

PhD thesis

Giving birth outdoors: Impact of thermal  
environment on sows' parturition and  
piglet survival

by

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Jeg har skrevet et sted,  
hvor jeg daglig må se,  
det manende tankesprog:  
T.T.T.

Når man føler hvor lidet  
man når med sin flid,  
er det nyttigt at mindes, at  
Ting Tar Tid

*Piet Hein*

Put up in a place  
where it's easy to see,  
the cryptic admonishment:  
T.T.T.

When you feel how depressingly  
slowly you climb,  
it's well to remember that  
Things Take Time



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## **PREFACE**

This thesis was submitted to the Graduate School of Science and Technology, Aarhus University, Denmark and is intended to fulfil the requirements for the degree of Doctor of Philosophy at the Department of Animal Science, Aarhus University. I declare that I have composed the present PhD thesis, and all work included is my own. The assistance I have received during this PhD project has been duly acknowledged, and the work presented has not been submitted for any other degree or professional qualification. The project period was interrupted once due to leave for working on another project.

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This thesis presents work from four separate studies. To avoid unnecessary repetition of the materials and methods used, the original research papers/manuscripts are presented in the back of the thesis.

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# TABLE OF CONTENTS

LIST OF ABBREVIATIONS.....	1
SUMMARY.....	3
SAMMENDRAG (DANISH SUMMARY).....	5
ZUSAMMENFASSUNG (GERMAN SUMMARY) .....	7
1. INTRODUCTION .....	11
2. ‘STATE-OF-THE-ART’.....	15
2.1 Background: Danish organic pig production.....	15
2.2 Thermoregulation .....	19
2.3 Thermal impact on the pig .....	24
3. OVERALL AIM.....	35
3.1 Research questions followed by their related hypotheses .....	35
4. LIST OF INCLUDED PAPERS.....	37
5. MATERIALS AND METHODS .....	39
5.1 Study population.....	39
5.2 Housing and animals from the two data sources .....	41
5.3 Data sampling and methods: arguments for choiches .....	46
5.4 Study designs: arguments for choiches.....	57
6. SYNOPSIS OF RESULTS .....	59
6.1 Hut climate and its effect on piglet mortality.....	59
6.2 The course of parturition and its effect on piglet mortality .....	62
6.3 Hut climate and its effect on the course of parturition .....	64
6.4 Physiological and behavioural thermoregulation in the farrowing field .....	65
7. GENERAL DISCUSSION .....	69
7.1 Thermal conditions and risk of neonatal mortality .....	69
7.2 The course of parturition.....	75
7.3 Do sows thermoregulate sufficiently? .....	83
7.4 Advantages of trees in the paddock.....	86
8. CONCLUSIONS .....	89
REFERENCES .....	90

PAPER I .....	105
PAPER II .....	115
PAPER III.....	139
PAPER IIII .....	140

## **LIST OF ABBREVIATIONS**

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**CI** = 95% Confidence Interval

**LCT** = Lower Critical Temperature

**MMA** = Mastitis-Matritis-Agalactica

**MST** = Maximum Surface Temperature

**RF** = Respiration Frequency

**RR** = Rate ratio

**UCT** = Upper Critical Temperature



## SUMMARY

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About one-third of the piglets born in organic pig production die before weaning at 7 weeks of age. Studies report varying piglet mortalities across the year with increases during summer and winter. The temperature inside the farrowing hut during summer may exceed the upper critical temperature for parturient and lactating sows, which may result in sows experiencing hyperthermia. This condition has been related to prolonged parturitions and lowered lactation performance. Thereby, hyperthermia increases the risk of stillbirth and postnatal mortality. Low temperature may cause hypothermia in piglets if nest temperature is insufficient and hypothermia is a common cause of early liveborn mortality. Thus, the main aim of the current PhD project was to quantify the thermal conditions inside the farrowing hut and to obtain knowledge about how these impact the course of parturition, thermoregulation in lactating sows and early piglet mortality.

