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Increased air velocity in the lying area improves pen hygiene and reduces ammonia emissions from houses with partly slatted pens for growing/finishing pigs

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HIGHLIGHTS

- Increased air velocity in the lying area improved pen conditions during warm periods.
- Pigs tended to lie less in the slatted area with increased air velocity in lying area.
- Improved pen hygiene with increased air velocity during warm periods.
- The higher proportion of time with increased air velocity the cleaner pens.
- Reduced ammonia emissions during the last part of the growing period.

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ABSTRACT

Partly slatted pens can offer growing/finishing pigs a better house environment than pens with fully slatted floors. Under thermoneutral conditions, pigs prefer to rest on a solid area and some litter can be provided as enrichment. Ammonia emissions are lower in systems with partly slatted pens, provided the pens are kept clean. However, under high-temperature conditions, pigs in partly slatted pens may begin lying on the slatted area and fouling on the solid floor area, resulting in increased ammonia emissions. This study examined the effects of increasing the air velocity (IAV) in the lying area from max 0.5 m s^{-1} to max 1.0 m s^{-1} on conditions for pigs in partly slatted pens during warm periods. Air velocity was increased by redirecting the inlet air from the ceiling inlets down into the animal zone.

The study was performed in a commercial growing/finishing house with 10 identical rooms, each containing 16 pens for 9-14 pigs growing from 25-30 kg to 115-120 kg live weight. Pigs were introduced simultaneously into two parallel rooms, one with IAV in the lying area and one without (control treatment). During two summers with six batches, concentrations of carbon dioxide (CO_2) and ammonia (NH_3), pig activity and choice of lying area in the pen, pen fouling and NH_3 emissions were recorded in both rooms on four measuring occasions (M1-M4) during the growing period. Gas concentrations were measured by photoacoustic analyser, pig activity and pig choice of lying area by machine vision techniques, and pen fouling by visual inspection. Climate parameters (air temperature, relative humidity) were logged continuously during the growing period. Ammonia emissions were calculated from the ventilation rate (determined by the indirect CO_2 tracer gas method) and the difference in ammonia concentration between outlet and inlet air.

Under high ambient temperatures, pigs in the IAV treatment were observed lying significantly more often ($p<0.05$) in the part of the lying area with the highest air velocity. Pigs tended to lie less in the slatted area ($p=0.052$) in the IAV treatment than in the control. Problems with pen fouling were significantly reduced with increased air velocity in the lying area and NH_3 emissions were reduced by 21% ($p=0.009$), from 8.4 to 6.6 g pig^{-1} day^{-1}, during the late growing period (M4).

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In conclusion, increasing air velocity in the lying area of partly slatted pens from max 0.5 to max 1.0 m s^{-1} influenced pigs' choice of lying area, improved pen hygiene and reduced ammonia emissions.

1. Introduction

Most growing and finishing pigs in Sweden are raised in confined and insulated buildings with partly slatted pens and mechanical ventilation. Under Swedish animal welfare regulations (Swedish National Board of Agriculture, 2019), a slatted floor for manure drainage is not permitted as a lying area for pigs and pigs must have access to bedding material. A solid lying area in the pen allows provision of some litter, which is considered to improve pig welfare (Beattie et al., 1995; Pedersen et al., 2014). Under thermoneutral environmental conditions, pigs in partly slatted pens prefer to lie on the solid lying area with a small amount of straw (100 g pig^{-1} day^{-1}) (Hillmann et al., 2004). Furthermore, pig houses with partly slatted floors in the pens have around 25% lower ammonia (NH_3) emissions than houses with fully slatted floors (Giner Santonja et al., 2017), due to smaller emitting surface area (Aarnink et al., 1996; Groot Koerkamp et al., 1998; Sun et al., 2008). However, during periods with high ambient temperatures pen fouling can occur, leading to impaired pen hygiene and air quality, extra manual work in scraping the fouled pen area, and increased NH_3 emissions (Larsen et al., 2018). Pen fouling in pens for growing/finishing pigs has increased in Sweden in recent decades, probably due to modern genotypes being more sensitive to heat stress (Renaudeau et al., 2011) and to climate change increasing outdoor temperatures in summer (Schauberger et al., 2019). Measures are needed to reduce this problem.

Pen fouling under high ambient temperatures is the result of behavioural changes due to sub-optimal thermal climate and insufficient space allowance (Larsen et al., 2018; Nannoni et al., 2020). Huynh et al. (2005b) describe the impact of increased ambient temperature on pigs as a sequence of behavioural adaptions that include decreased huddling, changes in lying posture, wallowing, increased lying on slatted areas and excretion on solid floor areas. Pigs also decrease their activity and lie more when ambient temperature rises (Huynh et al., 2005b). Above a certain temperature, pigs begin to lie in the slatted dunging area in a partly slatted pen as it tends to be cooler, increasing their heat loss (Aarnink et al., 2006; Hillmann et al., 2004; Huynh et al., 2005a; Savary et al., 2009). Hillmann et al. (2004) found that the temperature at which 20% of pigs began lying on the slatted floor in pens with some straw in the lying area (100 g per pig and day) was 27 °C, 23 °C and 22 °C for pigs weighing 25-35 kg, 50-70 kg and >85 kg, respectively. According to Savary et al. (2009), the proportion of pigs lying in the slatted area is higher in pens with straw than in pens with bare concrete during high ambient temperature. Once the slatted floor is preferred for lying, pigs start defecating and urinating in the lying area (Huynh et al., 2005a; Aarnink et al., 2006). Hence, the number of excretions on the solid floor also increases above a certain temperature (Aarnink et al., 2006; Huynh et al., 2005b). With increasing temperature, the number of urinations decreases, but the relative number on the solid floor increases (Huynh et al., 2005a, 2005b). The amount of fouling on the solid floor also increases as the pigs grow heavier (Aarnink et al., 2006, 1996; Hacker et al., 1994). Pigs require more space with increasing body weight and temperature (Spoolder et al., 2012). With a smaller area per pig, they spend more time in the slatted dunging area, which prevents access by other pigs (Hillmann et al., 2005, 2004). According to Aarnink et al. (2006, 1996), pens often become fouled late in the finishing period, due to insufficient area.

Several cooling technologies for modifying the thermal environment and/or increasing heat loss from pigs in confined housing systems under high ambient temperatures have been developed (Godyń et al., 2020). Cooling the pigs with increased air velocity during hot summer periods is a well-known method used in growing/finishing houses. Sällvik & Walberg (1984) showed that the optimum convective heat loss for a 70 kg pig in a confined housing system was induced by an air velocity of between 0.15-0.28 m s^{-1} and 0.74-1.31 m s^{-1} when the inside temperature was 16°C and 28°C, respectively. Insufficient air velocity lowers pen hygiene (Sällvik & Walberg, 1984). Bjerg et al. (2018) developed an equation that combines temperature, humidity and velocity of surrounding air to describe the thermal environment in pig houses (effective temperature). Applying that equation in computational fluid dynamics (CFD) simulations, Bjerg et al. (2018) investigated the effect of a ceiling inlet on air velocity in the lying area of a growing/finishing pig house with partly slatted pens and airflow of 100 m^3 h^{-1} pig^{-1}. They found that at an inlet air temperature increase of 9°C, it was possible to maintain the effective temperature in the pig lying area by increasing the air velocity in the area from 0.4 m s^{-1} to 0.8 m s^{-1}. However, the potential of increased air velocity in growing/finishing pig houses as a measure for cooling pigs has not been fully utilised and the effects on pig behaviour and pen fouling need further investigation.

One way to reduce the problem of pen fouling in existing buildings during hot summer periods could be to improve the thermal climate by readjusting the ceiling inlets and changing the air flow pattern to increase the air velocity in the lying areas. This study examined the effect on animal choice of lying area, pen fouling and ammonia emissions of readjusting the ceiling inlets to increase the air velocity in the lying area in a commercial growing/finishing house with partly slatted pens.

