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EFFECT OF A WATER-COOLED COVER ON THE THERMAL COMFORT OF PREGNANT SOWS IN HOT AND HUMID CLIMATE

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ABSTRACT In China, the hot and humid climate during the summer season has a strong impact on the production and health of pregnant sows. This prompted a design of a water-cooled cover purposely for heat stress relief for sows. The field experiment was conducted to test the cooling effect on 24 pregnant sows which were divided into 4 groups. The results showed that the sow-occupied zone ambient black globe temperature (BGT) of water-cooled cover with and without sows were 4.8 and 5.4°C lower on average than that of control respectively, when the indoor air temperature was 34.3°C. The temperature reduction of the cooled occupied zone was proportional to the temperature drop between inlet and outlet water. Moreover, the cooling effect was enhanced by increasing water flow during the hot period according to the economic and energy efficiency. All the respiratory rate and surface temperatures of sows underneath the cooled-covered were significantly lower than those exposed to the high ambient temperature (P<0.001). The pigs in the treatment group remained almost 74% of the time lying in the water-cooled cover, and the thermoregulatory behavior lagged behind the peak temperature. The result of the present work implies that the water-cooled cover could ease the heat stress of pregnant sows in hot and humid climate.

Keywords: Localized cooling, pregnant sows, heat stress

INTRODUCTION The environmental temperature has a great impact on the performance and health of pregnant sows in the hot-wet summer (Dong, 2001). Sows suffered from heat stress before service and during the first weeks of pregnancy (up to approximately 21 days) may negatively affect subsequent reproductive performance (Suriyasomboon *et al*., 2006). Mount (1968) reported that early pregnancy (35 days) was more easily affected by the high ambient temperature compared to pregnancy of 70 and 105 days.

Therefore, effective cooling methods should be adopted to avoid heat stress, especially in the most vulnerable period (2–4 weeks) of pregnancy. Sows dissipate heat through convection, conduction, radiation, or evaporation (Mount, 1975). Evaporative cooling such as water dripping, showing system and evaporative pads are common and effective way in practice (Bull *et al*., 1997), but limited to high relative humidity conditions with inducing additional water vapor into the animal occupied zone (Lucas *et al*., 2000). Barbari and Conti (2009) found that the high velocity air stream combined with wet floor was preferred by sows during the hottest period. Floor cooling could increase the lying behavior and improve the production together with reproductive performance of swine (Silva *et al*., 2006). However, few studies have been done to enhance heat loss of swine through radiation.

Under the high ambient temperature and humidity, the pigs would also rid themselves of excess body heat by panting or surface wetting in water or their own excreta (Huynh *et al*., 2006; Aarnink *et al*., 1996). For the animal welfare and thermal comfort, it's essential to provide a cooling microclimate for increasing heat loss and keeping the body clean. In addition, an energy-saving localized cooling method should be developed instead of cooling the whole house.

Based on these considerations, this field experiment aims to evaluate the effect of a water-cooled cover system on the pregnant sows in summer with hot and humid climate of China.

MATERIALS AND METHODS

Experimental design

The research was conducted in one gestation house with 8 pens at an intensive pig farm located in Kaifeng, China. Experiments were performed from July to August, 2009, when the weather was classified as hot and humid. The animals were moved into the gestation house after weaning in batches of 8 sows and distributed in a completely randomized experimental design between treatment (n=4) and control group (n=4) with and without a water-cooled cover system. Each animal was considered as an experimental unit. The sows remained in the experiment from weaning to 21 days post-service, and then sows were transferred to individual crate during pregnancy.

Animals

Twenty-four dry sows (twenty Yorkshire sows, two Landrace sows and two Duroc sows) with a parity number of 1 to 6 were used during the experiment. Sows were fed 2.4 kg/day of a dry sow diet containing maize, soybean meal, bran and soybean phospholipid which formulated to meet the requirements in terms of energy, minerals, vitamins and amino acids. All animals were fed twice a day at 5:30 and 18:30, and had free access to water located in the back activity yard of the pen.