Four studies were conducted. Study 1 was an observational study including data collection at five commercial organic pig-producing herds. At each herd, data loggers placed inside A-frame huts recorded and stored temperature and humidity, and farmers recorded production results. The study showed that piglet mortality varied across the year with lower risk of stillbirth during winter (Dec, Jan, Feb;  $P=0.004$ ) and lower risk of liveborn death until castration in spring (Mar, Apr, May;  $P=0.009$ ). During winter, the risk of stillbirth increased with increasing temperature variation between day 1 *pre-partum* and the day of parturition ( $P=0.013$ ). During the remaining part of the year, the risk of stillborn piglets increased at hut temperatures  $\geq 27^{\circ}\text{C}$  ( $P=0.002$ ). Hut temperature had no significant effect on postnatal mortality. Hut humidity affected neither the risk of stillborn piglets nor postnatal mortality.

Study 2 was an observational study conducted at an experimental farm. Eighty-seven parturitions were video filmed, and the time of birth of each piglet was recorded along with sow posture during parturition. The results showed that an increase in parturition duration increased the risk of having litters with stillborn piglets ( $P=0.003$ ) and the odds of liveborn piglets dying before day 4 *postpartum* ( $P=0.051$ ). The median parturition lasted 4.3 hours. Posture changes during parturition did not affect liveborn mortality.

Study 3 was also an observational study, and data were collected at an experimental herd and at a commercial organic pig-producing herd. Again, sow parturitions were video filmed, and information on time of birth of each piglet and sow posture was recorded. Furthermore, data loggers recorded and stored hut temperature, and on day 1 to 3 *postpartum* sow surface

temperature and respiration frequency were recorded. The results of Study 3 showed that the level of thermoregulation, on day 1 *postpartum* increased with increasing hut temperature, reflected by an increase in maximum surface temperature ( $P < 0.001$ ) and respiration frequency ( $P < 0.001$ ). Neither the duration of parturition nor the hourly number of posture changes during parturition were significantly related to hut temperature.

Study 4 was an experimental study conducted at a commercial herd where 57 sows had access to poplars in the farrowing field. Behavioural observations of sows' use of the paddock (14 sows with access to poplars and 14 without access) and sows' use of the area with poplar trees (57 sows with access) were conducted. During Study 4, access to poplars in interaction with hut temperature affected the sows' use of the farrowing hut ( $P = 0.001$ ). Sows with access to poplars were observed less inside the hut when hut temperature increased, whereas this was not the case for sows without access to poplars. The odds of observing sows inside the poplar tree area were not significantly affected by hut temperature. On the contrary; when sows were inside the poplar area, the odds of sows lying increased with increasing hut temperature ( $P < 0.001$ ).

Across the year, temperature inside insulated farrowing huts reached levels above the upper critical temperature of lactating sows and far below the lower critical temperature of neonatal piglets. High temperatures increased the risk of stillbirth, whereas no effect of high or low hut temperature could be shown for postnatal mortality. This could be due to 1) sows being able to thermoregulate through behaviour *postpartum* thereby avoiding potentially negative impacts of high temperature on lactation performance and 2) a sufficient microclimate in the nest reducing negative effects of low ambient temperature.

A prolonged parturition increased the risk of piglet mortality. However, hut temperature did not significantly affect the course of parturition, which was likely due to the relatively low hut temperatures measured even during the warmest periods of the study. Increasing hut temperature resulted in increased level of physiological thermoregulation reflected as increased sow surface temperature and respiration frequency. At increasing temperature, sows inside the poplars were more often lying, suggesting they thermoregulated using behaviour.

In conclusion, high hut temperature contributed to piglet mortality by increasing the risk of stillborn piglets, whereas, with proper management, low temperature appeared to have no negative impact on piglet mortality. Thus, counteracting high temperatures during the warm part of the year seems essential for piglet survival.