2. Material and methods

2.1. Experimental facility

The study was performed on an integrated commercial pig farm with 480 sows and 3600 growing/finishing places located in southern Sweden (latitude 55.5°N). The farm has two growing/finishing pig houses, one of which was used in this study. The house was built in 2013 and has a south-north orientation and 10 identical rooms. Each room has 16 partly slatted pens arranged in two rows, with an inspection alley between the rows (Fig. 1).

Each pen has a total area of 10.86 m^2 (4.825 m x 2.25 m), and each accommodated 9-14 fattening pigs at introduction during this study. The variation in number of pigs per pen reflected variation between batches, due to fluctuations in the number of weaners produced in the herd. However, in each batch the number of pigs was equally distributed between the two rooms compared. Along one of its long sides, each pen has a feeding trough that is shared with a neighbouring pen (Fig. 2). The partitions between the pens are closed except for a steel grid on the slatted floor between every second pen. Of the total pen area, 69% consists of solid concrete and 31% of slatted concrete floor. Pens with areas of urine and/or feces on the solid floor are manually cleaned/scraped once a day, early in the morning. After cleaning, the pigs are given a handful of straw for occupation. The inspection alley between the two rows of pens is part of the slatted area in the room. Below the slatted area is a slurry pit, from which slurry is removed by a vacuum removal system every week.

On the study farm, undocked pigs (LY x H; Piggham) (HK Scan, 2019) are moved each month from the nursery unit to the growing/finishing unit and two parallel rooms are filled simultaneously, one on each side of the central corridor.

2.2. Feed and water

All pigs in this study were fed (wet feeding system) four times a day and pigs in the two parallel rooms received feed simultaneously. The feed comprised a mixture of ingredients produced on the farm (35% wheat/26% triticale/35% barley/4% faba bean), together with distillers grain, rapeseed meal, soy and a premix from a Swedish feeding company (on average 139.5 g crude protein per kg dry feed). The pigs were fed semi-ad libitum up to 60-65 kg body weight and then restrictively (according to university norms; Göransson and Lindberg, 2011). Phase feeding, with three different phases during growth, was applied. Water was available ad libitum for 24 h per day from a nipple above the part of the trough in the slatted area.

2.3. Ventilation system

The ventilation in each room consists of a negative pressure system from Skov A/S. Each room has one exhaust unit (DA 600) and 16 ceiling inlets (DA 1540). The outside air is coming into the attic through openings along the eaves. One air inlet per pen is placed in the ceiling close to the rear wall, facing towards the centre of the room (Fig. 1). The maximum capacity of the exhaust unit is 13 000 m^3 h^{-1} at pressure 10 Pa, according to the manufacturer, and the unit is equipped with flaps controlling the minimum ventilation rate. Each inlet has a capacity of 1450 m^3 h^{-1} at 10 Pa and 30 cm opening. The climate inside each room is controlled by two temperature and humidity sensors, located in the room and the attic, connected to a climate computer (DOL 234F) with an emergency opening unit (DOL 278). The exhaust unit is placed over the slatted area, between pens 2 and 3 from the central corridor (Fig. 1).

The set-point air temperature in the control unit was adjusted during the batches according to Table 1. The set temperature started at 19.4 °C and was then successively decreased to 16.5 °C on day 84 of the batch. The relative humidity (RH) value controlling the minimum ventilation rate was set to 80%. The rooms had no heating devices.

2.4. Increased air velocity on lying area

Air velocity was changed by means of adjusting the air inlets. The air flow pattern and air velocity before and after adjusting the air inlets were examined in pens without pigs using smoke and a hand-held hot wire anemometer (VelociCheck 9515, TSI). At maximum ventilation rate, the ceiling inlets were normally opened 35° in the rooms, creating the airflow pattern shown in Fig. 3 (left panel). Maximum air speed in the lying area, about 0.5 m s^{-1}, occurred at the edge towards the slatted area, directed from the slatted area into the lying area. With the ceiling inlets opened 75°, the airflow pattern changed (Fig. 3, right panel). A large volume of inlet air was then directed directly down into the animal zone and the air velocity in the lying area was increased. The maximum air speed in the lying area, about 1.0 m s^{-1}, occurred at around one-third of the distance into the lying area from the wall.

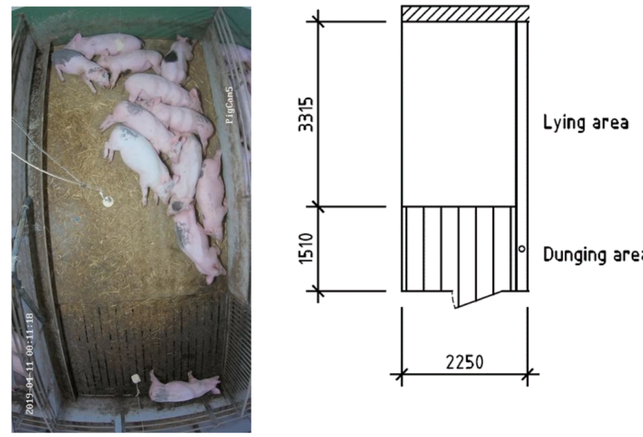

Fig. 2. Design of the pen used for growing/finishing pigs. The lying area consists of solid concrete and the dunging area of slatted concrete floor.

Table 1
Set-point temperatures in the rooms.

Day after introduction	Set temperature for room temperature, °C	Set temperature in inlet air, when inlets opened from 35 to 75°, °C (only treatment IAV)	Measuring period
1	19.4	27.0	-
7	19.2	25.9	-
14	19.0	24.6	-
21	18.5	23.4	M1
42	18.0	19.5	M2
56	17.0	17.0	M3
84	16.5	17.0	M4

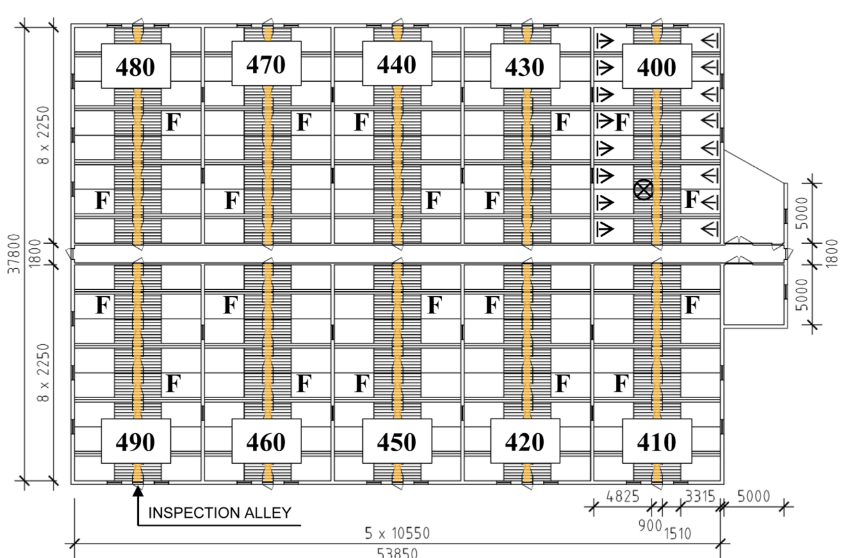

Fig. 1. Indoor layout of the building for growing-finishing pigs, with 10 identical rooms (nos. 400-490) and 16 partly slatted pens. Two focal pens were selected in each room (F). Position of exhaust fan and inlets shown in room 400.

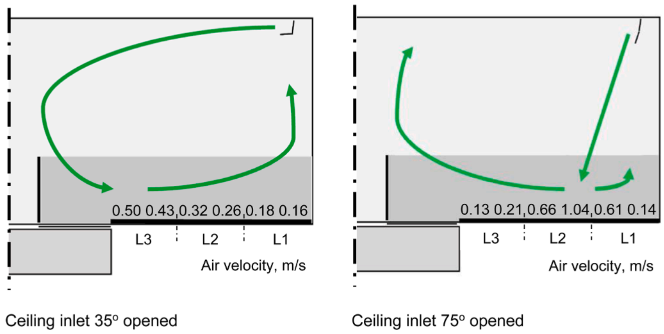

Fig. 3. Airflow pattern and air velocity in the middle of the lying area in the partly slatted pens with ceiling inlet 35° opened and 75° opened at maximum ventilation rate (L1-L3 = lying areas 1-3).

