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The long and short of showers: Effects of shower duration on behaviour, thermal comfort and soiling of organic growing-finishing pigs with access to outdoor runs

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ABSTRACT

Showers can be used in the outdoor run to improve thermal comfort and provide environmental enrichment for growing-finishing pigs. Showers may also reduce ammonia emissions by preventing excessive soiling in summer. Few studies have addressed water cooling measures for pigs in systems with concrete outdoor runs, and none have considered the operation of showers outdoors. We therefore investigated the effect of showers in the outdoor run on pigs' use of different pen areas, thermal comfort, and soiling of the pigs and the pen in multi-farm experiments in Austria and Switzerland. In a pilot experiment on three organic farms involving a total of 428 growing-finishing pigs in 15 groups with two to three assessment days each, we compared groups with access to showers to groups without showers. A subsequent larger trial (referred to as SHORT/LONG experiment) compared two different shower programmes (SHORT = 10-minutes; LONG = 30-minutes shower activation per hour), comprising a total of 472 pigs in 20 groups on three farms with six to seven assessment days each. The treatments SHORT and LONG were alternately applied with at least three replicates per farm. We assessed the pigs' behaviour (activity, lying posture), respiratory rate and cleanliness as well as soiling of the pens on a group level. The pilot experiment revealed increased activity ($p = 0.03$) and reduced lateral lying ($p = 0.08$) in pigs with access to showers compared to pigs without, which supports the potential of showers to improve thermal comfort. In the SHORT/LONG experiment, we found interactions between treatment and outdoor temperature: The proportion of pigs under the shower ($p < 0.01$), lateral lying in the shower area ($p = 0.01$) and respiratory rate ($p < 0.01$) increased more with rising temperatures in treatment LONG than in SHORT. In both treatments, high temperatures increased the use of the outdoor run ($p = 0.02$) and the shower area ($p < 0.001$) as well as the soiling of pigs ($p < 0.01$), while at the same time reducing activity in the shower area ($p = 0.02$). Interestingly, fewer pigs were present in the shower area during and at the end of shower activation compared to the time before ($p < 0.001$), indicating avoidance of the water spray. This casts doubt on whether showers, apart from reducing heat stress, provide appropriate means to allow all aspects of species-specific thermoregulation. Our results suggest complex interactions between outdoor temperature, shower duration, pig behaviour, and soiling (with potential impact on ammonia emission), which require further investigation especially in open-air settings.

1. Introduction

Pigs are susceptible to heat stress since they are barely able to sweat (Ingram, 1965). Their predominant strategy to cope with high temperatures is to adapt their behaviour by seeking shade (Blackshaw and Blackshaw, 1994), lying more laterally and without body contact on cool surfaces (Hillmann et al., 2004; Huynh et al., 2005) and wallowing in mud or other wet areas (Bracke, 2011; Huynh et al., 2005). When these behavioural adaptions are insufficient to regulate body temperature, pigs' respiratory rate increases (Scriba and Wechsler, 2021) and feed

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intake decreases, which can cause performance losses estimated at 4% less weight gain and 1% higher feed conversion rate per 1 °C ambient temperature exceeding the thermoneutral range in finishing pigs (Hörtenhuber et al., 2020). Yet, heat stress is above all an animal welfare issue that, given globally rising temperatures, is becoming increasingly important for pig husbandry, including in systems with open-air access. European organic legislation takes the thermal and behavioural needs of pigs into account by requiring means of regulating body temperature in open-air areas (including concrete outdoor runs) (Commission implementing regulation (EU) 2020/464; European Commission, 2020). One possibility to meet this requirement is to provide mud wallows that allow for highly effective evaporative cooling (Ingram, 1965) and additionally prevent pigs from sunburn and ectoparasites (Bracke, 2011). However, in systems with concrete outdoor runs, mud wallows or water baths are hardly feasible. They can become easily soiled (Huynh et al., 2006; Olsen et al., 2001), causing either a hygienic risk or high labour and water demand through necessary frequent cleanings. Showers or water sprinklers that wet the pigs' skin provide a feasible alternative and are proven effective in alleviating heat stress and reducing associated performance losses (Culver et al., 1960; Hsia et al., 1974; Huynh et al., 2006).

Besides animal welfare, the protection of the environment is an important principle of organic production (Regulation (EU) 2018/848; European Parliament, Council of the European Union, 2018). In housing systems with concrete outdoor runs, ammonia emissions from the soiled surface in the outdoor run, where pigs usually defaecate and urinate, represent the most important environmental impact (Wimmler et al., 2022). High temperatures can further increase soiling as pigs shift their lying places to the elimination area and increasingly lie or wallow in their own excrements (Aarnink et al., 2006; Huynh et al., 2005). In conventional indoor pig production, provision of showers reduced soiling and ammonia emissions, probably due to a combination of improved separation of lying and elimination areas and a dilution of the slurry with water from the showers (Jeppsson et al., 2021).

Providing showers in the outdoor run for organic growing-finishing pigs should therefore not only improve pigs' thermal comfort and enrich the housing environment but also prevent excessive soiling during summer. However, only few studies on alternative production systems where pigs have access to concrete outdoor runs have addressed water cooling measures (Huynh et al., 2006; Olsen et al., 2001) with none of them investigating the role of outdoor showers. Scientific studies on showers for pigs have been carried out mainly in standardised experimental set-ups under intensive production conditions with a focus on growth performance and physiological heat stress indicators (Culver et al., 1960; Hsia et al., 1974; Vajrabukka et al., 1987). Such studies applied indoor showers with a maximum duration of two minutes at various intervals between 20 and 90 min (Hsia et al., 1974; Huynh et al., 2006; Jeppsson et al., 2021; Vajrabukka et al., 1987). However, these studies presumably do not reflect the situation of alternative housing systems such as organic, where open-air access makes climatic conditions more variable and difficult to control. Additionally, pigs are free to choose whether or not to use showers. Providing showers in the outdoor run might therefore require shower programmes with longer activation time compared to existing indoor studies, which is already common on commercial organic farms but was so far not investigated. Additionally, to increase external validity, a multi-farm approach reflecting the diverse conditions of commercial organic pig production is preferable (Schodl et al., 2021).

Therefore, the present study aimed to investigate how the provision and different activation duration of showers in the outdoor run of three commercial organic pig farms affected 1) pigs' use of the outdoor run and the shower area; 2) pigs' thermal comfort determined by their behaviour (activity, lying posture) and respiratory rate; 3) soiling of the pigs and the pen area with manure (i.e. faeces and urine).

2. Animals, materials and methods

Experiments were conducted in Austria (**AT**) and Switzerland (**CH**) on commercial organic growing-finishing pig farms in summer 2019 (with/without access to showers; pilot) and 2020 (different shower duration; SHORT/LONG experiment).

2.1. Farms and animals

In total, two Austrian (AT01, AT02) and two Swiss (CH01, CH02) farms participated, of which CH02 was only included in the pilot experiment and AT02 only in the SHORT/LONG experiment. All farms were certified organic, in AT according to the Regulation (EU) 2018/848 (European Parliament, Council of the European Union, 2018), in CH according to the Bio Suisse (2020) standards. The pilot experiment included a total of 428 growing-finishing pigs in 15 groups on three farms; the SHORT/LONG experiment 472 pigs in 20 groups on three farms (Table 1). All farms used commercial cross breeds (sow: Large White or Landrace*Large White; boar: Large White, Piétrain and to a small extent Duroc). The pigs were kept in mixed-sex groups (females and castrated males) with farm-specific group sizes (farm medians of 7 – 41 pigs/pen; Table 1) in a weight range of 30–110 kg (CH) or 30–140 kg (AT) body weight (**BW**). Each farm had four to seven identical pens with partially roofed outdoor runs (Fig. 1, Table 1). The farms AT02 and CH01 were open barn systems with an indoor area consisting of a protected lying area covered with a lid, while the indoor areas of AT01 and CH02 were solid buildings. Straw bedding was provided in the indoor area, except for AT01 providing it only in the roofed part of the outdoor run. Feeders were positioned indoors except in farm CH01, where feeders were in the roofed part of the outdoor run.

