Thermal behaviour of growing pigs in response to high temperature and humidity

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Abstract

The effects of high ambient temperatures and humidities on thermal behavioural adaptation and pen fouling of group-housed growing pigs were assessed. Twelve groups of 10 gilts of an average initial body weight (BW) of 61.7 kg were used. During nine experimental days, ambient temperatures were increased by two degrees per day from 16 °C on day 1 to 32 °C on day 9 and fixed at one of three levels of relative humidity (RH) 50, 65, and 80%. Space allowance per pig was 1 m\textsuperscript{2}. The floor was 60\% solid and 40\% slatted. Lying, excreting and fouling behaviour were studied using video recordings. During the nine trial days a radar activity meter was used to record the physical activity of each group of 10 pigs every 6 min. A regression model was used to calculate the heat produced by activity from total heat production (HP). The lying position of the pigs was classified, e.g. Lateral, Sternal, Half lateral lying. Excreting behaviour was determined in terms of, e.g. urination and defecation. Furthermore, thermoregulatory lying behaviour (huddling and wallowing) were recorded. All behaviours were determined in terms of frequency and location. Temperature affected lying and excretion behaviours. The number of pigs lying on slatted floor increased with increasing temperature.

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The inflection point temperature (IPt) for the pigs to lie on slatted floor was on average 18.8 °C; below this IPt the pigs remained lying on the solid floor. The heat produced by activity was relatively constant below 24.2 °C, but once this IPt had been exceeded it down turned. Temperature was inversely related to huddling (p < 0.001) and positively related to wallowing (p < 0.001). The total excretions on solid floor increased with temperature (p < 0.05). The number of urinations was inversely related to temperature (p = 0.13). However, the relative number of urinations on the solid floor increased concomitantly with temperature (p < 0.05). It can be concluded that high temperatures greatly affect lying and excreting behaviour. At a relatively low temperature, pigs preferred to lie on the slatted floor. At high temperature, there was a clear increase in fouling of the solid floor. At high humidity, changes in behaviours occurred at lower temperatures.

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Keywords: Pig; Temperature; Relative humidity; Heat stress; Modified behaviour

1. Introduction

Previous research has demonstrated conclusively that behavioural elements such as lying posture and excretion are affected by ambient temperature (Hacker et al., 1994; Blackshaw and Blackshaw, 1994; Beattie et al., 1996; Aarnink et al., 2001; Peishi and Toshio, 2001). Ekkel et al. (2003) reported that in thermoneutral conditions fattening pigs spent 90% of the day lying. Furthermore, they found that lying laterally was the most dominant position (>60% of observations). Under experimental conditions, Geers et al. (1986) observed that on hot days pigs changed their lying position from sternal to lateral and avoided physical contact with other pen mates. Aarnink et al. (2001) found that the relative number of pigs lying laterally increased by 1.8% for each degree Celsius rise in temperature. Furthermore, they found that the number of pigs lying in physical contact with each other fell by 3.7% for each degree Celsius increase (16–32 °C).

Pigs are known to separate their lying and dunging areas. Stolba and Wood-Gush (1989) found that none of the defecation sites in their Edinburgh ‘Pig Park’ were closer than 5 m to a nest site, and none were further than 15 m from the nest. Under optimal housing conditions pigs will rest and sleep in a defined lying area and dung consistently in the dunging area (Hacker et al., 1994; Aarnink et al., 1997, 2001). Aarnink et al. (2001) reported a strong relationship between the percentage of the slatted floor used by pigs to lie on and the relative number of excretions on the solid floor, postulating that the pigs fouled the solid floor because the space remaining on the slatted floor was limited.

Despite the many advances made in recent decades in the technological control of indoor climate in animal buildings, ambient temperatures will not always be within the thermal comfort zone of the pig. Though results are available on the effects of temperature on behavioural changes, quantitative relationships between temperature and thermo-regulatory behaviour of pigs are lacking. Neither is information available on the effects of humidity at different temperatures on fattening pigs’ behaviour.

