45.7-cm (18-in.) height. The NUA for 125HOG, 125SLI, and 175PLP [0.155, 0.146, and 0.139 m^2 (1.67, 1.57, and 1.50 ft^2, respectively)] were not different. Lamp 100CZ20 had no NUA above the 45.7-cm (18-in.) height. Net usable area was similar for 125HOG, 125SLI, and 175PLP between heights of 45.7 and 55.9 cm (18 and 22 in.). Above 55.9 cm (22 in.), the NUA of 125HOG and 125SLI were drastically reduced. The NUA of 175CZ20 was reduced with increasing height, reaching zero at 66-cm (26-in.) height. At the 66-cm (26-in.) height, the NUA of 175PLP and 250SLI increased due to the reduction in HSA (table 2).

To evaluate the lamps on a per unit energy-input basis at the 45.7-cm (18-in.) lamp height, the NUA was expressed and compared in terms of the rated energy [cm^2/Watt (in.^{2}/Watt)] for each lamp (fig. 6). In addition to providing the largest NUA [0.275 m^2 (2.96 ft^2)], the 175CZ20 also proves the most efficient [15.7 cm^2/W (2.43 in.^{2}/W)] due to the lack of HSA. The large HSA of 175PLP and 250SLI make them the least efficient [7.9 and 7.4 cm^2/W (1.22 and 1.15 in.^{2}/W, respectively)] in the group.

Commercial Application

A typical commercial farrowing crate has a floor area of 1.52 × 2.13 m (5 × 7 ft) (Finger Farrowing Crate, Vittetoe Inc., Keota, Iowa). The creep area is 0.46 × 2.13 m (1.5 × 7 ft) on either side of the sow. In viewing the two vertical white lines in figure 7, it was assumed that the heat lamp was placed at the midpoint of the 0.46-m (1.5-ft) creep area dimension. Any radiant heat falling outside of these two white lines would be reflected or absorbed by the creep area partition or absorbed by the sow. At the 45.7-cm (18-in.) height, the HA's of 100CZ20, 125HOG, and 125SLI are within the creep area width. On the other hand, the radial heat spread of 175CZ20, 175PLP, and 250SLI extend past the creep area boundaries with maximum overcast temperatures of 33.7°C, 34.5°C, and 36.0°C (92.7°F, 94.1°F, 96.8°F), respectively.

The 175CZ20 shows the most potential for commercial applications because it had a uniform temperature distribution over the creep area, produced the largest NUA [0.276 ± 0.008 m^2 at 45.7 cm (18-in.) height] and was the most efficient (15.7 ± 0.5 cm^2·W^{-1}). Although the 175CZ20 would create some radiant overcast over the sow, the amount of overcast was the lowest of three and would decrease with increasing lamp height. The second choice in lamps would be the 125HOG or 125SLI in that they were the second most efficient lamps on a NUA-per-Watt basis and neither lamp created radiant overcast. In the study by Zhou et al.(1996), the piglets huddled under the 125W lamp for longer durations than under the 175W or 250W lamps as if supplemental heat had been insufficient. The 100CZ20, being the fourth most efficient, also produced a uniform temperature distribution. Although the 100CZ20 had the smallest NUA of the group, the large hotspots of 175PLP and 250SLI greatly reduced each lamp's efficiency. The 100CZ20 provided no usable heat when the lamp height exceeded 45.7 cm (18 in.). The 250SLI produced the largest lamp HA, however, it also had the largest HSA accounting for 83±2% of the creep area width (fig 7). Xin et al.(1997) showed that piglets avoided resting directly under 250W heat lamps. The HSA of the 175PLP spanned 68±0% of the creep area width. To comfortably utilize the 175PLP and 250SLI [heights ranging from 45.7 to 55.9 cm (18 to 22 in.)] the piglets would have to lie on each side of the hotspot in the creep area or next to the sow thus increasing the chance for crushing. The NUA [0.280 m^2 (3.01 ft^2)] of 250SLI at the 66-cm (26-in.) height is statistically equivalent to the area of 175CZ20 [0.275 m^2 (2.96 ft^2)] at the 45.7-cm (18-in.) height due to the reduced HSA.