Showers were installed in the non-roofed part of the outdoor run at a height between 1.5 m (CH02) and approximately 4 m (AT01) above solid concrete floor, defined as shower area (photographs provided in Fig. S1 of the Supplementary material). However, the area directly under the showers (Fig. 1) could only be estimated due to outdoor conditions (e.g. wind). Water drainage was provided either through a drainage channel (CH01, AT01) or through a slope towards the manure slot of the adjacent elevated slatted floor area (AT02, CH02). The showers consisted of nozzles that sprayed the water at low water pressure in fine droplets (mist-like), but still wetted the pigs' skin. Only AT02 provided showers with larger, more rain-like droplets. Nipple drinkers were also provided outdoors. Pens were cleaned every week on AT farms and every day in the morning before assessment on CH farms. Further farm characteristics and details on the showers are provided in Table 1, Figs. 1 and S1 in the Supplementary material.

2.2. Experimental design

In both experiments, showers were activated on days with a forecasted daily maximum temperature above 22 °C and no rain. This corresponds to the temperature at which first physiological reactions to heat occur in growing-finishing pigs (Huynh et al., 2007). Data collection always took place when showers had already run at least on the two preceding days (i.e. on the third day of consecutive treatment application). The shower activation schedule (intervals and duration) was controlled automatically through garden irrigation computers (GARDENA© Water Control Master, GARDENA GmbH, Ulm, Germany). In case of cool (< 22 °C) and/or rainy weather, farmers could manually pause the programme.

2.2.1. Pilot experiment

The pilot experiment was set up to compare groups of pigs in pens with shower (**SHOWER**) to control groups without shower (**CON**) in parallel. Half of the groups were assigned to SHOWER and the other half to CON throughout the experimental period. SHOWER and CON groups were balanced regarding weight (visual estimate of mean weight of the

Table 1
Housing characteristics of farms involved in the pilot and the SHORT/LONG experiment for farms AT01, AT02 (Austria), CH01 and CH02 (Switzerland).

Farms	AT01		AT02	CH01		CH02
Involvement in experiment	pilot	SHORT/LONG	SHORT/LONG	pilot	SHORT/LONG	pilot
Location	Upper Austria, AT		Styria, AT	Bern, CH		Thurgau, CH
Experimental period	Aug. – Sept. 2019	July – Aug. 2020	July – Sept. 2020	Aug. 2019	June – Aug. 2020	Aug. – Sept. 2019
Number of assessment days	3	8	6	2	6	3
Total number of pigs involved	201	312	51	90	109	137
Number of groups	6	8	6	5	6	4
Median number of pigs per group [min. – max.][a]	33 [28 – 45]	41 [22 – 52]	7 [3 – 12]	20 [7 – 20]	18 [4 – 21]	36.5 [7 – 42]
Median space allowance in m^2/pig [min. – max.][a]	2.76 [1.90 – 4.02]	2.32 [1.89 – 4.28]	3.53 [2.04 – 8.89]	1.58 [1.58 – 4.53]	1.76 [1.51 – 7.92]	1.85 [1.61 – 9.66]
Ratio of indoor and outdoor area (as % of total area)	43:57		23:77	24:76		40:60
Degree of roofing (as % of the outdoor surface)	70		< 10[b]	50		0[b]
Feeding system	Indoor Liquid feed 3 times/day		Indoor Dry feed Ad libitum	Outdoor (roofed) Liquid feed 3 times/day		Indoor Dry feed Ad libitum
Drinkers	4 nipple drinkers, outdoor		1 nipple drinker, outdoor	2 nipple drinkers, outdoor		1 nipple drinker, outdoor, several at the feeder
Number of shower nozzles/pen	1		2–3	3		2
Approximate flow rate per nozzle in litres/minute	≤ 0.5		0.5 – 1.0	1.0 – 1.5		≥ 2.0
Shower area in m^2 [per pig at median group size][c]	15.4 [0.47/pig]	15.4 [0.38/pig]	5.0 [0.71/pig]	12.2 [0.61/pig]	12.2 [0.68/pig]	19.3 [0.53/pig]
Mean [± SD] outdoor temperature (in °C)[d]	23.7 [± 2.4]	25.2 [± 3.1]	27.0 [± 3.2]	26.0 [± 3.8]	26.1 [± 3.2]	25.5 [± 5.5]
Mean [± SD] outdoor relative humidity (in %)[d]	57.5 [± 4.8]	57.9 [± 11.1]	56.5 [± 10.6]	57.8 [± 12.7]	50.0 [± 9.9]	62.0 [± 13.6]

BW = body weight.
[a] Small minimum group size / high maximum space allowance reflects the end of the fattening period, when the first pigs from the group have already gone to slaughter.
[b] In summer, a sun protection net covered the outdoor run with shade.
[c] Refers to the solid floor area as used for the scoring of pen soiling. The area directly under the shower can deviate and is indicated in grey shading (see Fig. 1).
[d] Temperature and relative humidity measured in the outdoor run between the first and the last observation of each assessment day.

group). Showers were activated from 10:00 h – 17:00 h for 30 min per hour (CH01, CH02) and for 30 min per 90 min (AT01), respectively. For animal welfare reasons, farmers were asked to activate showers for all pigs on days with a forecasted daily maximum temperature above 32 °C. No data collection occurred on these days. Data collection took place on three (AT01, CH02) and two (CH01) one-day farm visits, respectively, and comprised a total of eight SHOWER groups and seven CON groups (Table 1).

2.2.2. SHORT/LONG experiment

In the SHORT/LONG experiment, we applied two different shower treatments: Showers were activated every full hour between 11:00 h and 16:00 h (i.e. six rounds per day) for a continuous activation duration of either 10 min (treatment **SHORT**) or 30 min (treatment **LONG**). With these relatively long shower durations we considered existing practices of the participating farms and aimed to ensure sufficient time for all pigs to move to and use the showers. Each treatment was alternately applied to all experimental groups of the respective farm. After the pigs had received the treatment for at least two consecutive days, data collection took place on the third day at the earliest. Treatments were changed after each farm visit. The time between farm visits was at least 3 days and at most 10 days. Data collection comprised six (AT02, CH01) and seven (AT01) one-day farm visits, respectively, and included a total of 20 groups (Table 1). The treatments were repeated at least three times per farm and each group experienced each treatment at least once. On each assessment day, groups were assigned to weight classes (**SMALL**: $<$ 80 kg BW; **LARGE**: $>$ 80 kg BW) based on visual estimate of the mean weight of the group. Groups of both weight classes were present throughout the whole experimental period.

2.3. Data collection

The same three observers (two in CH, one in AT) collected the data in both experiments. Observer training for assessment of behavioural data and soiling took place prior to the experiments by means of live sessions, video and photo material. Inter-observer reliability testing was performed using video recordings for behavioural parameters and photo material for the soiling of pigs and pens. The percentage observer agreement was above 73% for all behavioural parameters (with one animal deviation tolerance) as well as for soiling of pigs and pen surface.

Throughout the experimental period, ambient temperature and relative humidity (**RH**) were measured every hour in the indoor area and in the outdoor run with largest possible distance to the shower using climate data loggers (in AT: HOBO© U23 Pro v2, Onset Computer Corporation, Bourne (MA), USA; in CH: TinyTag Ultra 2, TGU-4500, Gemini Data Loggers, West Sussex, United Kingdom).

2.3.1. Behavioural observation

On all farms, the observers conducted direct behavioural observations of the whole outdoor run from outside the pen. Direct observation was also possible for the indoor area of farms AT02 and CH01 with open barn systems, where observers could see the indoor area from the outdoor observer position. Whenever possible, two neighbouring groups were observed in parallel. For the two farms with indoor buildings (AT01 and CH02), video recordings were taken at the same time as the direct observations outdoors. Since the cameras could not cover the whole indoor area on AT01, observations included only part of the pigs being actually indoors. Using scan samplings, we determined the number of pigs in different areas, activity and lying posture as described in

