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Article

Influence of A Cooled, Solid Lying Area on the Pen Fouling and Lying Behavior of Fattening Pigs

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Abstract: Increasing demands on animal welfare and the higher temperatures in summer due to climate change make it necessary to adapt conventional pig husbandry systems. A cooled, solid lying area has the potential to increase lying comfort and reduce the heat stress, which improves animal welfare. In the present study, the effect of a cooled, solid lying area on lying and elimination behavior was investigated. In two fattening compartments, eight pens with 28 pigs each were rebuilt. Two pen designs, different in feeder place and type, were tested. The floor was cooled from 24.5 to 20 °C by cool water in half of the pens. A total of 672 fattening pigs were tested over three fattening periods. The lying behavior was recorded by video analysis three times per week and three times per day. In the pens with a cooled lying area, 14% (SED 2.9; $p = 0.002$), respectively 12% (SED 0.9; $p = 0.0382$) more pigs were lying on the solid lying area. Additionally, the fouling of the animals was reduced by the cooling in one pen design; the results were derived from weekly scores (0.42 vs. 0.67; SED 0.058 $p = 0.0006$). The fouling of the pen was not affected by the floor cooling, however, the fouling in all pens was very low.

Keywords: cooled lying area; lying behavior; pen fouling; animal fouling; fattening pigs; solid lying area

1. Introduction

The demands on animal welfare in German pig farming have increased over the last few years and various animal welfare labels have been introduced. These entail requirements to increase the animal welfare in conventional pig husbandry systems, such as a lower stocking density, offering materials to explore and manipulate, outdoor climate stimuli or solid surfaces in the lying area [1].

The potential of solid areas to increase animal welfare rests in the fact that pigs prefer solid surfaces to partial and fully slatted areas for lying [2] and fully slatted floors pose a higher risk of injury to the legs and lameness in pigs [3,4]. The main problem with solid areas in pig housing systems is the fouling of the solid surface [5,6] and the resulting poor indoor air quality and an increased workload because the surfaces usually must be cleaned by hand.

The division of the pen into different functional areas, such as the lying or elimination area, is influenced by a variety of factors. If the housing environment allows, pigs separate their elimination, feeding and lying area [7,8]. However, factors such as a high stocking density [9], draft in the lying area [10] or high ambient temperatures [6,11] can lead to a higher risk of fouling of the lying area.

Pigs prefer wet, cool areas with low activity for elimination [10,12]. Therefore, the position of the feeder and drinker can influence the division of the functional areas by the pigs [13,14]. In addition, pigs prefer to eliminate near walls or corners, and open pen partitions may lead to more elimination because of territorial functions [15–17]. Furthermore, the light intensity in the different functional areas has an important role. The pigs showed more resting behavior in areas with dimmer light intensity [18,19] and used the areas with high light intensity mainly for elimination [19]. A previous experiment of our group showed that a high light intensity in the slatted (designated) elimination area leads to more pigs lying on the solid lying area [20].

However, one of the most important factors influencing pig behavior and fouling is the indoor and surface temperature. Pigs are more sensitive to high environmental temperatures because of their inability to sweat and pant [21]. Pigs lie on cooler surfaces, wetting their skin or wallowing to regulate or lower their body temperature [21–23]. Therefore, with increased temperature, more pigs lie on the cooler slatted area [5,24] and, consequently, the fouling of the lying area may increase [6,11]. These problems can be exacerbated due to climate change and, therefore, rising annual temperatures and extremely hot temperatures over 40 °C during the summer months, thus increasing the frequency at which animals are exposed to heat stress [25]. Heat stress can cause a higher respiration rate, lower feed intake or an increased body temperature [26–28]. Furthermore, it can cause a poor reproductivity, reduced and inconsistent growth, decreased carcass quality, increase in morbidity, mortality and processing issues [29].

There are various cooling systems in pig housing systems to reduce the heat stress and the fouling of the lying area. One possibility is to reduce the indoor temperature by systems with increased air speed, drip water or fogging. However, these systems have some disadvantages. A higher air speed can lead to fouling of the lying area [10] and can expose pigs to unhealthy conditions compared to the conventional ventilation system [30]. Systems such as cool pads for cooling the inlet air, drip water or fogging lead to changes of environmental humidity and, thus, a worse indoor climate [30]. High indoor temperature combined with a high relative humidity has the potential to increase the heat stress [6]. Another possibility of cooling is to give the animals the opportunity to regulate their body temperature by lying on a cooled surface. In contrast to the previously mentioned cooling systems, which reduce the indoor temperature, the main purpose of the floor cooling system is to remove the heat emitted by the pigs to the floor via thermal conduction. The results of Bull et al. [26] showed that pigs preferred a conductive cool pad to a drip or snout cooler. Furthermore, different studies showed that a cooled lying area leads to a lower heart rate and respiration rate [26,31], higher feed intake [32], less fouling of the lying area [33] and more pigs lying on the lying area [33,34].

In the present study, the influence of a cooled, solid lying area on the pen and animal fouling and lying behavior of fattening pigs in two different pen designs was investigated during warm periods in Germany (March to October). The hypothesis was that the cooling reduces the fouling of the lying area and the animals and increased the percentage of pigs lying on the designated solid lying area.

2. Materials and Methods

The animal welfare label of "The German Animal Welfare Association–For more Animal Welfare" ("*Deutscher Tierschutzbund–Für mehr Tierwohl*") sets different requirements concerning the pig housing systems. The project "Label-Fit" approached the implementation of the requirements in conventional pig husbandry systems (January 2017 to July 2020). The main requirements of the entry level are: 1.1 m^2 per pig (0.6 m^2 solid lying area), straw or comparative material for exploration and manipulation, maximum 3:1 animal:feeding place ratio for an automatic dry feeder, maximum 8:1 animal:feeding place ratio for a mash feeder, maximum 12:1 animal:drinking place ratio and no tail docking. The focus of this contribution is the design of the solid comfort lying area. The effect of a cooled, solid lying area was tested in two fattening compartments at the federal pig research and training center "*Bildungs- und Wissenszentrum LSZ Boxberg*." The housing and management of the animals were conducted in accordance with German legislation (TierSchNutztVO, 2017) for farm animals. Animals were visually inspected daily for health issues.

2.1. Animals

A total of 672 crossbred pigs with undocked tail (German Hybrid × German Piétrain) were used in two compartments with four pens each over three fattening periods. Twenty-eight eleven-week-old pigs per pen, 50% females and 50% castrated males, were fattened over 17 weeks. The average live weight was 29.1 ± 3.8 kg per pig at the beginning and 117.9 ± 11.2 kg per pig at the end of the fattening period. To determine the daily weight gains for each pig, the difference between the weights on the first day of fattening and the day of slaughter was divided by the number of days of fattening. The daily weight gain was 930 ± 128 g per pig.

