Effects of Floor Cooling During High Ambient Temperatures on the Lying Behavior and Productivity of Growing Finishing Pigs

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Abstract. *Given that exposing rapidly growing pigs to high ambient temperatures can induce heat stress, which reduces their welfare and production, this study looked at the influence of floor cooling on pigs' behavior and performance. Pens in room 1 had a solid floor (60%) and a metal slatted floor (40%). The pens in room 2 had a concrete slatted floor at the front (15%), then a convex solid floor (45%), and a metal slatted floor at the back (40%). Each room was stocked with 144 pigs with a starting weight of around 29.3 kg (±4.1 kg). The area per pig was approximately 1.0 m^2. In half of the pens in each room, the floor could be cooled by cold water. The floor cooling was activated at ambient temperatures above 25°C in week 3 and above 20°C from week 7 onwards. Feed and water were accessible ad libitum. Cooling lowered the surface temperature of the solid floor (25.0°C vs. 26.8°C, $P < 0.001$), reduced the percentage of pigs lying on the slatted floor (15.0% vs. 22.2%; $P < 0.001$), and increased feed intake (2.04 vs. 1.95 kg d^{-1} pig^{-1}, $P < 0.01$) and growth rate (753.2 vs. 720.4 g d^{-1}; $P = 0.017$). Cooling and pen design affected fouling of the solid floor. The cooled pens were cleaner than the uncooled pens, and the pens in room 2 were cleaner than those in room 1. These results show that floor cooling can improve the thermal comfort and performance of intensively reared growing and finishing pigs during hot weather.*

Keywords. *Floor cooling, Heat stress, Lying behavior, Pen fouling, Thermal comfort.*

Petherick (1983) described how the space that pigs require for minimal welfare depends on the position they adopt while resting. According to Curtis (1983), pigs spend about 79% of the day (19 h) resting. This means that most of the time, a large part of the pig's body is in contact with the floor. Thus, the thermal comfort provided by the floor is very important. When the ambient temperature is high, pigs will change their position to increase their effective surface area for conductive and convective heat exchange (Steinbach, 1987). To be able to lie down fully to cool off, pigs need sufficient and comfortable floor space. Generally, there is not enough solid floor space in modern pig houses to enable all the pigs to lie down at the same time, so some pigs have to lie in the dunging area.

The European Union (such as Council Directive 91/630/EEC) and the Dutch government (Welfare Regulations) have legislated improvements to the welfare of pigs in intensive production systems. Under the Dutch regulations, since 1998, there has been a phasing out of fully slatted floors for growing−finishing pigs.

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Since a slatted floor is a cooler for pigs to lie on than an insulated solid floor, the number of pigs lying on the slatted floor is an important indicator that temperatures in the pig house are undesirably high. The surface temperature of a slatted floor is generally about 3°C to 5°C cooler than that of an insulated solid floor (Randall et al., 1983). On insulated solid floors, pigs are less able to dissipate their excess heat; this is particularly important at high ambient temperatures. Aarnink et al. (2001) showed that at increasing temperatures more pigs will lie on the slatted floor than on the solid floor. They also concluded that if many pigs lie on the slatted floor, the fouling of the solid floor will increase. This confirmed previous work by Hesse and Jackisch (1995).

In addition to causing thermoregulatory and behavioral problems, high ambient temperatures also have a detrimental economic effect. During the hottest months, average daily gain (ADG) and voluntary feed intake are lower, negatively affecting pig production. Generally, an ambient temperature range of 18°C to 21°C has been found to support optimal productive performance of growing finishing pigs. For each degree Celsius above a daily mean temperature of 21°C, pigs gained 36 to 60 g d^{-1} less body weight (Heitman and Hughes, 1949; Curtis, 1985). Quiniou et al. (1999) also showed that high ambient temperatures have a marked negative effect on voluntary feed intake in finishing pigs. Rinaldo et al. (2000) indicated that in the tropics, growth performance varies with the season and that during the warm season feed intake is a major factor limiting growth rate. Large daily fluctuations between extremes of hot and cold can also reduce performance (Nienaber et al., 1989).

The objective of this study was to determine how floor cooling in partially solid floor systems can change the behavior and improve the performance of growing−finishing

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pigs at high ambient temperatures. This study looked at effects of floor cooling on lying behavior, pen fouling, feed intake, average daily gain, and animal health.

MATERIAL AND METHODS

ANIMALS

A total of 288 crossbred pigs (Dutch Landrace boar × (Duroc boar × Great Yorkshire) sow) was used. The experiment started in May and lasted until September. Animals were allocated to one of two rooms that differed in pen design (figs. 1 and 2). Mean initial live weight in room 1 at the start of the experiment (May 22) was 30.1 kg (±3.2 kg). In room 2, mean initial live weight at the start of the experiment (June 1) was 28.5 kg (±4.9 kg). At the end of the experiment, average live weight in room 1 was 116.2 kg (±15.3 kg) on September 18, and in room 2 it was 109.2 kg (±12.3 kg) on September 25.