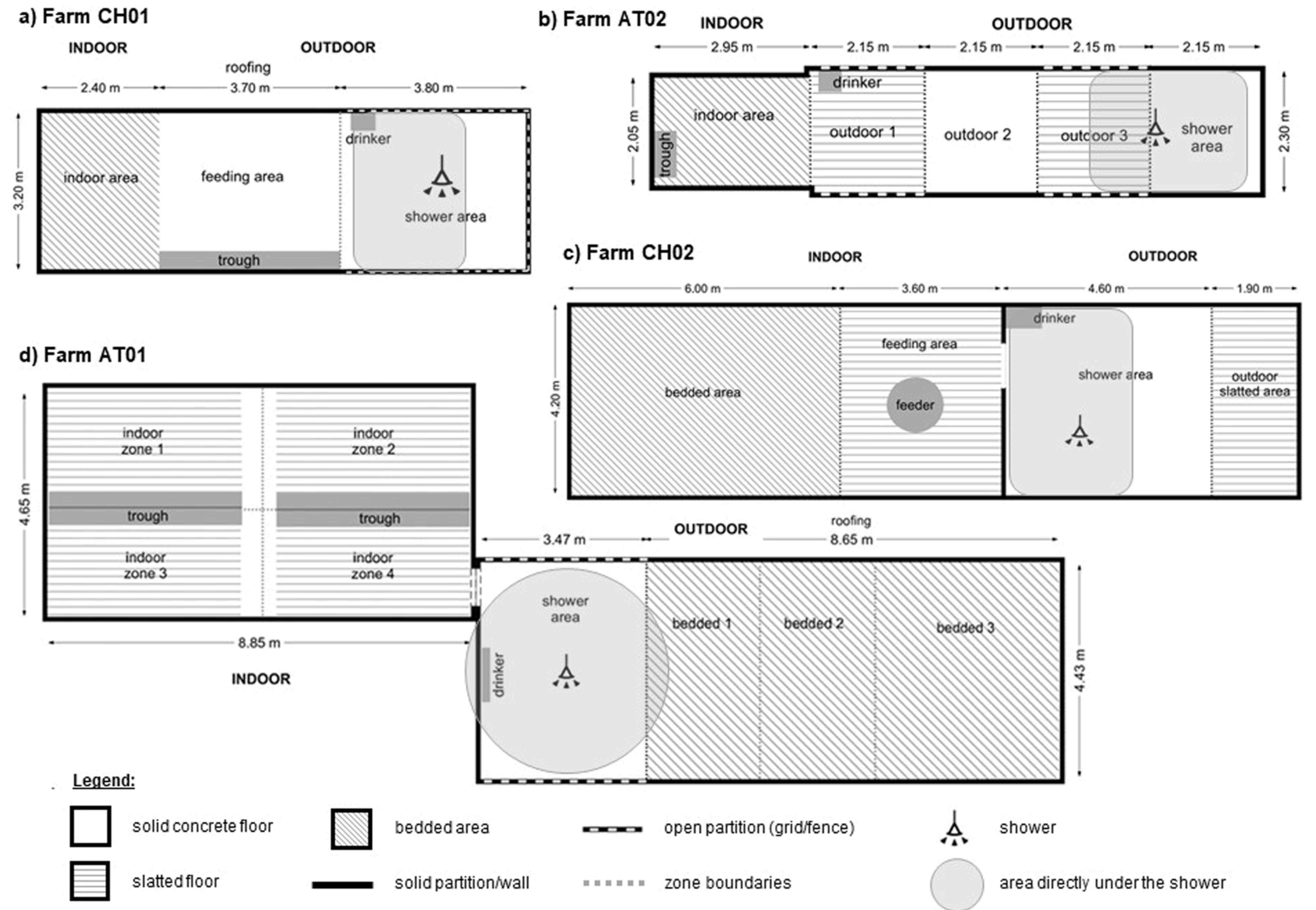

Fig. 1. Layout of fattening pens in Austrian farms AT01 (d), AT02 (b) and Swiss farms CH01 (a) and CH02 (c) indicating different pen zones (including the shower area characterised by solid floor) used for behaviour observation and scoring of pen soiling. Additionally, an estimation for the area directly under the showers in indicated in grey shading.

Table 2 for the three locations indoors, the outdoor run (including the shower area) and the shower area. The order of the groups was randomly selected on each assessment day by rolling dice. Before each new observation, the observers waited at least two minutes in front of the pen to standardise the behavioural reaction of the pigs to the presence of the observer. The video recordings were evaluated after completion of the experiments, assessing the same behaviours at the same time points as during the live observation.

In the pilot experiment, we performed scans of two neighbouring groups every 15 min starting at 10:00 h and ending with the last shower event at 16:30 h. Each group was observed in 8 – 12 scans per day (depending on the number of groups per farm), resulting in a total of 375 scan observations. In the SHORT/LONG experiment, three scans were conducted per hour (observation round) in parallel for two groups each, resulting in a total of 576 scan observations. Scan 1 was performed 10 min before shower activation, Scan 2 shortly before shower activation (at the full hour) and Scan 3 at 10 min after shower activation, which was at the end of a shower event in treatment SHORT and still during the shower in treatment LONG. In order to better compare the use of the showers between treatments, all pigs directly under the shower (Table 2) were additionally counted five minutes after start of the shower.

The presence of pigs in different pen areas is given as a proportion related to the total number of pigs in the group; the activity of pigs as a proportion related to the number of observed pigs in each respective area; and lying posture of pigs as a proportion related to the number of lying pigs in each respective area. While distinguishing only between indoor area and outdoor run in the pilot experiment, we additionally investigated the behaviour in the shower area in the SHORT/LONG experiment (Table 2). Due to poor visibility, lying posture indoors could not be assessed in the SHORT/LONG experiment in CH01.

2.3.2. Respiratory rate

Respiratory rate was recorded through visual observation of the flank movement directly after Scan 3 (after cessation of the shower in treatment SHORT, but while the shower was still running in treatment LONG) for two to four pigs of the observed groups (397 pigs assessed in total). Pigs were selected according to good visibility of the flank, motionless lying and balanced for location within the pen. It was not possible to visually distinguish whether they were wet or dry. To increase reliability, each pig was assessed twice in direct succession. We recorded the time required for 10 breaths, which was then converted to breaths per minute.

2.3.3. Soiling of pigs and the pen

Soiling of pigs and of the pen surface was assessed twice a day at each farm visit, in the morning before the shower started (**AM**) and in the afternoon after the last shower event ended (**PM**). In the pilot experiment, we additionally recorded soiling at **noon** (12:00 h – 13:00 h). The observers visually assessed the number of soiled pigs, which was defined as at least 10% of one body side soiled with manure. Figures are given as a proportion of soiled pigs per group. Pen soiling was scored visually using a three-point scoring scheme based on the proportion of the surface soiled with manure (see Knoll et al., 2021). Scoring of solid or

Table 2
Definitions of behavioural parameters assessed in the pilot and the SHORT/LONG experiment.

Behaviour	Description	Experiment
Location		
Outdoor	Outdoor run with concrete floor (bedded, solid or slatted) with open-air climate and partial roofing. At least the head and front legs of the pig are in the outdoor run.	Both
Shower area	Non-roofed, solid floor area within the outdoor run, above which the showers are located. At least the head and front legs of the pig are in the shower area.	SHORT/LONG
Under the shower	At least the head and front legs of the pig are directly under the water spray of the showers (Fig. 1).	SHORT/LONG
Indoor	Area covered and closed on three sides, which provides protection from outdoor climate (building or lying box). At least the head and front legs of the pig are in the indoor area.	Both
Activity		
Active	Standing, sitting or moving, (including running, jumping, feeding, drinking, social interaction, elimination, rubbing etc.) in the observation area. Activity and lying are mutually exclusive, i.e. the difference between active animals and observed animals equals the number of lying animals.	
1. Indoor		Both
2. Outdoor		Both
3. Shower area		SHORT/LONG
Lying posture		
Lateral lying	Lying on the left or right side of the body. All four legs are visible and outstretched away from the body (adapted from Olsen et al., 2001).	
1. Indoor		Both
2. Outdoor		Both
3. Shower area		SHORT/LONG
Lying with contact	Lying while a part (≥ 50%) of the trunk touches another pig's trunk (adapted from Olsen et al., 2001).	
1. Indoor		Both
2. Outdoor		Both
3. Shower area		SHORT/LONG

slatted concrete areas considered the surface soiled with wet or dry manure (Score 1: < 1/3, 2: ≥ 1/3 and 3: ≥ 2/3 of the surface). Scoring of straw bedded areas considered wet and moist surface soiled with manure and had a stricter Score 1 and 2 (Score 1: < 1/10, 2: ≥ 1/10 and 3: ≥ 2/3 of the surface). For scoring, the pens were divided into farm-specific sub-areas (Fig. 1) that were structurally distinguishable (e.g. by room layout, floor design, roofing). On AT farms, which did not remove the manure on a daily basis, the date of the last manure removal before the farm visit was recorded. On average, the last cleaning had taken place about two (maximum four) days preceding the visit.

2.4. Statistical analysis

We found positive correlations ($r = 0.95$; $p < 0.001$) between indoor and outdoor temperature in line with Olsen et al. (2001) as well as negative associations between outdoor temperature and RH ($r = -0.64$; $p < 0.001$) in line with Scriba and Wechsler (2021). Therefore, outdoor temperature was used as sole climate variable in the statistical models.