## SAMMENDRAG (DANISH SUMMARY)

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Omtrent hver tredje gris, som fødes i økologisk svineproduktion, dør inden fravæning ved 7 uger. Studier rapporterer, at pattegrisedødeligheden varierer hen over året med stigninger om vinteren og sommeren. Om sommeren kan temperaturen inde i farehytten overstige farende og diegivende søers øvre kritiske temperaturgrænse, hvilket kan resultere i, at søerne bliver varmestressede. Denne tilstand er relateret til forlængede faringsforløb og nedsat mælkeydelse; faktorer, der øger risikoen for dødfødsler og for at levendefødte grise dør. Lave temperaturer kan forårsage kuldestress hos pattegrisene, hvis redetemperaturen er utilstrækkelig. Kuldestress er en hyppigt forekommende årsag til tidlig pattegrisedød. Formålet med nærværende ph.d.-projekt var derfor at kvantificere temperaturforholdene i farehytten og opnå viden om, hvordan disse påvirker faringsforløbet, diegivende søers termoregulering og tidlig pattegrisedødelighed.

Fire studier blev gennemført. Studie 1 var et observationelt studie, der inkluderede dataindsamling ved 5 kommercielle økologiske svineproducenter. I hver besætning blev der opsat dataloggere i A-hytterne. Loggerne målte og lagrede temperatur- og luftfugtighedsdata, og landmændene noterede produktionsresultater. Studiet viste, at pattegrisedødeligheden varierede hen over året med lavest risiko for dødfødsler om vinteren (dec, jan, feb;  $P=0.004$ ) og lavest risiko for postnatal dødelighed om foråret (mar, apr, maj;  $P=0.009$ ). Om vinteren steg risikoen for dødfødsler med højere udsving i temperaturen mellem dagen før faring og faringsdagen ( $P=0.013$ ). Resten af året var risikoen for dødfødsler forøget ved temperaturer  $\geq 27^{\circ}\text{C}$  ( $P=0.002$ ). Hyttetemperaturen påvirkede ikke postnatal dødelighed signifikant. Luftfugtigheden i hytten påvirkede hverken risikoen for dødfødsler eller postnatal dødelighed.

Studie 2 var et observationelt studie, der blev gennemført på en forsøgsgård. Syvogfirs faringer blev videofilmet, og tidspunktet for fødsel af hver enkelt gris blev registreret sammen med oplysninger om søernes positur under faring. Resultaterne viste, at ved en længere faring forøgedes både risikoen for kuld med dødfødte grise ( $P=0.003$ ) og oddsene for, at levendefødte grise døde inden dag 4 ( $P=0.051$ ). Den mediane faringslængde var 4,3 timer. Der blev ikke fundet nogen effekt af antallet af positurskift per time for død af levendefødte.

Studie 3 var ligeledes et observationelt studie, hvor dataindsamling foregik to steder: på en forsøgsgård samt ved en kommerciel økologisk svineproducent. Søernes faringer blev også i dette studie filmet og information om tidspunkt for fødsel af hver gris og søernes positur under

faring registreret. Ydermere målttes hyttetemperaturen, og på dag 1 til 3 efter faring blev søernes overfladetemperatur og respirationsfrekvens målt. Resultaterne fra studie 3 viste, at søernes niveau af temperaturregulering, afspejlet i en forøget overfladetemperatur ( $P < 0.0001$ ) og respirationsfrekvens ( $P = 0.0002$ ) på dag 1 efter faring, steg med øget hyttetemperatur. Hverken faringslængden eller positurskifte under faring var signifikant relateret til hyttetemperaturen.

Studie 4 var et eksperimentalt studium, som blev gennemført i en kommerciel besætning, hvor 57 søer havde adgang til poppeltræer i faremarken. Der blev foretaget observationer af søernes brug af faremarken (adgang til poppeltræer vs ikke adgang til træer) og søernes brug af området med poppeltræer. Under studie 4 påvirkede adgang til poppeltræer i interaktion med hyttetemperatur søernes brug af farehytten ( $P = 0.001$ ). Søer med adgang til poppeltræer blev observeret mindre i hytten, når temperaturen steg, mens dette ikke gjaldt for søer uden adgang til poppeltræer. Oddsene for, at søer blev observeret inde på poppeltræsområdet, var ikke påvirket af hyttetemperaturen, men når søerne var i poppelområdet, lå søerne oftere ved højere hyttetemperatur ( $P < 0.001$ ).