To evaluate how pigs regulate their thermal regulatory behaviour under hot conditions we therefore designed an experiment with temperatures varying from low to high at three
humidities. The aim was to derive the upper limit of thermal neutral zone with respect to lying and excretion behaviour in growing pigs. We hypothesised that high ambient temperatures and high humidity will affect lying and excreting behavioural patterns, and that the relationship between this behaviour and temperature and humidity can be used to calculate upper critical temperatures.

2. Materials and methods

2.1. Experimental design

In this study 12 groups of 10 growing pigs (experimental unit) were each housed in a pen in one of two large respiration chambers. Before being housed in the chamber, the pigs were kept in similar growing pens for a preliminary period of 2 weeks to adjust to the experimental conditions. They were then placed in the respiration chambers for 13 days: four of these days were for habituation. During the 4th day habituation period the ambient temperature was gradually reduced: the respective day temperatures were 20, 18, 16, and 16 °C. During the 9th day experimental period, air temperature was gradually increased by two degrees daily, from 16 °C on day 1–32 °C on day 9. In the two parallel chambers, relative humidity (RH) was fixed pair wise at 50, 65, or 80% during the whole period of 9 days. Each group of pigs was assigned to one of the three levels of RH.

2.2. Animals

For each of the six rounds, 10 crossbred gilts originating from a cross between a synthetic boar (New–Dalland synthetic × 25% Pietrain) and F1 sow (Finnish Landrace × Large White). At 90 days of age the pigs were put in one of the pens in the two large respiration chambers and kept there for 13 days. The pigs were weighed on day 0 and also on day 13. Both weighing were done in the morning (09:00 h). At the beginning of the habituation period, average initial body weight (BW) was 61.7 kg (range: 58.0–65.5 kg). The pigs were offered a standard pelleted diet ad libitum, which contained 157 g kg−1 crude protein, and 16.1 MJ kg−1 gross energy. The pigs had free access to water.

2.3. Respiration chamber

Two respiration chambers as described by Verstegen et al. (1987) were used. Each had an inner capacity of 80 m3 air. Air was drawn from the chamber by means of a centrifugal fan with airflow of 2.3 m3 min−1. Air velocity at animal level was approximately 0.2 m s−1. The air removed from the chamber was replaced by outside air at a constant rate of 2.3 m3 min−1, which was equivalent to 3% capacity of chamber volume every minute. The amount of recirculated air was 158.4 m3 min−1, equivalent to an air exchange rate of twice per minute.

In order to allow the animals to adapt to the respiration chamber, the initial temperature on the arrival of the animals was the same as in the habituation pens and then was gradually decreased to 16 °C at the start of the 9th day experimental period. An additional humidifier
was used in each chamber to maintain the desired relative humidity. In each treatment, humidity remained constant (<5% fluctuation) throughout the 9th day experiment. The circulating air was heated or cooled, depending on the deviation from the set point temperatures.

As a result of the data collection procedures, in room 1, the temperature increase and the switching on and off of lights was 30 min earlier than in room 2. In room 1, temperature was increased daily at 09:00 h. Daylight was provided from 06:00 to 18:00 h, using nine fluorescent tubes that produced 400–450 lx at floor level. During the night (18:00–06:00 h) the illumination was from two light bulbs of 25 W (4–5 lx).

2.4. Pen

One pen was built within each of the two respiration chambers. Pen size was 2.5 m × 4.0 m. The pen floor was 60% solid (2.5 m × 2.4 m) with 4% slope, and 40% tribar metal slatted (2.5 m × 1.6 m) (see Fig. 1). Space allowance was approximately 1.0 m² pig⁻¹. A slurry tank underneath the slatted floor stored urine and faeces. The slurry tank was emptied at the end of each trial. The slats had tribar metal bars of 15 mm width; the slots were 15 mm wide. A dry feeder at the front of the pen on lying area provided the pigs with ad libitum feed. A bowl drinker was installed at the back of the pen on the slatted floor area; the pigs had free access to the drinker. The design of the drinker was the same as

![Pen layout, 60% solid and 40% slatted floor. Sectors 1–6 were used to determine lying and excreting locations of the pigs.](image-url)
in commercial pens and ensured that water did not spill on the floor. The floor surface area of the pen was divided into six sectors: sectors 1–4 were on the solid floor and the remaining two sectors were on the slatted floor. In practice, the two main sections (i.e. the solid floor and the slatted floor) were generally used. The division into six sectors enabled the location of fouling to be specified more precisely.