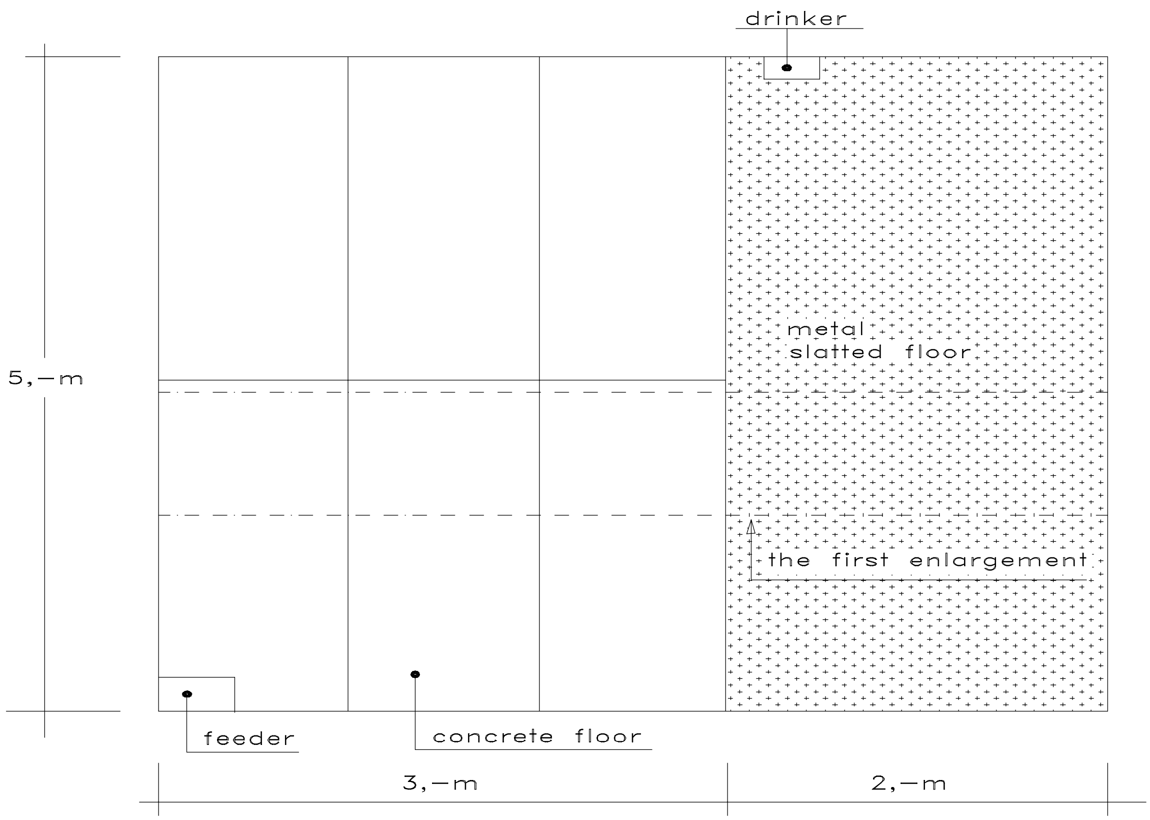

Figure 1. Layout of a pen in room 1. When the pigs reached 50 and 85 kg of weight, the pens were widened by removing a partition. The floor areas per pig were 0.6, 0.85, and 1.0 m^2, respectively.

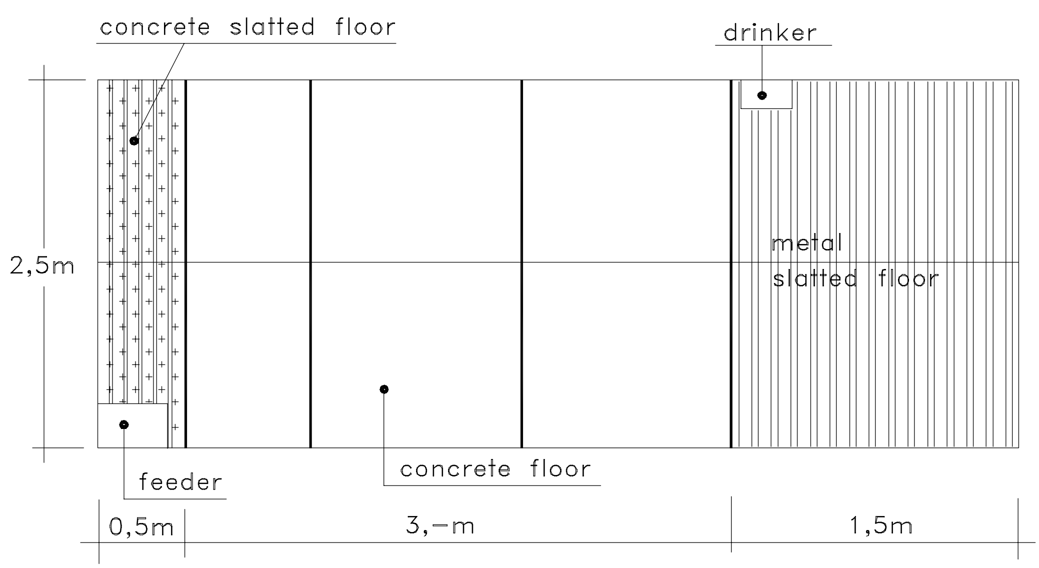

Figure 2. Layout of a pen in room 2.

Feeding

The animals were fed ad libitum with a normal commercial fattening diet. They received a two−phase feeding. At the start of the experiment, the diet contained 9.5 MJ NE (CVB, 2000) and 180 g kg^{-1} crude protein (CP). From day 77 of the experiment onward, the diet contained 9.8 MJ NE and 142 g kg^{-1} CP. The pigs had free access to water from a nipple water drinker.

Housing

Within each room, groups of animals were randomly assigned to the pens.

Room 1 contained six pens with 24 pigs in each. As the pigs grew, the pens were enlarged, from an initial size of 3 × 5 m to a maximum of 5 × 5 m by the time the pigs weighed approximately 85 kg. Sixty percent of the pen floor was solid (5 × 3 m) and had a 6% slope. At the back of the pen was a slatted floor of 5 × 2 m (fig. 1). The slats were tribar metal bars 15 mm wide with 15 mm gaps.

Room 2 contained 12 pens, each for 12 pigs. The pen size remained 2.5 × 5.0 m (fig. 2) throughout the fattening period. The first 10% of the floor at the front of the pen (2.5 × 0.50 m) was slatted concrete; the slats were 65 mm wide with 20 mm gaps. The next 60% of the floor area was a solid convex floor with a 6% slope to both sides. The remaining 30% of floor space, at the back of the pen (2.5 × 1.5 m), was metal slats similar to that in room 1.

Floor Cooling

In both rooms, heat exchange systems were embedded in the solid floor to heat or cool it. In room 1, a polyethylene plate heat exchanger system (figs. 3 and 6) was used. The plates were 140 mm wide, 15 mm high (fig. 4), and 100 mm apart. In room 2, a polyethylene piping heat exchanger system was used (figs. 5 and 7). The pipes had an internal diameter of 18 mm and were spaced 170 mm apart. An insulation layer underneath restricted heat exchange from the heat exchanger system to the ground. The water circulating within the floor was cooled within a water−water heat exchanger by groundwater of approximately 10°C.

Control of the Cooling System

In both rooms, the heat exchange system was used to cool the floor in pens on one side of the room. The pens on the other side of the room had no floor cooling. During the first two weeks of the fattening period, the floor cooling was off but the floor heating was on. During these weeks, the temperature of the water flowing into the floor fell linearly from 30°C to 25°C. From week 3 onwards, the floor cooling system was automatically controlled as follows:

The cooling setpoint (= the room temperature, measured at 1.5 m above floor level, at which cooling was turned on automatically) was decreased linearly from 25°C to 20°C between week 3 and week 7. From week 7 until the end of the fattening period, the cooling setpoint was kept at 20°C.