2.2. Housing

The effect of the cooled lying area was tested in two fattening compartments (B1 and B2) with four pens in each (Figure 1). The compartments were temperature controlled by forced ventilation with an air supply from outside through the attic and a porous ceiling. There was also the option of cooling the inlet air using a cooling pad. The cooling pad was switched on when the compartment temperature was over 23 °C and the relative humidity in the compartment was less than 50% and switched off when the relative humidity rose above 85%. According to the study by Pertagnol [35] at the "*Bildungs- und Wissenszentrum LSZ Boxberg*," the cooling pad lowered the temperature in the compartment by 4.9–5.2 °C. During the periods when the cooling of the lying area was tested, the set ventilation temperature decreased from 25 °C (day 0) to 22.5 °C (day 15) to 19 °C (day 60) and stayed at 18 °C (day 120) until the end of the fattening period. The minimum ventilation rate was 25%. The fattening compartments were illuminated by a total of six fluorescent tubes (warm white light) and three windows at the front of each compartment. The light in the compartments was switched on from 7 a.m. to 6 p.m.

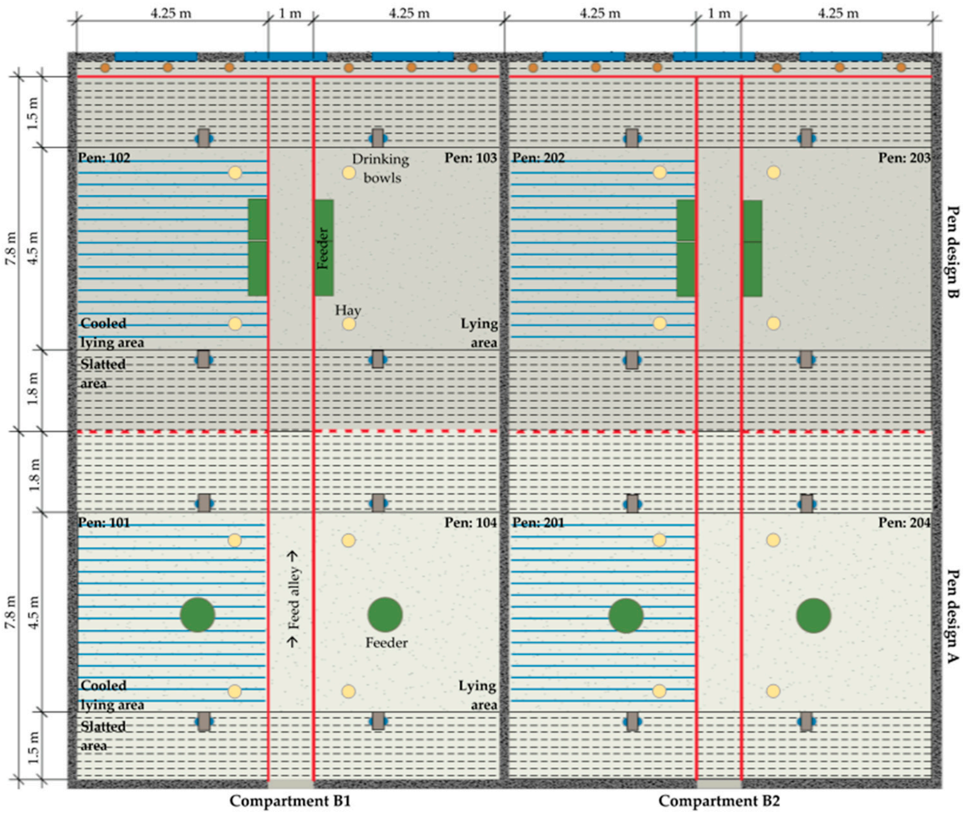

Figure 1. Two compartments with the experimental pen designs A and B.

Each pen had an area of 4.25 × 7.8 m, including a lying area of 4.25 × 4.5 m (58% of the total pen area, 0.6 m^2 per pig) between the slatted areas (Figure 1). The solid concrete lying area had a maximum perforation of 3% (drainage) and the concrete slatted floor had <15% perforation with a slat width of 17 mm and 83 mm between the slats.

Two pen designs (pen design A and B), different in placement and the type of the feeder, were tested in this experiment (Figure 1). The type of feeder used in pens of design A (pens 101/104, 201/204) was a round tube mash automat type "Optimat" (Schauer Agrotonic GmbH, Prambachkirchen, Austria) with a 3.5:1 animal:feeding place ratio (Figure 2a). Feeders were located in the middle of the lying area. The fattening pigs in pens of design B (pens 102/103, 202/203) were fed by a plateau combination feeder (L. Verbakel BV, Sint-Oedenrode, The Netherlands) with a 3.5:1 animal:feeding place ratio. These feeders were located in the middle of the partition of the pen towards the feed alley (Figure 2b).

(**a**) (**b**)

Figure 2. Photos of pen of (**a**) design A and (**b**) design B.

All pigs were fed ad libitum in a two-phase feeding regime. The diet in the beginning contained 13.3 MJ/kg and 170 g/kg crude protein. From a live weight of 80 kg, the diet contained 10.8 MJ/kg and 145 g/kg crude protein.

All pigs had free access to water from four drinking bowls, "Suevia 95S" (Suevia Haiges GmbH, Kirchheim/Neckar, Germany), which were located on both slatted areas.

The pigs had free access to hay, wooden beams and hamper rows, each at two locations in each pen, for exploration and manipulation. Approximately 30 g/pig of chopped straw was spread automatically on the lying area by the automatic straw distribution system "Spotmix Welfare" (Schauer Agrotonic GmbH, Prambachkirchen, Austria) twice per day (11 a.m. and 3 p.m.).

Food and straw were spread over the lying area and the slatted area on both sides was wetted by water before every fattening period. In case of fouling, the lying area was cleaned during the first five days by hand. If necessary, the lying area was cleaned up after the weekly scoring during the whole period in order to prevent a bad indoor climate.

2.3. Floor Cooling System

The lying area in two pens, one of each design, in both compartments, was cooled by water. Solid concrete floor elements made by the company "DELA" (DELA GmbH, Töging am Inn, Germany) with built-in stainless steel water pipes were installed to cool the floor. The floor elements were laid in three rows per pen and four to five elements were connected in a row (Figure 3).