Housing and facilities

The gestation room contained one row of eight pens separated by brick walls, with four adjacent pens being equipped with the cooling system, which consisted of four cooling units in series. The twenty-four sows were allocated into six groups, with two pens left to test the thermal condition without sows. The pens were 3.2 m in length and 2.77 m wide (Fig. 1), and each combined with a activity yard (2.77×3.27m) at which sows could excrete and drink outside. All pens and activity yards were solid concrete floor, and the excretion was removed manually by workers every morning. Eight windows (1.2×1.0m) were situated symmetrically on both sides in the house for natural ventilation, and the gestation house was opened so that the inside temperature followed the outside ambient temperature. The water-cooled cover systems were installed perpendicular to the windows, with 0.4m against the front wall of the pen as the feeding area, and with a rear communal area of 2.77×1.3m.

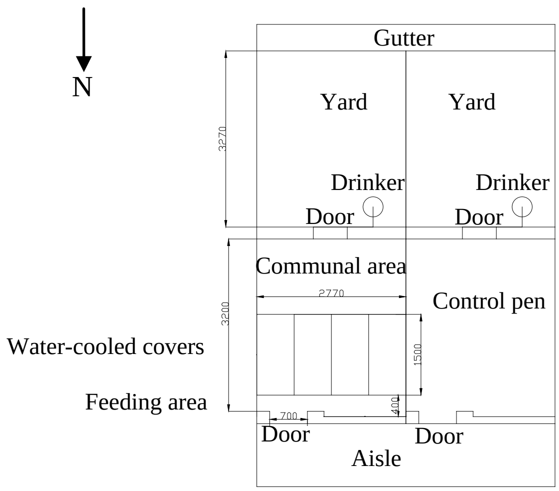

Figure 1. Layout of the gestation house

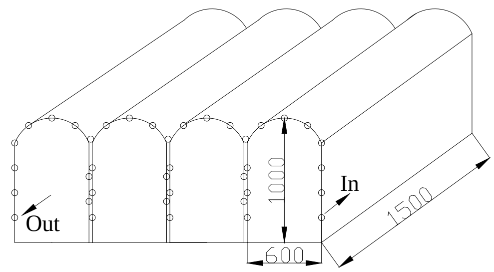

Figure 2. Stalls equipped with the water-cooled covers

The water-cooled cover system consisted of a steel frame, galvanized steel water pipes, an aluminum canopy and the heat insulating layer. The size of cooling cover was 1.5 m×0.6 m×1.0 m. The water pipes with a diameter of 25 mm and a length of 1.5 m were placed on the vaulted top and two parallel vertical surfaces of the arched cover (Figure 2). The water pipes were connected in parallel with a spacing of 20 cm, and left 20cm of the ground to provide space for the legs of laying sows. To increase the heat exchange between the aluminum canopy and cooling water pipes, outer surfaces of water pipes were made to contact closely with the aluminum canopy. The heat insulating layer clinging to the aluminum canopy has a low thermal inertia. The cooling water was provided directly from a well, and each inlet of four treatment pens was connected in parallel to make sure the uniform inlet water temperature. The cooled-water flow through the four cooled cover units in series, and the outlet water was supplied for production of the whole pig farm. The covered spaces occupied an area of 3.6 m^2 by using thirty-eight tubes each pen, with total 57 meters in length.

Measurements

<u>Thermal parameters</u>

The environmental parameters, including dry bulb temperature (DBT), relative humidity (RH), black globe temperature (BGT), and air velocity, were measured to describe the thermal conditions. Type-T (copper constantan) thermocouples connected to a data logger

(Agilent34970A, Agilent Technologies, California, USA) were used to measure the temperature at 10min intervals, including those of indoor air, inlet and outlet water, the water pipe surfaces, and the aluminum canopy. A black-globe thermometer (Tongfang Ltd., Beijing, China) was placed 5cm above the height of a lying sow to collect the BGT at a 1min interval. Twelve thermo recorders (model RS-11, Japan) were used to record the RH at a 10min interval, including the outdoor air temperature (*n*=2), indoor air temperature at the height of 1.5m (*n*=6), and the inner air temperature of the cooled-water covers without sows at the height of 0.87m (approximate standing height of sows, *n*=4). The air velocity of aisle, the inner of the stalls and pens was measured with a hot wire anemometer at 07:00, 09:30, 14:30 and 17:00 h, and the measuring points were about 1metre above the floor, by averaging five instantaneous values at each point. The water flow of each cooling system was recorded every hour by four rotameters. All instruments were calibrated prior to the experiment.

