Journal of Animal Science, 2022, **101**, 1–13
https://doi.org/10.1093/jas/skac413
Advance access publication 22 December 2022
Non ruminant nutrition

OXFORD

AMERICAN SOCIETY OF ANIMAL SCIENCE

Effects of thermal conditions on gestating sows' behaviors and energy requirements

Justine Abarnou, Maëva Durand, Jean-Yves Dourmad, and Charlotte Gaillard[1]

Institut Agro, PEGASE, INRAE, Saint Gilles, France
[1]Corresponding author: charlotte.gaillard@inrae.fr

Abstract

Room temperature and individual behavior may influence the energy requirements of gestating sows. These factors are not yet integrated on a daily and individual basis in the calculation of these requirements. The objective of this study was to quantify the effect of temperatures on the sows' behaviors, especially on the level of physical activity, and on the energy requirements of gestating sows. Over four consecutive weeks, the temperature of two gestation rooms was maintained at medium temperatures (16.7 °C and 18.5 °C, respectively, for room 1 and room 2) for the first and third week, at low temperatures (14.4 °C and 15.3 °C) for the second week, and at high temperatures (31.6 °C and 31.9 °C) for the fourth week. Individual behavior was manually recorded based on videos and the data used to estimate the physical activity and social interactions of 37 gestating sows separated into two groups. The videos were analyzed over two periods of 5 h ("Feeding period" from 2300 to 0400 hours, "Resting period" from 1330 to 1830 hours). The energy requirements were calculated by the InraPorc model, modified for gestating sows, on the basis of a thermo-neutral situation and an average activity of 4 h standing per day for all the sows. The sows of one group were less active in high than low temperatures (83 vs. 103 min standing or walking over 5 h, $P < 0.001$). Isolation for high temperatures or huddling for low temperatures could be observed when sows were lying down. The sows spent more time lying laterally with high temperatures than low temperatures (66% vs. 52% of time spent lying, respectively, $P < 0.001$). Both groups reacted differently to high temperatures, in one the sows changed their activity (lying more) whereas in the other they drank more water compared to medium temperatures (11 vs. 8.5 L/d, $P = 0.01$). In one group, with high temperatures the sows were fed above their requirements (they should have received 110 g of feed per day per sow less, $P < 0.001$) and with low temperatures the same group should have received 50 g/d per sow more to fulfill their requirements. For the second group of sows, the temperatures did not significantly affect the feed requirements. In conclusion, daily ambient temperature and individual physical activity seem to be relevant information to add in nutritional models to improve precision feeding.

Lay Summary

Ambient temperature may influence the energy requirement of gestating sows, but this factor is not yet integrated daily in the calculation of this requirement. The objective of this study was to quantify the effect of temperatures on sow's behavior, physical activity, and energy requirements on gestating sows. The 37 gestating sows were housed in two groups for which the temperature of each room was maintained at different temperatures during four consecutive weeks: the first and third weeks at 18 °C on average (medium temperature), the second week at 15.5 °C (low temperature), and the last one at 32 °C (high temperature). The sows modified their behavior regarding the room temperature even though these changes differed regarding the group of sows. Compared to medium temperature, high temperatures may induce an increase of water consumption or of the time spent lying, and of the rectal temperature of some sows. Low temperatures may induce huddling and/or an increase in aggressiveness. Low and high temperatures seem to impact energy costs even though it depends on the group of sows. Therefore, ambient temperature and individual activity are relevant information to add into nutritional models to improve their accuracy of energy requirement prediction.

Key words: behavior, energy requirements, gestating sows, physical activity, precision feeding, temperature

Abbreviations: BT, backfat thickness; BW, body weight; ESF, electronic sow feeder; RT, rectal temperature; SID lysine, standardized ileal digestible lysine; THI: temperature-humidity index

Introduction

Sow feeding represents about 40% of the total cost of weaning piglets' production (IFIP, 2018). This feed cost is directly linked to the nutritional requirements of gestating sows and therefore depends on several factors such as sow's body condition, parity, physical activity, and even the ambient temperature (Dourmad et al., 2008; Huber, 2019). Precision feeding is a recent strategy based on the adjustment of the amount and composition of the rations regarding individual sows' requirements in order to improve nutritional efficiency (Dourmad et al., 2017; Gaillard et al., 2019) and consequently to reduce feed cost and environmental wastes (Pomar et al., 2009; Monteiro et al., 2017; Brossard et al., 2020). This adjustment is possible thanks to the development of models, like the one for gestating sows derived from InraPorc (Dourmad et al., 2008; Gaillard et al., 2019), able to calculate individual nutrient requirements each day; and thanks to automatic feeder able to mix two diets and distribute individual rations. Unproductive energy requirements combined the requirements for maintenance, the requirements for thermoregulation when the room temperature is outside the sows' thermal comfort zone and the requirements for the

Received July 7, 2022 Accepted December 19, 2022.

physical activity. Even though thermoregulation requirements also vary between sows (Noblet et al., 1993; Dourmad et al., 2008), they are averaged at the group level or sometimes not even integrated in the nutritional models. Furthermore, pig production may also be sensitive to outdoor variations of temperature (Escarcha et al., 2018) that will increase with climate change. During a cold stress, depending on several factors like the room temperature but also the ration composition and the housing system (group or individual housing), the sows spend extra energy for thermoregulation (10 kJ/kgBW$^{0.75}$ d °C, Dourmad et al., 2008). In case of heat stress, the sows' requirements for thermoregulation should be impacted as well but quantification has not been published yet. High temperatures would result in gilts with higher body weight (**BW**) and backfat thickness (**BT**), and fewer nonfeeding visits to the electronic sow feeder (**ESF**) in association with a lower physical activity compared to gilts in thermo-neutral conditions (Canaday et al., 2013; Bjerg et al. 2020). The objective of this study is to determine the impact of temperatures (low or high) on physiological parameters (rectal temperature—RT, BW, BT, and behaviors—including physical activity and feeding behavior) and on nutritional requirements of gestating sows. It is expected that sows' behaviors (mainly physical activity) will be affected by these different temperatures, which would ultimately lead to changes in sows' nutritional requirements (increase or decrease under cold and hot conditions, respectively).

Materials and Methods

Animals and housing

The experiments took place in the Experimental Unit for Physiology and Phenotyping of Pigs (UE3P, https://doi.org/10.15454/1.5573932732039927E12) of the INRAE Bretagne-Normandie Centre located in Saint-Gilles (35), France. The Ethics Committee in Animal Experimentation in Rennes, France, reviewed and approved the protocol for the experiment (referral APAFIS#25883).

A total of 37 crossbred (Large White × Landrace) gestating sows (Table 1), including eight primiparous sows, were involved in the experiment. They were housed into two different rooms 2 d after their insemination: one group of 17 sows including three primiparous in room 1 (group 1) and one group of 20 sows including five primiparous in room 2 (group 2). Each group was housed on concrete floor in adjacent rooms of 7.5 × 8.2 m with four areas enriched with straw (Figure 1). Each room contained two ESF (Gestal, Jyga Technologies Inc., Canada) and two automatic water troughs (Asserva, France). Natural light was available, and additional artificial light was also provided to allow permanent video recording.

All the sows were allowed to eat each day an individual quantity of feed calculated ex-ante by the InraPorc nutritional model adapted for sows, as described by Gaillard et al. (2019), according to parity, expected prolificacy, and BW and BT at insemination and their target at farrowing, assuming that sows are housed in thermoneutrality. The ration composition was also adjusted daily, based on the sows' lysine requirements calculated according to Gaillard et al. (2020). The ration consisted of a mixture of two feeds (13.14 MJ ME/kg) that differed in standardized ileal digestible lysine (**SID**) content (8.5 and 3.3 g of SID lysine per kg of feed, rations described in Gaillard et al., 2022). The rations were available at the ESF each day at midnight. The ESF allowed to control if all the sows ate during the night and if not, it guided the farmers to help the detected sows to reach the ESF and identify a potential health problem.

Experimental design

The experiment was conducted over 4 wk on January and February 2021 during which the sows were exposed to three different temperatures. During the first and third weeks, the sows were housed in medium temperatures (**MED1** and **MED2**, respectively). Temperature was set at 19 ± 4 °C and ventilation on 30% minimal and 100% maximal. During the second week, low temperatures were induced (**LOW**) by opening the windows to generate a cold air inlet and lower indoor temperature, by turning on the ventilation at 50% and the thermostatic system on 12 ± 2 °C during 72 h. Similarly, during the last week, high temperatures were induced (**HIGH**) thanks to two heaters installed in each room (Figure 1). The thermostatic system was set at 32 ± 2 °C and ventilation on 10% minimal and 80% maximal to obtain a room temperature around 32 °C. Set-ups to induce cold and heat conditions were maintained from Monday to Thursday. On Monday morning, the sows waited in another room where they were weighted and their body condition recorded while the temperature was being set in the gestation rooms. They only re-entered their gestation room when the temperature was stabilized to the required temperature. On Thursday afternoon, the temperature was back to the medium temperature.