Conclusions

Spatial variations in radiant heat production of selected commercially available incandescent heat lamps were quantified with infrared thermography. The results revealed that heat lamps with the same power output do not necessarily produce the same temperature profiles on the heated surface, as the shape of temperature profile is greatly affected by the lamp lens prescription. The 175CZ20 lamp was shown to have the most potential in a commercial farrowing system in terms of spatial distribution of the heated surface temperature, net usable area (NUA) and energy utilization efficiency. Field evaluation of the 175CZ20 would be

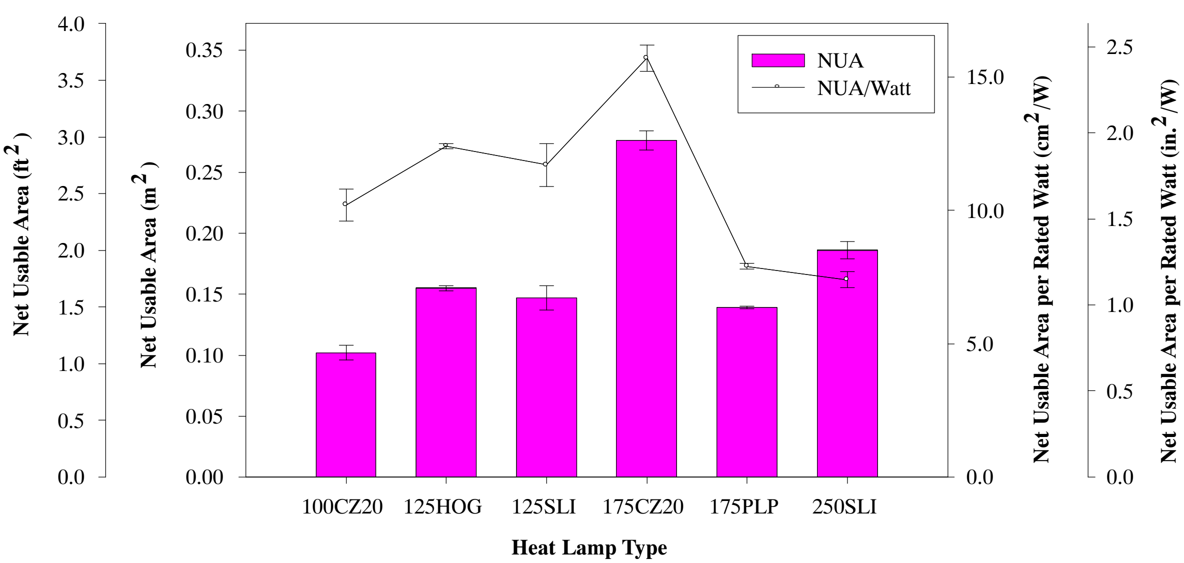

Figure 6. Net usable area (NUA) and NUA per rated power input (NUA/Watt) for each lamp at the 45.7-cm (18-in.) height.