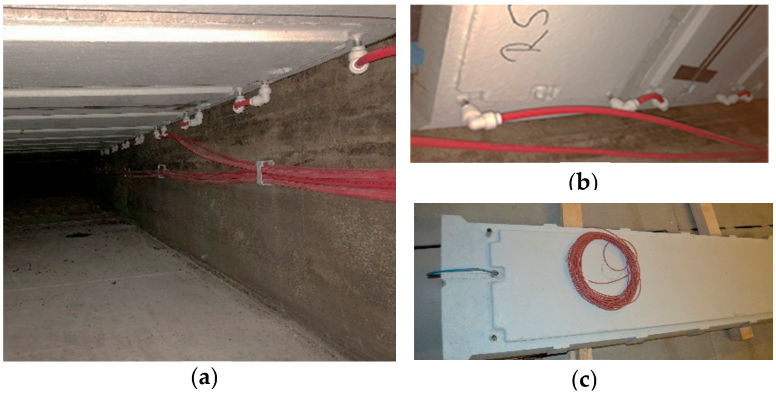

Figure 3. (**a**,**b**) Solid concrete floor elements connected in a row of four or five elements; (**c**) solid concrete floor element with built-in stainless steel water pipes and embedded temperature sensor.

The water required was cooled down to about 12 °C with a heat exchanger (Buderus, Bosch Thermotechnik GMBH, Wetzlar, Germany) and then mixed with warm water until the target temperature was reached. The temperature of the flow and the return were measured continuously to control the floor cooling system. The temperature for the lying area was regulated by the temperature of the return. The set temperature curve of the floor cooling system over the fattening period ranged from 24.5 °C (day 0) to 21.5 °C (day 28) and was kept at 20 °C (day 52) until the end of the fattening period. The floor cooling system was in operation during the first thirteen weeks of each period. Later on, the system was only used when needed, due to the lower stocking density and, therefore, lower heat production.

2.4. Data Collection

Thirty-two sensors, shown in Table 1, were installed in both fattening compartments.

Table 1. Overview of the sensors used in this study. All sensors recorded data every minute.

Measured Variable	Unit	Number/ Position	Measuring Range/Accuracy	Sensor Type
Relative humidity	%	2 per compartment, between the pens of each side, 1.5 m above the floor	Range 0%–100%, accuracy 5% (±2.5% for 23 °C)	MELA Feuchtesensoren IBF2.11.F100.C97.1K6
Room temperature	°C	6 per compartment, between pens of each side and above the lying area in each pen, 1.5 m above the floor	Range 190–260 °C	SensorShop 24, Kabelführer
Surface temperature		8 per compartment, embedded in the floor elements 1 cm below the surface of the lying and slatted area in each pen	Range 35–400 °C	SensorShop 24, Oberflächenfühler

From week thirteen the heaviest animals were slaughtered, so that the stocking density in the pens decreased weekly. From the fourteenth week, the number of animals per pen was mostly reduced and, thus, the data were no longer suitable for analysis. Consequently, the lying and elimination behavior was recorded during the first thirteen weeks of the fattening period. Each pen was monitored and recorded by two video cameras (HIKVision DS-2CD2125FWD-1) continuously during this time.

For determining the daily activity and resting pattern, three time slots per day were defined for recording the lying behavior. For this purpose, the percentage of lying animals was recorded every 15 min over one fattening period. The three time slots per day with the highest probability of lying pigs were 5–6 a.m. (morning), 10.30–11.30 a.m.; (noon) and 8–9 p.m. (evening). The lying behavior was recorded in these three time slots using scan sampling on three days in the fattening weeks 1–13. A total of 114 observations were usually made per period and pen, however, failures in data acquisition due to defects or contamination of the camera occurred occasionally. A screenshot of the first moment when all or the most pigs were lying was used during each time slot. These screenshots of the pen were segmented into fifteen parts: Nine parts on the lying area and six parts on the slatted area (Figure 4). The number of pigs lying in each segment were recorded. Pigs lying on the line were assigned to the segment in which more than half of the body or the head was located. All pigs lying on their side or belly with legs stretched out or folded underneath were counted. The percentage of all pigs lying on the solid floor was calculated for each time of sampling for each pen for the data analysis of the lying behavior. One person exclusively executed the evaluation of the lying behavior by video analysis.

Figure 4. Fifteen segments of pen 201 to determinate the lying behavior and the fouling.

The fouling of all pens and all animals by feces and urine was also recorded to assess the division and use of the functional areas by the pigs. For this, weekly scores, usually thirteen observations per fattening period and pen during the first thirteen fattening weeks, were used (failures in data were possible). These weekly scores were mainly done by the same person.

The pen was segmented into fifteen parts to determine the fouling of the surface (Figure 4). The scores for the fouled area were as follows: grade 0 (0%–10% fouling), 1 (>10%–25% fouling), 2 (>25%–50% fouling), 3 (>50%–75% fouling) and 4 (>75%–100% fouling).

Additionally, the fouling of the animals was scored weekly from the second to the thirteenth week of fattening at the same time as the pen fouling (usually twelve observations per fattening period and pen; failures in data were possible). Both sides of each pig were scored: 0 (not fouled), 1 (slightly fouled), 2 (one body part fouled), 3 (two or more body parts fouled) and 4 (completely fouled). The average grade of both sides of the body were divided into three categories for the data analysis: 0 (not fouled, average grade 0–1), 1 (slightly fouled, average grade 1.5–2.5) and 2 (heavy fouled, average grade 3–4).

2.5. Data Aggregation

Depending on the fattening week—and therefore the age of the pigs—the data of the lying behavior were aggregated in three fattening phases (phase 1 from weeks 1–4, phase 2 from weeks 5–8 and phase 3 from weeks 9–13). Means were calculated for each time of day (morning, noon and evening) for each of these fattening phases. Thus, nine means (three phases × three times of day) were used for each pen and fattening period in the data analysis.

The fouling of the lying area was analyzed by weekly average scores (grade between 0–4). A weekly average value was calculated from the amounts of the three categories for the fouling of the animals.

The indoor temperature may have a great influence especially regarding the acceptance of the cooled lying area. The difference between compartment and set ventilation temperature is defined as a deviation from the set ventilation temperature, which was used for the statistical analysis. Averages over the hour before data collection were used for the effect on the lying behavior because the fatteners can adapt their lying behavior quickly to the current temperature. The average temperatures over the three days before scoring were used for the fouling of the pen and animals.

2.6. Experimental Design and Statistical Data Analysis

The two compartments represented the spatial repetition of the cooling treatment in this experimental design. The three fattening periods represented the temporal repetitions. The pigs were allocated to the pens randomly, but an equal distribution of sex and weight over all pens was ensured. Thus, the measurements on the pen level were considered statistically independent.

A randomized arrangement of the two pen designs inside the compartments was not possible because the building alteration effort after each period would were too high. Therefore, the two pen designs are only compared descriptively, and the differences cannot be statistically evaluated.