The water temperature was initially set at 23°C. It was lowered by 1°C for every 2°C that the room temperature exceeded the cooling setpoint. The minimum water temperature was 18°C. From 24 July onwards, the water temperature was set 2°C lower, to increase the floor's cooling capacity, and the minimum water temperature was lowered to 16°C as well. The temperature of the water was measured by PT 100

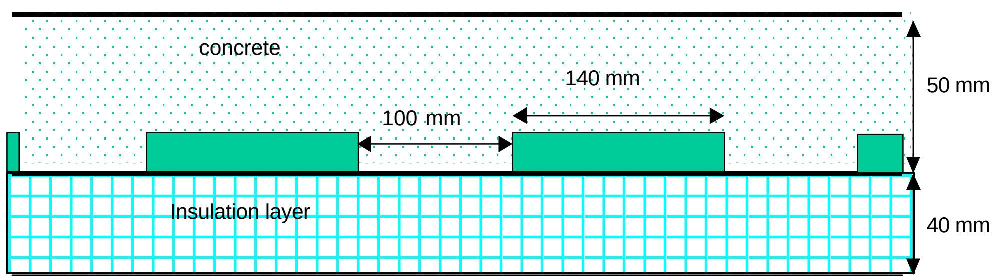

Figure 3. Cross−section of floor cooling with heat exchange plates in room 1.

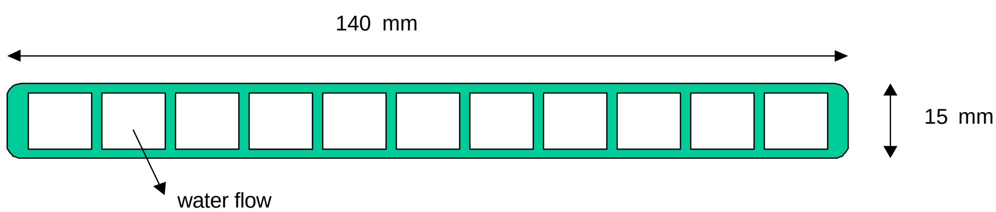

Figure 4. Cross−section of a heat exchange plate in room 1.

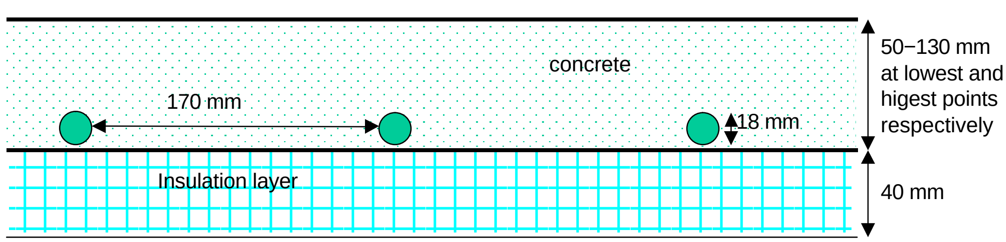

Figure 5. Cross−section of floor cooling with heat exchange pipes in room 2.

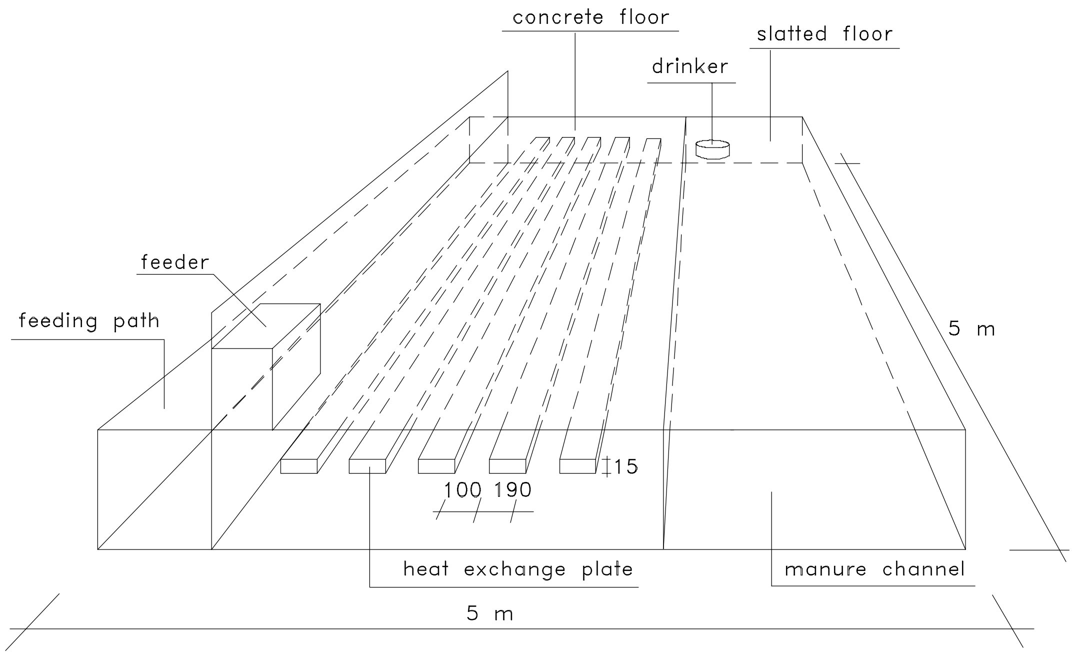

Figure 6. Layout of a pen in room 1, showing water plates.