All analyses were carried out with the statistical software R (version 4.1.3, R Core Team, 2022). Behavioural parameters, respiratory rate and soiling of pigs were analysed through (generalised) linear mixed-effects models using the commands "lmer" and "glmer" of the package "lme4" (Bates et al., 2015) as well as "mixed" of the package "afex" to calculate p-values by parametric bootstrapping (Singmann et al., 2021). For all statistical models we accounted for repeated measurements and dependencies within the experimental design by specifying a nested random effect of the observation nested within assessment day within group within farm and a crossed random effect of assessment day. Since we were only interested in the effect of showers across a range of farms, the farm was not included as fixed effect. Therefore, results on farm level are not presented here. Additionally, the nested random effect included the observation round for behavioural parameters and the animal for respiratory rate in the SHORT/LONG experiment.

Fixed effects in the pilot experiment were treatment (SHOWER, CON), outdoor temperature (scaled numeric variable) and their interaction. Additionally, shower activation (on/off), i.e. whether showers in SHOWER pens were activated at the time of observation (specified for both SHOWER and CON groups) was considered as fixed effect (with its interaction with treatment) for behavioural data. Assessment time (AM, noon, PM) and its interaction with treatment was a fixed effect for soiling of pigs.

Models for behavioural data of the SHORT/LONG experiment considered the fixed effects of treatment (SHORT, LONG), outdoor temperature (scaled numeric variable), scan number (1, 2, 3) and their respective two-way interactions with treatment. Weight class (SMALL, LARGE) was included to control for potential influence on behaviour. The model on pig soiling was set up in the same way, including assessment time (AM, PM) instead of scan number. For respiratory rate, we considered not only the interaction between treatment and temperature, but also between treatment and weight class. A detailed overview of experimental structure, sample size and fixed effects is provided in the Supplementary material for the pilot (Table S1) and the SHORT/LONG experiment (Table S2).

We evaluated model assumptions visually (Tukey Anscombe Plot for homogeneity of variance, Q-Q plots for normality of residuals and random effects, and boxplots for equal distribution of residuals at each level of the random effects). Some response variables required transformation since the model assumptions were not met. We used square root transformation for the proportion of pigs under the shower five minutes after start, active pigs indoors, lying with contact in the outdoor run (SHORT/LONG experiment) and log transformation for respiratory rate (SHORT/LONG experiment) and soiling of pigs (pilot experiment; values of zero were multiplied by 0.9 times the lowest value above zero). Due to insufficient variability in the proportion of pigs lying with contact in the indoor and shower area in the SHORT/LONG experiment, we transformed these to binary variables (0 = no pig lying with contact; 1 = at least one pair of pigs lying with contact). Results for behaviour, respiratory rate and soiling of pigs are provided as model estimates [95% confidence intervals (**CI**) in brackets].

The statistical model for pen soiling scores was only calculated for the SHORT/LONG experiment and included scores for the shower area, as this was the only comparable area across farms (outdoors, non-roofed, solid floor) and showed most of the variation. Accounting for the ordinal character of pen soiling scores, we calculated cumulative link mixed models using the command "clmm" of the package "ordinal" (Christensen, 2019). The model contained the same random effect structure as the one for soiling of pigs. The fixed effects were structured similarly, with the difference that temperature referred to the daily mean value (measured between 11:00 h – 15:00 h). The interaction between assessment time (AM, PM) and mean temperature was additionally considered. Estimates of soiling scores are given as odds ratios (**OR**), i.e. the chance of obtaining a higher soiling score e.g. in treatment SHORT compared to LONG. The observed frequencies of scores per pen area and farm of other sub-areas as well as for the pilot experiment are presented descriptively.

2.5. Ethical considerations

The trial on the Swiss farms was approved by the cantonal veterinary office Aargau, Switzerland (permission number AG 75′732) and all animal-related procedures were conducted according to the Swiss legislation on animal welfare. At the time of study realisation, no official ethical review body existed within the University of Natural Resources and Life Sciences, Vienna. The study did not require official approval in Austria since no animals were subjected to invasive procedures. Furthermore, farms complied with the high animal welfare standards of

EU and national (Swiss and Austrian) organic legislation. Written informed consent was obtained from the farmers involved in the study.

3. Results

Average outdoor temperature during farm visits was 25 °C with a range of 16.8–36.6 °C in the pilot and 26 °C with a range of 19.2–33.3 °C in the SHORT/LONG experiment. Average RH in the outdoor run during farm visits was 59.2% in the pilot, with considerable variation of 30.6–87.1%, and 55.4% in the SHORT/LONG with similar variation of 33.3–88.5%. The climatic conditions were comparable between days with SHORT and days with LONG shower duration in terms of outdoor temperature (SHORT: mean 26.0 °C ± 3.0; LONG: mean 26.1 °C ± 3.6) and RH (SHORT: mean 55.4% ± 11.6; LONG: mean 55.5% ± 10.5).

3.1. Use of the outdoor run and the shower area

In the pilot experiment, a lower proportion of pigs was observed in the outdoor run when a shower was provided than in control groups, though not statistically significant ($p = 0.11$; Table 3). The proportion of pigs in the outdoor run tended to increase with temperature ($p = 0.07$) and was not affected by shower activation or any interactions.

In the SHORT/LONG experiment (Table 4), about half of the pigs of a group were present in the outdoor run, without differences between treatments ($p = 0.63$) but an increase with rising temperatures ($p = 0.02$). Directly in the shower area, the proportion of pigs was low at 22 °C (< 0.10) and increased to 0.20 at 32 °C ($p < 0.001$). Although it tended to be higher in SHORT than in LONG ($p = 0.07$), the size of this effect was negligible. The proportion of pigs under the shower five minutes after activation increased more with increasing temperature in LONG than in SHORT (interaction: $p < 0.01$). In Scan 3 (i.e. end of the shower in SHORT, during the shower in LONG), fewer pigs were in the outdoor run ($p < 0.001$), especially in the shower area ($p < 0.001$), compared to Scan 1 and 2.

3.2. Activity and lying posture

In the SHOWER treatment of the pilot experiment, the proportion of active pigs in the outdoor run was higher compared to CON groups

Table 3
Results of behavioural parameters and soiling of pigs in the pilot experiment: Model estimates and 95% confidence intervals [CI in brackets] for the treatments SHOWER/CON (pens with access to showers/pens without showers) and shower activation (on/off; behavioural parameters) or time of assessment (soiling of pigs) as well as p-values for fixed effects and interactions.

		Model estimates [± CI] Shower activation		p-values for predictors				
Variable	Treatment	on	off	Treatment	Temperature	Shower activation	Treatment x Temperature	Treatment x Shower activation
Behaviour in the outdoor run[a]								
Proportion of pigs outdoors / pigs in the group	CON	0.60 [0.42–0.78]	0.62 [0.43–0.80]	0.11	0.07	0.79	0.69	0.43
SHOWER	0.48 [0.31–0.65]	0.47 [0.29–0.65]						
Proportion of active pigs / pigs outdoors	CON	0.30 [0.21–0.38]	0.29 [0.19–0.38]	0.03	0.57	0.10	0.16	0.17
SHOWER	0.46 [0.38–0.55]	0.39 [0.31–0.48]						
Proportion of lateral lying / lying pigs outdoors	CON	0.42 [0.30–0.53]	0.47 [0.36–0.58]	0.08	0.51	0.03	0.11	0.66
SHOWER	0.28 [0.17–0.39]	0.35 [0.24–0.46]						
Proportion of contact lying / lying pigs outdoors	CON	0.29 [0.12–0.46]	0.29 [0.13–0.46]	0.41	0.01	0.83	0.28	0.68
SHOWER	0.25 [0.08–0.42]	0.23 [0.07–0.40]						
Behaviour in the indoor area[b]								
Proportion of active pigs / pigs indoors	CON	0.53 [0.26–0.81]	0.51 [0.25–0.78]	0.94	0.19	0.08	0.55	0.27
SHOWER	0.55 [0.29–0.82]	0.45 [0.20–0.72]						
Proportion of lateral lying / lying pigs indoors	CON	0.33 [0.00–0.66]	0.31 [0.00–0.62]	0.44	0.80	0.71	0.43	0.73
SHOWER	0.26 [0.00–0.60]	0.26 [0.00–0.59]						
Proportion of contact lying / lying pigs indoors	CON	0.11 [0.00–0.23]	0.09 [0.00–0.21]	0.89	0.17	0.63	0.40	0.77
SHOWER	0.11 [0.00–0.22]	0.10 [0.00–0.22]						

		Assessment Time							
Soiling of pigs		AM	noon	PM	Treatment	Temperature	Time	Treatment x Temperature	Treatment x Time
Proportion of soiled pigs / pigs in the group[c]	CON	0.07 [0.03-0.15]	0.14 [0.06-0.31]	0.28 [0.12-0.65]	0.19	0.16	< 0.001	0.47	0.32
	SHOWER	0.04 [0.02-0.09]	0.09 [0.04-0.19]	0.10 [0.05-0.23]					

[a] The time component for behaviours is the shower activation (on/off), for soiling of pigs the observation time (AM, noon, PM).
[b] No models were calculated for the proportion of pigs indoors and lying pigs, as these variables behave inversely to the proportion of pigs in the outdoor run and activity, respectively.
[c] Statistical model with log transformed response variable (values of zero were multiplied by 0.9 times the lowest value above zero).