Opening of the inlets from 35° to 75° was controlled by the temperature of the inlet air, with settings as shown in Table 1. On day 1 of the batch, the ceiling inlets opened to 75° at an inlet air temperature of 27 °C. The set temperature for 75° opening was linearly decreased to 17 °C in inlet temperature at day 56, remaining constant throughout the rest of the growing period. The settings were selected so that the effective temperature of inlet air according to Bjerg et al. (2018) would not fall below the lower optimal temperature according to Hillman et al. (2004) with an increased safety marginal for the smaller pigs due to risk of draught.

Usage of increased air velocity in the IAV treatment room was calculated using the settings of the ventilation system and measurements of inlet temperature (T_{in}).

2.5. Experimental design and measurements

For each batch, two parallel rooms were investigated, comparing increased air velocity (IAV) in the lying area (75° opened ceiling inlets during periods with T_{in} above the settings in Table 1) with normal air velocity in the lying area (35° opened ceiling inlets) in the control. The investigation was conducted in the same pig house, during the same two summer periods and with the same set-up as a previous investigation on cooling growing/finishing pigs with showers in the slatted area (Jeppsson et al., 2021). In total, six consecutive batches were investigated (Table 2), one batch during the first summer and five batches during the second summer. In each room, two focal pens were selected for behaviour studies with video cameras (Fig. 1). The focal pens were in the same place in each room in relation to the exhaust unit.

Before introduction into the rooms, the pigs were weighed by farm personnel. Mean live weight of the pigs at introduction was 25-30 kg (SD 4.7 kg), which is slightly lower than the Swedish average (~30 kg). According to slaughter records, the pigs were sent to slaughter at live weight of around 115-120 kg (mean 117 kg). However, slaughter weight varied somewhat during the batches, due to changes in demand from the slaughterhouse.

For every batch, climate parameters (air temperature and RH) were recorded continuously. The concentrations of CO_2 and NH_3, pig activity and choice of lying area in the pen were recorded on four measuring occasions of 5-6 days (M1-M4) during the growing period (with the exception of measurement occasion M4 in batch 33 due to problems with the manure system). The first measurements (M1) were made about 3-4 weeks after introduction of the pigs into the pens and M2, M3 and M4 at around 6-7 weeks, 9-10 weeks and 12-13 week after introduction, respectively. Based on conditions for the study herd, the weight of the pigs at the four measurement occasions was estimated to be 40-45 kg (M1), 60-65 kg (M2), 80-90 kg (M3) and 100-115 kg (M4). On some occasions, individual pigs had been sent to slaughter by measurement occasion M4. The fouling in the pens were determined every week of the batches on the day of the visit.

The study farm was visited once a week (Wednesdays or Thursdays). On each visit, measurements and recordings during the previous week were downloaded and saved, and some of the measuring equipment (the video cameras, the multi-gas analyser and the multiplexer) was moved to the next two parallel rooms, according to the experimental schedule.

Table 2
Experimental design.

Batch	Month of pig introduction	Year	Name (number) of room Control	Increased air velocity	No. of pigs at introduction in control/increased air velocity treatment
31	August	1	410	400	228/229
32	March	2	490	480	191/191
33	May	2	420	430	191/189
34	June	2	440	450	189/189
35	July	2	460	470	210/210
36	August	2	480	490	191/191

2.6. Air temperature, relative humidity (RH) and temperature-humidity index (THI)

Temperature and RH in inlet and outlet air in each room were measured every 30 minutes during the batches, using wireless loggers (Rotronic, HL-RC-B logger and HC2A-S3 humidity and temperature sensor). Twelve loggers were used, two in the attic measuring the inlet air (T_{in}, RH_{in}) and one in each room measuring the outlet air (T_{out}, RH_{out}). The loggers in the attic were placed in the centre of the building, at 0.3 m height from the ceiling insulation, while the loggers in the rooms were placed at the exhaust fan. The humidity sensors were calibrated before and after each summer's measurements. Since the combined effect of temperature and RH is important for how animals experience their local environment, temperature-humidity index (THI) was calculated as Hahn et al. (2009):

$$THI = 0.8T_{out} + RH_{out}(T_{out} - 14.4) + 46.4 \quad (1)$$

2.7. Studies of activity and pigs' choice of lying area in the pens

Pig activity and pigs' choice of lying area in the pens were studied by means of video-recordings. Four video cameras (HIK Vision Network Camera) recorded the pigs (one image per minute) in two focal pens per room during measurement occasions M1-M4. Each camera was installed in the middle of the focal pen, just below and attached to the ceiling, with its lens pointing downward and covering the whole pen. From the video recordings, one 24-h period per measurement occasion (most often Tuesdays) was selected and the area in which pigs were lying and number of standing animals were scored using deep learning and machine vision techniques with accuracy 92-93% compared with visual scoring (Nasirahmadi et al., 2019). A region-based fully convolutional network (R-FCN) model combined with Residual Network (ResNet101) was used in the artificial intelligence monitoring system (Fig. 4). From the results, information was obtained about activity (active or lying; active = standing /walking/eating/sitting) and distribution of lying pigs (sum of lying pigs =100%) on the different pen areas (lying areas L1-L3 with solid floor (three areas with equal size of 2.5 m^2), slatted area (S) (size of 3.4 m^2), see Fig. 4) every 20 minutes during the 24-h data analysis periods.

2.8. Pen fouling

Scoring of pen fouling was carried out once a week (in the afternoon on the day of the visit) during the whole growing period (weeks 1-12) in all pens, rooms and batches in the trial. Each pen was divided into eight observation areas, six in the lying areas with solid floor (L1A, L1B, L2A, L2B, L3A, L3B) and two in the slatted area (SA and SB) (Fig. 4). Each area was scored for dirtiness (urine/wet and faeces) according to a seven-point scale, following the template in Table 3. A total fouling score for the lying

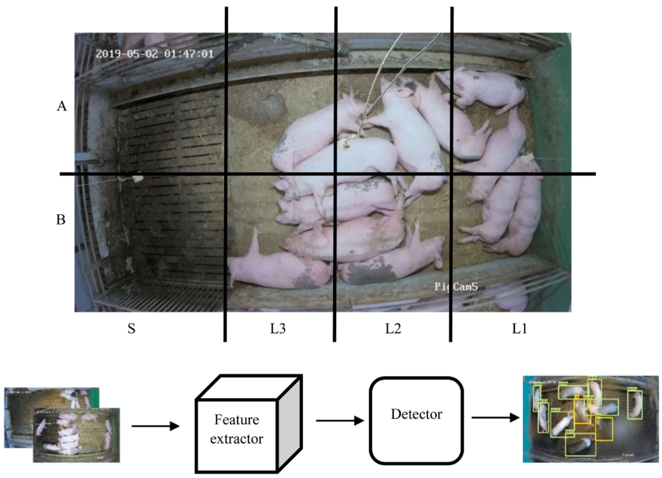

Fig. 4. Division of pen areas used in studies of pig occupation area and pen fouling. (L1-L3 = lying areas 1-3, S = slatted area) and illustration of the machine vision combined with deep learning approach used for scoring pig behaviour.

Table 3
Description of the seven-point scale used to score pen fouling.

Score	
0	The whole area is clean and dry
0.5	Wet spot in the area (>0 - <33%)
1	≥33% - <66% of the area is wet without or with a very small amount of faeces
1.5	≥66% - <80% of the area is wet with some faeces
2	≥80% of the area is wet with some faeces
2.5	100% of the area is wet + some faeces and single dirty pigs
3	The whole area is fouled and floating + dirty pigs

area was calculated as the average of the six lying areas with solid floor ((L1A+L1B+L2A+L2B+L3A+L3B)/6). The same person carried out all studies of pen fouling during the whole trial. A similar method has been used previously to evaluate pen fouling in the whole lying area or in sections of the pen (Hacker et al., 1994; Savary et al., 2009).