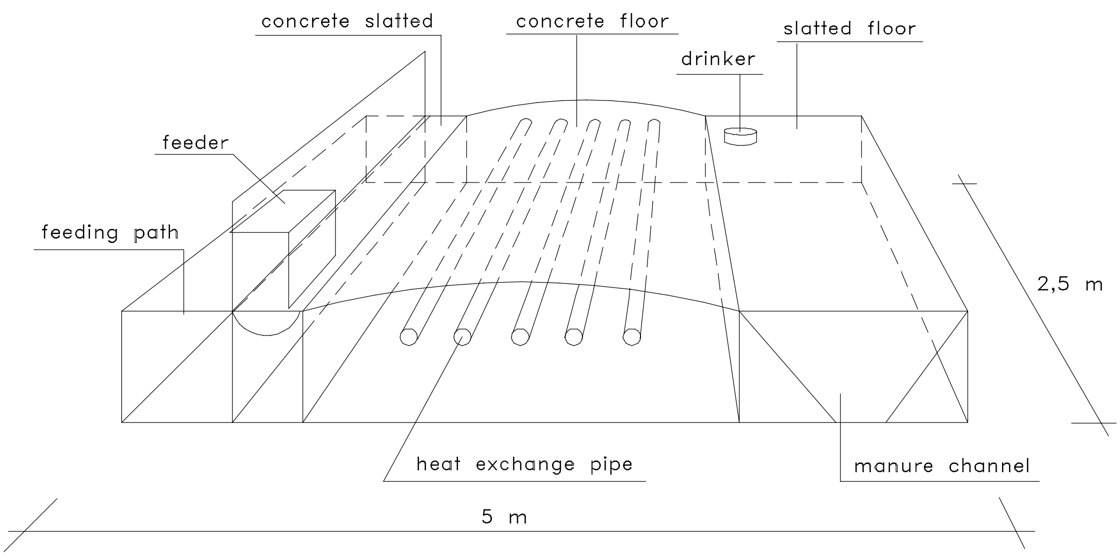

Figure 7. Layout of a pen in room 2, showing water pipes.

temperature sensors connected to a data logging system (Yokogawa, Japan) just before the water flowed into the floor.

Ventilation Control

An Ecovent (Fancom, Panningen, The Netherlands) ventilation system was used, with a central frequency controller that controlled all fans. In each room had two exhaust shafts with measuring fans. The ventilation rate was automatically controlled, depending on the number of days after the start of the fattening period (table 1). The airflow within rooms 1 and 2 is illustrated in figures 8 and 9, respectively.

MEASUREMENTS

Outside temperature and relative humidity and inside temperature and relative humidity (measured at 1 m above both the cooled and uncooled solid floors) were measured every 10 min in both rooms. Temperature and humidity were measured by the same combined instrument (Hygromer I100, Rotronic, Switzerland).

Temperature of the water flowing into and out of the floor was measured by PT 100 temperature sensors connected to a data logging system (Yokogawa, Japan). The energy uptake

Table 1. The various ranges of ventilation control.

No. of Days after Start of Fattening Period	Temperature (°C)		Ventilation Rate ($m^3 h^{-1}$)	
	During Min. Ventilation	During Max. Ventilation	Min.	Max.
1	26.0	30.0	8.6	30.0
3	25.0	29.0	8.6	30.0
7	24.0	28.0	10.9	35.0
14	22.0	27.0	12.7	40.0
50	21.5	26.5	16.8	60.0
100	21.0	26.5	24.0	70.0

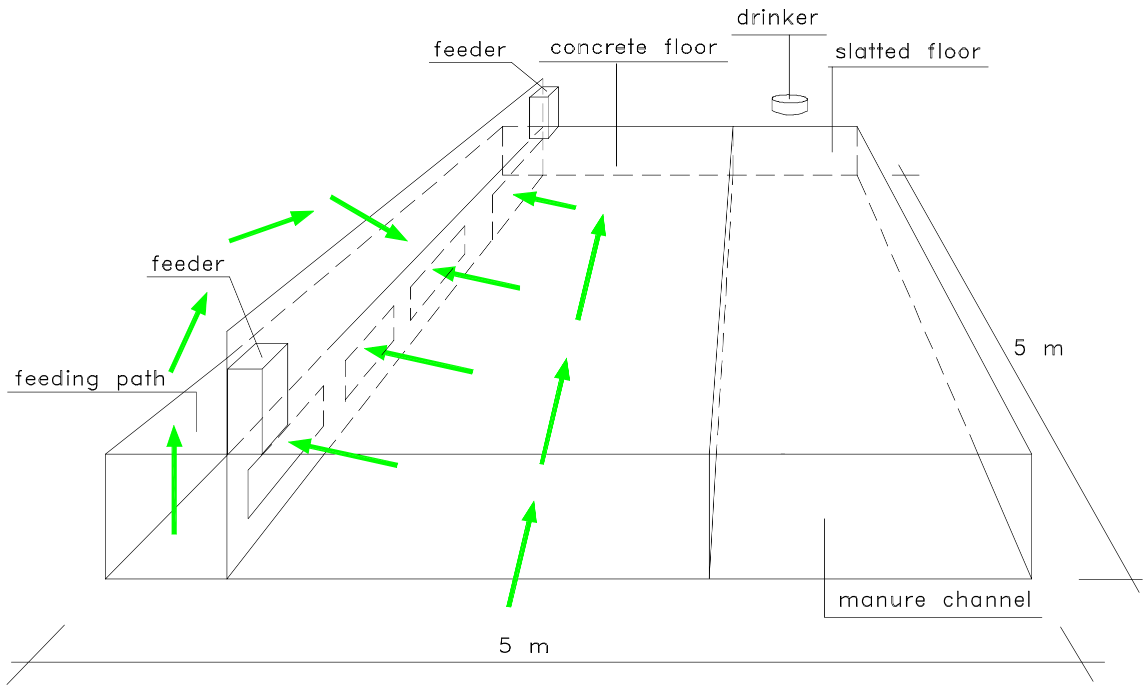

Figure 8. Layout of the pen in room 1, showing airflow.

