RESEARCH NOTE

Using Floor Cooling as an Approach to improve the Thermal Environment in the Sleeping Area in an Open Pig House

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In order to provide pigs a comfortable sleeping area in hot weather, a floor cooling system was designed and applied to production buildings. Experiments were conducted to compare the floor temperatures and to observe the lying behaviour of pigs in the sleeping area of the buildings with and without floor cooling system. The results showed that, without the floor cooling system, the floor temperature was nearly the same as the air temperature in the open pig house. With the floor cooling system, the floor temperature of the sleeping area was controlled at 22–26 °C, even though the air temperature was as high as 34 °C, which improved the comfort of the pigs in the sleeping area. The pig lying behaviour was greatly affected by the floor temperature. More than 85% of the pigs were lying in the sleeping area when the floor temperature was below 26 °C, while only 10–20% of the pigs were lying in the sleeping area when the floor temperature was about 30 °C, and hardly any when the floor temperature was above 33 °C.

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1. Introduction

In pig production, heat stress can be extremely detrimental to welfare and production over a range of thermal conditions. The results of heat stress may range from decreased feed intake and growth efficiency, reproduction and even hyperthermic death. In order to alleviate heat stress, many cooling systems for pig housing have been developed in recent years (Gates *et al.*, 1991; Panagakis *et al.*, 1996; Eigenberg *et al.*, 2002). In China, the approaches such as the fan and pad cooling system (mostly used for growing/finishing pigs), the drip cooling system (mostly used for gestating sows), the underground tunnel air cooling system have been used (Liu *et al.*, 1997; Dong *et al.*, 1998, 2001; Ma, 1997). Those systems were mainly designed and applied in confined pig production buildings. Although the indoor environment is improved, common problems of the cooling systems during operation arise, such as increasing humidity, wet and dirty floor, noise level, *etc.*,

which will damage pig health and decrease pig production. Many of those cooling systems cannot be used in an open type pig house.

Pig production systems with open structures and free access to an outdoors area are very common in China. The thermal conditions in these types of pig housing are very much dependent on the weather. In hot weather, feasible and effective cooling systems will be in great demand to provide a comfortable environment for the pigs.

Generally, on hot days pigs may cool themselves by wallowing or enjoying water sprinklers (Heitman *et al.*, 1962), and they may seek protection from the sun in the shade (Heitman *et al.*, 1962; Blackshaw & Blackshaw, 1994) if shading facilities are available. They may also attempt to increase their heat loss by moving away from hot places to a cooler area or to a place with higher air velocity, by changing their lying posture from the belly to the side, or by avoiding having body contacts with other pigs (Geers *et al.*, 1986). By rolling from side to

side in a wallow or a damp place, the pigs may benefit from the evaporative heat loss *via* cooling their moist upper skin and conductive heat loss *via* contact in water.

Since pigs spend more time resting than any other domestic animals, *i.e.* about 80% of the time daily (Haugse *et al.*, 1965), relaxation and sleep are very important for pig health and growth rate. Therefore, a cooling system to meet the lying demands of pigs in an open type house under hot weather conditions is essential for the optimal production as well as for the welfare of pigs. The objectives of this research were to design and validate a floor cooling system for the pig sleeping area in open structures, and to provide useful data for the development of a new type of cooling system for use in open pig houses at most farms.

2. Materials and methods

2.1. Floor cooling system design

2.1.1. Design concept

Water heating systems are applied in many pig housings with pipeline and radiator installed along the inside walls. In recent years, a floor heating system has been developed and used in a number of farrowing buildings for partly heating floor areas to meet the different temperature demands of sows and piglets (Hoy & Ziron, 1998; Ziron & Hoy, 2003). Since water has a relatively higher heat capacity and conductivity than air, it could also be used to cool other mediums by absorbing their heat. Based on this principle, pipelines may be installed under the pig's sleeping area, and underground water may be conducted through pipelines for floor cooling in hot weather. In this way, a relatively steady temperature of sleeping area may be maintained.

2.1.2. System design

The floor cooling system consists of the following five elements: underground or cold water, pump, pipeline, polyvinyl chloride (PVC) pipe or loops of heat pipe, controllers including valves and thermostat. A PVC pipeline was placed under the sleeping area [Figs 1(a) and (b)], and a 5 cm layer of concrete was added to fix the pipeline. Cold water could then flow from the pipeline inlet and be discharged to the drainage system. The inlet valve could be automatically controlled according to the temperature.

2.1.3. Advantages of the cooling system

The cooling system has the following advantages.