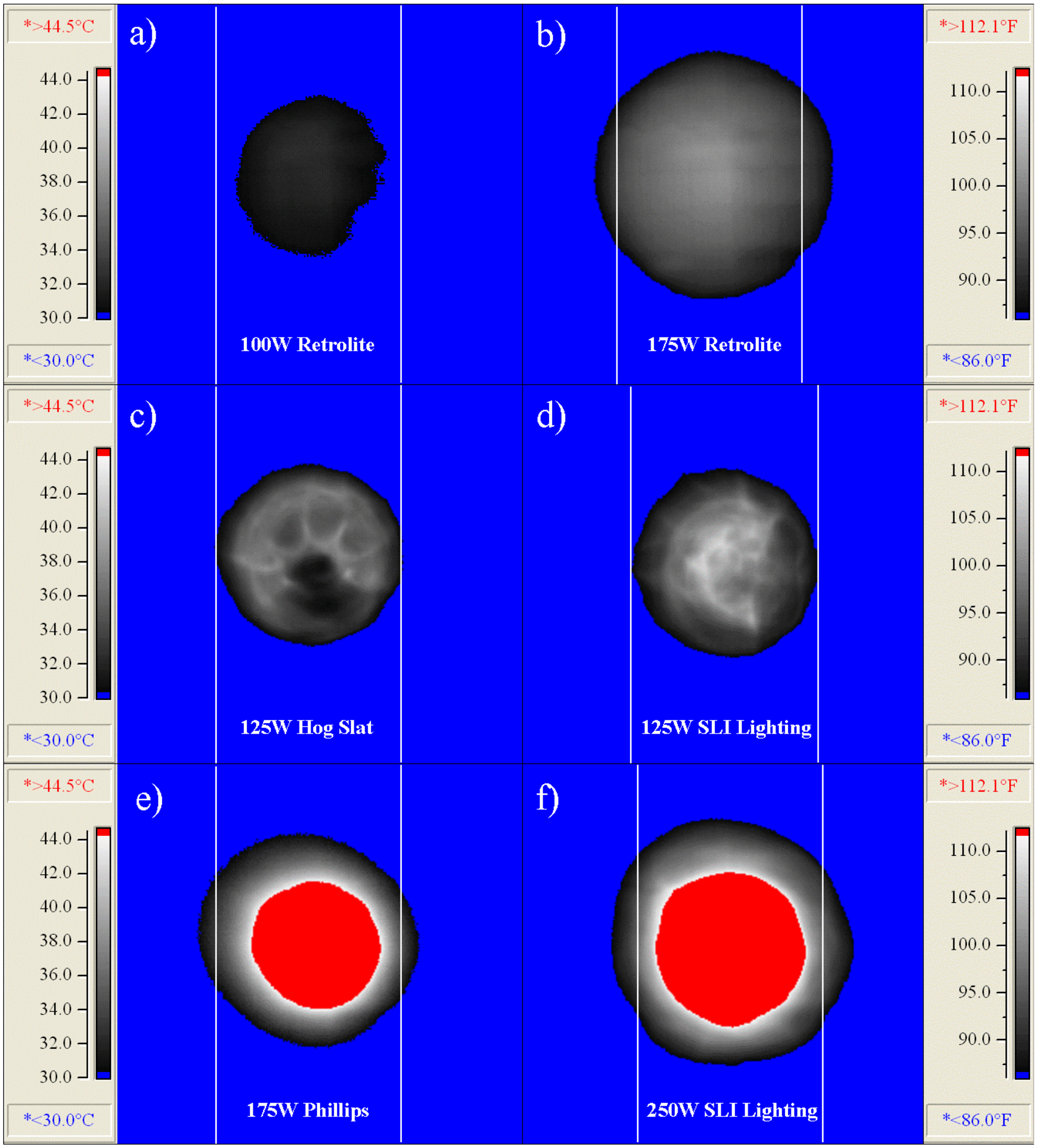

Figure 7. Infrared thermographs of each lamp type illustrating the unheated mat area (blue), the net usable area (gray shading) and hotspot area (red) at the 45.7-cm (18-in.) height. The two vertical white lines represent the creep area boundaries.

desirable to further quantify piglet utilization of the heat source, to understand the effects of partitions in reflecting heat in the creep area, and to quantify actual energy consumption.

Acknowledgements

Funding for this study was provided in part by the Retrolite Corp. of America. The authors thank Nathan Albers for his assistance with the data collection.

References

Hrupka, B. J., V. D. Leibbrandt, T. D. Crenshaw, and N. J. Benevenga. 1998. The effect of farrowing crate heat lamp location on sow and pig patterns of lying and pig survival. *J. Anim. Sci*. 76(12): 2995-3002.

MacDonald, R., T. Feldmann, and M. Wrigglesworth. 2000. Comparison of heat lamp to heat pad creep heat in farrowing units. In *Swine Housing: Proc. First Int. Conf.*, 357-364. St. Joseph, Mich.: ASAE.

National Animal Health Monitoring System (NAHMS). 2002. Part III: Reference of swine health & environmental management in the united states, 2000. Fort Collins, Colo.: USDA APHIS VS. Available at www.aphis.usda.gov/vs/ceah/ncahs/nahms/swine. Accessed 1 June 2006.

Retrolite Corporation of America. 2005. The Comfort Zone 20™ Heat Lamp. Warminster, Pa.: Retrolite Corporation of America. Available at www.retrolite.com/comfortZone.htm. Accessed 4 April 2008.

Titterington, R. W., and D. Fraser. 1975. The lying behavior of sows and piglets during early lactation in relation to the position of the creep heater. *Appl. Anim. Ethol.* 2: 47-53.

Xin, H., H. Zhou, and D. S. Bundy. 1997. Comparison of energy use and piglet performance between conventional and energy-efficient heat lamps. *Applied Engineering in Agriculture* 13(1): 95-99.

Zhang, Q., and H. Xin. 2000a. Effects of creep heat type and location on its usage by piglets in farrowing crates. In *Swine Housing: Proc. First Int. Conf.,* 365-374. St. Joseph, Mich.: ASAE.

Zhang, Q., and H. Xin. 2000b. Modeling heat mat operation for piglet creep heating. *Transactions of the ASABE* 43(5): 1261-1267.

Zhou, H., H. Xin, and D. S. Bundy. 1996. Dynamic thermoregulatory behaviors of neonatal piglets exposed to heat lamps. ASAE Paper No. 964084. St. Joseph, Mich.: ASAE.

Zhou, H., and H. Xin. 1999. Effects of heat lamp output and color on piglets at cool and warm environments. *Applied Engineering in Agriculture* 15(4): 327-330.