Monitoring and measurements

Each sow wore two RFID ear-tags, one for the ESF and the other for the water troughs, recording each individual visit (duration and quantity eaten or drunk) in the automatons and

Table 1. Description of the gestating sows' characteristics of each group

	Group 1	Group 2
Number of sows	17	20
Number of primiparous	3	5
Parity	4.4 ± 2.5	3.5 ± 2.4
BW[1], kg	228 ± 43.5	207 ± 45.8
BT[2], mm	16.2 ± 3.2	15.9 ± 2.8
Stage of gestation	Early gestation (between 12 and 38 d after AI)	Early gestation (between 34 and 60 d after AI)

Data are presented as means and standard deviations (± SD)
[1]BW, body weight.
[2]BT, backfat thickness.

identifying the animal. An accelerometer ear-tag (RF-track, France) was also fixed before entering the gestation room to monitor the sow's activity by recording the time spent (in minutes) in different positions (standing, lying down, moving), and the number of position changes during an hour.

Each Monday morning, the sows were moved out of the gestation room to be weighed individually with a scale (Schippers, The Netherlands, precision ± 0.5 kg). During the contention in the scale, the BT was measured with an ultrasound portable device behind the last dorsal rib, at a distance of 3.5 cm from the spine. On Tuesday, Wednesday, and Thursday at 0800 hours, rectal temperature was measured using a digital thermometer (precision ± 0.01 °C), without restraining the sows in their room.

The room temperature and humidity were automatically recorded by five sensors (Lascar Electronics, United Kingdom, precision ± 0.45 °C), installed in different places in each room at 1.5 m above the ground (Figure 1) to prevent the sows from reaching them.

The sows' behaviors were monitored using two cameras (Ro-main RS-CCPOE280IR4-DH, Canada) installed on the ceiling. The video recordings were analyzed manually by one person using the software Boris (version. 8.0.8, Friard and Gamba, 2016) to detect the individual behaviors presented in Table 2. The beginning and the end of each localization, position, and occupation were registered for each sow (Table 2). The observations were done from 1330 to 1830 hours ("Resting period") and from 2300 to 0400 hours ("Feeding period"), 3 d, from Monday to Wednesday each week for MED1, LOW,

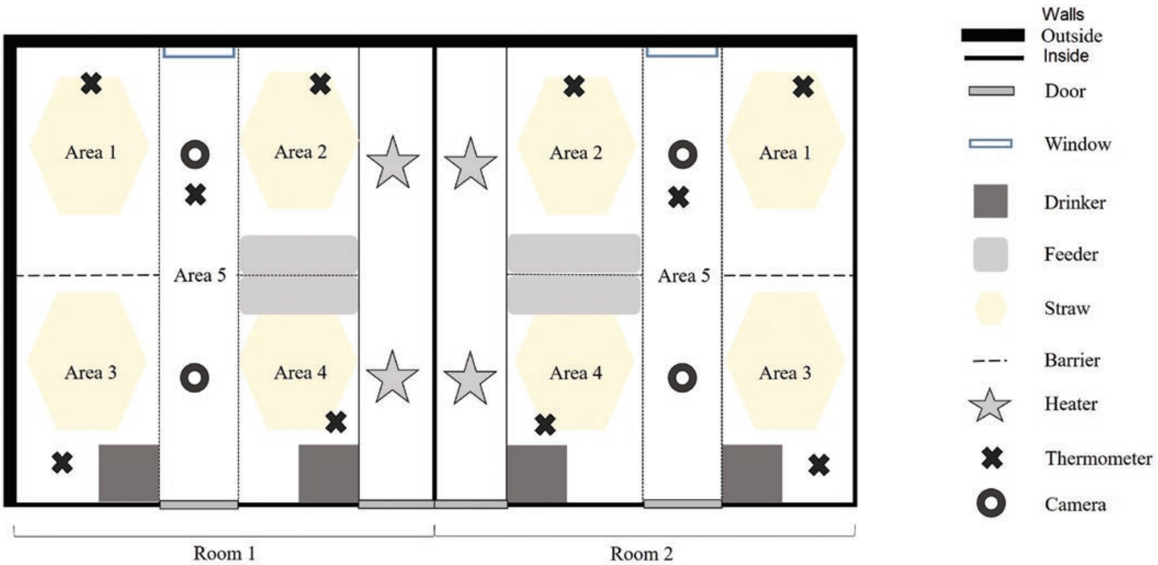

Figure 1. Schematic representation of the two gestating sows' rooms and materials.

Table 2. Gestating sows' positions and behaviors observed manually on the video recordings

Behavior	Description	
Position		
Sitting	Chest off the ground, front legs straight, back legs on the ground	
Lying alone or with other sow(s)	Laterally	4 legs on the same side, flank fully on the ground
	Ventrally	1 or more legs not visible or on the same side, flank not fully touching the ground
Standing	Immobile	4 legs still
	Trampling	1 or 2 legs moving a few centimeters, slowly
	Walking	4 legs active
Behavior		
Exploring ESF	Exploring the ESF (contact with the snout)	
Exploring rest	Exploring the rest of the environment (walls, fence, troughs, floor), contact with snout or digging with paws	
Eating	Sow in the ESF, door closed, head in feed trough	
Drinking	Standing with head and two forelegs in the trough	
Observing	Head is raised and may be moving	
Positive contact	Snout to snout, sniffing, or licking another sow	
Negative contact	Head butting, pushing, or biting another sow	

ESF, electronic sow feeder.

and HIGH but not for MED2 due to the extensive hours of work that it represents. The number of position changes was also calculated taking into account all positions reported in Table 2 including ventral and lateral lying. "Active behavior" was calculated as the sum of the time spent standing and moving (including trampling and walking). Concerning feeding behavior, the number of visits to the ESF and the duration of these visits were used to characterize feeding behavior. Visits were separated into two types: feeding visits (with feed intake) and nonfeeding visits (without feed intake). The total number of visits was calculated as the sum of these two types of visits.

As described above, two methods (accelerometers and video analyses) were used to analyze sows' physical activity. Indeed, the accelerometers allowed the continuous and automatic recording of sows' postures, needed to calculate the energy requirements over 24 hours, but many of these sensors did not last during all the gestation so the information was missing for few sows. Therefore, the video analysis provided the physical activity of all the sows but over short periods during the day, to get a partial view of the sow activity and at least be able to interpret the temperature effect on the physical activity and energy requirements. Moreover, the video analysis allowed the observations of more behaviors (i.e., social interaction, localization) compared to the accelerometers.

Calculations

Ex-post nutritional requirements were calculated according to Gaillard et al. (2020), using the measured performance and physical activity of sows, as well as the recorded ambient daily temperature (Table 3).

Unproductive energy requirements calculations were based on the activity measurements recorded by the few functional accelerometers on 7 sows in group 1 and on 11 sows in group 2, to get the activity over 24 h.

In order to evaluate the intensity of thermal stress on the sows, the Temperature-Humidity Index (**THI**) was calculated thanks to the formula and thresholds provided by Wegner et al. (2016)

$$\mathrm{THI} = [(1.8 \times \mathrm{T}) + 32] - [(0.55 \times (\mathrm{RH}/100)] \times [((1.8 \times \mathrm{T}) + 32) - 58]$$

Table 3. Main equations used to calculate gestating sows' daily unproductive part of energy requirements adapted from Dourmad et al. (2008)

Equations
$ME_m = 0.44 \times [(BW_{AI}\ BW_{bf}) / 2]^{0.75}$ (for 4 h of activity per day) [1]
$ME_{thermo} = (LCT\ \ T) \times 10 \times BW_t^{0.75} / 1000$ [2]
$ME_{act} = (Act\ \ 4) \times 60 \times 0.3 \times BW_t^{0.75} / 1000$ [3]
$ME_{total} = ME_m + ME_{thermo} + ME_{act}$

ME_m, metabolizable energy for maintenance including 4 h of standing activity per day (MJ/d); ME_{thermo}, metabolizable energy for thermoregulation taking into account the effect of the room temperature for group-housed sows with a LCT at 16 °C; ME_{act}, metabolizable energy taking into account the individual daily physical activity; ME_{total}, total metabolizable energy (MJ/d).
t, days after insemination; BW, body weight of the sow (kg); AI, artificial insemination; bf, before farrowing; LCT, lower critical temperature; T, daily temperature (°C); Act, daily individual activity (h/d).

with RH and T corresponding to the daily ambient relative humidity (%) and temperature (°C), respectively. A mild heat stress was defined when THI was above 74, a moderate heat stress when THI was above 79, and a severe heat stress when THI was above 84 (Wegner et al., 2016; He et al., 2019). No threshold for cold stress has been found in the literature. To define it, it would require further experimental investigation, so in this paper, it was assumed that cold stress may occur below 16 °C and lead to extra heat production costs (Dourmad et al., 2008).

Statistical analyses

Statistical analyses were performed using the R studio software (version 4.0.3, R Foundation, Vienna, Austria). In order to characterize the impact of each temperature (MED1, MED2, HIGH, LOW) on the variables studied (physiological measures, feeding behaviors, and positions), linear mixed-effects models (Laird and Ware, 1982) were used applying the LME function of the NLME package (Pinheiro et al., 2018) followed by an ANOVA test. The fixed factors used for these analyses were the temperature (MED1, MED2, HIGH, LOW), the period of the day studied during the video analyses (Resting period vs. Feeding period), and the group (group 1 vs. Group 2) as well as the interactions between these factors. The random factor used for the analyses was the sow. Post-hoc Tukey tests were performed to determine which variables were significantly different from each other using the EMMEANS function of the package of the same name (Lenth et al., 2022). The threshold of significance chosen was a P value < 0.05. When the P value was between 0.05 and 0.1, we considered that as a trend toward significance.