- (1) The system can provide comfortable sleeping area for pigs in hot and humid weather.

Fig. 1. (a) The pipe layout of floor cooling systems; (b) sensor positions for floor temperature measurements, T_f ; (c) sensor positions for air temperature measurements, T_a

- (2) Potential energy saving, as this system will cool only the floor in the sleeping area and not the whole room/house.
- (3) The system can be used in confined and open type houses, and low cost, simple building construction.
- (4) The system can be used in farrowing house for cooling sow lying area only without cooling the whole room, which would solve the problems of different temperature demands of sow and piglets.
- (5) As the water flows in a closed system, the humidity in room air will not be increased in cooling process; besides, the used water could be used for other purposes, *e.g.* drinking, irrigation, *etc.*

The underground water is kept about 15 °C (Zhen *et al.*, 2001), which could be used for cooling system in hot weather and for heating system in cold winter for pigs.

2.2. Experimental facility

The experiment was conducted at a small pig-producing farm with open type housing located in Hebei province of China, during the period from 27 July to 30 August 2000.

A shed above the pig sleeping area was constructed at one end of each pen. The shed was built of concrete. The partition walls were built of bricks, and floor under the shed was concrete too. There were seven pigs in each of the pens for finishing pigs and two sows in each of the pens for gestating sows. In summer, the water was poured over the outside lower floor for the pigs to wallow.

2.3. Measurement

2.3.1. Temperature

The floor and air temperatures were monitored every day at 8:00, 12:00, 16:00, 20:00 and 24:00 h by a Thermo TP2 sensor (Cascadia Instrumentation, Inc., Canada). The sensor was placed in the middle of floor with direct contact to the floor surface [Fig. 1(b)] to measure floor temperature T_f . To measure the air temperature T_a , the sensor was placed near to a sidewall without direct exposure to sunshine [Fig. 1(c)]. The data was sampled every 4 h from 8:00 to 24:00 during the experimental period, and at each sampling three data reading were logged, and the average was recorded.

2.3.2. Lying behaviour

The activities and the behaviour of the pigs were monitored following the same schedule as for the temperature measurements, *i.e.* over five 30-min periods a day. The numbers of pigs lying in the sleeping area

were recorded at each monitoring. The comfortable lying postures were defined as: limb stretching, lying separately, side-body lying, and head exposed to the outside.

2.4. Test groups

Two pens with a total of 14 finishing pigs and two pens with total of four gestating sows were chosen and divided as a control group and a reference group. All growing conditions were maintained the same for all groups except for the control group where the designed cooling system using underground water was applied in the bedding area.

3. Results and discussion

3.1. Temperature

During the experiment, the average monthly temperature was 27.7°C, the maximum temperature was 35.3°C, and the minimum temperature was 21.4°C. When the air temperature was higher than 26°C, the water cooling system started to work, and the used water was used as irrigation water. The temperatures of the air, the floor of control group and the reference group are shown in Fig. 2. The air temperature exceeded 26°C from 8:00 to 20:00, and was in 22–25°C from 20:00 to next day at 8:00. The floor temperature of the reference group was as the same as the outside temperature, but the floor temperature of the control group was kept at 22–26°C, which is quite comfortable for finishing pigs and sows.

Fig. 2. Air temperatures and floor temperatures in the sleeping area of (a) the flattening house and (b) the gestating house: —□—, air temperature; —×—, floor temperature for the control group; —△—, floor temperature for the reference group

Fig. 3. Number of pigs lying at different air temperatures: $\square$ —, control group; $\times$ —, reference group

3.2. Lying behaviour

According to published research literature (Chen & Wang, 1997), the comfortable temperature for finishing pigs is 20–28 °C, and for sows 20–27 °C. The design and control of the pig housing system should be able to maintain the environment according to the demands of pigs to avoid heat stress. Pig lying duration accounts for about 80% of the total lifespan, so relaxation and sleep are very important to the health and the growth rate of pigs. When pigs feel comfortable, they lie in a stretched side-body position, but when pigs feel hot, they will choose to lie in a cool area.

3.2.1. Lying behaviour at different air temperatures

The lying behaviour of the finishing pigs at different air and floor temperatures is shown in Fig. 3. During the test, more than 85% of the finishing pigs in the control group were lying comfortably in the sleeping area, but the finishing pigs in the reference group showed obviously different result: when the air temperature was at 23–25 °C, 85% of the pigs were lying comfortably, and 57% of the pigs were lying in the sleeping area at air temperature of 25–30 °C, and only 10–20% of the pigs were lying in the sleeping area at air temperature of 30–33 °C. When the air temperature was higher than 33 °C, no pigs were lying in the sleeping area. Lying or standing behaviours of the pigs in the playing area with water was observed in the reference group during test, when air temperature was higher than 30 °C.