Hen over året nåede temperaturen i isolerede farehytter op over den diegivende søs øvre kritiske temperaturgrænse og langt ned under nyfødte pattegrises nedre kritiske temperaturgrænse. Høje temperaturer medfødte en øget risiko for dødfødsler, mens der ikke kunne påvises en effekt af hyttetemperaturen på postnatal dødelighed. Dette kunne skyldes: 1) at søerne var i stand til at termoregulere ved hjælp af adfærd efter faring, hvorved de potentielt negative effekter af høje temperaturer for mælkeydelsen blev undgået og 2) et tilstrækkeligt mikroklima i reden, hvorved de negative konsekvenser ved lave temperaturer blev undgået.

En forlænget faring øgede risikoen for pattegrisedødelighed, men hyttetemperaturen påvirkede ikke faringsforløbet signifikant, hvilket formodes at skyldes de relativt lave temperaturer målt under selv den varmeste del af studieperioden. Øget hyttetemperatur medførte et øget niveau af fysiologisk termoregulering, hvilket blev afspejlet i, at søerne øgede deres overfladetemperatur og respirationsfrekvens. Ved øget hyttetemperatur lå søerne inde i poppelområdet mere, hvilket tyder på, at de termoregulerede ved hjælp af adfærd.

Det konkluderedes, at høj hyttetemperatur bidrog til pattegrisedødeligheden ved at øge risikoen for dødfødte grise, hvorimod lave temperaturer, når managementrutinerne var i orden, tilsyneladende ikke havde konsekvenser for pattegrisedødeligheden. Derfor er det essentielt at modvirke de høje temperaturer i den varme del af året for at øge pattegriseoverlevelsen.



## ZUSAMMENFASSUNG (GERMAN SUMMARY)

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Ungefähr jedes dritte Schwein, das in der ökologischen Schweineproduktion geboren wird, stirbt vor der Entwöhnung bei 7 Wochen. Studien berichten, dass die Saugferkeltödlichkeit im Laufe des Jahres mit Ansteigen im Winter und im Sommer variiert. Im Sommer kann die Temperatur in der Ferkelnhütte die obere kritische Temperaturgrenze der säugende und ferkelnden Säue übersteigen, was zur Folge haben kann, dass die Säue hitzestress werden. Dieses ein Zustand, der oft längere Ferkelverläufe und geringere Milchleistungen bewirkt, Faktoren, die das Risiko für Totgeburten vergrößert und dafür, dass lebengeborenen Ferkelchen sterben. Niedrige Temperaturen können Kältestress bei den Ferkeln verursachen, wenn die Nesttemperatur ungenügend ist. Kältestress ist ein häufiger Grund für ein frühes Saugferkelsterben. Der Zweck des gegenwärtigen PH.d-Projektes war deshalb, die Temperaturverhältnisse der Ferkelhütte zu quantifizieren, und dadurch das Wissen zu erzielen, wie diese den Ferkelverlauf, die Termoregulierung säugender Säue und frühe Sterblichkeit der Saugferkel beeinflussen.

Vier Studien wurden durchgeführt. Studie 1 war eine observationelle Studie, die Dateneinsammlung bei 5 kommerziellen Schweineproduzenten umfasste. In jedem Schweinebestand wurden in den A-Hütten Datalogger aufgestellt. Die Logger messten und lagerten Temperatur und Luftfeuchtigkeitsdaten und die Landwirte notierten die Produktiosresultate. Die Studie ergab, dass die Saugferkeltödlichkeit im Laufe des Jahres mit niedrigstem Risiko für Totgeborene im Winter (Dez, Jan, Feb;  $P=0,004$ ) und niedrigstes Risiko für postnatale Tödlichkeit im Frühling (Mar, Apr, Mai;  $P=0,009$ ) variierten.