All data were analyzed with a linear mixed model (procedure GLIMMIX, SAS 9.4®). The fattening compartments (B1 and B2), the cooling (with and without) and their interaction were used as fixed effects for the daily weight gain. The fattening period (1–3) was set as a fixed design effect.

The factors fattening phase (1–3), time of day (morning, noon, evening) and cooling (with and without) and their interactions were taken as fixed effects for the lying behavior. The design effect fattening period (1–3) was also set as a fixed effect. The deviation from the set temperature was used as a covariate because of an expected influence on the lying behavior. In addition, the interactions of the covariate with cooling were also tested. The method by Kenward and Roger [36] was used for computing the denominator degrees of freedom for the tests of fixed effects. The random effects for period*compartment and period×compartment×pen were assumed to be serially correlated across the levels of phase and time of day, thus, accounting for the repeated measures nature of the data. The anisotropic power covariance structure was assumed for both random effects, allowing for separate autocorrelations for phase and time of day.

The fouling of pens and animals was also analyzed with a linear mixed model (procedure GLIMMIX, SAS 9.4®). The factors week (1–13), cooling (with and without) and their interaction were taken as fixed effects. The fattening period (1–3) was set as a fixed design effect. Similar to the analysis of the lying behavior, the deviation from the set ventilation temperature was used as a covariate. The interactions of the covariate with cooling (with and without) was also tested. The method by Kenward and Roger [36] was used for computing the denominator degrees of freedom for the tests of fixed effects. The effect of week (1–13) was also considered as a random effect for the interactions period*compartment, period×compartment×pen and period×compartment×cooling. The anisotropic power covariance structure was used to estimate the random effects.

Approximate normal distribution and homogeneity of variance of the studentized residuals were confirmed graphically for both models using QQ plots and plots of residuals versus predicted values. The data of pen and animal fouling were not normally distributed; therefore, they were transformed by taking the square root. No fixed or design effects were removed from the models. Comparisons of means were conducted using the Edwards–Berry procedure for controlling the family wise type I error rate at a level of $\alpha = 5\%$ [37]. Furthermore, estimated effects with $p < 0.1$ were considered to be suggestive of real effects. We are reporting differences of adjusted means as measures of effect size, along with the mean standard errors of a difference (SED) and p-values in the main text.

3. Results

3.1. Temperature and Relative Humidity

The mean indoor temperature and relative humidity of all sensors for each compartment and period are shown in Table 2.

Table 2. Average temperature and relative humidity (± standard deviation) for each fattening compartment and period (records taken every minute).

Period	Measuring Period (Day/Month/Year)	Compart-ment	Temperature (°C)	Relative Humidity (%)
1	11.07.18–07.10.18	B1	22.1 ± 3.0 (min. 15.1; max. 30.5)	53.0 ± 5.1 (min. 36; max. 84)
	01.08.18–24.10.18	B2	23.3 ± 2.3 (min. 12.1; max. 28.8)	49.0 ± 7.3 (min. 20; max. 85)
2	20.03.19–16.06.19	B1	21.2 ± 1.9 (min. 16.4; max. 32.7)	42.9 ± 8.5 (min. 17; max. 68)
	09.04.19–07.07.19	B2	23.2 ± 2.1 (min. 17.2; max. 32.3)	42.8 ± 9.6 (min. 20; max. 69)
3	24.07.19–20.10.19	B1	22.2 ± 2.6 (min. 15.3; max. 30.0)	51.1 ± 2.9 (min. 30; max. 63)
	14.08.19–10.11.19	B2	20.9 ± 2.3 (min. 13.2; max. 27.9)	48.7 ± 5.4 (min. 32; max. 68)

Hourly averages were determined based on records taken every minute. Data were collected over 16,180 h during the three fattening periods. The temperature was over 23 °C in 5455 h and, thus, the cooling pad was active for the same time. The temperature in the compartments was above 28 °C in 181 h.

3.2. Daily Weight Gain

The data of 631 fattening pigs were used for the analysis of the daily weight gain. Data from 24 pigs were not used as they were removed from the pens due to injury or disease. The average daily weight gain in both pen designs was nearly the same (Table 3).

Table 3. Average daily weight gain for each pen design. *n* = number of pigs; usually 168 pigs per pen design and treatment. SD = standard deviation.

Pen Design	Treatment	*n*	Mean (g/d)	SD (g/d)	Min. (g/d)	Max. (g/d)	Median(g/d)
A	Cooling	162	940	94	673	1188	937
	Control	163	942	102	635	1198	948
B	Cooling	150	942	109	667	1196	950
	Control	156	939	118	597	1142	956

The cooling had no effect on the daily weight gain of the pigs, but both the fattening compartment and the fattening period had an influence. The daily weight gain in pen design B in compartment B1 is higher than in B2 (pen design A: B1 949 g/d vs. B2 933 g/d, SED 9.5, $p = 0.0838$; pen design B: B1 967 g/d vs. 915 g/d, SED 11.2, $p < 0.0001$). Furthermore, the periods had a significant effect on the daily weight gain in all pens: In pens of design A: period 1:992 g/d, period 2:879 g/d and period 3:952 g/d (mean SED 8.2, $p < 0.0001$) and in pens of design B: period 1:976 g/d, period 2:868 g/d and period 3:980 g/d (mean SED 8.2, $p < 0.0001$).

3.3. Floor Cooling System and Surface Temperature

The temperatures of the surfaces and of the flow and return were examined in more detail to assess the functionality of the floor cooling system. Therefore, mean values for the temperatures were formed from the records taken every minute over all periods.

Figure 5 shows the average profile of all surface temperatures of the lying areas and the flow, return and set temperature of the floor cooling system over all fattening periods.