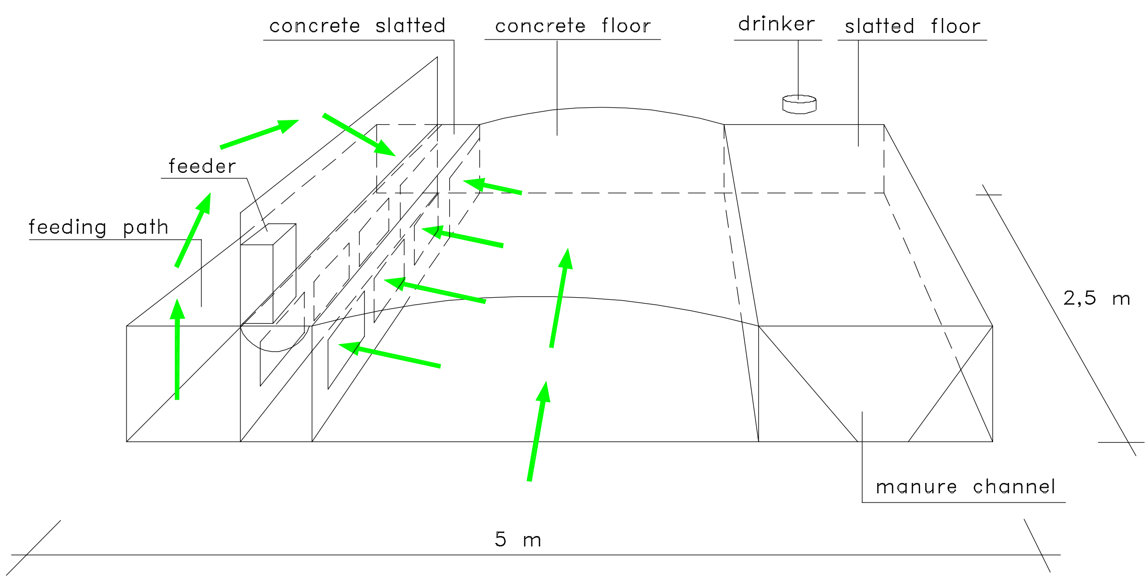

Figure 9. Layout of the pen in room 2, showing airflow.

by the cooling system was determined by means of an energy−flow measuring instrument (Q 2.5E, Raabkärcher, Viterra Energy Service, Germany). This instrument measured the flow rate and temperature difference between the entering and leaving water.

Twice a week, the surface temperature of the floor was determined randomly between 08:00 and 15:00 h. On six sections of the solid floor and on two sections of the slatted floor (figs. 1 and 2), the floor surface temperature was measured by infrared thermography (Quicktemp 850−1, Testo B.V., The Netherlands).

Feed was weighed and delivered to each pen automatically. Total feed intake per pen was recorded for each two−week period. The average daily gain of pigs was determined by weighing the pigs at the start of the fattening period and when they went to the slaughterhouse.

Pig Behavior

Lying Behavior

The lying behavior was recorded by round−the−clock video observations. The pigs were recorded with four cameras, two in room 1 and two in room 2, from June through August. Each camera observed one pen. The cameras were switched between pens approximately once every two days. One digital picture (frame) was stored every 15 min.

The observations were done pairwise in each room, and simultaneously in two pens: one pen with floor cooling and the opposite pen in the same room without floor cooling. To determine the effects of floor cooling on the pigs' lying behavior during hot periods, we analyzed data for days on which the average inside temperature between 09:30 and 21:30 h exceeded 25˚C.

From the pictures taken at 15 min intervals, we determined the number of pigs lying in the different sections of the pen (figs. 1 and 2) and the lying position of the animals, which we classified as follows:

- Side: pigs lying flat on one side of the body.
- Sternal belly: pigs lying on their belly, with their legs folded under them.
- In between: in between the above two positions, with only one or two legs folded under the belly.

For analysis, the data were split into two periods per day: 09:30 to 21:30 h (the period with high ambient temperature) and 21:30 to 09:30 h (the cool period).

Pen Fouling

Daily, except for the weekends, the fouled areas were drawn on a plan of the pen layout, on which a grid had been superimposed. The grid squares were used to calculate the percentage of area fouled with urine and feces. At the end of the fattening period, the grid was used to determine the extent of the manure crust (the dried mixture of feces and urine) on the different sections of the solid floor. The crust, which was classed as thin (<1 mm), medium (1 to 10 mm), or thick (>10 mm), was qualitatively assessed by the same person for each section of all pens.

Health Records

Health records were kept. They included any application of drugs, other veterinary treatments, and the reasons for removing animals from the experiment.

Statistical Analysis

The data collected were analyzed in a linear mixed model using the residual maximum likelihood method (REML) of Genstat 5, release 4.2, 5e edition. The fixed effects in the model were cooling (d.f. = 1, no or yes) room (d.f. = 1, room 1 or 2), the cool/warm period of the day, and the two-way interactions between these factors. These were tested against the random pen within room variation. The surface temperatures of the floor were analyzed with the same statistical model, but without the effect of period of the day. To ascertain the effect of cooling on the lying behavior of the pigs, the inside temperature was included in the fixed model to correct for temperature differences between rooms. Interaction effects were excluded from the model when not significant. The experimental units for lying behavior were the 24 h observation periods per pen; the experimental units for pen fouling were the manure crust, feed intake, and growth rate.

Results

Cooling System and Floor Temperature

The floor cooling systems were controlled separately for each room. The mean floor surface temperatures were 26.8˚C for the cooled pens and 24.9˚C for the uncooled pens (s.e. 0.14; $p < 0.001$). The difference between the cooled and uncooled pens was 2.4˚C for room 1 and 1.3˚C for room 2 (s.e. 0.14; $p < 0.001$). In room 1, the difference between the surface temperature of the solid floor and the slatted floor was +3.6˚C in the uncooled pens and +2.3˚C in the cooled pens. In room 2, these values were + 2.7˚C and +1.9˚C, respectively. The temperature of the solid floor in the uncooled pens was 1.6˚C higher in room 1 than in room 2. The equivalent value for the cooled pens was 0.5˚C (table 2).

Figure 10 shows the bi-weekly averages of outside temperature, ambient temperature, and energy uptake by the cooled floor. It can be seen that the temperature in room 1 was slightly higher than the temperature in room 2. The energy uptake of the floor was clearly higher in room 1 than in room 2.

Room Climate and Number of Observation Days

The floor cooling system was used from June 12 until September 18 in room 1 and from June 12 until September 25 in room 2. Table 3 gives the numbers of video observations per pen. The reason that the number of observations per pen is not the same is that we excluded observation days on which the mean temperature during the warm part of the day was below 25˚C.

The average temperature of the cool period (21:30 to 09:30 h) of the observation days was 24.1˚C in room 1 and 24.7˚C in room 2. During the warm period of the day (from 09:30 to 21:30 h), the average temperature was 26.6˚C in room 1 and 26.5˚C in room 2. During the cool period of the day, the average relative humidity was 59.9% in room 1 and 54.0% in room 2. During the warm period, it was 54% in room 1 and 48% in room 2. The energy absorbed by the cooled floors during the cool period of the observation days was 38.3 W per pig in room 1 and 28.3 W per pig in room 2. The comparable figures during the warm period were 45.0 W per pig in room 1 and 28.7 W per pig in room 2. Table 4 shows the average inside temperature above the uncooled and cooled pens for the observation days on which the average temperature from 09:30 to 21:30 h exceeded 25˚C.