2.5. Measurements

Two video cameras (Panasonic wv-bl 200 with 2.8 mm fisheye lens) were used to record the temporal patterns of lying, excretion and fouling behaviour of pigs. The cameras were installed inside each chamber and covered the whole pen area. Pictures from the cameras were transferred to time-lapse video tape recorders (Panasonic AG-6024-e). From these videotapes, scan samples were taken at 30-min intervals, resulting in 48 observations per pen per day. The lying and excreting behaviours that occurred on each of the six sectors (Fig. 1) were recorded. Frequencies and percentages of behaviours were calculated per group.

2.5.1. Lying position

The ethogram of lying postures consisted of the following mutually exclusive behavioural elements:

- Lateral lying: the pig lies flat on one side of its body, not supported by legs.
- Sternal lying: the pig lies on its belly and has three or four legs supporting its body.
- Half lateral lying: the pig reclines, with its body supported by one or two legs. This lying posture is intermediate between sternal and lateral lying.

2.5.2. Thermoregulatory lying

- Huddling: pigs lying with over 50% of their lying side in contact with another pig.
- Wallowing: this behaviour was scored from the tapes. Wallowing was defined as rolling or rubbing the body in a mixture of faeces and urine. The frequency of wallowing was determined the same way as excretion.

2.5.3. Excretion

The method of recording and analysing this behaviour is similar to work done by Aarnink et al. (2001) and Huynh et al. (2004). Excretion was scored using the behaviour sampling technique from continuous video recordings; any occurrence of this behaviour was recorded, and the frequency of the events was analysed. Two behavioural elements were identified: defecation and urination. Finally, analysing videotapes estimated the area of fouled solid floor as well. Scan samples were taken at 60-min intervals, resulting in 24 pictures per sector per pen per day. Fouled areas in each sector were counted as percentage of the area covered with urine and faeces. When analysing the frequency of excretions on solid floor, only sectors 1 and 2 were taken into account. This was because faulty construction of the floor resulted in sectors 3 and 4 often being already fouled at the start of each experimental period by urine produced in those sectors that could not run off the solid floor.
2.6. Heat production

Heat production (HP) was calculated using indirect calorimetric methods (Verstegen et al., 1987). Energy expenditure was obtained from data on the volume of incoming and outgoing air and the percentage of CH$_4$, O$_2$, and CO$_2$. Heat production was expressed in kJ day$^{-1}$ W$^{-0.75}$. The rate of O$_2$ consumption and CO$_2$ production and energy expenditure were computed as proposed by Brouwer (1965), Yousef (1985) and Verstegen et al. (1987). Gas samples of air entering and leaving the chamber were collected and analysed every 6 min during the 9th day experiment. Physical activity was recorded using radar activity meters. The principle of this method is based on the Doppler effect: the frequency of reflected radar waves emitted by the meters changes when the animals move, and the change of frequency is converted to a signal (electrical pulses), recorded continuously by the data acquisition system. To convert the number of pulses to energy expenditure, the energy expenditure per pulse should be known. Within the day, variation within physical activity causes variation in heat production. By recording activity and heat production in distinct time periods and regressing heat production on activity counts, the heat production per activity count can be calculated. For this purpose, a regression analysis was performed on heat production as a function of activity counts each experimental day. The slope of the regression line (=\(b\)) then represents the heat production per activity count. Average activity heat production per day then can be calculated as average amount of activity pulses \(\times b\).