2.9. Concentrations of CO_2 and NH_3

The concentrations of CO_2 and NH_3 were measured using a Photoacoustic Multi-gas analyser 1412 and a Multiplexer 1309 (Lumasense Technologies S/A, Denmark). Before each year of measurements, the multi-gas analyser was calibrated by Lumasense Technologies S/A in Ballerup, Denmark. The detection thresholds were 1.5 ppm CO_2 and 0.2 ppm NH_3. According to datasheets from the manufacturer, the multi-gas analyser has repeatability of 1% and a range drift of ± 2.5% of the measured value.

Air sampling and analyses were performed at 30-minute intervals during the four measuring periods of 5-6 days for each batch. In total, air samples were pumped to the multi-gas analyser from six different measuring points; two in the attic from inlet air (CO_{2in} and NH_{3in}) and two in each room from outlet air (CO_{2out} and NH_{3out}). The sampling sites in the attic were in the centre of the building at 0.3 m height from the ceiling insulation, while the sampling sites in the rooms were at the exhaust fan. Air sampling was performed in 3.2 mm PTFE tubes equipped at the inlet with PTFE filters (Millex®-FA) to trap large particles.

2.10. Calculations of ventilation rate and NH_3 emissions

The ventilation rate was determined using the indirect CO_2 tracer gas method, calculated according to CIGR calculation rules (VERA, 2018). This is a less accurate method for determining ventilation rate than the fan wheel anemometer (Blanes and Pedersen, 2005), but is an approved measuring method according to the VERA test protocol for livestock housing and management systems (VERA, 2018). Total heat production, Φ_{tot}, and metabolic CO_2 production was calculated using the equations in CIGR (2002) and the factor for converting heat production into CO_2 production, 0.200 $m^3\ h^{-1}\ hpu^{-1}$, taken from Pedersen et al. (2008). In order to establish a growth curve and calculate metabolic CO_2 production, two focal pens per room were selected for weighing on 3-4 occasions during growth. The ventilation rate (VR) in each room was calculated as:

$$VR = \frac{CO_{2prod}}{(CO_{2out} - CO_{2in}) \cdot 10^{-6}} \cdot \Phi_{tot} \quad (2)$$

where VR is the ventilation rate on a 24-h basis [$m^3\ h^{-1}\ pig^{-1}$], CO_{2prod} is CO_2 production in a room for growing/finishing pigs (Pedersen et al., 2008) [0.200 $m^3\ h^{-1}\ hpu^{-1}$], CO_{2out} is average CO_2 concentration in outlet air on a 24-h basis for each room [ppm], CO_{2in} is average CO_2 concentration in inlet air on a 24-h basis for each room [ppm] and Φ_{tot} is average total heat production by the pigs at current room temperature on a 24-h basis in each room [$hpu\ pig^{-1}$].

The ammonia emission (E_{NH3}) rate in each room was calculated as:

$$E_{NH3} = VR(C_{out} - C_{in}) \quad (3)$$

where E_{NH3} is ammonia emission rate [$mg\ pig^{-1}\ h^{-1}$], C_{out} is average NH_3 concentration in outlet air on a 24-h basis for each room [$mg\ m^{-3}$] and C_{in} is average NH_3 concentration in inlet air on a 24-h basis for each room [$mg\ m^{-3}$].

2.11. Statistical analyses

Mean values per 24-h and measuring occasion (M1-M4), room (n=2) and batch (n=6) were calculated for climate parameters (24-h averages from 5-6 days of measurements per measuring occasion), pig activity/lying area in the pens (24-h average from two video cameras per room and measuring occasion), fouling score in the pens (average from scoring in 16 pens per room and measuring occasion), CO_2 and NH_3 concentration, ventilation rate and NH_3 emissions (24-h averages from 5-6 days of measurements per measuring occasion; same days as for the climate parameters). Significant differences were tested using the mixed effects model in Minitab Version 18.1 (Minitab Inc., n.d.). Treatment (Tr) (control/IAV), measurement occasion/period (M) (M1-M4) and interaction Tr x M were fixed factors and batch (B), B x Tr and B x M were random factors in the model. Pairwise differences were tested with the Tukey method at significance level $p<0.05$.

2.12. Ethical considerations

This study was conducted in accordance with the decision by the Swedish National Board of Agriculture (Dnr 5.8.18-16260/2017) on using pigs for research.

3. Results

Measurements were carried out on the six batches (31-36) during the very warm summer of 2018 and 2019 in southern Sweden. Due to periods with high outside temperature during the batches, the pigs experienced high ambient temperatures in the house. For batches 33-35, starting in early May, June and July, the outlet temperature from the rooms was above 25 °C between 43-57% of the days (Fig. 5). Maximum T_{out} was 32.2 °C and the difference between outlet and inlet air (dT) was at most 6 °C when the inlet air was 20 °C. T_{out} was above the room set temperature for 63.7, 31.0, 88.6, 89.6, 88.6 and 66.4% of the time during the six consecutive batches (batch 31-36), respectively. The climate parameters in inlet and outlet air during the measuring periods in the six batches are presented in Table 4. During the measuring

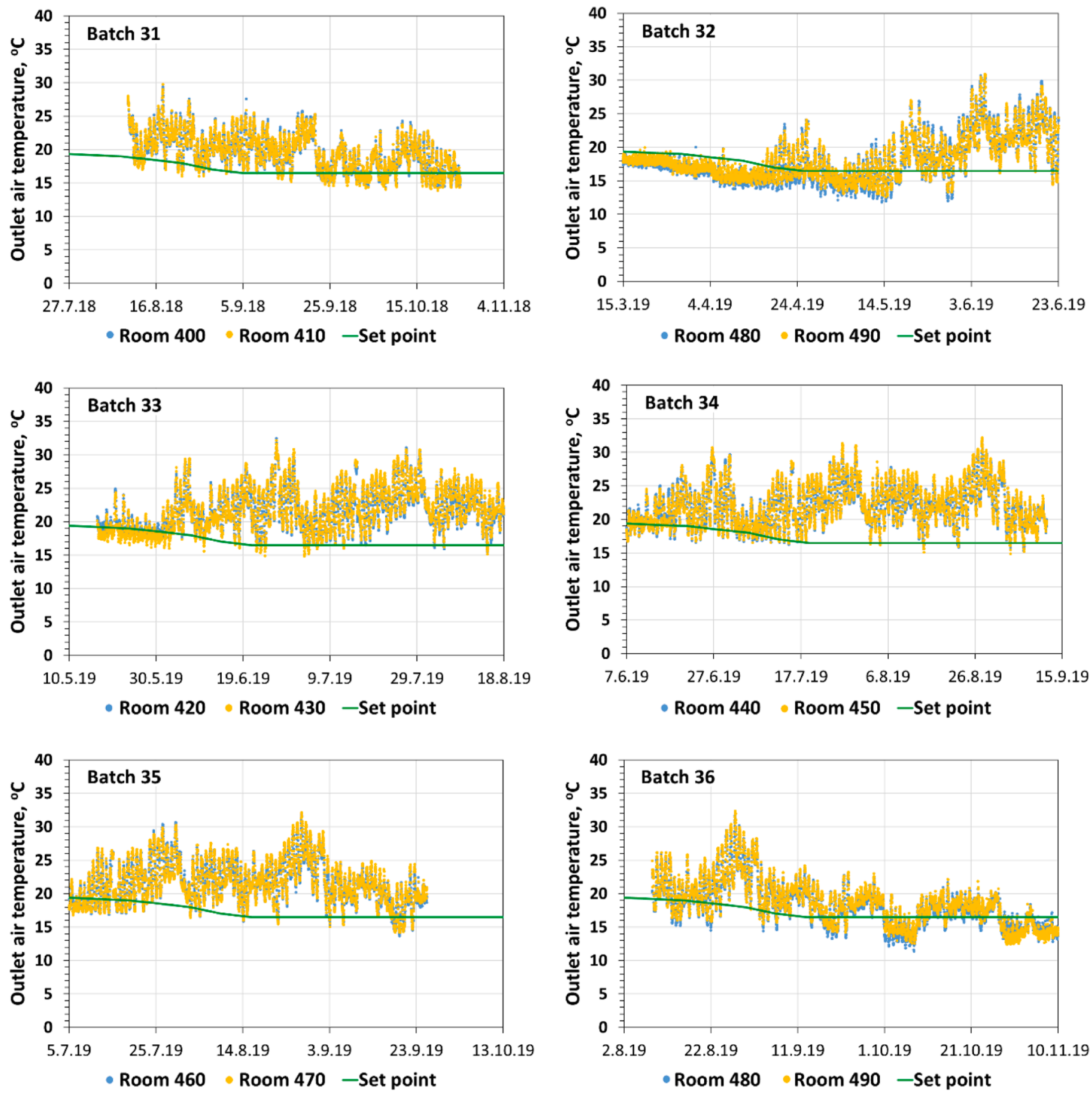

Fig. 5. Variation in indoor air temperature in the rooms (T_{out}) during six consecutive batches (31-36) starting late July in year 1 and mid-March, mid-May and beginning of June, July and August in year 2.