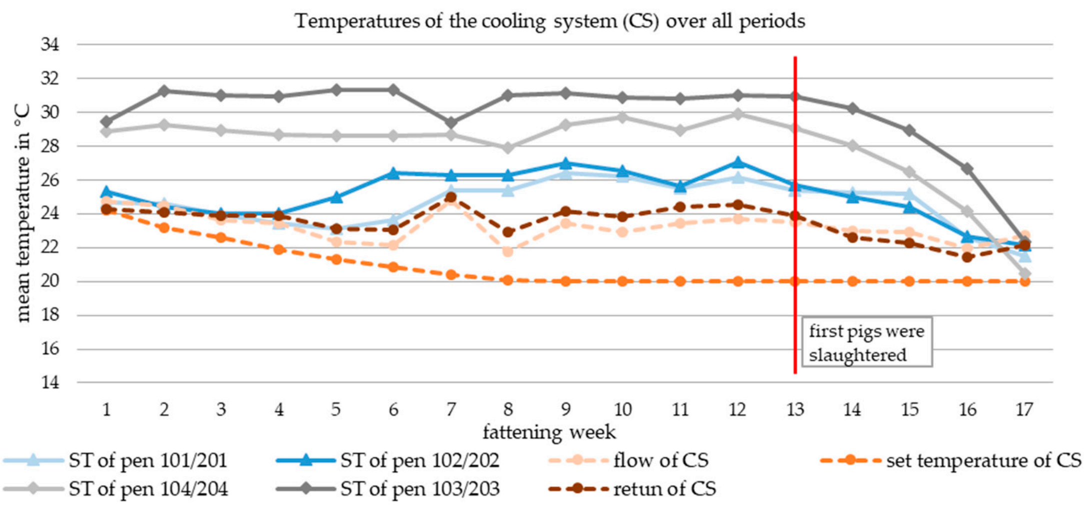

Figure 5. Average profile of all surface temperatures (ST) of the lying areas and the flow, return and set temperature of the floor cooling system (CS) over all fattening periods. The mean temperatures for each fattening week, which were formed from the records taken every minute by thirteen sensors over the three fattening periods, are shown. Each profile, except the set temperature of the floor cooling system, contains data of two sensors, one in each compartment.

The mean temperature of the water that entered the floor cooling system (flow) was 23.1 ± 3.3 °C. The mean return temperature was 2.6 ± 2.5 °C higher than the set temperature of the floor cooling system. Furthermore, the mean flow temperature was 1.9 ± 3.7 °C lower than the surface temperature. Although the temperature of the flow and return of the floor cooling system was mostly higher than the set temperature of the floor cooling system, the surface temperature of the cooled lying areas over all fattening weeks was clearly lower than that of the control pen lying areas.

The mean surface temperatures of the lying areas over all three periods and pens were as follows: with cooling 25.1 ± 3.0 °C (pen design A 24.7 ± 2.9 °C; pen design B 25.4 ± 3.3 °C) and without cooling 29.7 ± 3.3 °C (pen design A 27.7 ± 4.4 °C; pen design B 30.4 ± 3.1 °C). The mean difference in surface temperatures between the cooled and control lying areas was 3.8 ± 6.7 °C (pen design A: 2.6 ± 8.2 °C; pen design B: 5.3 ± 3.8 °C).

3.4. Lying Behavior

The average proportion of animals actually lying at the times of day chosen were calculated to verify the choice of the three times of day for the evaluation of the lying behavior. The average proportions for the three times of day were morning 99.85%, noon 94.69% and evening 99.83%.

The cooling of the lying area has a significant effect on the lying behavior in both pen designs (Figure 6). About 73% of the pigs lay in the lying area in pens of design A with cooling; only 59% lay on the solid lying area in the control pens without cooling (SED 2.9; $p = 0.002$). A similar effect was seen in pens of design B, with 74% with cooling and 62% without cooling (SED 2.9; $p = 0.0098$). The time of day also has a significant effect on the lying behavior in pens of the design A. About 67% of the pigs lay on the solid lying area in the morning, about 64% at noon and about 66% in the evening. The difference between morning and noon was significant (SED 0.9; $p = 0.0382$).

The deviation from the set ventilation temperature in the pens of design A had a significant effect on the lying behavior ($p = 0.0257$). Furthermore, the deviation of the set ventilation temperature in pens of design B has a tendential effect on the lying behavior ($p = 0.0873$). Regardless of the deviation from the set ventilation temperature, more pigs usually lay on the cooled lying areas (Figure 7).

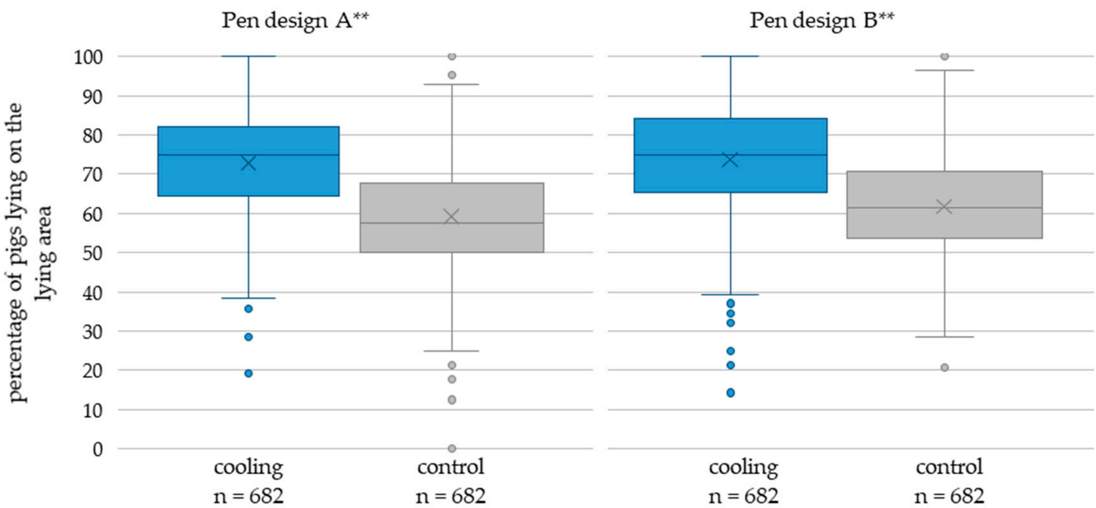

Figure 6. Effect of the floor cooling on percentage of pigs (relative to total number of lying pigs) lying on the solid lying area for pen design A (73% vs. 59%; SED 2.9; $p = 0.002$) and B (74% vs. 62%; SED 2.9; $p = 0.0098$) (* = significant effect with ** < 0.01; n = number of observations, usually 114 per and period, each boxplot contains data of two pens).