2.7. Statistics

The daily means of the groups of 10 pigs were used for data analysis. For determining the effects of temperature and relative humidity on behavioural changes of growing pigs, the percentage (relative value) or number (absolute value) of each variable was used. Data from the first round were excluded due to a technical problem. The effects of temperature and humidity were determined by using two models: a linear model and a broken stick model. First, the broken stick model was applied to the data. If the model failed to converge (indicating no inflection point in the data), the linear model was used. Room temperature was included as a continuous variable, and humidity as a factor.

The linear model was run with the REML procedure (residual maximum likelihood technique). A Chi-square test was used to test differences between treatments. The model can be described as follows:

\[
Y_{ijk} = \mu + \beta T_i + RH_j + (\beta T \times RH)_{ij} + e_{ijk}
\]

where \(Y\) is dependent variable, e.g. lying pigs, urinations, defecations on solid floor, and excretions on solid floor, \(\mu\) is the overall mean, \(\beta\) is the regression coefficient of room temperature, \(T_i\) is room temperature (16–32 °C), RH$_j$ is the effect of relative humidity (50, 65, and 80%), \((\beta T \times RH)_{ij}\) is the interaction between variable room temperature and factor humidity \(e_{ijk}\) is the residual error, where there was no significant effect of the interaction, this element was excluded from the model.

A broken stick analysis was done (Aarnink et al., 2001; Huynh et al., 2004) in order to estimate quantitatively the upper limit of behavioural thermoneutral zone of the pig. The
model calculated the inflection point temperatures (IPt) above which there were clear changes in the pigs’ behaviour. The model can be described as:

\[ Y = c + z(T - \text{IPt}_{\text{RH}}) \quad \text{when} \quad T \geq \text{IPt}_{\text{RH}} \]

\[ Y = c \quad \text{when} \quad T < \text{IPt}_{\text{RH}} \]  

(2)

where \( Y \) is the dependent variable, e.g. relative frequency of lying pigs on slatted floor, activity heat production. \( c \) is a constant, \( z \) is a regression coefficient, \( T \) is the room temperature, IPt is the inflection point temperature at 50, 65, or 80% RH.

All analyses were performed with the Genstat software (Genstat 5, release 6.1, 7th ed.).

3. Results

Due to technical problems data from the first series had to be excluded.

Tables 1 and 2 give data on the effects of room temperature on the lying and excretion variables. As Table 1 and Fig. 2 show, there was a tendency for room temperature to be related to percentage of lying pigs (\( p < 0.1 \)): for each degree Celsius increase in room temperature, this percentage increased by 0.2%. At 80% humidity there were significantly more pigs lying than at 50% humidity (\( p < 0.05 \); Table 1). Room temperature also significantly affected the lying posture of the animals (Table 1). Relative humidity had no effect on these variables (\( p > 0.05 \)). On average, 12.4% of pigs lay sternally, 15.4% lay half laterally, and 72.0% lay laterally. For each degree Celsius increase, the percentage of pigs

<p>| Table 1 |</p>
<table>
<thead>
<tr>
<th>Effects of room temperatures and humidity on lying behaviour and thermoregulatory behaviours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent variables</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Lying pigs (%)</td>
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<td></td>
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<tr>
<td></td>
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<tr>
<td>Sternal lying (%)</td>
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<tr>
<td>Half lateral lying (%)</td>
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<td></td>
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<tr>
<td>Lateral lying (%)</td>
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<td></td>
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<tr>
<td>Huddling (%)</td>
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<td></td>
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<tr>
<td>Wallowing (%)</td>
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</tbody>
</table>

n.s.: Non-significance; letters a, b within a row, means without a common letter (not in superscript) differ, \( p < 0.05 \).

\(^a\) Simple regression analysis with room temperature as a variable and relative humidity as a factor.

\(^*\) \( p < 0.05 \). Levels of significant difference from 0.

\(^*\)\(^\dagger\) \( p < 0.001 \). Levels of significant difference from 0.