Results

Environmental conditions and physiological response

Environmental condition

Figure 2 presents the daily temperature and THI in each gestation room and outdoor. The outdoor temperature was below 16 °C during all the experiment, and it was particularly cold during the nights with temperatures below 4 °C. During daytime, the outdoor temperature ranged between 5 °C and 16 °C. On average during the two MED weeks, the temperature in the rooms was maintained at 16.7 °C in room 1 and 18.5 °C in room 2. Temperatures were the same in room 2 during both MED weeks (18.5 °C vs. 18.6 °C, respectively, for MED1 and MED2, $P = 0.28$) whereas in room 1, temperatures were significantly different (16.7 °C vs. 15.5 °C, respectively, for MED1 and MED2, $P < 0.001$). During MED1 and MED2, the temperature in both rooms were different (MED1: + 1.7 °C in room 2 compared to room 1, $P < 0.001$; MED2: +3.1 °C in room 2 compared to room 1, $P < 0.001$).

During the LOW week, the temperature was of 14.4 °C and 15.3 °C in rooms 1 and 2, respectively, and of 31.9 °C and 31.6 °C during the HIGH week (Table 4). During the MED weeks, relative humidity was on average of 70% in both rooms (Table 4). When the temperature decreased, the humidity increased by 6 percentage points on average in both rooms. When the temperature increased, the humidity decreased by 13 and 7 percentage points for room 1

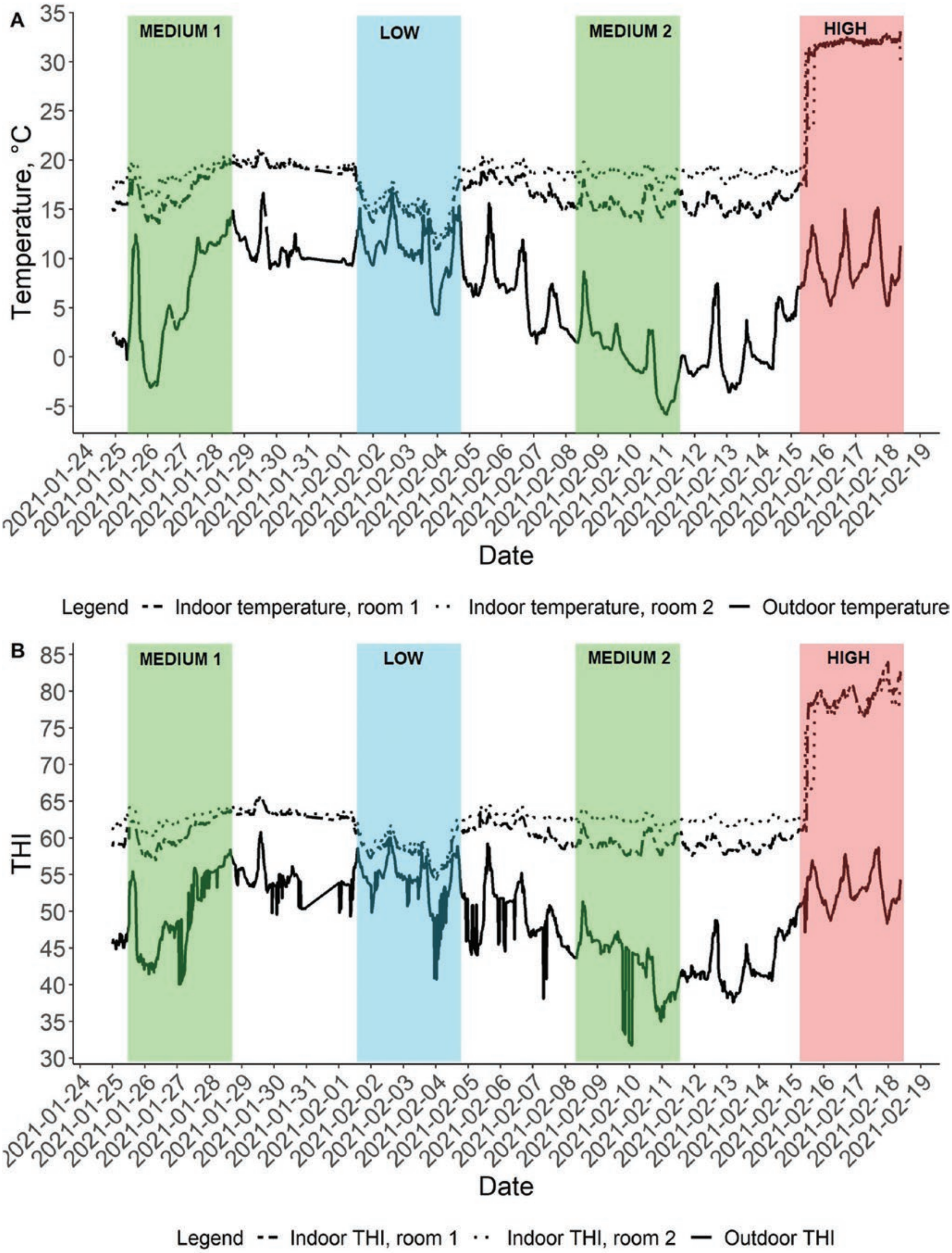

Figure 2. Daily variations of (A) temperature and of (B) the temperature-humidity index (THI), in each gestation room and outdoor. The THI was calculated according to the formula of Wegner et al. (2016). Temperature induced: 18 °C (MED1), 15 °C (LOW), 18 °C (MED2), and 32 °C (HIGH).

and 2, respectively. The THI values were all in the comfort range during MED and LOW weeks (< 74), while during HIGH week THI was above 74 indicating heat stress. The THI in room 1 always exceeded 76 (mild heat stress), and during 10 hours it exceeded 80 (high heat stress, Figure 2). In room 2, THI exceeded 74 in hot conditions except the first afternoon where THI was between 66 and 74.

Rectal temperature

The thermal conditions and the group affected RT (significant interaction, Tables 5 and 6). HIGH temperatures increased the RT of group 1 (37.7 °C (MED1), 37.5 °C (MED2), 37.6 °C (LOW), vs. 38.3 °C (HIGH), $P < 0.01$) whereas thermal conditions did not affect the RT of group 2 (on average 38.1 °C, $P = 0.94$). On average, RT was higher in group 2 than in group 1 ($P < 0.01$). In each group, sows had the same RT during MED1 and MED2 weeks.

Body weight and backfat thickness gains

BW increased during the experiment in both groups (Tables 5 and 6, $P < 0.001$). The thermal conditions and the group affected both BW and BT gains over the week studied ($P < 0.001$ for BW gain, and $P = 0.007$ for BT gain, Tables 5 and 6). In group 2, sows gained more BW during the LOW week than the HIGH week (+6.3 vs. +0.2 kg, respectively, $P = 0.02$) whereas in group 1, sows gained more BW during the HIGH week than the MED1 week (+8.4 vs. +1.4 kg, respectively, $P = 0.001$). Sows in group 1 gained more BT during the LOW week than the HIGH week (+1.1 vs. −0.6 mm, respectively, $P < 0.001$) whereas thermal conditions had no effect on sows BT gain of group 2 (on average 0.4 mm, $P = 0.94$).

Sows' postural behavior and position changes

Activity

The period, temperature, and group affected significantly the time the sows spent active (triple interaction, $P = 0.001$, Figure 3A). During Feeding period, the sows in group 1 were less active with HIGH than LOW temperatures (83 (HIGH) vs. 103 (LOW) min active over 5 h, $P < 0.001$). There was no effect of temperatures on group 2 during Feeding period (65.8 (MED1), 73.1 (HGH), 69.9 (LOW), min active over 5 h, $P = 0.99$). During Resting period, the temperatures had

Table 4. Weekly average temperature (°C), relative humidity (%) and THI presented as means ± standard error

	Temperature, °C	Humidity, %	THI
Room 1			
Neutral 1	16.7 ± 1.8	72.4 ± 5.1	60.4 ± 1.8
Cold	14.4 ± 1.5	78.3 ± 4.5	58.0 ± 1.6
Neutral 2	15.5 ± 0.9	69.1 ± 4.0	59.1± 1.0
Hot	31.9 ± 0.4	57.6 ± 7.6	79.5 ± 1.6
Room 2			
Neutral 1	18.5 ± 1.1	69.8 ± 5.3	62.5 ± 1.1
Cold	15.3 ± 1.6	75.7 ± 4.3	58.8 ± 1.6
Neutral 2	18.6 ± 0.5	72.1 ± 4.4	62.5 ± 0.6
Hot	31.6 ± 1.9	63.3 ± 7.8	78.2 ± 2.9

Neutral 1: 18 °C; Neutral 2: 18 °C; Cold: 15 °C; Hot: 32 °C; THI: temperature-humidity index.