Im Winter stieg das Risiko für Totgeburten mit höheren Schwankungen der Temperatur zwischen dem Tag vor dem Ferkeln und dem Ferkelntag ( $P=0,013$ ). Der restliche Teil des Jahres war das Risiko für Totgeburt bei Temperaturen über 27 Grad C ( $P=0,002$ ) vergrößert. Die Hüttentemperatur hatte keinen signifikanten Einfluss auf die postnatale Sterblichkeit. Die Luftfeuchtigkeit in der Hütte beeinflusste weder das Risiko für Todesgeburt noch die postnatale Tödlichkeit.

Studie 2 war eine Observationsstudie, die in einem Versuchshof durchgeführt wurde. 87 Ferkeln wurden Video verfilmt und der Zeitpunkt jeder einzelnen Geburt wurde zusammen mit Auskünfte über Positur der Säue während des Ferkelns registriert. Die Resultate ergaben, das während eines längeren Ferkelns wurde sowohl das Risiko für Ferkeln mit totgeborenen

Ferkeln ( $P=0,003$ ) vergrössert als auch die Möglichkeit dafür, dass lebendgeborene Ferkel innerhalb 4 Tagen starben. ( $P=0,051$ ). Die mediane Ferkelnslänge war 4,3 Stunden. Kein Effekt der Zahl von Positurwechsel pro Stunde für das Sterben von lebendgeborenen wurde festgestellt.

Studie 3 war ebenfalls eine Observationsstudie in der die Dateneinsammlung an zwei Lokalitäten durchgeführt wurde: In einem Versuchshof samt bei einem kommerziellen, ökologischen Schweineproduzenten. Die Ferkel der Säue wurden auch in dieser Studie verfilmt, und Information über Zeitpunkt der Geburt jedes einzelnen Ferkels und die Positur der Säue während des Ferkelns wurden registriert. Ausserdem wurde die Hüttentemperatur gemessen, und an Tag 1 bis 3 nach dem Ferkeln wurden die Oberflächentemperatur der Säue und Respirationsfrequenz gemessen. Die Ergebnisse der Studie 3 ergaben, dass das Niveau der Temperaturregelung der Säue, in einer erhöhten Oberflächentemperatur ( $P<0,001$ ) und Respirationsfrequenz ( $P<0,001$ ) abgespiegelt an Tag eins nach dem Ferkeln mit erhöhten Hüttentemperatur, stieg. Weder die Ferkellänge oder Positionswechsel während des Ferkelns war signifikant auf die Hüttentemperatur bezogen.

Studie 4 war eine experimentelle Studie in einem kommerziellen Schweinebestand wo 57 Säue zu Pappelbäumen auf den Ferkelsäckern Zutritt hatten. Observationen von der Benutzung der Säue von dem Ferkelsacker (Zutritt zu Pappelbäumen oder nicht) und die Benutzung der Säue von dem Gebiet mit Pappelbäumen wurden gemacht. Während Studie 4 beeinflusste Zutritt zu Pappelbäumen in Interaktion mit der Hüttentemperatur die Benutzung der Säue von der Ferkelhütte ( $P=0,001$ ). Säue mit Möglichkeit für Pappelbäume wurden weniger in der Hütte observiert, wenn die Temperaturen stiegen, aber für die, die keine Möglichkeit für Pappelbäume hatten war dieses nicht der Fall. Die Odds dafür, dass die Säue in dem Pappelgebiet observiert wurden waren nicht von der Temperatur beeinflusst, aber wenn sich die Säue im Pappelgebiet befanden, lagen die Säue öfter bei höherer Temperatur ( $P<0,001$ ).