<u>Respiration rate and skin temperature measurements</u>

Respiration rate were measured three times a day, at 9:00 after feeding when the sows were quite, at14:00 during the hottest period, and at 17:00 before feeding. Respiration rate was recorded three times each measurement by counting the time needed for 10 flank movements by means of a stopwatch when the sows were quite, and the average value was converted units to breaths min^{-1}(BPM). Skin temperature was measured at four points (ear, shoulder, rib, ham) using an infrared radiation thermometer (Models-881C-1881F, Japan) by setting the emissivity to 0.96. Measurements were performed four times per day at 7:30, 11:30, 14:30 and 17:30.

<u>Behaviour observations</u>

The sow’s behaviours were classified into lying (lateral and sternal lying) and thermoregulatory behavior including drinking and wallowing as defined by Huynh et al. (2005).The duration of using water cooled cover system was calculated.

The location was classified into indoor area (feeding, resting and communal area in treatment groups), communal area (in treatment groups) and the outdoor yard as shown in Figure.1. The four cooled-covers are also defined in sequence to find the preference of using cooled-covers.

<u>Statistical analysis</u>

The thermal parameters were collected to determine the cooling effect of the water-cooled cover systems. Sows' respiration rate and skin temperature were tested to evaluate the treatment effects according to t-test. The lying behavior and thermoregulatory behavior (drinking & wallow frequency) between treatments were compared using t-test. A LSD means separation test was used to find the preference of lying location in the cooling system.

The statistical analyses were realized using the statistical program 17.0 SPSS Inc. Chicago, Illinois, USA.

RESULTS AND DISCUSSION

Cooling efficacy

The environmental parameters collected during the experiment are shown in Table 1. The sows from treatment group were exposed to a cooler environment due to the water-cooled cover. From the data in Table 1, the total average temperature in the gestation house was decreased by 3 °C with a water-cooled cover, while compared to without cooling. Especially when the ambient air temperature in the house reached to 34.5 °C, the maximum reduction could fall to 6.7 °C. In addition, the treatment group obtained a better thermal comfort even in a hot circumstance. Figure 3 shows that the sow occupied zone BGT of water-cooled cover with and without sows were 4.8 and 5.4 °C lower than the control group on average, respectively. Thus a water-cooled cover can effectively alleviate heat stress during the hot weather. However, the inner air RH increased due to the decline of the air temperature, by 16% on average.

Table.1 Maximum, minimum and average dry bulb temperature (DBT), relative humidity (RH) during the experiment

	DBT, °C			RH, %		
	Outdoor	Indoor	Cooled	Outdoor	Indoor	Cooled
Max	40	34	29	94	85	97
Min	24	26	24	28	49	71
Mean	31 ± 5	30 ± 3	27 ± 2	66 ± 22	70 ± 11	86 ± 8

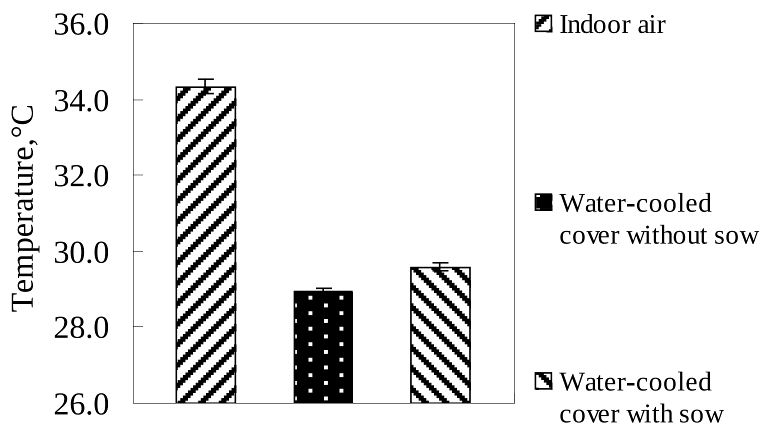

Figure 3. Black globe temperature of indoor air and the water-cooled cover with or without sow occupied during the hot period