Pig Behavior

Lying Behavior

Table 5 presents the percentage of pigs lying on the slatted floor during the cool period (from 21:30 to 09:30 h) and warm period (from 09:30 to 21:30 h) of the day for uncooled and

Table 2. The mean floor surface temperatures of solid and slatted floor with and without floor cooling.

		Temperature (°C)		Effect		
Floor Type	Cooling[a]	Room 1	Room 2	Room s.e	Cooling s.e	Room × Cooling s.e
Solid	0	27.6	26.0	0.1	0.1	0.2
	1	25.2	24.7	(p < 0.001)	(p < 0.001)	(p < 0.001)
Slatted	0	23.9	23.3	0.1	0.1	0.1
	1	22.9	22.8	(p = 0.003)	(p < 0.001)	(p < 0.001)

[a] 0 = without cooling; 1 = with cooling.

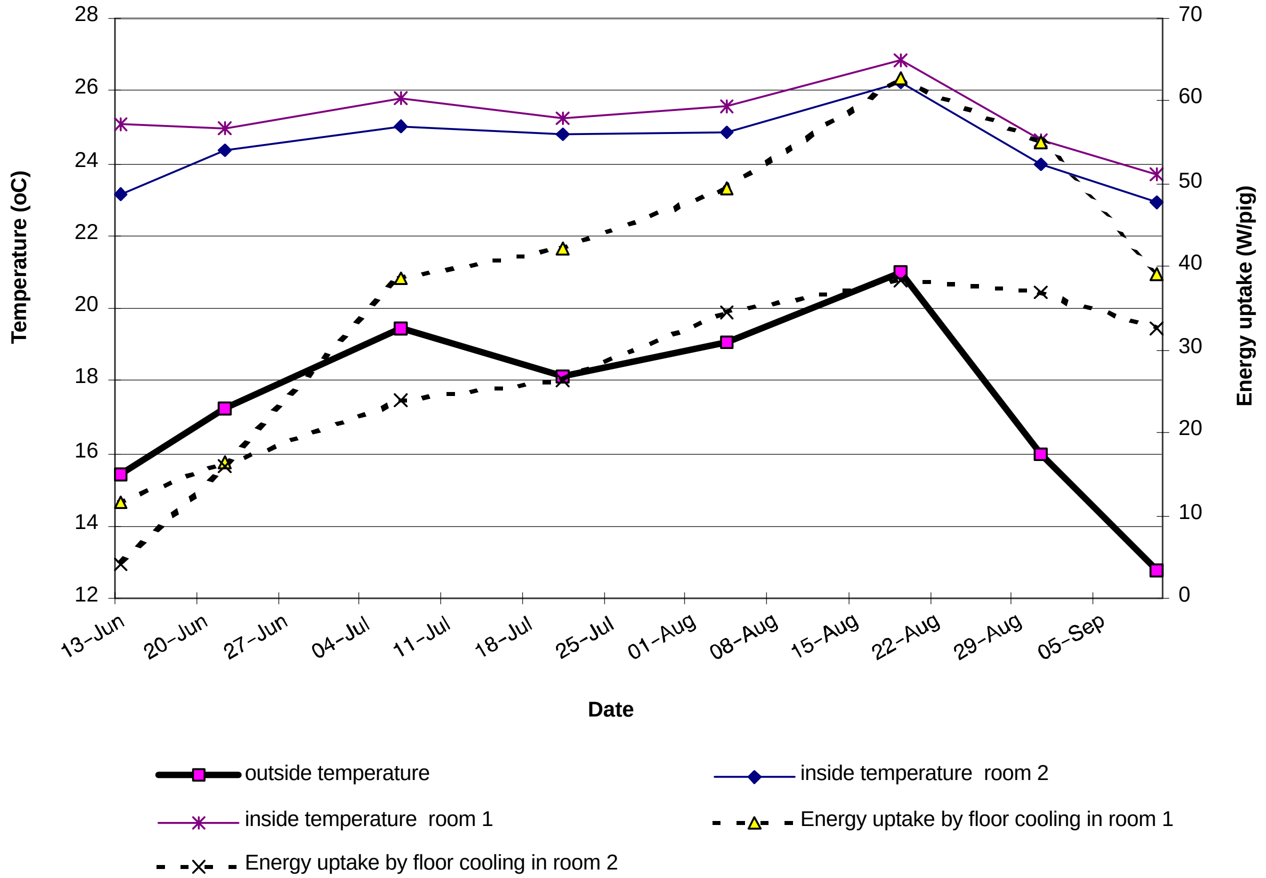

Figure 10. Variation in outside and room temperatures, and energy uptake by the cooled floors.

Table 3. Number of observation days (*n*) with mean indoor temperatures above 25˚C during the warm part of the day (from 09:30 to 21:30 h).

Room	Pen	*n*
1	1	13
	2	16
	3	8
		37 total
2	1	3
	2	6
	3	6
	4	4
	5	3
	6	5
		27 total

cooled pens in both rooms. In the uncooled pens, more pigs lay on the slatted floor than in the cooled pens (22.16% vs. 15.03%; s.e. 0.67; $P < 0.001$). More pigs lay on the slatted floor during the warm period of the day than during the cold period (19.55% vs. 17.63%; s.e. 0.67; $P < 0.01$). In room 1, more pigs lay on the slatted floor than in room 2 (24.36% vs. 12.83%; s.e. 1.8; $P < 0.001$). No interactive effects were found between cooling and room, period and room, and cooling and period of the day.

There were no differences ($P > 0.05$) in the lying positions of pigs between rooms or between floor cooling treatments. However, during the warm period of the day, more pigs lay on their side than during the cool period of the day (5.17% more for room 1, and 2.00% more for room 2; $P < 0.05$) (table 5).

Pen Fouling

The areas fouled with urine, feces, and with a mixture of urine and feces were determined. The areas fouled with urine were larger in room 1 than in room 2 ($P < 0.001$). There were no statistical differences between uncooled and cooled floors for the three types of fouling. However, there were differences between cooled pens and uncooled pens; in the cooled pens, the percentage of floor fouled was less than in the uncooled pens (table 6).