Table 5. Influence of the thermal conditions (MED1, MED2, HIGH, or LOW) on the physiological measures, feeding and drinking behaviors of group 1 gestating sows

GROUP 1	Condition						Statistical analysis[1]		
Item	MED1	MED2	HIGH	LOW	Mean	RSD			
Number of sows	17	17	17	17			T	G	T×G
Physiological measures									
Rectal temperature, °C	37.7[a]	37.5[a]	38.3[b]	37.6[a]	37.8	0.02	<0.001	0.004	<0.001
Body weight, kg	247[a]	255[b]	264[c]	250[d]	254	0.2	<0.001	0.05	<0.001
Body weight gain, kg	1.4[a,c]	5.0[c]	8.4[b,c]	3.7[a,c]	4.6	0.8	<0.001	0.32	<0.001
Backfat thickness gain, mm	−0.1[ac]	0.5[a,b]	−0.6[c]	1.1[b]	0.2	4.3	<0.001	0.16	<0.001
Physical activity (accelerometers), h/d	4.4[a]	4.6[a]	3.0[b]	4.3[a]	4.2	0.3	<0.001	0.35	0.002
Feeding and drinking behavior									
Daily feed intake, kg/d	2.74	2.74	2.71	2.75	2.74	0.1	0.86	0.95	0.40
Time spent at ESF, min/d	79.2[a]	64.1[a,b]	49.4[b]	69.6[a]	65.5	0.8	<0.001	0.22	0.01
Time spent at ESF without feed, min/d	41.2[a]	27.5[a,b]	22.9[b]	28.5[a]	30.0	1.0	0.01	0.10	0.03
Number of visits at ESF/d	5.6	5.3	4.8	5.7	5.3	0.6	0.06	0.66	0.61
Number of nonfeeding visits at ESF/d	4.7	4.3	4.1	4.8	4.5	0.7	0.15	0.63	0.71
Water consumption, L/d	7.1	6.0	6.5	6.3	6.5	0.8	0.92	0.13	0.06
Time spent at water trough, min/d	7.6	6.9	8.9	7.3	7.7	0.8	0.08	0.07	0.54
Number of visits at water trough/d without drinking	2.3	2.3	5.5	2.7	3.3	1.3	<0.001	0.21	0.10
Number of visits at water trough/d	11.8[a,b]	10.7[a,b]	13.6[a]	10.5[b]	11.6	0.6	0.01	0.02	0.18

MED1: 18 °C, MED2: 18 °C, HIGH: 32 °C, LOW: 15 °C; RSD, residual standard deviation; ESF, electronic sow feeder; NS, nonsignificant.
[1]Data were analyzed using a generalized linear model including the effect of Temperatures (T), Groups (G), and interactions between T and G (T × G) and a random sow effect, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.
[a,b]Means within a row with different superscripts significantly differ ($P < 0.05$).

Table 6. Influence of the thermal conditions (MED1, MED2, HIGH, or LOW) on the physiological measures, feeding, and drinking behaviors of group 2 gestating sows

GROUP 2	Condition						Statistical analysis[1]		
Item	MED1	MED2	HIGH	LOW	Mean	RSD			
Number of sows	20	20	20	20			T	G	T×G
Physiological measures									
Rectal temperature, °C	38.2	38.1	38.2	38.0	38.1	0.01	<0.001	0.004	<0.001
Body weight, kg	218[a]	228[b]	225[b]	224[c]	224	0.18	<0.001	0.05	<0.001
Body weight gain, kg	4.8[a,b]	3.7[a,b]	0.2[a]	6.3[b]	3.8	1.3	<0.001	0.32	<0.001
Backfat thickness gain, mm	0.2	0.1	0.6	0.8	0.4	2.2	<0.001	0.16	<0.001
Physical activity (accelerometers) h/d	4.7[a]	4.4[a]	3.8[b]	4.8[a]	4.5	0.3	<0.001	0.35	0.002
Feeding and drinking behavior									
Daily feed intake, kg/d	2.73	2.71	2.77	2.70	2.73	0.1	0.86	0.95	0.40
Time spent at ESF, min/d	61.3	63.2	58.9	60.5	61.0	0.6	<0.001	0.22	0.01
Time spent at ESF without feed, min/d	24.9	27.5	27.3	25.6	26.3	1.1	0.01	0.10	0.03
Number of visits at ESF/d	6.0	6.0	5.9	6.5	6.1	0.6	0.06	0.66	0.61
Number of nonfeeding visits at ESF/d	5.1	4.9	5.0	5.5	5.2	0.6	0.15	0.63	0.71
Water consumption, L/d	9.7	8.9	11.3	8.5	9.6	0.8	0.92	0.13	0.06
Time spent at water trough, min/d	10.7	9.6	13.6	10.2	11.0	0.7	0.08	0.07	0.54
Number of visits at water trough/d without drinking	3.7	3.7	4.8	5.0	4.3	1.1	<0.001	0.20	0.10
Number of visits at water trough/d	15.6	13.6	16.0	15.5	15.2	0.4	0.01	0.02	0.18

MED1: 18 °C, MED2: 18 °C, HIGH: 32 °C, LOW: 15 °C; RSD, residual standard deviation; ESF, electronic sow feeder; NS, nonsignificant.
[1]Data were analyzed using a generalized linear model including the effect of Temperatures (T), Groups (G), and interactions between T and G (T × G) and a random sow effect, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.
[a,b]Means within a row with different superscripts significantly differ ($P < 0.05$).

no effect on the physical activity of both groups (between 22 and 36 min active over 5 h).

Lying behavior

The period of the day and temperature had an effect on the time spent lying laterally (Figure 4A, $P < 0.001$). During the Resting period, the sows spent most of their lying time laterally with HIGH temperatures compared to MED1 or LOW temperatures where the time spent lying ventrally or laterally was more balanced (82.2% (HIGH) vs. 58.7% (MED1) and 53.2% (LOW) of time spent lying over 5 h, $P < 0.001$). During Feeding period, no difference was found, the sows spent the same amount of time lying laterally with the three temperatures (on average 52% of time spent lying over 5 h, $P > 0.05$). However, the time spent lying laterally tended to decrease with LOW temperatures compared to MED1 temperatures (46.3% vs. 56.2% of time spent lying over 5 h, $P = 0.05$).

Furthermore, temperature and group had an effect on the time spent lying laterally (Figure 4B, $P < 0.001$). Group 1 spent more time lying laterally with HIGH temperatures (68.6%) compared to MED1 (49.1%) and LOW (49.8%). Group 2 spent less time lying laterally with LOW temperatures compared to HIGH and MED1 temperatures (55.0% (LOW) vs. 64.8% (MED1) and 65.1% (HIGH)).

Position changes

During the Feeding period, temperatures had no effect on the number of position changes per hour for group 2 (8 times per hour on average, $P = 0.98$) while the sows in group 1 changed position more often with HIGH temperatures than with MED and LOW temperatures (7.4 (HIGH) vs. 4.6 (LOW) and 4.3 (MED1), $P = 0.002$ and 0.04, respectively, Figure 5A). During the Resting period, the sows of group 2 changed less position with high temperatures than with LOW temperatures (3.2 vs. 5.3 ± 0.55 changes per hour, $P = 0.01$) whereas there was no effect of temperatures on the number of position changes per hour in group 1 (3.0 ± 0.4 changes per hour in average).

Feeding and drinking behavior

The temperatures and group did not have any effects on the amount of feed intake ($P = 0.59$ and 0.88, respectively). On average the sows ate 2.65 kg per day.

The temperature and group did not have any effect on the number of feeding or nonfeeding visits to the ESF (Tables 5 and 6). However, there was a tendency for the total number of visits per day to the ESF to be higher with LOW temperatures than with HIGH temperatures (6.1 vs. 5.4 visits per day at the ESF, $P = 0.06$). Temperature and group significantly affected the time spent in the ESF (double interaction, $P = 0.04$). Sows from group 2 spent the same amount of time in the ESF independently of the temperature (on average 60.5 min, $P = 0.99$) while in group 1, they spent more time in the ESF with MED1 than with HIGH temperatures (79.2 vs. 49.4 min per day, respectively, $P = 0.03$). The sows of group 1 spent more time for nonfeeding visits with MED1 temperatures than HIGH temperatures (41.2 vs. 22.9 min per day, respectively, Table 5).

There was an interaction between temperature and group on water consumption ($P = 0.06$, Tables 5 and 6). Group 1 drank the same amount of water independently of the temperature (on average 5.2 L/d, $P = 0.99$), whereas group 2 seemed to drink more water with HIGH temperatures than with LOW temperatures (11.3 vs. 8.5 L/d, respectively). Moreover, temperature had an effect on the daily number of visits to the water troughs independently of groups ($P = 0.01$).