Since the experiments were performed on a small farm, only four sows were used at the test field. Anyhow, the analysis showed the similar results as for finishing pigs. At different air temperatures, the control group were lying comfortably in the sleeping area; but the reference group were lying in the sleeping area at air

Table 1
Numbers of lying sows in control pen and reference pen at different temperatures

Air temperature, °C	Monitoring occasions	Control group, Number of pigs	Reference group, Number of pigs
23–26	42	2	2
26–29	35	2	1
29–34	23	2	0

temperatures of 23–26 °C, and no sows were lying in the sleeping area at air temperatures of 29 °C, Table 1.

3.2.2. Influence of floor temperature on pig lying behaviour

Table 2 shows the percentages of lying finishing pigs in the sleeping area at different air and floor temperatures. Most pigs in the control group were lying on the cooled floor 60% of the time every day, even though the air temperature varied from 23 to 34 °C during a 24-h period. This result indicates that the floor cooling system could provide comfortable sleeping conditions for the pigs in hot weather, and the sleeping area could be kept at 22–26 °C throughout the test, thus guaranteeing that pig lying behaviour was not influenced by the air temperature. In the reference group, however, the numbers of pigs lying in the sleeping area showed different results: *i.e.* at 8:00 and 24:00 with air temperatures between 23 and 27 °C, most pigs were lying in the sleeping area; at 12:00–16:00 with air temperature at 28 °C and higher, very few pigs were lying in the sleeping area; after 20:00, when the air temperatures decreased, more than 50% of the pigs were lying in the sleeping area; from 24:00 to the next day at 8:00, most pigs were lying in the sleeping area, which

Table 2
Finishing pigs lying data of a 20-day monitoring period

Time, <i>h</i>	Air temperature, °C	Reference group		Control group	
		Floor temperature, °C	Percentage of lying pigs, %	Floor temperature, °C	Percentage of lying pigs, %
8:00	23–27	23–27	78 ± 19	23–25.5	83 ± 20
12:00	28–31.5	29–31.5	37* ± 59	23.5–26	91 ± 3
16:00	27–34	27–34	43* ± 65	22–26	90 ± 6
20:00	23–30	23–30	66* ± 49	23–25	82 ± 16
24:00	23–27	23–27	87* ± 10	22.5–26	94 ± 4

*The difference is significant between the control and reference groups probability ($P < 0.01$).

indicates that the cooling system could be turned off during this period.

Without the floor cooling system, the floor temperature was directly related to the air temperature. The air temperature and the floor temperature affected the proportion of pigs lying in the sleeping area. When the air temperature was below 27 °C, most pigs were lying in the sleeping area. A similar observation on the growing pig was also reported by Fraser (1985). When the air temperature was higher than 28 °C, very few pigs were lying in the sleeping area even if there was a shed. The pigs sought the water and wallowed. This indicated that a shed alone was not enough to make up a comfortable environment for pigs at high air temperatures, and consequently, a cooling system was needed.

With the floor cooling system, the floor temperature was kept at 22–26 °C and most pigs were lying in the sleeping area, even the air temperature reached 34 °C. It showed that the floor temperature influenced the lying behaviour of the pigs in the sleeping area. It also shows that it is important to be able to regulate the floor temperature in the sleeping area to ensure a comfortable zone for pigs.

4. Conclusions

The floor cooling system using underground water can be used in open type pig houses to alleviate heat stress on pigs.

With the floor cooling system, the temperature of the sleeping area can be kept at 22–26 °C, even at air temperatures up to 34 °C.

Temperature of the sleeping area is a key factor influencing pig lying behaviour. At temperatures below 26 °C, more than 85% of the pigs were lying in the sleeping area; at temperatures above 30 °C, and only 10–20% of the pigs were lying in the sleeping area; and at temperatures above 33 °C, no pigs were lying in the sleeping area.

Due to the limited test condition, the temperature field of the entire controlled sleeping area was not tested. Since the water temperature increased from the inlet to the exit of the pipeline during the cooling process, and knowing temperature differences might occur at different part of the sleeping area, further studies on how to utilise the temperature difference to meet the thermal demands of the different part of pig's body and how to improve the floor cooling system.

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