Table 4
Results of behavioural parameters, respiratory rate and soiling of pigs in the SHORT/LONG experiment: Model estimates and 95% confidence intervals [CI in brackets] for the treatments SHORT (10 min) and LONG (30 min shower activation per hour) at outdoor temperature of 22 °C and 32 °C as well as p-values for fixed effects and interactions.

Variable	Treatment	Model estimates [±CI]		p-values for predictors					
		Temperature							
		22 °C	32 °C	Treatment	Temperature	Scan / Time[a]	Weight	Treatment x Temperature	Treatment x Scan / Time
Behaviour in the outdoor run									
Proportion of pigs outdoors / pigs in the group	SHORT	0.51 [0.42–0.62]	0.58 [0.48–0.70]	0.63	0.02	< 0.001	0.57	0.27	0.81
	LONG	0.47 [0.37–0.56]	0.61 [0.51–0.72]						
Proportion of active pigs / pigs outdoors	SHORT	0.43 [0.31–0.56]	0.33 [0.21–0.47]	0.20	0.12	< 0.001	0.11	0.99	0.10
	LONG	0.38 [0.27–0.50]	0.29 [0.16–0.43]						
Proportion of lateral lying / lying pigs outdoors	SHORT	0.35 [0.20–0.49]	0.48 [0.34–0.61]	0.88	0.06	0.58	0.02	0.89	0.41
	LONG	0.37 [0.23–0.49]	0.47 [0.33–0.60]						
Proportion of contact lying / lying pigs outdoors[b]	SHORT	0.09 [0.00–0.31]	0.08 [0.00–0.31]	0.10	0.91	0.10	0.49	0.75	0.37
	LONG	0.11 [0.01–0.37]	0.12 [0.01–0.37]						
Behaviour in the shower area of the outdoor run									
Proportion of pigs in shower area / pigs in the group[b]	SHORT	0.07 [0.02–0.16]	0.20 [0.11–0.33]	0.07	< 0.001	< 0.001	0.13	0.28	0.35
	LONG	0.02 [0.00–0.07]	0.20 [0.10–0.33]						
Proportion of pigs under the shower 5 min after start / pigs in the group	SHORT	0.10 [0.02–0.18]	0.14 [0.06–0.22]	0.80	0.01	NA	< 0.01	< 0.01	NA
	LONG	0.00 [00–0.08]	0.23 [0.15–0.30]						
Proportion of active pigs / pigs in shower area	SHORT	0.64 [0.44–0.85]	0.52 [0.30–0.75]	0.66	0.02	< 0.001	< 0.01	0.10	0.28
	LONG	0.79 [0.59–1.00]	0.40 [0.19–0.63]						
Proportion of lateral lying / lying pigs in shower area	SHORT	0.36 [0.22–0.51]	0.23 [0.09–0.38]	0.93	0.31	0.03	< 0.01	0.01	0.76
	LONG	0.15 [0.00–0.31]	0.44 [0.29–0.58]						
Proportion of observations with contact lying in shower area[c]	SHORT	0.15 [0.00–0.36]	0.12 [0.00–0.30]	0.82	0.89	< 0.01	0.07	0.55	0.84
	LONG	0.10 [0.00–0.28]	0.15 [0.00–0.34]						
Behaviour in the indoor area[d]									
Proportion of active pigs / pigs indoors[b]	SHORT	0.23 [0.11–0.41]	0.04 [0.02–0.22]	0.12	0.75	0.18	0.15	0.02	0.91
	LONG	0.09 [0.02–0.21]	0.17 [0.06–0.34]						
Proportion of lateral lying / lying pigs indoors[e]	SHORT	0.39 [0.19–0.60]	0.56 [0.32–0.77]	0.45	0.31	0.28	0.19	0.25	0.12
	LONG	0.50 [0.23–0.72]	0.49 [0.28–0.72]						
Proportion of observations with contact lying indoors[c,e]	SHORT	0.07 [0.00–0.33]	0.08 [0.00–0.38]	0.42	0.34	0.60	0.29	0.24	0.24
	LONG	0.28 [0.00–0.72]	0.03 [0.00–0.18]						
Respiratory rate									
Breaths / minute[f]	SHORT	20.3 [13.0–30.2]	29.0 [18.9–44.1]	0.56	< 0.01	NA	< 0.001	< 0.01	NA
	LONG	16.8 [11.0–25.1]	37.6 [23.9–56.0]						
Soiling of pigs									
Proportion of soiled pigs / pigs in the group	SHORT	0.21 [0.00–0.48]	0.53 [0.24–0.81]	0.31	< 0.01	0.15	0.02	0.09	0.26
	LONG	0.24 [0.00–0.49]	0.37 [0.09–0.65]						

NA = not applicable.
[a] The time component for behaviours is the scan number (1, 2, 3), for soiling of pigs the observation time (AM, PM). For respiratory rate, no time component was included in the model.
[b] Statistical model with square root transformed response variable.
[c] Generalised linear mixed effect model with binary variable (0 = no pig lying with contact, 1 = at least a pair of pigs lying with contact).
[d] No models were calculated for the proportion of pigs indoors and lying pigs, as these variables behave inversely to the proportion of pigs in the outdoor run and activity, respectively.
[e] Lying posture indoors could be only observed in AT farms but not in CH01.
[f] Statistical model with log transformed response variable.

(p = 0.03; Table 3). Independent from the treatment, about half of the pigs in the indoor area were active, and the proportion of active pigs tended to increase when showers were activated in the outdoor run (p = 0.08). Lateral lying in the outdoor run tended to be lower in the SHOWER treatment than in CON (p = 0.08; Table 3). For both treatments, lateral lying was lower when showers were activated in SHOWER pens (p = 0.03). Lying in contact with other pigs in the outdoor run did not differ between treatments (p = 0.41) but decreased with increasing temperature (p = 0.01). None of the predictors affected lying postures in the indoor area.

In the SHORT/LONG experiment, activity was highest in the outdoor run, especially in the shower area, while pigs in the indoor area were less active (Table 4). The proportion of active pigs in the shower area decreased with increasing temperature (p = 0.02). In the indoor area, activity decreased with increasing outdoor temperature in treatment SHORT, while increasing in LONG (interaction: p = 0.02). Pigs in the outdoor run (p < 0.001) and the shower area (p < 0.001) were more active in Scan 3 compared to the scans before, noting that there were also fewer pigs in these areas in Scan 3. On average, about one third to half of the lying pigs were lying laterally across all pen areas and only one tenth of lying pigs in the outdoor run were lying in contact with other pigs (Table 4). At higher temperature, lateral lying in the outdoor run tended to increase by 0.10 from 22 °C to 32 °C (p = 0.06). An increasing effect of temperature on lateral lying in the shower area was also evident in the LONG but not in the SHORT treatment (interaction: p = 0.01). Scan 3 revealed a lower proportion of lateral lying (p = 0.03) and lying with contact (p < 0.01) in the shower area. Lying postures in the indoor area were not affected by any of the predictors.