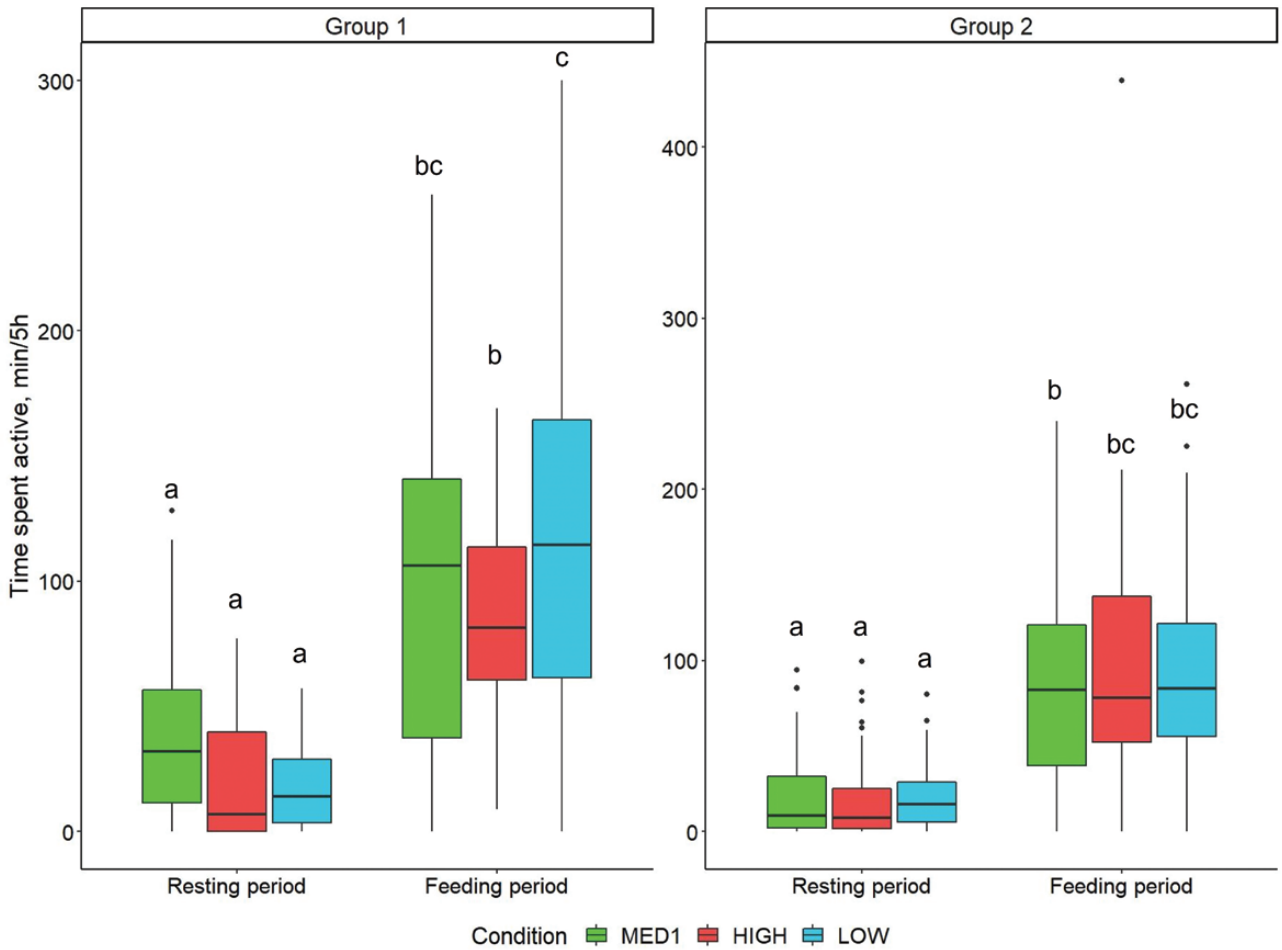

Figure 3. Boxplot of the time the sows spent active according to temperatures (MED1, HIGH, or LOW), group (1 or 2), and Period of the day (Resting period or Feeding period[2]). [2]Resting period: 5-h period between 1330and 1830 hours, Feeding period: 5-h period between 2300 and 0400 hours. [a,b,c,d,e]Means with different superscripts significantly differ ($P < 0.05$).

The number of visits was higher with HIGH temperatures compared to MED1 or MED2 temperatures (Tables 5 and 6).

Concerning the visits to the water trough without drinking, there was a significant difference according to the temperature ($P < 0.001$). The sows visited more the water troughs with HIGH temperature (5 visits per day) compared to MED temperature (3 visits per day in average).

Social behavior

Huddling behavior of sows varied with temperatures. The sows isolated themselves to rest with HIGH temperatures (109 [HOT] vs. 30.5 min [MED1 and LOW] over 10 h, $P < 0.001$). There was no groups of six sows with HIGH temperatures and groups of five were rare (on average 3 min over 10 h, Figure 6).

Concerning aggressive behavior, the interaction between group and temperatures was significant (Figure 7A, $P = 0.04$). In group 2, sows were more aggressive with LOW temperatures than with HIGH temperatures (1.9 (LOW) vs. 0.7 (HIGH) aggressive behaviors over 10 h per sow, $P = 0.009$) whereas in group 1, there was no effect of temperatures on aggressive behaviors ($P = 0.99$). Group 2 was also more aggressive than group 1 with LOW temperatures (1.9 vs. 0.5 aggressive behaviors over 10 h per sow, respectively, $P = 0.02$). Finally, the period of the day also affected the number of aggressive behaviors (Figure 7B, $P = 0.002$). Indeed, group 2 was more aggressive during Feeding period than during Resting period (1.8 vs. 0.8 aggressive behaviors over 10 h per sow, $P = 0.003$) whereas there was no difference in group 1 (on average 0.3 aggressive behaviors over 10 h per sow, $P = 0.67$).

Nutritional requirements

Ex-post calculations included daily temperature and daily individual activity. Temperatures had an effect on the ex-post amount of feed and ME required by the sows (Figure 8). For group 1, with HIGH temperatures the sows would have required less feed per day than with the other temperatures, corresponding to a decrease of 7.8% of the initial requirements. To summarize, numerically, group 1 would have required 2.44 (HIGH), 2.6 (LOW), 2.57 (MED1), and 2.62 (MED2) kg/d instead of the 2.55 kg/d distributed. Group 2 would have required 2.53 (HIGH), 2.61 (LOW), 2.59 (MED1), and 2.58 (MED2) kg/d instead of the 2.55 kg/d distributed.

Discussion

Experimental conditions

During MED weeks, a constant ambient temperature was set at 19 °C to reach a temperature within the thermo-neutral zone of the sows. However, room 1 was slightly colder

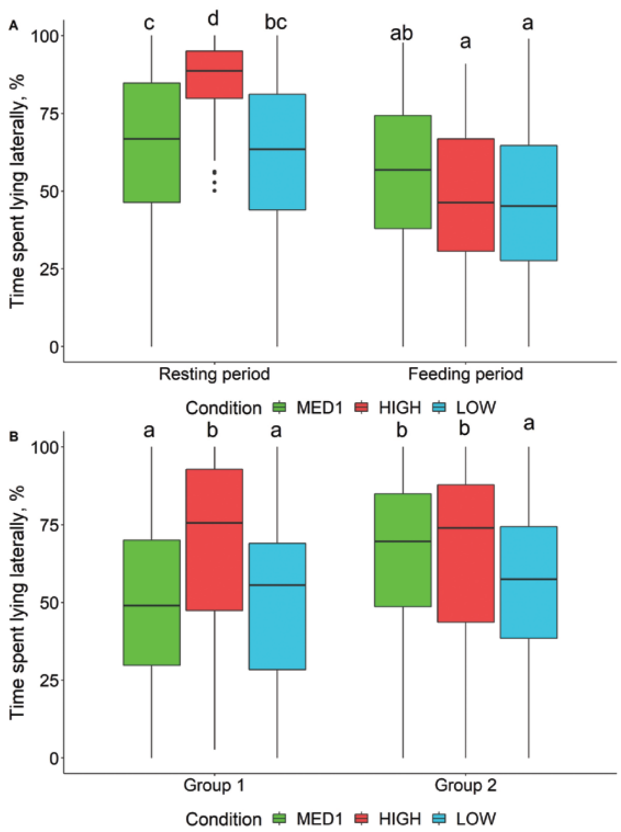

Figure 4. Boxplots of the time the sows spent lying laterally (percentage of time spent lying) according to temperatures (MED1, HIGH, or LOW), group (1 or 2), and Period of the day (Resting period or Feeding period[2]). (A) Time spent lying laterally according to Temperature, and Period of the day. (B) Time spent active according to Temperature and Group. [2]Resting period: 5-h period between 1330 and 1830 hours, Feeding period: 5-h period between 2300 and 0400 hours. [a,b,c,d]Means with different superscripts significantly differ (*P* < 0.05).

than room 2 (around 2 °C difference) due to two walls facing the outside against only one wall in room 2. Room 2 was therefore better isolated from the cold outdoor conditions. In addition, during the MED2 week, in room 1 the temperature was lower during 1 d than planned due to a technical problem (broken window and snow conditions) for few hours, so this week is not the best to serve as a reference. Moreover, this succession of lower temperatures during 2 wk could have an impact on the result of the following week (HIGH week).

The room temperatures during the LOW week could have been lower to ensure that the sows were stressed by the cold event, but it was difficult to reach due to the outside temperatures unexpectedly high for this time of the year (10.6 °C). Creating high temperatures was easier. Indeed, during the HIGH week the rooms' temperatures were over 30 °C and THI values indicated a mild to moderate heat stress. It has to be mentioned that the placement of the thermometers may have caused a bias in the evaluation of the thermal stress intensity, as they were located around 1.5-m high to avoid their destruction by the sows. Therefore, the temperature measured was not the actual ground temperature felt by the sows, which one might be slightly lower as the heat is known to stay up in a room. It would have been nice to have a system measuring ground temperature.