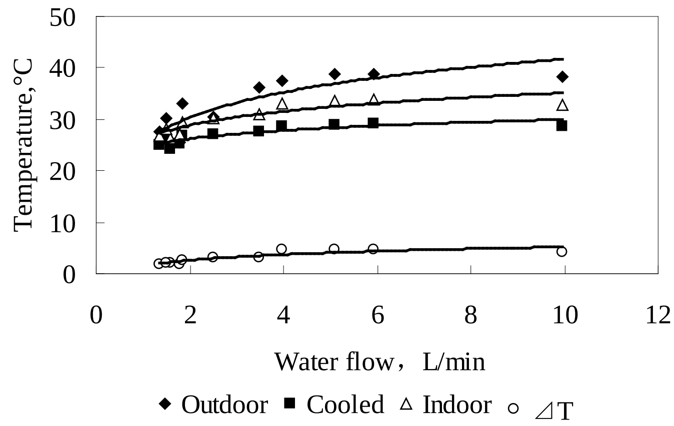

Figure 4. Relationship between the water flow and the outdoor temperature (Outdoor), indoor temperature (Indoor), water-cooled cover inside temperature (Cooled) and the temperature reduction of the sow occupied zone (⊿T).

As shown in Figure. 4, with the increase of the outdoor ambient temperature, the surrounding air of both treatment and control also gradually increased. But the temperature depression of the cooled occupied zone also intensified with the accelerated water flow, due to the connection with other pig houses as a whole. When the climate was hot during the day, the water use of the pig farm was also increased to supply for the demand of cooling facilities in different houses, drinking and so on. Meanwhile, the water flow would speed up during the hot period with lower inlet water temperature. On the contrary, the water use was declined at low ambient temperature during the night when the farm was quiet, and the lower water flow kept the temperature of cooled occupied zone closed to the ambient air at about 25 °C. Thus the water-cooled cover systems worked according to the energy efficiency.

Effect of the water-cooled cover system on the respiratory rate and skin temperature of the pigs

The respiratory rate and surface temperatures obtained from sows during the hot period are shown in Tables 2 and 3, respectively. All the respiratory rate and surface temperatures of sows underneath the cooled-covered were significantly lower than that of the control (P<0.001), except when the measured in the morning. Considering that the respiration is an important mode to increase heat loss as Huynh (2007) reported, the observation here indicates that the control group suffered greater heat stress. The results also agreed with the observations reported by Silva *et al.* (2006) when the breathing rate was increased from 8 to 20 breaths/min/°C in hot climate. Moreover, the present result on skin temperature also increased with increasing ambient temperature.

Table.2 Respiratory rate (breaths min^{-1}, BPM) of sows and the air temperature outside the room, inside the room and the cooled-occupied-zone.

Time	Ambient Temperature, °C			Respiratory rate, BPM		P^a
	Outdoor	Cooled	Indoor	C	NC	
9:00am	33.2 ± 1.1	26.8 ± 0.4	29.5 ± 0.6	11.2 ± 3.1	16.3 ± 9.9	*
14:00pm	39 ± 0.4	29.2 ± 0.1	33.8 ± 0.1	12.8 ± 5.0	47.7 ± 24.8	***
17:00pm	38.6 ± 0.2	28.8 ± 0.2	33.5 ± 0.1	19.0 ± 9.6	61.6 ± 31.8	***

[a] Statistical significance: *** $P < 0.001$,** $P < 0.01$,* $P < 0.05$, NS $P > 0.05$

Table.3 Average skin temperature (the area behind the ear, shoulder, rib, and ham) of sows and the air temperature outside the room, inside the room and the cooled-occupied-zone.

Time	Ambient Temperature, °C			Skin Temperature, °C		P^a
	Outdoor	Cooled	Indoor	C	NC	
7:30am	26.5 ± 0.6	24.8 ± 0.2	26.7 ± 0.1	34.1 ± 0.9	34.4 ± 0.7	NS
11:30am	37.3 ± 0.9	27.9 ± 0.3	31.4 ± 0.4	34.0 ± 0.7	36.0 ± 0.6	***
14:30pm	38.8 ± 0.3	29.1 ± 0.2	33.8 ± 0.0	34.3 ± 0.8	36.7 ± 0.4	***
17:30pm	36.9 ± 0.5	28.4 ± 0.0	33.0 ± 0.2	34.1 ± 0.5	36.6 ± 0.4	***

[a] Statistical significance: *** $P < 0.001$,** $P < 0.01$,* $P < 0.05$, NS $P > 0.05$