\(^\dagger\) \( p < 0.1 \). Levels of significant difference from 0.
lying sternally decreased by 0.3% (n.s.), but the pigs lying half laterally decreased significantly (by 0.4%) and the pigs lying laterally increased significantly (0.8%) (in both cases, \( p < 0.001 \)). Huddling was negatively affected by temperature (\( p < 0.001 \)) (Table 1 and Fig. 3): for each degree Celsius increase there was a 4.9% decrease in number of

![Graph](image)

Fig. 2. Relationship between lying pigs (%) and room temperature. (□, ◊, △) were means of measured data.

Table 2

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Adjusted ( R^2 )</th>
<th>Parameters of model(^a)</th>
<th>Factors 50% RH</th>
<th>65% RH</th>
<th>80% RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urination, time pig(^{-1}) day(^{-1})</td>
<td>0.41</td>
<td>Average Regression coefficient</td>
<td>3.4 a (±0.1) 4.0 b (±0.2)</td>
<td>-0.03 (^{n.s.}) (±0.02)</td>
<td>3.0 c (±0.16)</td>
</tr>
<tr>
<td>Defecation, time pig(^{-1}) day(^{-1})</td>
<td>0.45</td>
<td>Average Regression coefficient</td>
<td>2.0 a (±0.1) 2.3 a (±0.2)</td>
<td>-0.07 (^{**}) (±0.02)</td>
<td>2.6 b (±0.2)</td>
</tr>
<tr>
<td>Urination on solid floor (%)</td>
<td>0.22</td>
<td>Average Regression coefficient</td>
<td>3.3 (±1.1) 6.1 (±1.7)</td>
<td>0.60 (^{**}) (±0.21)</td>
<td>5.5 (±1.5)</td>
</tr>
<tr>
<td>Defecation on solid floor (%)</td>
<td>0.04</td>
<td>Average Regression coefficient</td>
<td>1.1 (±0.5) 2.7 (±0.7)</td>
<td>0.11 (^{n.s.}) (±0.09)</td>
<td>1.1 (±0.6)</td>
</tr>
<tr>
<td>Total excretions on solid floor (%)</td>
<td>0.24</td>
<td>Average Regression coefficient</td>
<td>3.2 a (±0.8) 5.4 b (±1.2)</td>
<td>0.49 (^{**}) (±0.15)</td>
<td>4 a (±1.1)</td>
</tr>
<tr>
<td>Fouling solid floor (%)</td>
<td>0.06</td>
<td>Average Regression coefficient</td>
<td>16.3 (±1.9) 14.4 (±2.8)</td>
<td>0.69 (^{**}) (±0.34)</td>
<td>16.8 (±2.4)</td>
</tr>
</tbody>
</table>

n.s.: Non-significance; letters a, b, c within a row, means without a common letter (not in superscript) differ, \( p < 0.05 \).

\(^{a}\) Simple regression analysis with room temperature as a variable and relative humidity as a factor.

\(^{*}\) \( p < 0.05 \). Levels of significance difference from 0.

\(^{**}\) \( p < 0.01 \). Levels of significance difference from 0.
huddling pigs. The pigs started to decrease huddling at a relatively low ambient temperature (Fig. 3). Table 1 and Fig. 4 show that the relative frequency of wallowing increased with increasing temperature ($p < 0.001$). For each degree Celsius increase in ambient temperature, wallowing increased by 1.2%.