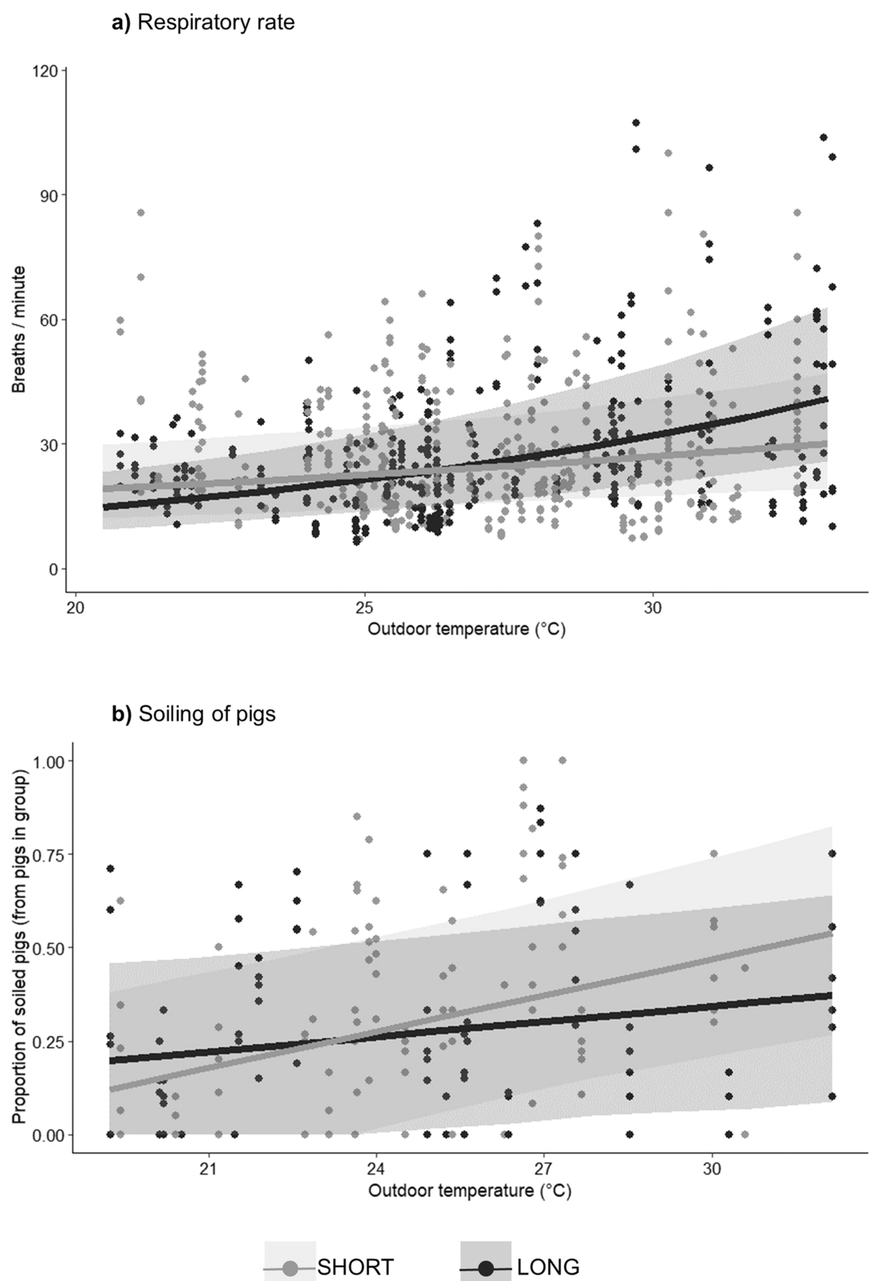

Fig. 2. Observed values (dots), model estimates (lines) and confidence intervals (shaded bands) for a) respiratory rate (in breaths/minute) and b) proportion of soiled pigs in relation to temperature (in °C) at 10 min (SHORT = light grey) and 30 min (LONG = dark grey) shower duration per hour.

3.3. Respiratory rate

Respiratory rate was only assessed in the SHORT/LONG experiment and ranged between 6.2 and 107.3 breaths/minute (Fig. 2a). Respiratory rate did not differ between treatments but increased with higher temperatures ($p < 0.01$; Table 4). Additionally, we found an interaction effect of treatment with temperature indicating a stronger increase of respiratory rate with increasing outdoor temperature in treatment LONG compared to SHORT ($p < 0.01$; Fig. 2a). There was no interaction effect of treatment with weight class ($p = 0.24$).

3.4. Soiling

In the pilot experiment, the showers did not significantly affect the proportion of soiled pigs ($p = 0.19$). However, there were considerable absolute differences between SHOWER and CON groups and a significant effect of time ($p < 0.001$): The least pigs were soiled in the morning and the most in the afternoon with numerically lower proportions in SHOWER compared to CON groups (Table 3). The pen area was mostly rated as clean across different zones (% of Score 1 observations: AT01 = 53%, CH01 = 72% and CH02 = 92%). Most soiling (41% of Score 2 observations and 100% of Score 3 observations) occurred in the shower area of the outdoor run.

The proportion of soiled pigs varied considerably in the SHORT/LONG experiment and was not affected by treatment, time of assessment or its interaction with treatment (Table 4). Soiling significantly increased with higher temperatures ($p < 0.01$), with a tendency for an interaction with treatment ($p = 0.09$; Fig. 2b). Results for pen soiling scores in the SHORT/LONG experiment are provided in Fig. 3. The cumulative link mixed model for soiling of the shower area revealed a significant interaction between treatment and time ($OR_{SHORT,\ PM} = 8.2$; $p = 0.03$) with a greater chance of obtaining higher soiling scores at PM observations compared to AM in treatment SHORT. Moreover, there was an interaction between time and daily mean temperature ($OR_{Temp.,\ PM} = 0.32$; $p = 0.05$): The chance of obtaining higher scores at PM observations compared to AM decreased on hotter days.

4. Discussion

The pilot experiment demonstrated that more pigs were active and fewer pigs were lying laterally in pens with showers than without. In the SHORT/LONG experiment, the effect of shower duration depended on the ambient temperature with e.g. a stronger increase in the proportion of pigs under the shower and of pigs lying laterally in the shower area and a stronger increase in respiratory rates with increasing temperatures in treatment LONG compared to SHORT. Fewer pigs were in the outdoor run and in the shower area at shower activation than at non-shower times. Results on soiling of pigs and of the pen indicate positive effects of LONG shower duration with increasing temperatures.

With on average more than half of the pigs being outdoors, the use of the outdoor run was high in both experiments compared to previous studies, in which 10 – 40% of the pigs were outdoors during the day (Knoll et al., 2021; Olsen et al., 2001; Vermeer et al., 2015). Similar to Olsen et al. (2001) and Knoll et al. (2021), we found an increased use of the outdoor run as temperatures rose. Outdoor areas offer more differentiated climatic conditions, e.g. in terms of air velocity, making it probably more attractive at higher temperatures, while indoor areas become more unappealing. Our results furthermore indicate that pigs increasingly sought for cooling through the showers at higher temperatures, as the proportion of pigs under the shower increased with rising temperatures in the SHORT/LONG experiment.

Previous studies showed that showers improve the welfare of pigs by reducing heat stress (Culver et al., 1960; Huynh et al., 2006), which is reflected in an increased activity and less lateral lying in pigs with showers in the pilot experiment. Activity decreased and lateral lying increased as temperatures rose in both experiments, which was also shown by Olsen et al. (2001) for pigs with a water bath in the outdoor run. Further, we observed an increase in respiratory rate with rising temperature, but estimates were within the normal range of 25 – 40 breaths/minute for growing-finishing pigs (Ramirez and Karriker, 2012). However, individual animals showed higher respiratory rates, which may indicate heat stress.

Regarding different shower duration, we found interactions between treatment and temperature for several indicators. In treatment LONG, only a small proportion of pigs was under the showers at moderate temperatures, but in the upper temperature range the proportion exceeded that of treatment SHORT. Unexpectedly, lateral lying in the shower area and respiratory rate increased also more in the LONG than in the SHORT treatment. In contrast, Vajrabukka et al. (1987) found a reduction in respiratory rate at two-minute compared to 0.5-minute sprinkler activation every 30 min, albeit in pigs kept in conventional indoor housing at controlled high temperatures and with an average respiratory rate exceeding 70 breaths/minute. In our study shower duration was much longer than two minutes and climatic conditions varied. Therefore, it is possible that LONG shower duration had a greater reducing effect on air temperature, as it was shown for water cooling measures in indoor systems (Godyn et al., 2020; Gomes et al., 2021). When cooling of the air and the wet surface was apparently sufficient at moderate temperatures in treatment LONG, pigs avoided direct contact with the showers. When temperatures were high, the floor under the shower provided a cool surface for a longer time, which may have stimulated the pigs to lie there, especially in a lateral position also during shower activation. In treatment SHORT, the unroofed shower area dried and warmed up faster, reducing its attractiveness for lying. Longer shower activation might also increase relative humidity, making it more difficult to dissipate heat (Godyn et al., 2020; Huynh et al., 2007). This could explain the steeper increase in respiratory rate with rising temperatures in LONG compared to SHORT. However, our measurements did not indicate differences in relative humidity or temperature for the two treatments. Moreover, showers proofed to reduce respiratory rate also in regions with humid climate (Huynh et al., 2006). Increased activity could also explain higher respiratory rates. Despite measuring respiratory rate in pigs lying calmly, we could not consider how long the pigs had been lying or whether and how much they had been active before. Since the showers were still activated when assessing the respiratory rate in treatment LONG but not in SHORT, we explain the higher respiratory rate in LONG with generally increased activity during shower activation combined with an increased proportion of pigs under the shower at higher temperatures.