Crust formation on the solid floor was assigned to three classes: light, medium, and heavy. The data, shown in table 7, reveal an effect of cooling on the crust classed as "heavy"

Table 4. Average indoor temperatures on observation days.

	Indoor Temperature above Uncooled Pen (°C)[a]		Indoor Temperature above Cooled Pen (°C)[a]			
Room	Average	Range	Average	Range	Mean	SD
1	25.3	21.0−31.6	25.6	21.3−32.2	25.5	0.2
2	25.9	22.8−31.7	25.7	21.7−31.3	25.6	0.1

[a] Temperature sensors hung at 1.5m above the floor.

Table 5. Effects of period of the day, cooling, and room on percentage of pigs (relative to total number of lying pigs) that were lying on the slatted floor and were lying on their side during the cool (from 21:30 to 09:30 h) and warm (from 09:30 to 21:30 h) periods of the day.

			Effect				
			Room		Period	Cooling	Room
Behavior	Period	Cooling[a]	1	2	s.e.	s.e.	s.e.
Lying on slatted floor	Cool[b]	0	26.8	15.1	0.7 (p < 0.005)	0.7 (p < 0.001)	1.8 (p < 0.001)
		1	20.4	8.2			
	Warm[c]	0	29.0	17.8			
		1	21.2	10.2			
Lying on side	Cool	0	50.1	52.4	1.2 (p < 0.05)	1.2 (n.s.)	2.5 (n.s.)
		1	47.5	50.9			
	Warm	0	54.3	53.5			
		1	52.7	52.9			

[a] 0 = without cooling; 1 = with cooling.
[b] From 21:30 to 09:30 h.
[c] From 09:30 to 21:30 h.

(P < 0.05). There was more crust formation on the solid floor in room 1 than in room 2. This can be seen from table 7; room 1 had a significantly larger area in the "medium" category and a significantly smaller area in the "light" category.

Health Records

Seven pigs were removed from the experiment (2.43% of all pigs), all from room 1. Six were from uncooled pens; one was culled from a cooled pen. The pigs from the uncooled pens were culled because of respiration problems and slow daily gain. The reason for culling the pig in the cooled pen was rectal prolapse. Overall incidences were too low to differentiate between treatments.

Voluntary Feed Intake

There were significant differences in feed intake between the cooled and uncooled pens. The pigs in the cooled pens consumed more feed than those in the uncooled pens (P < 0.01). No difference in feed intake was observed during the first part of the fattening period (fig. 11). There was also a higher voluntary feed intake in room 1 than in room 2 (P < 0.05; table 8).

Average Daily Gain

Weight gain was somewhat higher (32.8 g d^{-1} pig^{-1}) for pigs in the cooled pens than for pigs in the uncooled pens (table 8). There were no differences in daily gain between the two rooms. A tendency was found (P = 0.056) for a room and cooling to interact with regard to pig weight gain. The difference in growth performance between cooled and uncooled pens was more pronounced in room 1.

Discussion

Housing systems confine animals in a particular environment and restrict their opportunity to find an area with maximal thermal comfort. This is a major constraint to production, especially when ambient temperatures are high. Our results demonstrate that cooling the solid pen floor in pig houses affects the lying and excreting behavior and performance of growing finishing pigs. Lying on the slatted floor, or more generally in the excretion area, indicates that pigs are suffering thermal discomfort, especially when the temperature inside the room is high (Aarnink et al., 2001; Hesse and Jackisch, 1995; Randall et al., 1983). Our results show that floor cooling reduces the number of pigs lying on the slatted floor at high ambient temperatures. These cooling-induced changes in the pigs' lying behavior might have improved their thermal comfort and welfare conditions during hot weather.

The area of the solid floor fouled with urine or feces did not differ much between the uncooled and cooled floors. We had expected a larger difference, given an earlier finding (Aarnink et al., 2001) that pen fouling increased as more pigs lay on the slatted floor. One factor that might explain the difference in the results could be the very strictly controlled indoor climate in the current experiment, in which for nine consecutive days the temperature was increased by 2°C every day, from an initial temperature of 16°C to 28°C. In addition, the short duration of the heat stress scheme might have caused the changes in excreting behavior to be larger

Table 6. Effects of cooling and room on fouling of solid floor area (in % of total floor area) fouled with urine, feces or with a mixture.

		Effect			
		Room		Cooling	Room
Fouling	Cooling[a]	1	2	s.e.	s.e.
Urine	0	3.2	0.9	0.2	0.2
	1	3.0	0.7	(p = 0.2)	(p < 0.001)
Feces	0	0.6	0.8	0.1	0.2
	1	0.6	0.7	(p = 0.7)	(p = 0.4)
Mixture	0	2.1	3.6	1.5	1.9
	1	1.8	0.8	(p = 0.3)	(p = 0.9)
Total fouled	0	6.1	5.1	1.8 (p = 0.2)	1.9 (p = 0.9)

[a] 0 = without cooling; 1 = with cooling.

Table 7. Effects of cooling on degree of crusting on solid floor (as % of total floor area).

		Effect			
		Room		Cooling	Room
Crusting	Cooling[a]	1	2	s.e.	s.e.
Light	0	3.0	65.8	11.6	17.8
	1	12.7	92.0	(p =.0.08)	(p < 0.001)
Medium	0	73.7	10.8	6.7	7.1
	1	82.7	0.0	(p = 0.5)	(p < 0.001)
Heavy	0	23.3	23.3	6.7 (p < 0.05)	14.6 (p = 0.9)

[a] 0 = without cooling; 1 = with cooling.