Effect of the water-cooled cover system on behaviour of sows

Behaviour of sows and preference of water-cooled cover systems

There is a significant difference between the control and treatment groups in the duration of lying behaviour and visiting the outside yard (Table 4). Pigs without cooling system lay most of the time in the pen avoiding contact with each other and kept panting during the heat stress period, while the pigs in treatment group remained 74% of the time lying in the water-cooled cover (Table 5). Bull et al. (1997) reported the use time of the cooling system was 79.7% during the heat stress time. When the ambient air temperature exceeded 30 °C, the pigs in the treatment group preferred to stay in the water-cooled cover system. The dominant sows occupied most of the time using the cooling systems, especially the first stall as shown in Figure. 1. In addition, pigs attempted to get into the first stall if it was available. Compared to the other stalls, the duration to stay in the fourth stall adjacent to the wall was the least. The least dominated sow in the treatment groups often stayed at the communal space with the head or body contacting with the cooled structure of the cooling systems except during the peak time, while the lower position pigs in the control groups had to rest in the activity yard. It also happened during the feeding time, pigs with stalls can keep eating food at the same time while some pigs of the control group had to stay in the activity yard while waiting the dominant pigs to almost consume most of the food. Moreover, pigs in the treatment group could choose the cover system as a shelter when fighting in the activity yard or the communal area, but some pigs in the control group have to jump out of the pen. So the relationship among the pigs and their feeding mode should be considered in the future study.

Table 4. The lying duration of control (no cooling) and treatment (with water-cooled cover system) groups under heat stress period.

Behaviour	Treatments	Mean	S.E.M.	P^a
lying,%	No cooling	94.3	0.86	*
	Cooling	87.7	1.84	
standing,%	No cooling	4.6	0.95	NS
	Cooling	6.7	1.26	
sitting,%	No cooling	0.2	0.13	NS
	Cooling	0.3	0.12	
outdoor,%	No cooling	1.0	0.21	*
	Cooling	5.3	0.93	

[a] Statistical significance: *** $P < 0.001$,** $P < 0.01$,* $P < 0.05$, NS $P > 0.05$

Table 5. The duration of pigs using water-cooled cover system and the preference in location under heat stress period

Items	Location of the cooling systems			
	1	2	3	4
cooling duration, %	27.8 ± 6.3 [a]	27.8 ± 4.1 [a]	25.8 ± 5.2 [a]	18.7 ± 7.5 [b]
Total duration, %	74.4 ± 7.8			

[a,b] Values with different superscript differ ($P < 0.05$)

The thermoregulatory behaviour

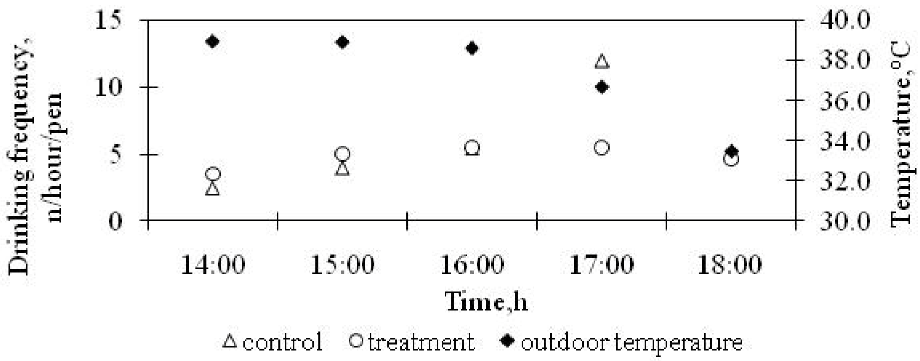

Figure 5. Effect of average ambient air temperature on the drinking frequency per hour of both control and treatment groups.

As shown in Figures 5 & 6, the drinking frequency of pigs increased with the outdoor temperature and kept rising even when the ambient temperature tends to decline. The observed peak period was from 15:00-17:00. The peak period of wallow frequency was from 16:00-17:00. It is interesting to note that the thermoregulatory behaviour was at 14:00 lagged behind the peak temperature. The pigs without cooling system kept panting and seldom moved until the temperature decreased. The pigs were also found to cool themselves by wallowing in wet areas under the drinker or even their excreta to cope with heat stress and tried to use skin wetting directly as reported by other researchers (Huynh et al. 2007). The water-cooled cover system provided a way to loss heat and improved the animal welfare.