periods, the average inlet temperature ranged from 5.8 to 21.7 °C. Average outlet temperature was 15.1-25.2 °C and 15.6-25.6 °C for the control and IAV treatment, respectively, and average RH in outlet air was 54-84% and 51-79%, respectively. Statistical analysis showed a significant interaction between treatment and measuring occasion for T_{out} and dT. However, pairwise tests (Tukey) at significance level $p<0.05$ revealed no significant differences between treatments on the different measuring occasions. The significant interaction between treatment and measuring occasion for T_{out} and dT was explained by the fact that the averages in treatment IAV on measuring occasions M3 and M4 were slightly larger than in the control compared to measuring occasions M1 and M2. There was no significant difference between treatments regarding RH in outlet air (Table 7).

The maximum THI value during the six consecutive batches was 74, 71, 82, 83, 81 and 75, respectively. In spite of the high indoor temperature on many days, THI was only above the alert limit of 74 (Hahn et al., 2009) during 0-19.8% of the time in the six consecutive batches. Due to relatively cold nights, the diurnal variation in T_{out} resulted in large variation in THI. Hence, the average THI was only 64, 61, 68, 70, 69 and 64 during the six consecutive batches, respectively. The difference in THI between control and IAV treatment was not significant for the measuring periods (Table 7).

Due to differences in ambient temperature between the batches, the IAV treatment varied in terms of usage of increased air velocity (actual proportion of 75° opened ceiling inlets) within the IAV treatment. During batches 33-35, in the hot summer of 2019, the average proportion of time with IAV during the measuring occasions was between 0.12 and 0.81 per 24 h (Table 4). For five days during these batches, the ceiling inlets were opened 75° during the whole day and night. The proportion of time with 75° opening during batches 31, 32 and 36 was lower, since batch 32 started in early spring and batches 31 and 36 ended in late autumn.

The proportions of pigs active in the whole pen and lying in different areas of the pen during the 24-h data analysis of each measuring periods are presented in Table 5. The proportion of active pigs was 14.2-18.2%, which corresponded to 81.8-85.8% total lying. Pig activity decreased throughout the batches. There was no significant difference in activity of the pigs between treatments (Table 7). However, pigs in rooms with IAV treatment used lying area L2 more often for lying, and the slatted area less often, compared with pigs in control rooms. The proportion of lying performed in lying area L2 was significantly different ($p<0.05$) and the p-value for the difference of lying on the slatted area was 0.052. The proportion of pigs lying in area L1 and L3 was not significantly different between treatments (Table 7).

Table 4

Climate conditions in inlet and outlet air (B=batch, M=measuring occasion). T_{in}= temperature (°C) in inlet air, RH_{in}= relative humidity (%) in inlet air, T_{out}= temperature (°C) in outlet air, RH_{out}= relative humidity (%) in outlet air, pA= proportion of time with increased air velocity per 24 h.

		Inlet air						Outlet air Control						Increased air velocity						Increased air velocity		
B	M	T_{in} (°C)			RH_{in} (%)			T_{out} (°C)			RH_{out} (%)			T_{out} (°C)			RH_{out} (%)			pA		
		mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max
31	M1	16.7	11.3	23.5	92	62	100	20.8	16.4	25.0	76	65	85	20.5	16.6	24.8	79	63	90	0.19	0	0.31
	M2	10.6	0.8	15.9	84	42	100	17.3	14.6	20.3	67	50	83	17.3	14.9	20.4	70	48	85	0	0	0
	M3	11.5	3.9	19.0	95	61	100	18.2	14.0	23.8	76	63	85	18.1	14.3	24.3	78	62	88	0.08	0	0.23
	M4	9.1	1.3	18.5	95	67	100	17.1	13.9	22.8	78	65	89	17.1	14.2	22.7	78	65	89	0.02	0	0.17
32	M1	5.8	-6.0	18.7	78	44	97	16.0	14.4	19.7	64	43	77	15.6	13.8	19.8	64	41	76	0	0	0
	M2	10.6	-0.7	21.9	62	31	97	17.3	14.4	22.5	54	33	72	16.8	13.5	23.5	51	32	73	0.03	0	0.21
	M3	9.1	-1.6	17.5	74	32	97	15.9	12.6	21.0	64	40	79	15.7	11.8	21.2	63	39	81	0.02	0	0.06
	M4	12.5	4.0	19.6	82	37	97	18.1	13.3	22.8	71	47	86	18.1	12.0	23.8	68	37	84	0.17	0	0.27
33	M1	17.9	8.9	30.0	80	49	97	20.9	17.5	29.0	71	56	84	20.8	16.0	29.4	73	56	88	0.18	0	0.44
	M2	18.4	9.9	26.8	79	45	97	21.8	17.3	26.4	73	52	88	21.9	16.1	26.9	72	51	89	0.35	0.12	0.48
	M3	15.4	9.5	24.4	83	36	97	19.7	16.3	24.7	77	48	91	20.1	15.9	25.6	70	42	85	0.34	0.08	0.50
34	M1	18.3	7.5	28.0	75	34	97	21.6	16.6	27.7	65	32	88	21.7	16.7	28.0	65	36	82	0.17	0	0.42
	M2	18.4	9.0	27.7	76	36	97	21.5	16.6	26.7	65	44	86	21.7	16.6	27.3	66	41	79	0.35	0.19	0.46
	M3	18.2	10.0	28.1	84	42	97	21.9	16.3	27.8	80	58	93	22.1	16.2	28.6	76	58	93	0.56	0.25	0.83
	M4	21.7	11.4	32.7	80	36	97	25.2	18.5	31.8	79	60	94	25.6	18.8	32.2	75	56	96	0.81	0.62	1.00
35	M1	19.6	12.0	27.5	81	43	97	22.1	17.4	27.4	64	46	73	22.1	17.3	28.0	74	45	91	0.19	0	0.33
	M2	18.1	7.6	27.3	82	47	97	22.0	15.9	26.8	58	53	69	22.2	16.0	27.3	71	50	86	0.33	0.10	0.46
	M3	18.2	7.8	27.6	86	47	97	22.7	15.3	28.5	84	69	96	23.1	15.1	29.3	74	51	90	0.52	0.15	0.83
	M4	13.0	4.1	20.6	82	44	97	19.3	14.3	24.1	80	68	96	19.6	14.2	24.8	69	53	85	0.12	0	0.33
36	M1	17.3	9.4	25.0	88	52	97	19.9	14.5	25.0	79	53	93	20.3	16.0	25.8	76	53	89	0.02	0	0.10
	M2	15.0	8.4	21.3	90	61	97	19.2	14.6	23.2	79	60	92	19.6	15.7	23.9	75	58	87	0.01	0	0.04
	M3	8.4	1.9	15.9	87	55	97	15.1	11.9	19.7	76	56	88	15.9	13.0	19.8	74	63	89	0	0	0
	M4	11.8	7.8	17.2	96	67	97	17.5	14.5	21.7	81	67	88	18.0	15.0	22.2	79	66	90	0	0	0.02

Table 5
Activity of the pigs (%) and occupation area when lying (% of total lying), (mean ± SE), M1-M4= measuring occasions.