Interestingly, pigs seemed to avoid being directly under the showers. In the pilot experiment, fewer pigs were outdoors during shower activation than in-between. Correspondingly, in the SHORT/LONG experiment, fewer pigs were in the shower area during or shortly after shower activation (Scan 3) than before. Increased activity during shower activation in both experiments could be due to resting pigs standing up and leaving the shower area, or due to pigs actively approaching the showers, even if only for a short while (which could not be differentiated with our data). The low proportion of pigs under the showers could indicate that the animals did not experience heat stress. This is plausible for small pigs with higher temperature requirements, but not for pigs > 80 kg, as temperatures in the experiment were mostly above the thermoneutral range for pigs of this weight (Aarnink et al., 2006; Hillmann et al., 2004). Showers not being an attractive cooling option may be another reason for the presumed avoidance, especially when heat stress is not severe. Under semi-natural conditions pigs use a mud wallow for thermoregulation, where they can immerse and which they use even at low temperatures for skin care, social behaviour (sexual behaviour and social cohesion) and, presumably, pleasure (Bracke, 2011; Olsen et al., 2001). Little knowledge exists as to whether pigs also appreciate water from above as in rain (Olsen et al., 2001) or showers. Huynh et al. (2006) reported that pigs used showers less frequently than a water bath, and it is questionable whether a shower can fulfil all the

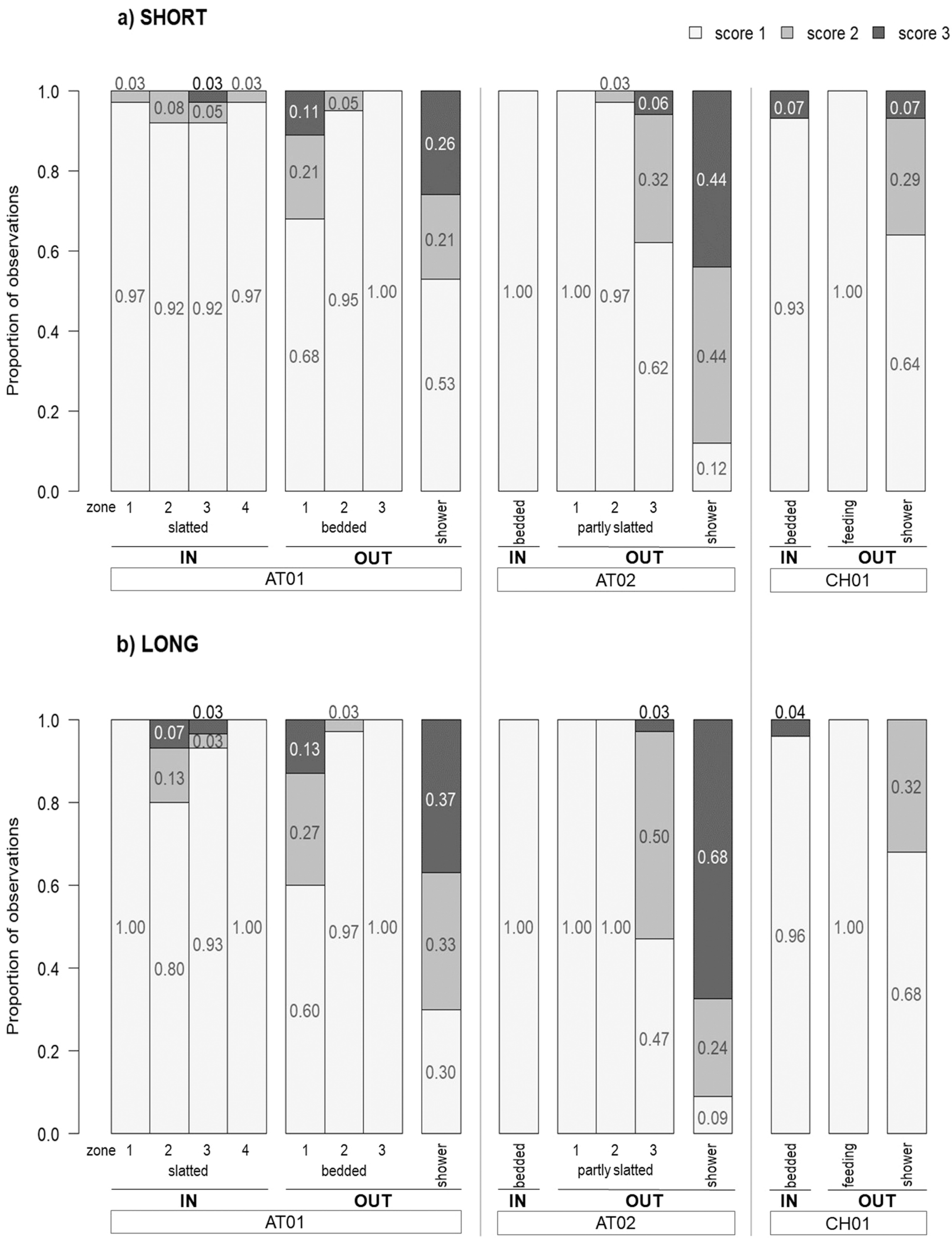

Fig. 3. Proportions of observed pen soiling scores (Score 1 = light grey, 2 = grey, 3 = dark grey) in the SHORT/LONG experiment for farms AT01, AT02 and CH01 in different pen zones (numbered if applicable; IN = indoors; OUT = outdoors) at a) SHORT (10 min) and b) LONG (30 min) shower activation every hour.

above-mentioned functions. Our findings underline the importance of providing enough space indoors and outdoors so that pigs can choose to use or avoid the shower area during shower activation. Besides the direct effect of spraying water on the pigs, lying in the wet shower area may be even more attractive for cooling. Indeed, a higher proportion of pigs was lying laterally at increasing temperatures in the LONG treatment, where the floor under the shower remained wet for longer.

A change in lying behaviour could also explain the higher soiling of pigs at rising temperatures as pigs lie more on cool surfaces, including areas covered with manure (Aarnink et al., 2006; Huynh et al., 2005). In the pilot experiment, the showers tended to improve the cleanliness of pigs compared to the CON groups. The higher increase in soiling in the SHORT than in the LONG treatment supports the positive effect of showers, especially with longer duration. Concurrently, the soiling of the shower area was increased in PM compared to AM observations in the SHORT but not in the LONG treatment. Longer shower duration might have prevented further accumulation of manure over the day, either through a direct cleaning effect or by shifting elimination towards other places when pigs lie more in the shower area (Aarnink et al., 2006; Jeppsson et al., 2021), which we observed in treatment LONG at higher temperatures (typical for PM observations). On the other hand, previous studies found that pigs eliminate to a considerable extent in or near a water bath (Huynh et al., 2006; Olsen et al., 2001), which is in line with a generally higher frequency of Score 3 (i.e. over 2/3 of the surface soiled) in the LONG treatment of our study. However, the relation between wet areas and elimination behaviour is not straightforward (Wimmler et al., 2022). Finally, it should be noted that the larger parts of the pens were clean in both experiments. We therefore see no indication that showers pose an increased risk for overall pen soiling.

The great variability of the present results demonstrates the difficulties arising from the many known and unknown influencing factors in multi-farm experiments. Therefore, it is important to standardise data collection as much as possible, including a thorough definition of the parameters, training and inter-observer reliability. Nonetheless, we found considerable agreement with findings from previous studies conducted under more standardised conditions. This supports our results and underlines their external validity, as they were obtained under a range of different housing conditions (e.g. in terms of roofing, location of bedding and feeders, manure management). Since our results suggest complex interactions between outdoor climate, shower duration and pig behaviour, future research should focus on these combined effects especially in an open-air setting. The fact that weight class often had a significant influence, as described in literature on thermoregulation (Aarnink et al., 2006; Jeppsson et al., 2021), suggests that different shower programmes are useful depending on the age of the pigs. However, since we could not consider the interaction effect between treatment and weight class, further studies are needed in this respect. Additionally, showers could contribute to reduce ammonia emissions, not only through improved cleanliness but also through diluting the manure by adding water (Jeppsson et al., 2021), which should be confirmed for the outdoor situation by ammonia measurements.