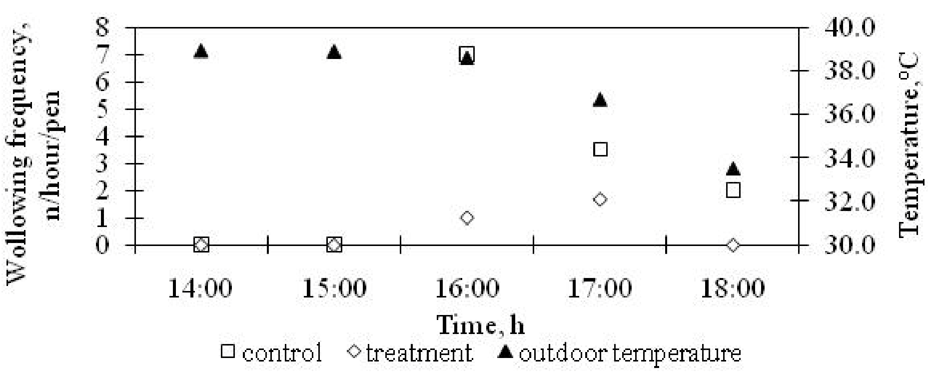

Figure 6. Effect of average ambient air temperature on wallow frequency per hour of both control and treatment groups.

CONCLUSIONS

The water-cooled cover for pregnant sows was designed and evaluated for the cooling efficacy in reducing thermal loads in the sow occupied zone. The following conclusions were drawn from the experiments.

The sow occupied zone ambient BGT of water-cooled cover with and without sow were 4.8 and 5.4°C lower than the control group on average, when the indoor air was 34.3°C.

The cooling effect was enhanced by speeding up water flow during the hot period according to the economic energy efficiency.

All the respiratory rate and surface temperatures of sows underneath the cooled-covered were significantly lower than those exposed to the high ambient temperature ($P<0.001$), which indicated that the water-cooling cover could ease heat stress.

During the hot and humid periods, there was a significant difference between the control and treatment groups in the duration of lying behaviour and visiting the activity yard outside. The pigs in treatment group stayed 74% of the time lying in the water-cooled cover.

The thermoregulatory behaviour lagged behind the peak temperature. The pigs without cooling system kept panting and seldom moved until the temperature decreased. The water-cooled cover system provided a way to loss heat and improved the animal's welfare.

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REFERENCES

Aarnink A J A; van den Berg A J; Keen A; Hoeksma P; Verstegen M W A (1996). Effect of slatted floor area on ammonia emission and on the excretory and lying behaviour of growing pigs. Journal of Agricultural Engineering Research, 64(4): 299-310.

Barbari M; Conti L (2009). Use of different cooling systems by pregnant sows in experimental pen. Biosystems engineering, 103 (1): 239-244.

Bull R P; Harrison P C; Riskowski G L; Gonyou H W (1997). Preference among cooling systems by gilts under heat stress. Journal of Animal Science, 75(8): 2078-2083.

Dong H; Tao X; Li Y; Xin H (2001). Comparative evaluation of cooling systems for farrowing sows. American Society of Agricultural Engineers, 17(1): 91–96.

Huynh T T T; Aarnink A J A; Heetkamp M J W; Verstegen M W A; Kemp B (2007). Evaporative heat loss from group-housed growing pigs at high ambient temperatures. Journal of Thermal Biology, 32 (5): 293-299.

Huynh T T T; Aarnink A J A; Truong C T; Kemp B; Verstegen M W A (2006). Effects of tropical climate and water cooling methods on growing pigs' responses. Livestock Science, 104(3): 278-291.

Lucas E M; Randall J M; Meneses J F (2000). Potential for evaporative cooling during heat stress periods in pig production in Portugal (Alentejo). Journal of Agricultural Engineering Research, 76(4): 363-371.

Mount L E (1968). The climatic physiology of the pig. Edward Arnold (Publishers) Ltd, London, UK.

Mount L E (1975). The assessment of thermal environment in relation to pig production. Livestock Production Science, 2 (4): 381-392.

Silva B A N; Oliveira R F M; Donzele J L; Fernandes H C; Abreu M L T; Noblet J; Nunes C G V (2006). Effect of floor cooling on performance of lactating sows during summer. Livestock Science, 105 (1-3): 176-184.

Suriyasomboon A; Lundeheim N; Kunavongkrit A; Einarsson S (2006). Effect of temperature and humidity on reproductive performance of crossbred sows in Thailand. Theriogenology, 65, 606- 628.