Accelerometers

Only 48% of the sows had a functional accelerometer during all the experiment because some sows pull them out (Chapa et al., 2020), or broke the sensor, or the sensor had difficulties to connect to the server. Furthermore, accelerometers are expensive (around 140 € per sensor), fragile (few sensors remained in place throughout gestation) and invasive (sows are immobilized to fix the sensor on the ear which is potentially painful and stressful). However, knowing daily individual physical activity is essential to calculate energy requirements and accelerometers allowed a continuous and automatic monitoring compared to manual video analyses (only 10 h per day analyzed in this study). The video analysis on a short period of the day does not allow to generalize the level of activity of the sows over 24 h because it varies over the day and according to the individual, like showed by Ramonet and Bertin (2015) and personal source. Automatic video analysis software are being developed to analyze continuously the videos, and report different individual behaviors and positions of lactating or gestating sows (Yang et al., 2020; Durand et al., 2022). The recognition software developed by Yang et al. (2020) measures the time spent per behavior with a reliability of over 88%. For gestating sows, housed in groups, additional difficulties are added as the animals are group-housed so they need to be identified and tracked.

Strategy under high temperatures

With high temperatures, sows in both groups isolated themselves from the group to limit contacts with others and to maximize heat loss (Huynh et al., 2005). However, both groups did not totally react the same way to similar high temepratures. In accordance with several studies (Canaday et al., 2013; He et al., 2019; Bjerg et al., 2020), with HIGH temperatures the rectal temperature increased in group 1 by 0.03 °C compared to MED1 temperatures. This value is similar to the one obtained by Lucy and Safranski (2017) during an experimentation involving gestating sows exposed to similar ambient temperatures (17.5 °C and 32 °C). However, sows' RT in group 2 did not change with HIGH temperatures. Meanwhile, on average, sows in group 2 drank more water than those in group 1 to improve their thermoregulation and stabilize their rectal temperature (Nadel et al., 1980; Sawka et al., 1998). Sows in group 1 adopted another strategy, they were lying longer (at least for the multiparous sows) and pushing the straw from the floor to absorb the freshness of the concrete. This strategy increases the conduction and sensible exchanges of heat between the floor and the skin of the sow.

Indeed, in group 1, sows were less active with high temperatures than with low temperatures. High temperatures were previously shown to decrease sows' activity (Canaday et al., 2013; Lucy and Safranski, 2017) allowing them to decrease their heat production. In the present study, sows also spent more time lying in lateral position with high temperatures compared to medium temperatures. Others studies on gestating sows (Canaday et al., 2013) and growing pigs (Huynh et al., 2005) showed the same behavioral changes during heat stress and linked it to thermoregulation processes. Indeed, the concrete floor temperature might be lower than the room temperature, and maybe wet, which could help the sows to maximize heat dissipation. In the present study, with high temperatures, sows changed more often postural positions.

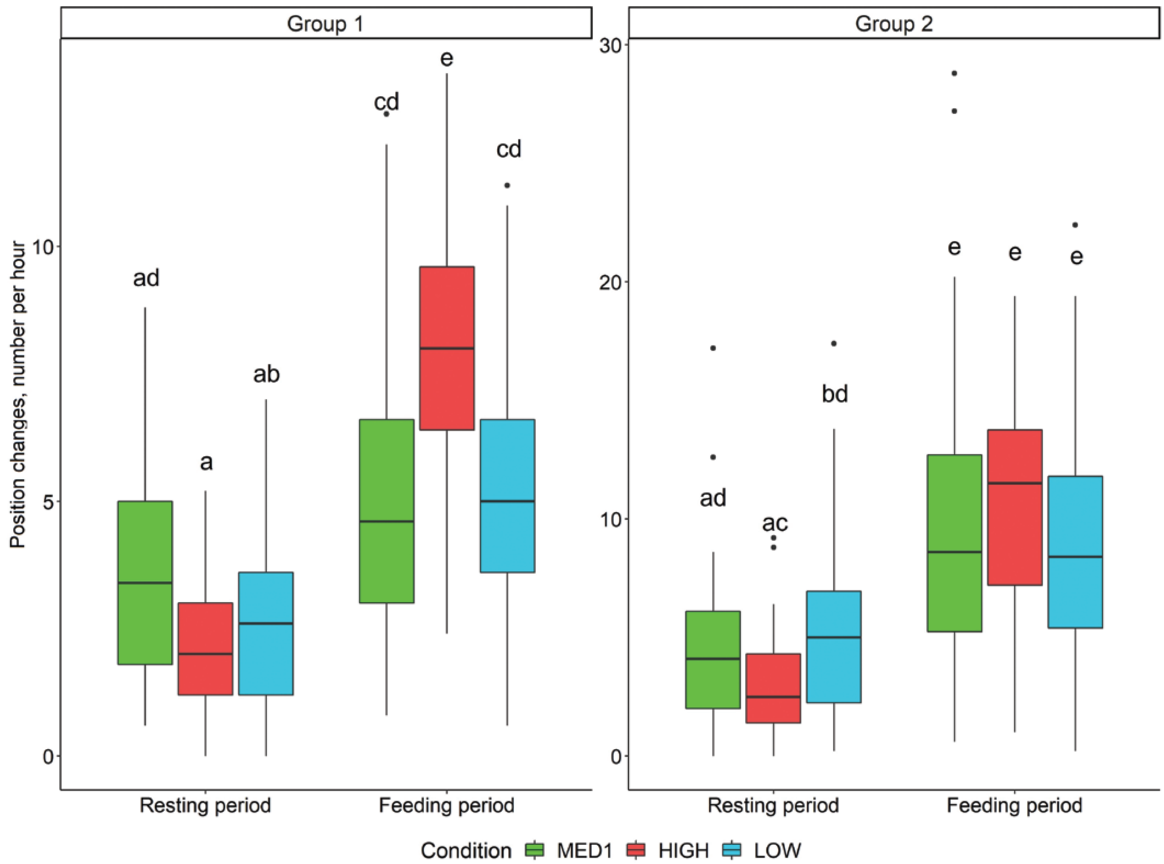

Figure 5. Boxplots of the number of position changes per hour according to temperatures (MED1, HIGH, or LOW), Group (1 or 2), and Period of the day (Resting period or Feeding period[2]). [2]Resting period: 5-h period between 1330 and 1830 hours, Feeding period: 5-h period between 2300 and 0400 hours. [a,b,c,d] Means with different superscripts significantly differ ($P < 0.05$).

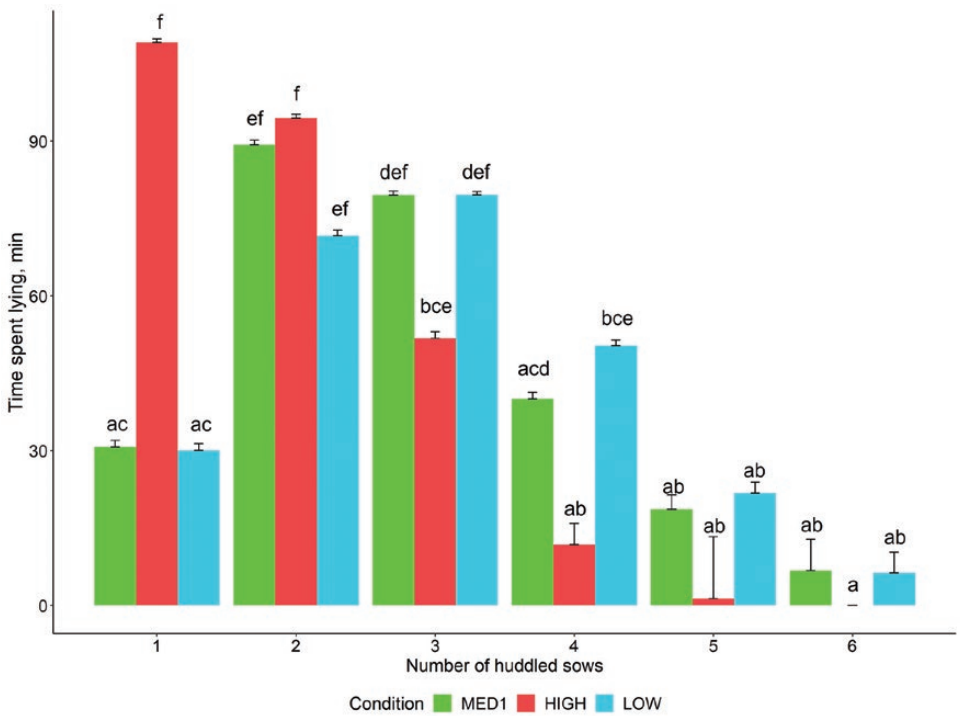

Figure 6. Time the sows spent lying down over 10 h regarding the number of sows huddling (i.e., 1 corresponds to a sow lying alone while 6 corresponds to a sow surrounded by five other sows). Data are presented as means and SE. [a,b,c,d,e,f]Means with different superscripts significantly differ ($P < 0.05$).