5. Conclusions

Showers in the outdoor run showed the potential to improve thermal comfort of growing-finishing pigs, which is reflected in a tendency for reduced lateral lying and an increased activity in pigs with showers compared to control groups without. Interactions between shower duration and outdoor temperature suggest that a temperature-dependent shower programme is appropriate in terms of animal welfare and cleanliness of the pen. At moderate temperatures, shorter shower activation seems to be sufficient for cooling and limits water demand. With increasing temperatures, longer shower activation seems to be beneficial as it ensures sufficient access to cooling. However, pigs seemed to avoid direct contact with the water from above, which should be acknowledged by providing enough space indoors and outdoors, and which calls for a broader debate on species-appropriate cooling opportunities. Our study revealed future research needs to understand the complex interactions between different shower programmes, micro-climatic conditions, thermoregulatory behaviour, age of the pigs and ammonia emissions in systems with outdoor runs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Conflict of interest

The authors declare that there is no conflict of interest.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2022.105826.

References

Aarnink, A.J.A., Schrama, J.W., Heetkamp, M.J.W., Stefanowska, J., Huynh, T.T.T., 2006. Temperature and body weight affect fouling of pig pens. J. Anim. Sci. 84, 2224–2231. https://doi.org/10.2527/jas.2005-521.

Bates, D., Mächler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. J. Stat. Softw. 67, 1–48. https://doi.org/10.18637/jss.v067.i01.

Bio Suisse, 2020, Standards for the Production, Processing and Trade of "Bud" Products. [WWW Document]. URL ⟨https://www.bio-suisse.ch/media/VundH/Regelwerk/2020/EN/bio_suisse_richtlinien_2020_-_en.pdf⟩.

Blackshaw, J.K., Blackshaw, A.W., 1994. Shade-seeking and lying behaviour in pigs of mixed sex and age, with access to outside pens. Appl. Anim. Behav. Sci. 39, 249–257. https://doi.org/10.1016/0168-1591(94)90160-0.

Bracke, M.B.M., 2011. Review of wallowing in pigs: Description of the behaviour and its motivational basis. Appl. Anim. Behav. Sci. 132, 1–13. https://doi.org/10.1016/j.applanim.2011.01.002.

Christensen, R.H.B., 2019, ordinal - Regression Models for Ordinal Data.

Culver, A.A., Andrews, F.N., Conrad, J.H., Noffsinger, T.L., 1960. Effectiveness of water sprays and a wallow on the cooling and growth of swine in a normal summer environment. J. Anim. Sci. 19, 421–428. https://doi.org/10.2527/jas1960.192421x.

European Commission, 2020, Commission implementing regulation (EU) 2020/464 of 26 March 2020 laying down certain rules for the application of Regulation (EU) 2018/848 of the European Parliament and of the Council as regards the documents needed for the retroactive recognition of pe, Official Journal of the European Union.

European Parliament, Council of the European Union, 2018, Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007, Official Journal of the European Union.

Godyn, D., Herbut, P., Angrecka, S., Corrêa Vieira, F.M., 2020. Use of different cooling methods in pig facilities to alleviate the effects of heat stress - a review. Animals 10, 1–14. https://doi.org/10.3390/ani10091459.

Gomes, N.F., Pandorfi, H., Barnabé, J.M.C., Guiselini, C., de Almeida, G.L.P., de Holanda, M.C.R., de Holanda, M.A.C., da Silva, M.V., 2021. Behavior of pigs subjected to climate control system in the Semi-arid Region of Pernambuco, Brazil. DYNA (Colomb.) 88, 34–38. https://doi.org/10.15446/dyna.v88n218.93887.

Hillmann, E., Mayer, C., Schrader, L., 2004. Lying behaviour and adrenocortical response as indicators of the thermal tolerance of pigs of different weights. Anim. Welf. 13, 329–335.

Hörtenhuber, S.J., Schauberger, G., Mikovits, C., Schönhart, M., Baumgartner, J., Niebuhr, K., Piringer, M., Anders, I., Andre, K., Hennig-pauka, I., Zollitsch, W., 2020. The effect of climate change-induced temperature increase on performance and environmental impact of intensive pig production systems. Sustainability 12, 1–17. https://doi.org/10.3390/su12229442.

Hsia, L.C., Fuller, M.F., Koh, F.K., 1974. The effect of water sprinkling on the performance of growing and finishing pigs during hot weather. Trop. Anim. Health Prod. 6, 183–187. https://doi.org/10.1007/BF02380715.

Huynh, T.T.T., Aarnink, A.J.A., Gerrits, W.J.J., Heetkamp, M.J.H., Canh, T.T., Spoolder, H.A.M., Kemp, B., Verstegen, M.W.A., 2005. Thermal behaviour of growing pigs in response to high temperature and humidity. Appl. Anim. Behav. Sci. 91, 1–16. https://doi.org/10.1016/j.applanim.2004.10.020.

Huynh, T.T.T., Aarnink, A.J.A., Truong, C.T., Kemp, B., Verstegen, M.W.A., 2006. Effects of tropical climate and water cooling methods on growing pigs' responses. Livest. Sci. 104, 278–291. https://doi.org/10.1016/j.livsci.2006.04.029.

Huynh, T.T.T., Aarnink, A.J.A., Heetkamp, M.J.H., Verstegen, M.W.A., Kemp, B., 2007. Evaporative heat loss from group-housed growing pigs at high ambient temperatures. J. Therm. Biol. 32, 293–299. https://doi.org/10.1016/j.jtherbio.2007.03.001.

Ingram, D.L., 1965. Evaporative Cooling in the Pig. Nature 207, 415–416.

Jeppsson, K.H., Olsson, A.C., Nasirahmadi, A., 2021. Cooling growing/finishing pigs with showers in the slatted area: Effect on animal occupation area, pen fouling and ammonia emission. Livest. Sci. 243, 104377 https://doi.org/10.1016/j.livsci.2020.104377.

Knoll, M., Bokkers, E.A.M., Leeb, C., Wimmler, C., Andersen, H.M.-L., Thomsen, R., Früh, B., Holinger, M., 2021. Rooting for feed: Mixing corn pellets into rooting material tends to increase the presence of grower and finisher pigs in the rooting area but not its cleanliness. Appl. Anim. Behav. Sci. 241, 105379 https://doi.org/10.1016/j.applanim.2021.105379.

Olsen, A.W., Dybkjaer, L., Simonsen, H.B., 2001. Behaviour of growing pigs kept in pens with outdoor runs. Ii. Temp. Regul. Behav., Comf. Behav. dunging Prefer. Livest. Prod. Sci. 69, 255–264. https://doi.org/10.1016/S0301-6226(01)00173-7.

R Core Team, 2022, R: A language and environment for statistical computing.

Ramirez, A., Karriker, L.A., 2012. Herd evaluation. In: Zimmermann, J.J., Karriker, L.A., Ramirez, A., Schwartz, K.J., Stevenson, G.W. (Eds.), Diseases of Swine. Wiley-Blackwell, Chichester (UK), pp. 5–17.

Schodl, K., Winckler, C., Leeb, C., 2021. Higher space allowance and straw in a rack improve pig welfare on commercial fattening farms. Anim. Welf. 8, 1–10. https://doi.org/10.3389/fvets.2021.656211.

Scriba, M.F., Wechsler, B., 2021. Behavioural and physiological indicators of heat stress in fattening pigs. Agrar. Schweiz 12, 181–188. https://doi.org/10.34776/afs12-181e.

Singmann, H., Bolker, B., Westfall, J., Aust, F., Ben-Shachar, M.S., 2021, afex: Analysis of Factorial Experiments.

Vajrabukka, C., Thwaites, C.J., Farrell, D.J., 1987. The effects of duration of sprinkling and temperature of the drinking water on the feed intake and growth of pigs at high ambient temperature. J. Agric. Sci. 109, 409–410. https://doi.org/10.1017/S0021859600080850.

Vermeer, H.M., Altena, H., Vereijken, P.F.G., Bracke, M.B.M., 2015. Rooting area and drinker affect dunging behaviour of organic pigs. Appl. Anim. Behav. Sci. 165, 66–71. https://doi.org/10.1016/j.applanim.2015.01.007.

Wimmler, C., Vermeer, H.M., Leeb, C., Salomon, E., Andersen, H.M.-L., 2022. Review: Concrete outdoor runs for organic growing-finishing pigs – a legislative, ethological and environmental perspective. Animal 16, 100435. https://doi.org/10.1016/j.animal.2021.100435.