Table 2 gives the results for excreting behaviour. Per day, on average, a pig urinated 3.5 times and defecated 2.3 times. Urinations differed significantly between humidities

![Fig. 3. Relationship between huddling pigs (%) and room temperature. (□, ◊, △) were means of measured data.](image)

![Fig. 4. Relationship between wallowing pigs (%) and room temperature. (□, ◊, △) were means of measured data.](image)
(Table 2). On average, frequency of urination decreased by 0.03 times for each degree Celsius increase. However, across humidities the number of urinations on the solid floor rose by 0.6% °C⁻¹ increase (p < 0.01; Table 2). No significant effect of humidity on this parameter was found. Room temperature was also found to be inversely related to defecation (Table 2): defecations decreased by 0.07 for each degree Celsius increase (p < 0.01). On average, defecations on the solid floor increased by 0.11% for each degree Celsius rise in ambient temperature (n.s.). The frequency of excretions on the solid floor was positively related to temperature (Fig. 5): it rose by 0.5 °C⁻¹ increase (Table 2). To ascertain how increasing temperature would affect floor hygiene, the percentage area of

![Fig. 5. Relationship between excretions on solid floor (%) and room temperature. (□, ◊, △) were means of measured data.](image)

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Inflection point temperatures at which pigs changed their behaviours</th>
</tr>
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<tbody>
<tr>
<td>Dependent variables</td>
<td>Percentage variance accounta</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Lying on slatted floor (%)</td>
<td>88</td>
</tr>
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<td></td>
<td></td>
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<tr>
<td>Activity heat production (kJ W⁻⁰.⁷⁵ day⁻¹)</td>
<td>52</td>
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</tbody>
</table>

Letters a, b within a row, means without a common letter (not in superscript) differ, p < 0.05.
a For validity of the nonlinear model (%).
b Nonlinear regression model analysed with room temperature is variable and humidity is factor.
solid floor fouled with excrement was estimated (Table 2). For each degree Celsius increase in room temperature, the solid floor area became 0.7% more fouled with urine and faeces ($p < 0.05$; Table 2). There were no interactive effects of temperature and humidity on excreting behaviour.

Fig. 6. Broken stick relationship between lying on slatted floor (%) and room temperature. (□, ◊, △) were means of measured data.

Fig. 7. Broken stick relationship between activity heat production and room temperature. (□, ◊, △) were means of measured data.
Two variables clearly showed a broken stick relationship with room temperature (see Table 3). The IPt above which the relative frequency of pigs lying on slatted floor started to raise, was on average, 18.8 °C (Table 3 and Fig. 6). Humidity had no effect on this inflection point. When room temperature exceeded IPt the relative frequency of pigs lying on the slatted floor increased. Humidity affected this response (Table 3) shows that at 50%, the increase was less than at 65 and 80% humidity ($p < 0.05$). On average, activity heat production of the pigs decreased above 24.2 °C (Table 3 and Fig. 7). It fell approximately 11.7 kJ W$^{-0.75}$ day$^{-1}$ °C$^{-1}$ rise. Table 3 shows that when ambient temperature was below inflection point temperature, the activity heat production within the three levels of humidity was different ($p < 0.05$): at 65% RH it was lower than at 50 and 80% RH.

4. Discussion

This study investigated the behavioural adaptation of confined finishing pigs to increasing temperatures at different humidities. The pigs responded to increasing temperatures by modifying their lying, excretion and wallowing behaviour. High humidity accentuated the effects of temperature on the pigs’ behaviour. The upper critical temperatures of some variables could not be estimated, due to large variations. As a result, for some variables the broken stick model failed to estimate the different parameters of the model, yet in a previous study (Aarnink et al., 2001), the broken stick model had proved to be the best model to fit data on pen fouling at increasing temperatures. There are two possible reasons for this difference: (1) in the present study, the groups of pigs were larger than in the Aarnink et al. (2001) study (10 versus 5 pigs per pen); (2) often, part of the solid floor (sectors 3 and 4) was already fouled at the start of observations. This might have contributed to the greater variation in the fouling of sectors 1 and 2, as well. When no broken stick model could be applied, a linear regression model was chosen to provide a general view of pigs’ behaviours at increasing temperatures and at different humidities.

Our finding that on average the pigs lay for 88.0% of the day (24 h) agrees with Ekkel et al. (2003), who found that finishing pigs rested for 90% of their time. Blackshaw and Blackshaw (1994) reported 67.6% of growers lay in the shade (at 15–20 °C), but that above 35 °C this figure rose to 93.9%. We found that pigs spent slightly more time lying when humidity increased from 50 to 80%.