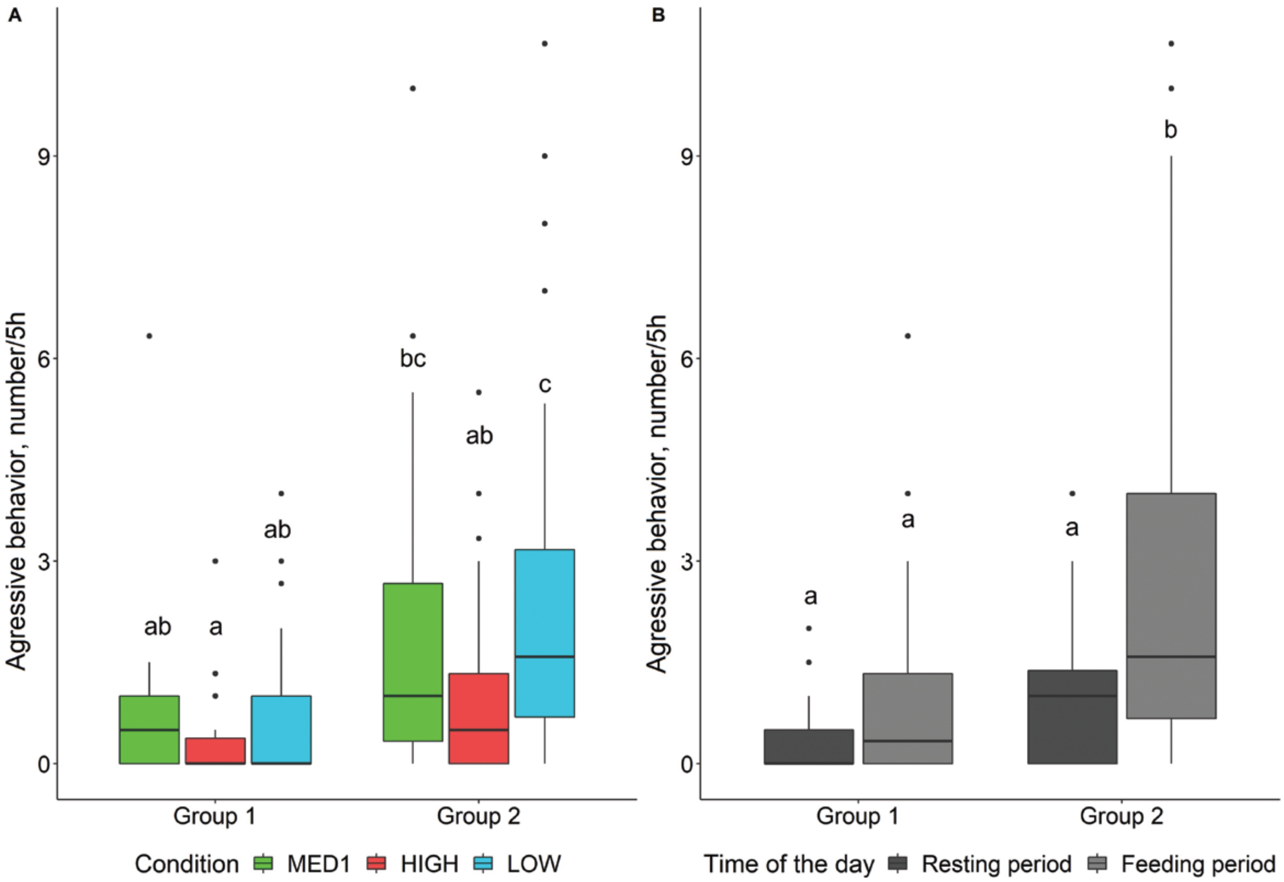

Figure 7. Boxplots of the number of aggressive behaviors during 5-h period according to temperatures (MED1, HIGH, or LOW), Group (1 or 2), and Period of the day (Resting period or Feeding period[2]). (A) Number of aggressive behaviors according to Temperatures and Group. (B) Time spent active according to Group and Period of the day. [2]Resting period: 5-h period between 1330 and 1830 hours, Feeding period: 5-h period between 2300 and 0400 hours. [a,b,c,d]Means with different superscripts significantly differ ($P < 0.05$).

This number of changes in the present study is doubled compared to previous studies (3 to 8 changes per hour vs. 2 to 4 changes per hour in Canaday et al., 2013), probably because the present numbers included the changes between "lying ventrally" and "lying laterally" not counted in previous studies. However, this increase of changes of positions might also involve an increase in energy expenditure that will need to be yet determined.

Low temperatures

With low temperatures, sows should have been more active (Canaday et al., 2013) due to a tendency to avoid contact with (potentially cold) concrete floor or to warm up. However, in the present study, with low temperatures the sows did not increase their activity compared to medium temperatures because they were group-housed and could huddle with each other. This allowed the sows to maintain their body temperature without having to increase their physical activity as observed for individually housed sows (Canaday et al., 2013). The presence of straw on the floor might also explain this behavior, provided insulation from the floor so they were not reluctant to lay down. When lying, huddling behaviors increased as well as the number of huddling sows (groups of two or more) which is in accordance with the results of Huynh et al. (2005). Probably because of the proximity that huddling induces, aggressive behaviors were higher with low temperatures which can generate certain stress (Groo et al., 2018).

Physical activity over the day

Generally, the sows were more active during the night than during the afternoon due to a start of the feeding cycle at midnight. The feed is distributed from midnight for several reasons: to facilitate the work of the employees when they have to clean the manure and mulch the ground again, to keep the sows calm when the employees come, to identify problem sows, that is, sows that have not eaten in order to treat them and guide them to the ESF. Jensen et al. (2000) studied different herds with different starts of the feeding cycle. Even if the feeding cycle started during the night (2200, 0000, or 0400 hours), they observed an activity peak during the afternoon between 1400 and 1800 hours not observed in the present study. Instead, a small peak of activity occurred after 0800 hours when the farmers clean and provide new straw in the rooms.

Body weight and feed intake

With high temperatures, it was expected that the sows would gain more BW and BT due to a decrease of physical activity, while in low temperatures it would be the opposite due to a greater mobilization of energy to produce enough heat to keep the body at a constant temperature (Canaday et al., 2013; Lucy and Safanski, 2017). However, in the present study, BW and BT gains were less affected by the temperature than in these previous studies maybe due to a shorter duration of exposure to these temperatures (30 vs. 4 d, respectively).

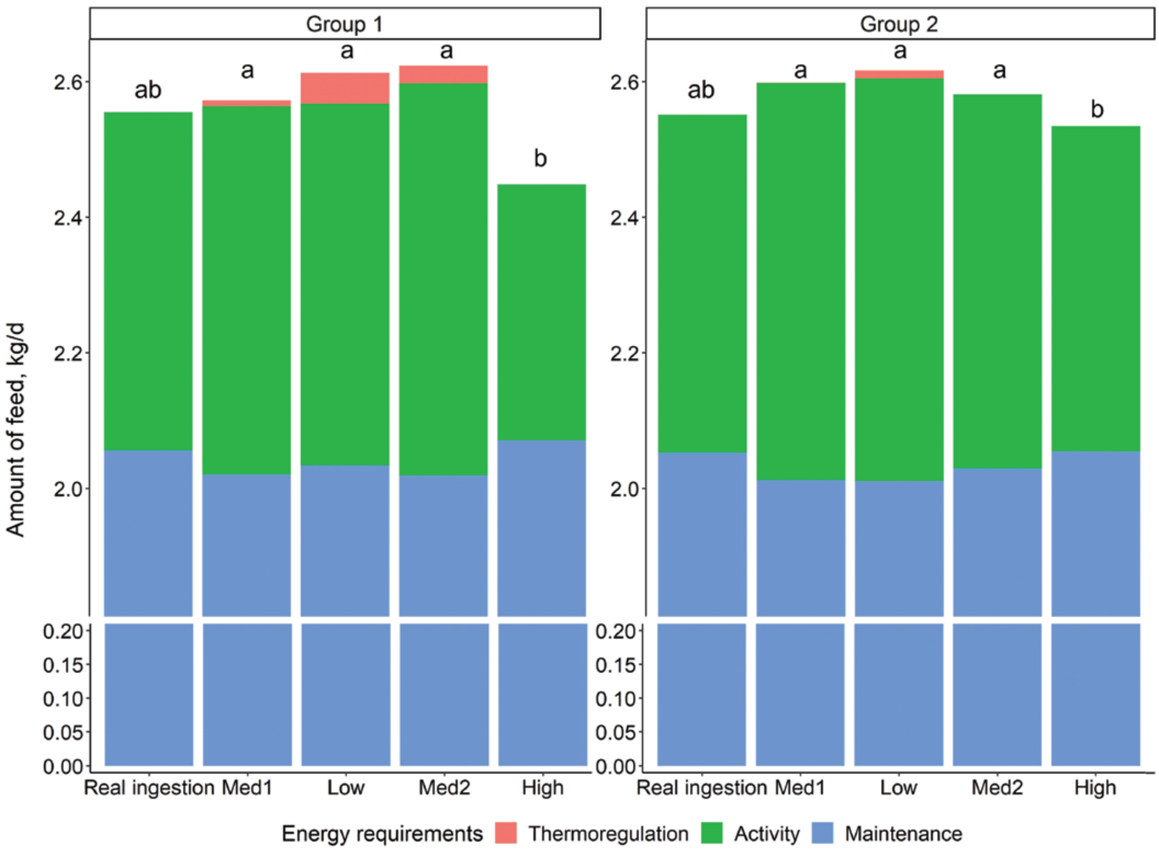

Figure 8. Amount of feed really distributed or required (ex-post calculations) by the gestating sows of two groups during different thermal conditions.

In several studies, the increase in ambient temperature was shown to lead to a reduction of feed intake (Renaudeau et al., 2002; Bjerg et al., 2020), this decrease being estimated at 230 g/d °C by Bjerg et al. (2020) for lactating sows. Sows were fed restrictively in the present study, which explains why there was no reduction of feed intake. The sows kept eating all their rations independently of the temperature. However, sows in group 1 spent less time in the ESF with high temperatures, which could be due to the lower physical activity according to Bjerg et al. (2020).