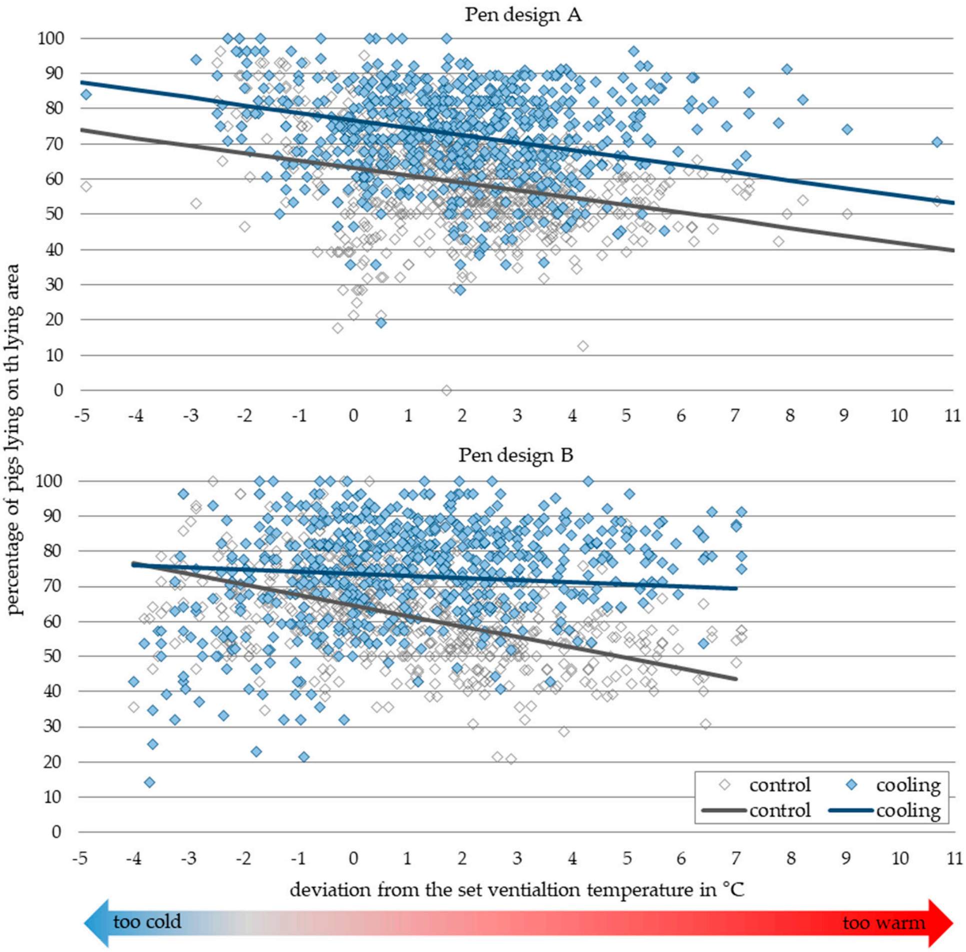

Figure 7. Effect of the deviation from the set ventilation temperature on the percentage of pigs (relative of the total number of lying pigs) lying on the solid lying area in pen design A and B. The diamonds show the raw data and the lines show the trend line.

With increasing positive deviation, the number of pigs lying on the solid lying area decreased in all pens, except for the pens of design B with floor cooling.

3.5. Fouling of Lying Area and Animals

The mean fouling of the lying area (Figure 8) in all pens was lower than score 1 (>10%–25% fouling). The mean fouling of the animals in all pens was also lower than score 1 (slightly fouled). No significant effect of the floor cooling on the fouling of the lying area was found.

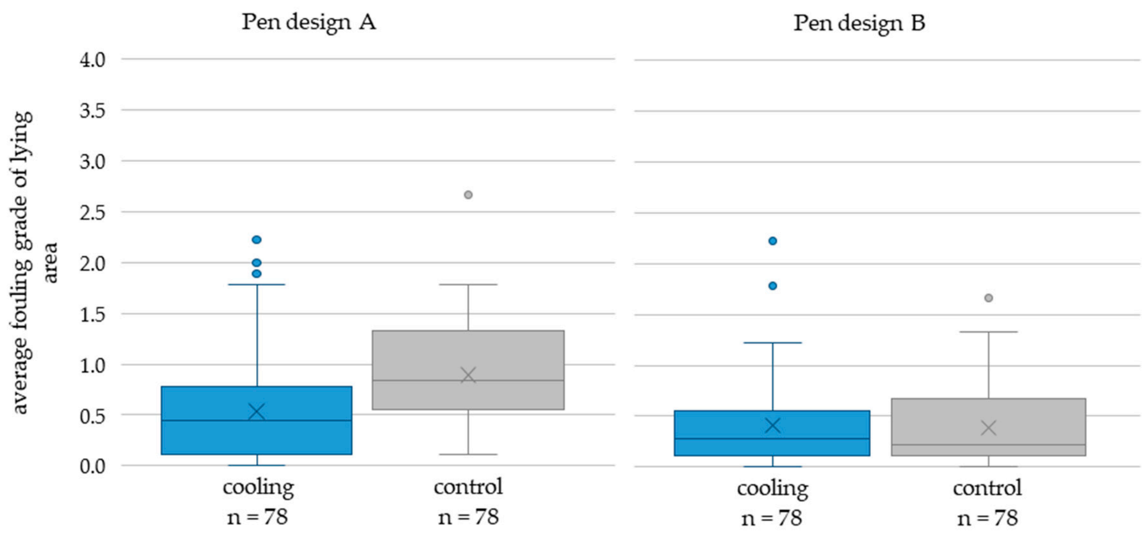

Figure 8. Scoring results of the fouling of the lying area for pen design A and B (*n* = number of observations; usually 12 observations per period and pen, each boxplot contains data of two pens).

The cooling of the lying area effected the fouling of the animals in pens of design A (Figure 9). The fouling score in pens with cooling was about 0.42 and in those without cooling about 0.67 (SED 0.058, $p = 0.006$). Furthermore, the fattening period effected the fouling of the animals in all pens, regardless of the cooling (pen design A: SED 0.05, $p = 0.0094$; pen design B: SED 0.062, $p = 0.0391$). The fouling of the animals was lowest during the second period (pen design A: 0.43; pen design B: 0.47) and highest during the third period (pen design A: 0.65; pen design B: 0.62).