Surprisingly, we found that activity heat production fell with increasing room temperature. Below 24.2 °C activity heat production remained constant; at higher temperatures it declined—probably because of increased lying behaviour. Furthermore, even though we could not identify an IPt for lying in general, it is likely that activity heat production did have an IPt, due to an influence of the lying factor.

On average 72% of pigs lay on their lateral side. In contrast, Petherick (1983) presumed that the average floor area occupied by resting pigs under thermoneutral conditions could be estimated assuming on a half lateral lying posture of the pigs. In our study, at room temperatures between 16 and 18 °C (so-called thermoneutral range as defined by Petherick (1983)), only 22.6% of pigs lay half laterally, and sternal and half lateral lying gradually declined with increasing room temperature. The pigs reduced the
percentage of lying in this position by 0.4% for each degree Celsius increase. This switch from half lateral-to-lateral lying was gradual: within the temperature range we investigated there was no clear inflection point. The relative number of pigs lying on their lateral side increased with increasing room temperature. In a previous study with the same group of animals and experimental design, Huynh et al. (2004) reported that pigs’ skin temperature rose by 0.25°C for each degree Celsius increase in ambient temperature. It is likely that the pigs in the present study lay laterally to increase their body surface in contact with the cooler floor in order to disseminate the increased body heat brought about by the rise in ambient temperature. This agrees with Close et al. (1981), who reported that pigs housed at high temperatures will spend more time lying on their side in order to transfer as much of their excess body heat to the environment as possible.

Lying location changed with increasing temperature. When room temperature was below 18.8 °C, the pigs chose to lie on the solid floor only. As temperature increased, they changed their preferred lying location to the slatted floor, because in partially slatted pens such floors are about 3.6 °C cooler than solid floors (Huynh et al., 2004a,b). When room temperature was above 30 °C, the percentage of lying pigs on this area peaked (30–35%). This percentage is less than could be expected. Petherick and Baxter (1981), Petherick (1983) and Ekkel et al. (2003) introduced an equation to estimate the area occupied by a lying pig, assuming a 60 kg growing pig and pigs lying fully on their side: 0.7 m². Based on this, approximately 50% of the lying pigs could share the slatted floor area, but we observed only a maximum of three to four pigs (30–35%) on the slatted floor per time. There are three likely explanations for this: (1) At high temperatures, 90% of pigs prefer to lie, effectively obstructing access to the slatted floor. (2) At high room temperatures, pigs avoid lying in close contact with each other, to maximise heat loss through radiation. Our study did indeed show a negative linear relationship between percentage of huddling pigs and room temperature. This is in agreement with Geers et al. (1986), Riskowski et al. (1990) and Olsen et al. (2001), who found that as temperature rose, pigs tried increasingly to avoid body contact with other pigs. This means that the estimates of space required made by Petherick (1983) and Ekkel et al. (2003) are too low for pigs are kept at higher temperatures. (3) The third possible reason is that pigs stay on the solid floor because the floor is soiled and they can lose heat there. As described earlier, in our study the solid floor was fouled at an early stage and the pigs used this foul area as a dunging area. At high ambient temperature they used this area to cool themselves by wallowing in excrement.