	Control	Increased air velocity
No. of batches	6	6
No. of focal pens	12	12
No. of measurements	23	23
Active, whole pen		
- M1	18.0 ± 1.2	18.2 ± 2.8
- M2	17.9 ± 2.3	15.8 ± 2.7
- M3	15.1 ± 1.7	16.2 ± 2.5
- M4	16.1 ± 2.4	14.2 ± 1.9
Lying L1		
- M1	38.5 ± 3.6	47.3 ± 7.7
- M2	26.5 ± 3.6	32.2 ± 3.7
- M3	25.6 ± 2.8	29.0 ± 3.2
- M4	18.3 ± 4.5	29.0 ± 3.9
Lying L2		
- M1	26.7 ± 1.6	26.7 ± 0.8
- M2	21.1 ± 5.0	27.2 ± 3.1
- M3	24.4 ± 4.2	27.2 ± 1.6
- M4	16.3 ± 4.0	23.3 ± 1.9
Lying L3		
- M1	24.5 ± 2.1	15.9 ± 3.4
- M2	23.6 ± 4.2	24.8 ± 2.4
- M3	26.8 ± 3.8	27.8 ± 0.5
- M4	29.5 ± 1.2	23.9 ± 1.3
Lying slats		
- M1	10.3 ± 2.0	10.1 ± 5.5
- M2	28.7 ± 11.2	15.8 ± 5.2
- M3	23.2 ± 9.5	15.9 ± 4.7
- M4	35.9 ± 8.5	23.9 ± 6.0

The results of pen fouling scoring showed that fouling increased throughout the measuring periods in both the control and IAV rooms (Fig. 6). On lying areas L1-L3, the fouling score increased from 0.6-0.8 to 1.7-1.8 in the control pens and from 0.4-0.7 to 1.2-1.7 in the IAV pens (Fig. 6). There was a significant difference ($p<0.05$) in pen fouling in the lying area between the control and IAV rooms (Table 7). Furthermore, the fouling score for the slatted area was at the same level (1.5-1.7) for the IAV treatment and the control throughout the batches (Fig. 6).

The average CO_2 concentration in inlet air (CO_{2in}) during the measuring periods ranged between 385 and 471 ppm (Table 6), with a minimum value of 363 ppm and a maximum value of 690 ppm. The average CO_2 concentration in outlet air from control and IAV rooms (CO_{2out}) during the measurement periods was 808-1540 ppm and 850-1484 ppm, respectively. Maximum CO_{2out} was 3036 ppm. The difference in CO_2 concentration between treatments was not significant (Table 7). The CO_2 concentrations and calculated heat production from the pigs resulted in an average VR of 58.7 and 60.8 m^3 h^{-1} pig^{-1} for control and IAV rooms, respectively. There was no significant difference in VR between the control and IAV rooms (Table 7).

The NH_3 concentration in inlet air (NH_{3in}) ranged from 0.5 to 3.8 ppm during the measuring periods and the average was 1.0-2.8 ppm (Table 6). In the outlet air from control rooms and IAV rooms, average NH_3 concentration (NH_{3out}) was 3.9-14.4 and 3.7-11.0 ppm, respectively (Table 6). Statistical analysis showed a significant interaction between treatment and measuring occasion. Pairwise tests (Tukey) at significance level $p<0.05$ revealed a significant difference between treatments on measuring occasion M4 (Table 7).

Mean NH_3 emissions during the measuring periods increased from 3.3 to 8.4 and from 3.4 to 6.6 g pig^{-1} day^{-1} for control and IAV rooms, respectively. For NH_3 emissions, there was also a significant interaction between treatment and measuring occasion. Pairwise testing of the combinations revealed a significant difference between control and IAV rooms on measuring occasion M4 (Table 7).

4. Discussion

Our results showed no effect of treatment IAV on the overall climate parameters in the room as measured in the outlet air. Thus, there were no significant differences for T_{out}, RH_{out}, and consequently THI, between the IAV and control treatments affecting the interpretation of the results. Nor on the pigs' activity did IAV have a significant effect. This could be interpreted as a consequence of an equivalent indoor temperature and RH. However, an increase in heat loss due to increased air velocity in the lying area (IAV) could be expected to have an effect on the activity. The lack of effect might be because the IAV treatment was not enough to cool the pigs to a more significant extent. Probably, they just experienced a slight improvement in their thermal environment.

In general, animal activity decreased slightly during the individual batches, which was expected because of the increasing size of the pigs. Heavier pigs are less active, especially at high ambient temperatures (Spoolder et al., 2012). The activity levels corresponded well to previous findings in the same pig house (Jeppsson et al., 2021). However, the activity level was somewhat lower than in growing/finishing pigs in

Control

	M1		M2		M3		M4	
L1	0.7±0.1	0.7±0.1	1.2±0.2	1.4±0.1	1.7±0.2	1.7±0.2	1.7±0.2	1.7±0.2
L2	0.6±0.1	0.6±0.1	1.1±0.2	1.2±0.1	1.6±0.2	1.7±0.2	1.8±0.2	1.7±0.2
L3	0.7±0.1	0.8±0.1	1.2±0.1	1.3±0.2	1.7±0.2	1.7±0.2	1.8±0.1	1.8±0.2
S	1.5±0.1	1.6±0.1	1.6±0.1	1.5±0.1	1.6±0.1	1.6±0.1	1.5±0.1	1.5±0.1

Increased air velocity

L1	0.5±0.1	0.4±0.1	0.8±0.1	0.8±0.1	1.1±0.2	1.1±0.2	1.2±0.1	1.2±0.1
L2	0.4±0.1	0.4±0.1	0.7±0.1	0.8±0.1	1.1±0.2	1.2±0.2	1.3±0.2	1.3±0.2
L3	0.7±0.1	0.6±0.1	0.9±0.1	1.0±0.1	1.3±0.2	1.3±0.2	1.6±0.2	1.7±0.2
S	1.6±0.1	1.7±0.1	1.6±0.1	1.5±0.1	1.7±0.1	1.6±0.1	1.6±0.1	1.6±0.1

Fig. 6. Pen fouling results for rooms in the control and increased air velocity treatments on measuring occasions M1 to M4 (mean ± SE.). A seven-point score was used: 0 (=no fouling), 0.5, 1, 1.5, 2, 2.5 and 3 (heaviest fouling). Darker blue indicates a more fouled area.

Table 6
Gas concentrations in inlet and outlet air (B=batch, M=measuring occasion). CO_{2in}=CO_2-concentration in inlet air, NH_{3in}=NH_3-concentration in inlet air, CO_{2out}=CO_2-concentration in outlet air, NH_{3out}=NH_3-concentration in outlet air.