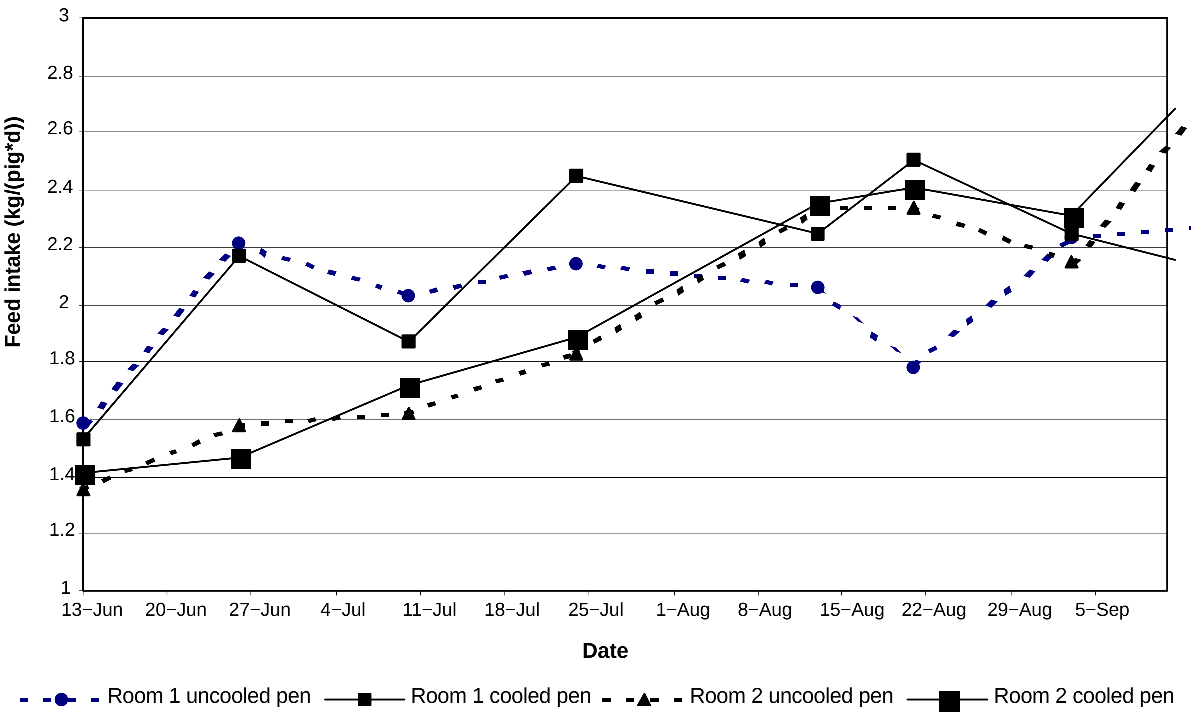

Figure 11. Comparison of voluntary feed intake.

than in our long duration exposure. It seems likely that there will be differences between short−term and long−term effects. Another reason for the discrepancy with the earlier experiment (Aarnink et al., 2001) is that in that experiment the air was introduced through a perforated ceiling, while in the current experiment the fresh air came from the feeding passage and flowed down directly into the lying area.

The main reason for the greater pen fouling in room 1 than in room 2 could be that during the hot periods of the experiment the pigs in room 1 were heavier than those in room 2. Various researchers (e.g., Hacker et al., 1994; Aarnink et al., 1996) have shown that heavier pigs foul their pens more. Furthermore, in room 1 the group size was larger than in room 2 (24 vs. 12 pigs per pen), and the shape of the pens was different, especially the shape of the floor. On the convex floor in room 2, the urine probably drained to the manure pit much faster than on the sloping floor in room 1. Buré (1986) demonstrated experimentally that long, narrow pens like those in room 2, in which the lying and excreting areas adjoin along the narrow side, had less fouling than pens in which these areas adjoined along the wide side. This may have been a contributory factor in our study.

Table 8. Effects of cooling on voluntary feed intake (kg/pig) and average daily gain (g d^{-1} per pig) during the entire fattening period.

		Effect			
		Room		Room	Cooling
	Cooling[a]	1	2	s.e.	s.e.
Feed intake[b]	0	220.4	213.2	6.9	5.0
	1	242.0	221.2	($p < 0.05$)	($p < 0.01$)
Average daily gain[c]	0	717.5	723.4	14.7	11.3
	1	771.9	734.4	($p = 0.28$)	($p = 0.017$)

[a] 0 = without cooling; 1 = with cooling.
[b] kg/pig.
[c] g d^{-1} per pig.

Although the solid floor was cooled, its surface temperature was always higher than that of the slatted floor. However, the difference decreased at higher cooling capacity (cooler inflowing water). To keep the pigs lying on the solid floor at high ambient temperatures, the temperature of the solid floor should be the same as or lower than that of the slatted floor. Some of the factors limiting the cooling system were the system's capacity and the fact that the water warmed up somewhat as it flowed from the heat exchanger to the room floor. The temperature of the inflowing water in room 2 was higher than in room 1 because room 2 was farther from the cooling water unit (25 m vs. 10 m). This implies that one way to improve the results would be to increase the capacity of the cooling system.

During the warm period of the day, from 09:30 to 21:30 h, the pigs lay somewhat more on the slatted floor than during the cool period of the day. The differences in mean inside room temperature between the cool and warm periods of the day were small: 2.5°C for room 1 and 1.8°C for room 2. When differences are larger, e.g., in spring and fall, it might be worth cooling the floor during the warm period of the day only and turning off the cooling during the night. According to Curtis (1983) and Steinbach (1987), at higher ambient temperatures pigs lie on their sides more in order to maximize their body contact with the floor and thus maximize heat loss. Our findings confirm this: the pigs lay more on their sides during the warm period of the day than during the cool part of the day. We found no effect of cooling on the lying position. A possible reason is that, regardless of whether or not the floor is cooled, pigs generally prefer to lie on their side rather than on their belly. It seems likely that as the floor temperature falls, a point will be reached at which the pigs will lie less on their sides in order to reduce their heat loss to the floor.

The effect of cooling on feed intake became visible after approximately 6 weeks of the fattening period. This confirms

Verstegen's (1971) contention that the critical temperature decreases with increasing live weight. In pigs weighing 50 to 90 kg, this decrease in temperature with increasing weight is slightly faster than in younger pigs weighing 20 to 50 kg. When no cooling is applied, apart from adapting their behavior, the only way pigs can limit their stress at temperatures above the comfort zone or above their upper critical temperature is by eating less. In this experiment this was clearly shown: the pigs in the uncooled pens ate less than pigs in the cooled pens, and consequently, the growth rate in the uncooled pens was lower. This effect on pig growth rate can be an economic justification for installing a cooling system in houses for growing finishing pigs. Thus, cooling pig pens during hot summer weather not only improves the pigs' welfare, but may benefit the farmer economically as well.

Conclusion

In this study, we have demonstrated that cooling a solid pen floor improves the lying behavior of growing and finishing pigs at high ambient temperatures: more pigs chose to lie on the cool solid floor instead of on the slatted floor. We have also demonstrated that floor cooling significantly increased the pigs' feed intake and growth rate under summer conditions. The system might be further refined if more were known about how the cooling requirements of the pigs varies with ambient temperature and animal weight.

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