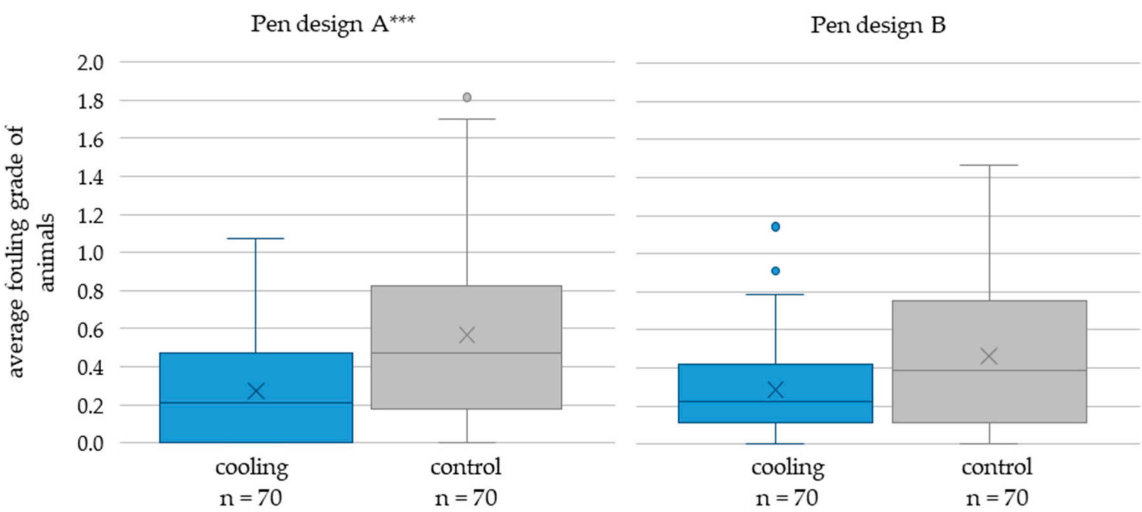

Figure 9. Effect of the floor cooling on the average fouling of the animals for pen design A (0.42 vs. 0.67; SED 0.058 $p = 0.0006$) and B. (* = significant effect with *** < 0.0001; *n* = number of observations; usually 12 observations per period and pen, each boxplot contains data of two pens).

The deviation from set ventilation temperature had a highly significant effect on the fouling of animals in both pen designs (pen design A: $p < 0.0001$; pen design B: $p < 0.0001$). Regardless of the deviation from the set ventilation temperature, the pigs in pens with a cooled lying area were usually less fouled (Figure 10). The higher the positive deviation, the higher the fouling of the animals.

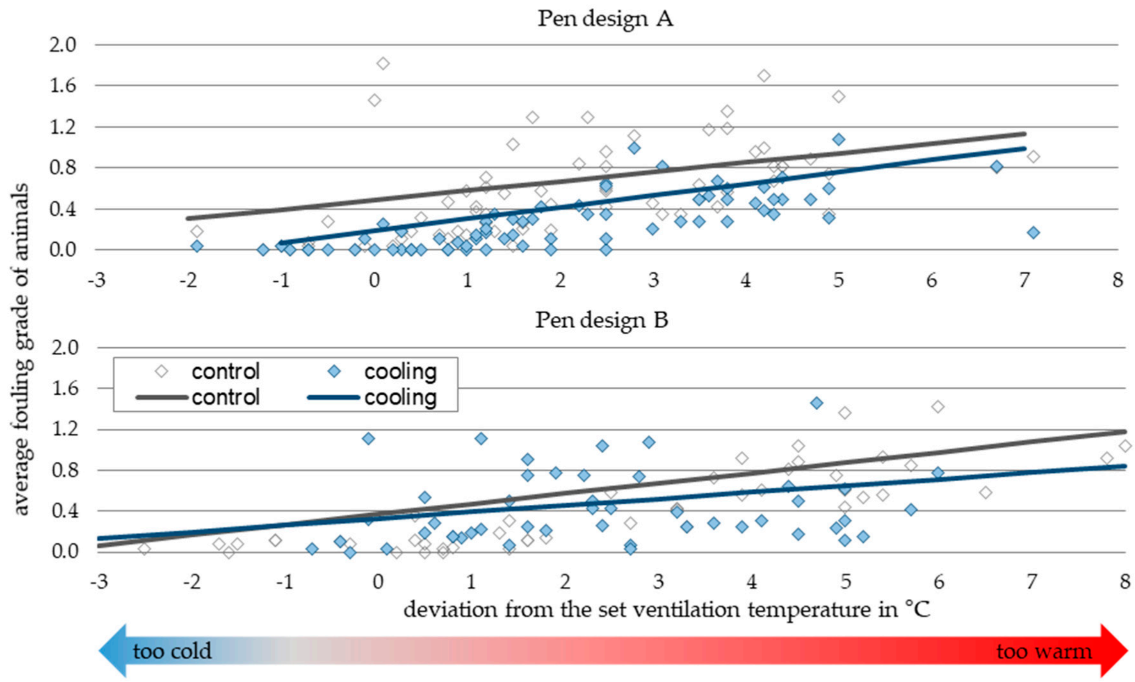

Figure 10. The effect of the deviation from temperature on the average fouling of the animals. Diamonds show the single data and the lines shown the trend line.

4. Discussion

4.1. Experimental Setup

The pen structure proved to be functional and no adjustments were necessary. The time slots defined for the evaluation of the lying behavior of the animals appeared suitable. The time of day has a significant effect on the lying behavior in pens of design A. The difference between morning (67%) and noon (64%) could be related to the diurnal rhythm of the pigs. Pigs show the lowest activity during the night phase [38,39]. Furthermore, the feeders were refilled between 9 and 10 a.m. if necessary, which could lead to more activity just before noon.

4.2. Temperature and Relative Humidity

The relative humidity was low during all fattening periods with means between 41% and 53%. These low values could be achieved despite the activity of the cooling pad over 33% of the time. The median of the relative humidity on days with the active cooling pad and temperatures above 22 °C during a previous study in Boxberg with this cooling pad (active at an outside temperature of over 24 °C, maximal relative humidity at 80%) was 72.2% [35]. According to DIN 18910-1 [40], the relative humidity in stables without heating should be between 60% and 80% and between 40% and 70% in houses with heating. A low relative humidity can have a positive effect on the pigs. If the relative humidity is high, it has the potential to reinforce the effects of high temperatures and cause heat stress. Furthermore, a low relative humidity can reduce the urination on solid areas [6]. A negative effect of a low humidity could be an increased dust content and, as a result, a higher risk of disease transmission through the dust and a higher risk of respiratory diseases [41–43]. Unfortunately, the relative humidity requirements were not always met during these tests. However, it was not possible to find why the relative humidity was that low.

4.3. Functionality and Efficiency of the Floor Cooling System

The entire floor cooling system worked very well. The return temperature deviated by an average of 2.6 ± 2.5 °C from the set temperature. Thus, the regulation by the return temperature proved to be a good possibility to control the floor cooling system. Furthermore, the mean differences between the surface temperature and the flow show the cooling efficiency of the system. The cooling efficiency seemed to be very good, with a mean difference of 1.9 ± 3.7 °C for all four pens with floor cooling systems. Yuan et al. [30] tested different water-based cooling lying beds for pigs. Beds made of iron and concrete showed the smallest differences between the water and the surface temperature (5.54 °C and 3.91 °C) and the system with concrete and PVC pipes had the highest difference.