		Inlet air						Outlet air Control						Increased air velocity					
B	M	CO_{2in} (ppm)			NH_{3in} (ppm)			CO_{2out} (ppm)			NH_{3out} (ppm)			CO_{2out} (ppm)			NH_{3out} (ppm)		
		mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max
31	M1	403	381	561	1.5	1.0	2.1	920	746	1271	5.0	3.6	8.5	884	750	1082	4.9	3.3	9.2
	M2	385	363	402	1.4	0.8	2.5	1142	738	2369	7.3	4.1	13.3	1119	756	2341	6.7	3.7	14.3
	M3	398	371	486	1.8	1.0	3.0	1223	885	1884	8.8	6.1	14.9	1189	869	1874	8.0	5.7	14.7
	M4	416	384	562	1.9	1.0	3.0	1390	991	2262	12.0	8.4	19.1	1329	976	1917	9.7	7.0	17.2
32	M1	413	388	502	1.0	0.7	1.3	1540	726	3036	5.3	2.7	8.1	1484	736	2867	4.8	2.5	7.3
	M2	422	399	482	1.0	0.6	1.3	1194	739	2396	5.0	3.0	8.9	1131	758	2273	4.3	2.6	7.8
	M3	443	410	558	1.2	0.7	2.0	1286	830	2252	6.2	3.6	10.0	1249	783	2129	5.6	3.7	9.7
	M4	446	420	502	1.9	1.1	2.8	1275	1013	1617	9.2	6.5	13.0	1214	995	1564	7.1	5.4	11.0
33	M1	437	404	558	1.3	0.8	1.8	1006	815	1599	4.9	3.6	7.7	943	723	1409	4.4	3.3	6.7
	M2	449	406	659	1.6	1.0	2.2	1073	829	1370	6.3	4.3	10.4	1022	822	1273	6.1	4.0	9.6
	M3	435	417	485	1.8	1.2	2.6	1129	941	1479	8.8	6.8	13.0	1037	843	1455	6.6	5.1	9.4
34	M1	453	410	636	1.4	0.5	2.5	993	690	1858	5.3	3.2	9.4	1038	719	2044	5.5	3.4	9.7
	M2	453	414	594	1.6	0.9	2.3	1031	791	1511	5.8	4.2	8.9	1038	868	1646	5.7	4.1	7.9
	M3	462	414	637	2.0	1.3	3.2	1075	809	1412	7.5	5.5	13.4	1083	813	1487	6.9	4.9	11.1
	M4	457	424	638	2.8	1.7	3.8	1245	793	1765	14.4	8.1	24.2	1254	861	1956	11.0	5.8	23.0
35	M1	450	416	598	1.6	0.8	2.4	914	794	1239	3.9	2.9	5.7	889	7 58	1114	4.3	3.1	6.3
	M2	444	416	558	1.5	0.8	2.3	1138	938	1472	6.0	3.9	11.2	1072	821	1413	5.3	3.8	10.1
	M3	471	427	690	2.4	1.2	3.8	1373	981	1824	12.9	9.2	20.8	1290	953	1730	8.0	5.6	15.9
	M4	439	424	467	2.0	1.4	3.0	1445	1150	1925	13.8	9.5	22.4	1348	1115	1726	9.5	7.1	14.1
36	M1	450	428	617	1.4	0.8	2.0	808	628	1026	4.0	2.9	8.8	850	648	1157	3.7	2.8	7.6
	M2	453	425	580	1.6	1.0	2.4	1034	838	1318	7.4	5.8	11.9	1105	893	1418	6.6	5.2	9.7
	M3	437	416	487	1.3	0.8	2.2	1248	949	1797	7.7	5.7	12.4	1364	1036	1991	8.5	6.3	12.3
	M4	445	430	483	1.7	1.1	2.6	1185	951	1735	8.7	6.4	16.9	1236	984	1800	8.5	6.4	13.1

Table 7
Indoor climate parameters, activity, pig occupation in the pen when lying, pen fouling, CO_2 concentration in outlet air, ventilation rate (VR), NH_3 concentration in outlet air, and NH_3 emissions (E_{NH3}) (mean ± SE). Effect of treatment (Tr) (control/IAV), measuring occasion (M) (M1-M4) and interaction Tr x M.

	Control	IAV	p-value		
			Tr	M	Tr x M
No. of batches	6	6			
No. of measurements	23	23			
T_{out}, °C	19.6 ± 0.5	19.7 ± 0.6	0.330	0.684	0.001
dT, °C (out-in)	5.0 ± 0.4	5.1 ± 0.4	0.330	0.327	0.001
RH_{out}, %	72.1 ± 1.7	71.2 ± 1.4	0.495	0.005	0.094
THI	65.8 ± 0.8	65.9 ± 0.8	0.515	0.818	0.906
Activity, %					
- Standing, sitting, eating	16.8 ± 0.9	16.2 ± 1.2	0.759	0.176	0.454
- Lying	83.2 ± 0.9	83.8 ± 1.2	0.759	0.176	0.454
Occupation area, lying, %					
- Lying area, L1	27.6 ± 2.3	34.6 ± 2.9	0.141	0.000	0.654
- Lying area, L2	22.4 ± 2.0	26.2 ± 1.0	0.011	0.232	0.318
- Lying area, L3	25.9 ± 1.6	23.1 ± 1.4	0.118	0.105	0.172
- Slatted area	24.0 ± 4.4	16.1 ± 2.7	0.052	0.059	0.645
Fouling of pen, (scale 0-3)					
- Lying area 1+2+3	1.3 ± 0.1	1.0 ± 0.1	0.029	0.000	0.361
CO_{2out}, ppm	1159 ± 38	1138 ± 35	0.337	0.032	0.319
VR, $m^3\ h^{-1}\ pig^{-1}$	58.7 ± 2.1	60.8 ± 2.2	0.271	0.462	0.702
NH_{3out}, ppm	7.7 ± 0.6	6.6 ± 0.4	0.013	0.000	0.022
- M1	4.7 ± 0.3	4.6 ± 0.2	1.000		
- M2	6.3 ± 0.4	5.8 ± 0.4	0.972		
- M3	8.6 ± 0.9	7.3 ± 0.4	0.190		
- M4	11.6 ± 1.2	9.1 ± 0.7	0.009		
E_{NH3}, g $pig^{-1}\ day^{-1}$	5.8 ± 0.5	5.1 ± 0.3	0.001	0.000	0.019
- M1	3.3 ± 0.4	3.4 ± 0.4	1.000		
- M2	5.1 ± 0.5	4.9 ± 0.4	0.998		
- M3	6.7 ± 0.5	5.6 ± 0.4	0.167		
- M4	8.4 ± 0.6	6.6 ± 0.5	0.009		

other investigations (Botermans et al., 2000; Street and Gonyou, 2008; Zoric et al., 2015). This was probably a consequence of our study being performed in warm seasonal conditions.

Even though no differences were found between IAV and control in animal activity, a significant difference was observed in choice of pen area when the pigs were lying. In the IAV treatment, the pigs were observed lying more in lying areas L1 and L2 and less in area L3 and in the slatted area (S). The difference in lying on area L2 was significant, while the difference in lying on the slatted area was close to significant (p=0.052). When the ceiling inlets in the IAV treatment were in the 75° position, the inlet air was directed directly down on the lying area, hitting the central part of the lying area midway between L1 and L2. The increased air velocity on this area also increased the possibility of heat loss, which might explain the increased lying in pen area L1 and L2 in that treatment.

The level of pen fouling in the control treatment corresponded well with previous findings for growing/finishing pigs in the same house (Jeppsson et al., 2021). Pen fouling increased during the batches for both treatments but was in total significantly worse in the control treatment than in the IAV treatment. On the first measuring occasion (M1), 3-4 weeks from introduction, there was no difference between the treatments in pen fouling in either the lying or the slatted area. From introduction to M1, the pigs weighed 30-45 kg and at this size/weight they can withstand higher ambient temperature than pigs with higher body weight (Aarnink et al., 2006; Hillmann et al., 2004; Savary et al., 2009). The settings for the IAV treatment was also high during this period, between 22-27°C in T_{in} as a condition for opening to 75°. Hence, the IAV treatment was only in operation for a limited time in this period of growing. Pen fouling differed significantly between IAV and control for measuring occasions M2, M3 and M4. The solid lying area was generally cleaner in the pens in the IAV treatment, but there were still individual pens in the rooms with IAV in which the lying areas were completely fouled. This could be because the heat loss due to forced convection was insufficient and because, in some pens, other factors such as social space (Jeppsson et al., 2021; Spoolder et al., 2012) caused the change in behaviour. However, the main explanation for the significant difference in pen fouling was probably the increased air velocity in the lying area in the IAV treatment.

It is not entirely clear whether the effect of IAV on pen fouling was an indirect consequence of where the pigs chose to lie, or a more direct effect of where the pigs chose to urinate and/or defecate. The change in choice of lying area was small and barely significant. However, the less pen fouling in the IAV treatment compared to control was clearly significant and was dependent on the proportion of time with the ceiling inlets 75° opened. Fig. 7 show the difference in pen fouling (average of scoring from 16 pens on the day of the visit) between the treatments and the proportion of time with IAV (average from 5-6 days) for measuring occasions M3 and M4. Measuring occasions with a high proportion of time with 75° opened ceiling inlets had a clear effect on pen fouling and even a limited time with IAV, 10% of the day, appeared to have an effect.