Several previous studies have reported that at high ambient temperatures pigs housed indoors on partially slatted flooring will shift their lying behaviour towards the slatted dunging area, and will dung on the solid floor (Randall et al., 1983; Hacker et al., 1994; Aarnink et al., 1996, 2001). Some authors have also added that this behaviour is most obvious when pigs are heavy (Hacker et al., 1994; Ni et al., 1999; Aarnink et al., 2001). Aarnink et al., (2001) reported that above a certain temperature, which ranged from 25.9 to 21.7 °C for pigs weighing 25–105 kg, the percentage of excretions on the solid floor increased. Ni et al. (1999) reported that floor contamination could be seen already at 17.5 °C room temperature. When studying the effects of floor cooling in commercial housing for fattening pigs at an average ambient temperature above 25 °C, Huynh et al.
(2004a) saw an increase of lying on slatted floor and also of dunging on the solid floor. Our results confirm those of the studies mentioned, but in addition we observed that with increasing temperature, pigs become uncomfortable and inactive, extending their bodily contact with the floor while lying, and avoiding physical contact with other pigs. These stretched-out pigs restricted access to the dunging area even though space allowance was acceptable. We therefore suggest that future space allowance studies should take account of thermoregulatory behavioural changes when determining the physical space pigs require. This means that physical space should increase with increasing temperature, as when they are hot, pigs show less space sharing and lie more laterally. In addition, the number of pigs lying on slatted floor could be an indicator that pig welfare suffers when pigs are exposed to high ambient temperatures. As shown in Section 3, humidity had no effect on the IPt for lying on slatted floor, but did affect the increase (regression coefficient) of this response at ambient temperature above IPt. At low humidity the increase was slightly less than at 65 and 80% RH. This meant that at high humidity the temperature effect was more pronounced.

In our study we observed a distinctive form of pig behaviour: wallowing in a mixture of urine and faeces. Wallowing by wild pigs serves two purposes: coating the body with a layer of mud to protect against external parasites, and increasing evaporative heat loss when temperature is high (Schein and Hafez, 1969). However, pigs will avoid lying or wallowing in their own excrement. In our study, at 80% relative humidity the pigs wallowed at relatively low ambient temperature; wallowing increased gradually with increasing room temperature. In the groups subjected to 50 and 65% RH, the change in wallowing activity seemed to occur later (data not shown). The temperature at which wallowing was induced was higher than the temperature at which outdoor pigs start to wallow in mud. We found that at 80% humidity the pigs wallowed very early at the start of temperature increase. This showed that at high humidity the pigs felt the need to cool down earlier than at low humidity, and that the immediate options for relieving heat load were wallowing in excrement and lying on the slatted floor. This suggests a conflict between the motivation to stay clear of excrement and the need to increase evaporative heat loss by getting wet. For the pig to start wallowing in its own urine and faeces, the natural desire to avoid contact with excrement had to be abandoned.

The cause of the decrease in frequency of urinating might be that at high temperatures pigs increased their evaporative heat loss (Huynh et al., 2004). By increasing respiratory frequency, much water containing body heat could be dissipated. In addition, an increase in urination on the solid floor was observed when room temperature increased. At lower humidity, the urinations of pigs on solid floor were lower. As discussed earlier, at high humidity the pigs experienced heat stress stronger and sooner. The main reason for urinating on the solid floor at high temperature might be the lack of space due to changes in lying behaviour: the increased number of pigs lying on the slatted floor when temperature increased would have hampered other pigs from reaching the slatted floor and finding an unoccupied quiet place to urinate. Finally, although neither recorded in detail nor mentioned in Section 3, when temperature rose there was a dramatic increase in the incidences of pigs being showered with urine from other pigs and in urinating while lying. These behaviours again demonstrate the overriding desire of the pigs to cool themselves at these temperatures.
5. Conclusion

From this study we conclude that temperature has a strong effect on the lying and excreting behaviour of growing pigs. Humidity has a minor effect. Growing pigs at 60 kg body weight regulated their thermal behaviour at an early stage when exposed to high temperatures. There are ranges of critical temperatures for growing pigs. We found that from 16.6 °C huddling was reduced; above 18.8 °C lying on slatted floor was increased, from 20 °C the excretions on solid floor increased, and above 24.2 °C the activity heat production was reduced. On the basis of our findings on thermoregulation we recommend that when determining the physical space required by fattening pigs the behavioural changes at increasing temperatures should be taken into account. The current study demonstrates clearly that the changes in pigs’ behaviour induced by heat should be taken into account when assessing pen design and indoor climate conditions. Finally, the number of pigs lying on slatted floor could be an indicator for assessing the welfare of pigs exposed to high ambient temperatures.

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