Finally, with low temperatures, the extra energy required for thermoregulation has been quantified in previous studies (below a LCT of 16 °C, heat production increased of 10 kJ.kg.BW$^{-0.75}$d^{-1} °C^{-1}, Dourmad et al., 2008), but not with high temperatures. Moreover, experiments done in respiration chambers also reported that the heat production increased over the gestation due to changes in the composition (protein vs. fat) and localization of the energy gain (Noblet and Etienne, 1987). This should be added into the nutritional model to estimate the energy requirements more accurately.

Conclusion

High temperatures induced mainly activity changes (postural changes, drinking and feeding behaviors) while low temperatures had an impact on sows' social behavior (huddling, aggressiveness), and their physiology (energy costs, BW). Both groups did not adopt the same strategy to cope with high temperatures. In one group, the sows changed their behavior (decrease in activity, number of position changes, and way of lying), had a high rectal temperature, and drank the same amount of water than in medium temperatures. In the other group, the sows drank more water and did not change their behaviors. Taking into account the daily room temperature and individual activity into the calculation of energy requirement is relevant to obtain more accurate estimations of the feed quantities and energy composition to be distributed.

Acknowledgments

This work was supported by the French National Research Agency under the Investments for the Future Program, referred as ANR-16-CONV-0004. We gratefully acknowledge Clémence Orsini, Carole Guerin, Patrick Touanel, Yannick Surel, and Daniel Boutin for their precious help throughout the project.

Conflict of Interest Statement

The authors declare no real or perceived conflicts of interest.

Literature Cited

Bjerg, B., P. Brandt, P. Pedersen, and G. Q. Zhang. 2020. Sows' responses to increased heat load - A review. *J. Thermal Biol.* 94:18. doi:10.1016/j.jtherbio.2020.102758

Brossard, L., M. Marco, J. Y. Dourmad, J. van Milgen, J. Pomar, V. Lopez, and N. Quiniou. 2020. Application d'un programme d'alimentation de précision chez le porc en croissance alimenté à volonté: effet sur les performances et l'utilisation des nutriments. *Journées de la Recherche Porcine* 52:111–112. https://hal.science/hal-02473702/document

Canaday, D. C., J. L. Salak-Johnson, A. M. Visconti, X. Wang, K. Bhalerao, and R. V. Knox. 2013. Effect of variability in lighting and temperature environments for mature gilts housed in gestation crates on measures of reproduction and animal well-being. *J. Anim. Sci.* 91:1225–1236. doi:10.2527/jas.2012-5733

Chapa, J. M., K. Maschat, M. Iwersen, J. Baumgartner, and M. Drillich. 2020. Accelerometer systems as tools for health and welfare assessment in cattle and pigs - A review. *Behav. Proc.* 181:104262. doi:10.1016/j.beproc.2020.104262

Dourmad, J. Y., M. Etienne, A. Valancogne, S. Dubois, J. van Milgen, and J. Noblet. 2008. InraPorc: A model and decision support tool for the nutrition of sows. *Anim. Feed Sci. Tech.* 143:372–386. doi:10.1016/J.ANIFEEDSCI.2007.05.019

Dourmad, J. Y., L. C. Brossard, J. Pomar, P. Pomar, Gagnon, and L. Cloutier. 2017. Development of a decision support tool for precision feeding of pregnant sows. In Proc of the 8th European Conference on Precision Livestock Farming, Nantes, France, 584–592.

Durand, M., M. Simon, J. Foisil, JY. Dourmad, C. Largouët, and C. Gaillard. 2022. Evaluation of the physical activity of a group of gestating sows using an artificial neural network. In Proc of the 73rd EAAP, Porto, Portugal. Oral presentation

Escarcha, J. F., J. A. Lassa, and K. K. Zander. 2018. Livestock Under Climate Change: A Systematic Review of Impacts and Adaptation. *Climate* 6:7. doi:10.3390/cli6030054

Friard, O., and M. Gamba. 2016. BORIS: a free, versatile open-source event-logging software for video/audio coding and live observations. *Met. Ecol. Evol.* 7:1325–1330. doi:10.1111/2041-210X.12584

Gaillard, C., and J. Y. Dourmad. 2022. Application of a precision feeding strategy for gestating sows. *Anim. Feed Sci. Tech.* 287. doi:10.1016/j.anifeedsci.2022.115280

Gaillard, C., R. Gauthier, L. Cloutier, and J. Y. Dourmad. 2019. Exploration of individual variability to better predict the nutrient requirements of gestating sows. *J. Anim. Sci.* 97:4934–4945. doi:10.1093/jas/skz320

Gaillard, C., N. Quiniou, R. Gauthier, L. Cloutier, and J. Y. Dourmad. 2020. Evaluation of a decision support system for precision feeding of gestating sows. *J. Anim. Sci.* 98:1–12. doi:10.1093/jas/skaa255

Groo, Z., P. Szenczi, O. Banszegi, Z. Nagy, and V. Altbacker. 2018. The influence of familiarity and temperature on the huddling behavior of two mouse species with contrasting social systems. *Behav. Proc.* 151:67–72.

He, J. W., W. J. Zheng, M. Z. Lu, X. J. Yang, Y. Q. Xue, and W. Yao. 2019. A controlled heat stress during late gestation affects thermoregulation, productive performance, and metabolite profiles of primiparous sow. *J.Thermal Biol.* 81:33–40.

Huber, L. A. 2019. Sow feeding strategies: gestating sows. in Proc. of the London Swine Conference 2019, Ontario. *Canada* 51–55.

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

IFIP. 2018. *Le Porc par les Chiffres*, IFIP, Paris, 25 pages.

Jensen, K. H., L. S. Sorensen, D. Bertelsen, A. R. Pedersen, E. Jorgensen, N. P. Nielsen, and K. S. Vestergaard. 2000. Management factors affecting activity and aggression in dynamic group housing systems with electronic sow feeding: a field trial. *Anim. Sci.* 71:535–545.

Laird, N. M., and J. H. Ware. 1982. Random-effects models for longitudinal data. *Biometrics* 38:963–974. doi:10.2307/2529876

Lenth, R.V., P. Buerkner, M. Herve, J. Love, F. Miguez, H. Riebl, H. Singmann. 2022. *EMMEANS: Estimated Marginal Means, aka Least-Squares Means*. R package version 1.7.2. https://CRAN.R-project.org/package=emmeans

Lucy, M. C., and T. J. Safranski. 2017. Heat stress in pregnant sows: Thermal responses and subsequent performance of sows and their offspring. *Mol. Repro. Dev.* 84:946–956. doi:10.1002/mrd.22844

Monteiro, A., T. M. Bertol, P. A. V. de Oliveira, J. Y. Dourmad, A. Coldebella, and A. M. Kessler. 2017. The impact of feeding growing-finishing pigs with reduced dietary protein levels on performance, carcass traits, meat quality and environmental impacts. *Livest. Sci.* 198:162–169. doi:10.1016/J.LIVSCI.2017.02.014

Nadel, E. R., S. M. Fortney, and C. B. Wenger. 1980. Effect of hydration state on circulatory and thermal regulations. *J. Appl. Physiol.* 49:715–721. doi:10.1152/jappl.1980.49.4.715

Noblet, J., and M. Etienne. 1987. Metabolic utilization of energy and maintenance requirements in pregnant sows. *Livest. Prod. Sci.* 16:243–257. doi:10.1016/0301-6226(87)90042-x

Noblet, J., X. S. Shi, and S. Dubois. 1993. Energy cost of standing activity in sows. *Livest. Prod. Sci.* 34:127–136. doi:10.1016/0301-6226(93)90041-f

Pinheiro, J., D. Bates, S. DebRoy, D. Sarkar, and R.C. Team. 2018. *NLME: Linear and Nonlinear Mixed Effects Models*. R package version 3.1-137. https://CRAN.R-project.org/package=nlme

Pomar, C., L. Hauschild, G. H. Zhang, J. Pomar, and P. A. Lovatto. 2009. Applying precision feeding techniques in growing-finishing pig operations. Rev. Brasil. Zoot. Brazil. *J. Anim. Sci.* 38:226–237. doi:10.1590/S1516-35982009001300023

Ramonet, Y., and C. Bertin. 2015. Utilisation d'accéléromètres pour évaluer l'activité physique des truies gestantes logées en groupes. *Chambre d'agriculture de Bretagne* 12. https://hal.science/hal-01780152

Renaudeau, D., N. Quiniou, S. Dubois, and J. Noblet. 2002. Effects of high ambient temperature and dietary protein level on feeding behavior of multiparous lactating sows. *Anim. Res.* 51:227–243. doi:10.1051/animres:2002020

Sawka, M. N., W. A. Latzka, R. P. Matott, and S. J. Montain. 1998. Hydration effects on temperature regulation. *Int. J. Sports Med.* 19:S108–S110. doi:10.1055/s-2007-971971

Wegner, K., C. Lambertz, G. Das, G. Reiner, and M. Gauly. 2016. Effects of temperature and temperature-humidity index on the reproductive performance of sows during summer months under a temperate climate. *Anim. Sci. J.* 87:1334–1339. doi:10.1111/asj.12569

Yang, A., H. Huang, B. Zheng, S. Li, H. Gan, C. Chen, X. Yang, and Y. Xue. 2020. An automatic recognition framework for sow daily behaviours based on motion and image analyses. *Biosys. Engin.* 192:56–71. doi:10.1016/j.biosystemseng.2020.01.016