Instead of the less fouled pens in the IAV treatment being due to a change in lying area of the pigs, there are alternative explanations. For example, the air velocity in the IAV treatment was perhaps sufficient for the pigs to feel acceptably comfortable, while the pigs in the control treatment needed to cool down by wallowing in their urine and faeces on the solid floor. Manual checks on the video recordings revealed dirtier pigs in the control treatment than in the IAV treatment. Since dirty pigs were included in the protocol for pen hygiene scoring, these dirtier pigs also contributed to the poorer pen hygiene scores in the control treatment. In this study, it was not possible to determine whether the pigs deliberately urinated and defecated on the solid floors in order to wallow, but this explanation has been suggested by others (Hillmann et al., 2004; Huynh et al., 2005a; Nannoni et al., 2020; Webb et al., 2014). The overall conclusion from this study was that increased air velocity had an effect on pen fouling. Therefore, readjusting the ceiling inlets and increasing the air velocity in the lying area is suggested as a measure of reducing pen fouling in buildings for growing/finishing pigs in Sweden, without large investment costs (Pexas et al., 2021). The potential for utilising forced convection to create an option for the pigs to increase their heat loss needs to be further investigated.

Ammonia emissions increased during the batches for both treatments, but were on average lower for the IAV treatment than the control. Mean ammonia emission rate for the six batches was 5.8 g pig^{-1} day^{-1} and 5.1 g pig^{-1} day^{-1} for the control and IAV treatment, respectively. These levels correspond well to previous findings for growing/finishing pigs in the same house (Jeppsson et al., 2021). In other investigations, Aarnink et al., (1996) reported 5.7 and 6.4 g pig^{-1} day^{-1} for an experimental building with 25% and 50% slatted floor, respectively, above a slurry pit with vacuum removal system, while Ngwabie et al., (2011) reported values between 4.32 and 4.80 g pig^{-1} day^{-1} for an experimental building with 35% slatted area and daily manure removal by scrapers. The average ammonia emissions from the IAV treatment were only significantly lower than those in the control on the last measuring occasions M4. The most likely explanation is that the difference in ammonia emissions was due to the difference in pen fouling between the two treatments. Lower ammonia emissions from a cleaner lying area could be explained by smaller emitting area (Ni et al., 1999) and better drainage of urine compared with a mix of urine and faeces on a fouled area. Another possible cause could be the difference in airflow patterns between the treatments. When the ceiling inlets were 35° opened the path of the inlet air was across the slatted area (see Fig. 3), which may have enhanced air exchange through the slatted floor (Ye et al., 2009). Alternatively, the increased air velocity in the lying area in the IAV treatment may have increased the ammonia emissions from fouled areas of the pens. However, the difference in ammonia emissions between treatments was most likely due to the reduced pen fouling in treatment IAV.

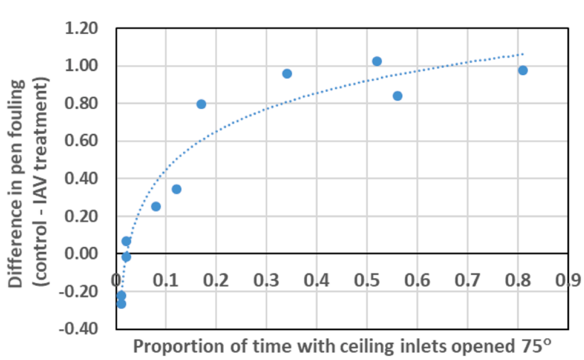

Fig. 7. Difference in pen fouling scores, for measuring occasions M3 and M4, between the control and the increased air velocity (IAV) treatment as a function of proportion of time with ceiling inlets opened 75°.

Compared to an investigation with showers in the slatted area performed in the same growing/finishing house and with the same experimental design and measurements (Jeppsson et al., 2021), the improvement in pen hygiene and the reduction in ammonia emission was inferior with IAV treatment. The ammonia emission was significantly reduced with IAV-treatment by 21% during measuring occasion M4 and the reduction for an entire summer batch could be estimated to 12%. With improved design and usage of increased air velocity in the lying area, the effect of the measure would probably be enhanced.

When the ceiling inlets switched from 35 to 75° opening, the increased air velocity (AV) at the point where the inlet air reached the lying area, decreased the minimum effective temperature for the 30 kg pigs, by around 5 °C, from 26.5 (AV= 0.50 m/s) to 21.5 °C (AV=1.04 m/s), calculated according to Bjerg et al. (2018). For the 80 kg pigs the change of the ceiling inlets meant a decrease of the minimum effective temperature by about 9 °C, from 14.5 to 5.5 °C. At 30 °C temperature in the inlet air, the minimum effective temperature on the lying area was around 28 °C in the control pens and 23 °C in the pens with IAV treatment. According to Hillman et al. (2004), the upper thermal tolerance level for pigs in a partly slatted pen with lightly bedded lying area is 21 °C for growing pigs weighing about 30 kg and 17 °C for pigs weighing more than 50 kg. Hence, despite the IAV treatment, the ambient (effective) temperature for the pigs sometimes exceeded the upper thermal tolerance level. To keep the effective temperature below the upper tolerance level according to Hillmann et al. (2004), the air velocity should be about 1.2 m s^{-1} for pigs weighing about 30 kg and about 1.7 m s^{-1} for pigs weighing more than 50 kg at an inlet air temperature of 30 °C. Furthermore, the minimum effective temperature was only achieved in a small zone of the lying area. From the area where the inlet air reaches the lying area and out into the corners of the lying area, effective temperature probably increased as the air velocity decreased. Pigs lying or standing on the lying area also affect the airflow pattern (Smith et al., 1999). However, a gradient in effective temperature on the lying area could be favourable, since different sized pigs and individuals in the pen could prefer different effective temperatures.

Thermal gradient within pig pens as an important factor affecting pig behaviour and the risk of pen fouling is discussed by Larsen et al. (2018). Airflow patterns and air velocity in the room are important in creating temperature gradients within the microenvironment of pigs in confined housing systems (Hacker et al., 1994). In the present study, the gradient in effective temperature changed from a minimum in area L3 in the control treatment to a minimum at the transition between L1/L2 in the IAV treatment. The direction of the gradient in effective temperature might be important, especially in narrow pens with the slatted area in one end, as used in this investigation. In the control rooms, the pigs were often observed lying packed in area L3, with the highest air velocity, while the pigs in IAV rooms were more concentrated in areas L1 and L2.

The control and set-point of increased air velocity are crucial in pig production, especially for the small pigs just introduced to the house or in conditions with large diurnal variation in outdoor temperatures. To avoid problems with draught for the smaller pigs, when adjusting the inlets and increasing the air velocity, a safety marginal could be included to the settings as was performed in this study. Cold and draughty lying areas for the pigs could change their choice of pen area for lying to a place with less heat loss, e.g. the slatted area, with a fouled lying area as a possible outcome (Randall et al., 1983). Furthermore, increased air velocity resulting in environmental conditions below thermoneutral can impair pig performance (Stolpe, 1986), while draughts increase total activity of the pigs, including explorative behaviour on pen mates (earbiting and tailbiting) and agonistic behaviour (Scheepens et al., 1991a; Schrøder-Petersen and Simonsen, 2001). Draughts can also increase the incidence of pig diseases such as coughing, diarrhoea and pneumonia (Scheepens et al., 1991b) and disturb the immune system (Scheepens et al., 1994; Randall et al., 1983).

5. Conclusions

This study examined the effects of increased air velocity in summer in the lying area of partly slatted pens in a commercial growing/finishing house in terms of animal choice of lying area, pen fouling and ammonia emissions. Comparative measurements were performed during six batches in two parallel rooms with 16 pens containing 9-14 pigs.

With increased air velocity on the lying area during periods with high ambient temperatures, it was found that the pigs spent significantly more time lying in the part of lying area with the highest air velocity, and less time lying on the slatted area. The problem of pen fouling in the lying area of partly slatted pens for growing/finishing pigs was found to be significantly reduced with increased air velocity in the lying area. Another positive effect of increased air velocity in the lying area was the reduction of NH_3 emissions by 21%, from 8.4 to 6.6 g pig^{-1} day^{-1} during the late growing period (M4) compared with the control.

CRediT authorship contribution statement

Knut-Håkan Jeppsson: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Anne-Charlotte Olsson:** Conceptualization, Formal analysis, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. **Abozar Nasirahmadi:** Data curation, Formal analysis, Methodology, Resources, Software, Validation, Visualization, Writing – review & editing.

Declaration of Competing Interest

Not applicable

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