The main purpose of the floor cooling system is not to reduce the indoor temperature, but to remove the heat emitted by the pigs to the floor via thermal conduction. The total heat production of pigs in the weight range from 54 to 118 kg, depending on the temperature, was from 2.82 W/kg (16 °C) to 2.19 W/kg (28 °C) [44]. The mean temperature of the water that entered the floor cooling system was 23.1 ± 3.3 °C and caused the mean surface temperature to be 25.1 ± 3.0 °C. By comparison, the mean surface temperature without cooling was about 29.5 ± 3.7 °C. Therefore, the removal of the heat by the floor cooling system was determined. In the study by Silvia et al. [32], water circulates at about 17 °C and resulted in floor temperatures of 27.6 °C and 35.8 °C. The ideal cooling lying bed in Yuan et al. [30] has a low flow temperature (15–18 °C) for adult pigs exposed to air temperatures above 30 °C. The heat pump failed temporarily during the first fattening period (end of B1 to the middle of B2). Consequently, the water flowed through the floor at about 22 °C (min. 17 °C and max. 28.5 °C). However, the floor was cooler, and the heat of the pigs was removed even in these periods. Therefore, a floor cooling system that uses groundwater for cooling would be conceivable.

The most important effect is the acceptance of the cooled floor by the animals. With 73%/74% (pen design A/B) of pigs resting on the lying area, a surface temperature of 24.5/25.3 °C (pen design A/B) seems to be comfortable for the them. Similar results were shown in the study of Shi et al. [34], where more than 85% pigs lay on the solid floor when the surface temperature was below 26 °C, while only 10%–20% of the pigs lay there when the floor temperature was about 30 °C. The difference in the percentage of pigs lying in the lying area between Shi et al. [34] and our study can be explained by the indoor temperature. In our study, the indoor temperature of 22.9 °C over all fattening periods was clearly lower than in the other study with 27.7 °C.

4.4. Effect of Floor Cooling on Weight Gain and Behavior

The daily weight gain of the pigs was not affected by the cooling. Several studies showed that a cooling can led to a higher feed intake and growth rate [32,33,45]. On the other hand, heat stress can cause reduced feed intake, depressed growth rates and body weight loss [46]. However, the air temperatures were significantly higher in other studies than in this study, which could explain the lack of a cooling effect on the daily weight gain in this study. Furthermore, the pigs in this study with daily gains of 939–942 g per pig performed very well (German average of 842 g [47]). Under higher ambient temperatures or in systems with less performing animals this floor cooling system has the potential to raise the production performance and therefore the profitability, which could compensate the higher costs of the system.

The cooling had a significant effect on the lying behavior and, therefore, also on the acceptance of the designated lying area by the pigs. A total of 73%/74% (pen design A/B) of the pigs lay on the lying area in pens with cooling, while only 59%/62% (pen design A/B) lay on the lying area in pens without cooling. Further studies showed that a cooling of the lying area could lead to more pigs lying on the lying area [33,34]. If the proportion of the lying area regarding the entire pen area (58%) is considered, the animals seems to have spread over the entire pen area in pens without cooling. When pigs expanded their body surface with a temperature increase by lying on their sides and lay less against other pigs, they needed more space for lying [5,48].

When evaluating the cooling effect, it is important to consider the indoor temperature and the thermoneutral zones. In this study, the indoor temperature was considered in the form of the deviation from the set ventilation temperature. This deviation was an efficient measure to assess the influence of the indoor temperature on the pigs, because the different thermal needs depending on the life weight were considered. Hillmann et al. [49] showed that the thermal tolerance of pigs with a bodyweight of 25–35 kg is 19–21 °C, 10–17 °C for pigs between 50–70 kg and 5–17 °C for pigs heavier than 85 kg. The results of the lying behavior show the positive effect of floor cooling very well, because even when the indoor temperature is too high, the pigs did not change their lying behavior and stayed on the solid area. The effect that with increasing temperature more pigs lay on the slatted floor has been shown in many studies [5,6,24,33,48]. The results of Spoolder et al. [48] showed that 1.39% more pigs lay on the slatted floor with every increasing degree from 16 to 30 °C. This effect was reduced or even avoided by the floor cooling in this study.

No significant effect of the floor cooling on the fouling of the lying area was found. However, the mean fouling of the lying area in all pens was very low. The results of Huynh et al. [33] showed less fouling of the solid lying area by cooling of the floor. Aarnink et al. [5] showed that above a certain inflection air temperature, the fouling of the solid area increased. The inflection air temperature was about 24 °C and above 26 °C when 50% of the solid floor was fouled by excrement. This effect could be slightly reduced by the floor cooling in this study.

The cooling had a positive effect of the fouling of the animals in pen design A. The intention to record the fouling of the animals was to recognize whether the animals were lying on the slatted designated elimination area or started wallowing because of higher air temperatures [50–52]. The feeders in pen design A had an open water surface, which allows the pigs to wet the area around the trough for wallowing. This behavior could be observed during the weekly scoring in both pens of design A, but the floor cooling reduced the fouling of the animals significantly. If the fouling of the animals is attributed to wallowing for body temperature regulation, this effect could show that cooling improves the welfare of the pigs by reducing heat stress. This assumption can be supported by the fact that the pigs in the cooled pens were less fouled even if the temperature was too high (Figure 10).

4.5. Effect of the Pen Design

Since a randomization of the pen arrangement within the compartments was not possible, the differences between the two pen designs can only be evaluated descriptively. With respect to all investigated parameters no huge differences were found between the two designs of pen structure. Considered subjectively, pen design B showed a better performance in fouling of the lying area than pen design A. This could be due to either the location or the type of the feeding system. As has already been mentioned, the feeder of pen design A had an open water surface, which could lead the pigs to wet the area around the trough for wallowing and eliminate in this wet area. The feeding in pen design B located in the middle of the partition of the pen towards the feed alley, apparently led the pigs to separate the functional areas better. The pigs in this design had the opportunity to eliminate as far as possible away from the feeding, as they seem to prefer it [7,53]. This experience had already been acquired in previous experiments of this project with similar pen designs [20].

5. Conclusions

The results show that a cooled, solid lying area leads to a higher percentage of pigs lying in this lying area—even if the indoor temperature is too high. The cooling had no effect on the fouling of the surfaces, but it reduced the fouling of the animals. This effect was not affected of the placement and the type of feeder. Cooling has the potential to improve the use of the lying area in warmer conditions. In conclusion, cooling of the lying area seems to be a promising tool for further improvements of the lying and elimination area. An intelligent control that automatically adjusts the cooling depending on the indoor temperature would be an option for optimization. Furthermore, this system could be used to heat the floor during colder ambient temperatures. The system can also be economically optimized when used for cooling and heating by utilizing a heat exchange concept. In view of the current climate developments, it is very important to optimize the house climate in pig holding systems. The floor cooling here offers a clear advantage that the relative humidity is not increased and is, therefore, a good option to combine systems that lower the air temperature, such as cooling pads or water misting.

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