Im Laufe des Jahres erreichten die Temperaturen in isolierten Ferkelnshütten über die obere kritische Temperaturgrenze der säugende Sau, und weit unter der niedrigsten Temperaturgrenze zu neugeborener Saugferkel. Hohe Temperaturen verursachten ein vergrössertes Risiko für Todesgeburt. Man konnte dagegen kein Effekt auf die Hüttentemperatur auf postnatale Tödlichkeit nachweisen. Dieses konnte darauf zurückgeführt werden: 1. Dass die Säue imstande waren, termozuregulieren durch Hilfe von Benehmen nach Ferkeln, wodurch die potentiell negative Effekte von hohen Temperaturen für die Milchleistung

vermieden wurden, und 2. Ein genügendes Mikroklima in dem Nest wodurch die negativen Konsequenzen bei niedrigen Temperaturen vermieden wurden.

Ein verlängertes Ferkeln vergrösserte das Risiko für Saugferkelsterblichkeit, aber die Hüttentemperaturen beeinflussten nicht signifikant den Ferkelnverlauf, welches vermutlich auf die relativ niedrige Temperaturen während der sogar wärmsten Teil der Studienperiode zurückzuführen ist. Erhöhte Hüttentemperatur verursachte ein vergrössertes Niveau von physiologischen Termoregulierung zur Folge, welches darin abgespiegelt wurde, dass die Säue ihre Oberflächentemperatur und Respirationsfrequenz erhöhten.

Bei erhöhter Hüttentemperatur lagen die Säue im Pappelgebiet mehr, was darauf deutet, dass sie mit Hilfe von Benehmen termoregulierten.

Es wurde konkludiert, dass hohe Hüttentemperatur dazu beitrug, dass die Saugferkelntödlichkeit grösser wurde. Dagegen trugen niedrigere Temperaturen nicht dazu, dass die Saugtödlichkeit grösser wurde. Es ist deshalb essentiell, die hohen Temperaturen in dem warmen Teile des Jahres entgegenzuarbeiten um die Saugferkeln-Überlebung zu vergrössern.



# 1. INTRODUCTION

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Since the late twentieth century, public concerns for animal welfare have been growing (Kristiansen and Merfield, 2006; Fraser, 2008). More than nine in ten Europeans (94% of 27,672 survey respondents) consider the protection of farm animal welfare important, and more than half (59%, asked outside the shopping situation) are willing to pay extra for animal welfare-friendly products (Eurobarometer, 2016). When asked about what constitutes good animal welfare, consumers underline the importance of ‘naturalness’, i.e. animals should have access to an outdoor area and possibility of performing species-specific behaviour (reviewed by Thorslund et al., 2017). The possibility of performing natural behaviour is also specified in the principle of fairness, which is one of the four ethical principles of organic agriculture developed by The International Federation of Organic Agriculture Movements (IFOAM, 2005). The principles are the principles of health, ecology, fairness and care. In accordance with the principle of fairness, the outdoor conditions in organic production allow animals increased expression of species-specific behaviour compared to conventional indoor conditions.

Concurrently with the rising concerns for animal welfare, organic agriculture has grown and is now recognised by both the public and governments as a valid alternative to conventional agriculture (Kristensen et al., 2006). Organic pig production has followed the trend of organic agriculture in general, and thus, across Europe, organic pig production is growing (Früh et al., 2014). In accordance with the four ethical principles, organically farmed pigs receive, for example, GMO-free feed and less antibiotics than conventionally housed pigs and have access to an outdoor area, roughage, more space etc. In cooperation with several non-governmental organisations, Danish organic pig farmers updated the code of conduct of Danish organically housed pigs in 2017 (Anonymous, 2017b) to further comply with the ethical principles. For example, it is specified that from 1 May 2018 animals must be able to lie in the shade during summer in the farrowing field. Thus, not only consumers but also farmers acknowledge the expression of species-specific behaviour as a mean for improving animal welfare. However, some welfare concerns remain evident within Danish organic pig production – one being the high piglet

mortality. A large Danish study conducted in 2014-2015 showed that the average pre-weaning piglet mortality in the nine largest Danish organic pig-producing herds was 29.5% (average weaning age minimum seven weeks, Rangstrup-Christensen et al., 2018). This mortality is considerably higher than the 21.3% total pre-weaning (weaning age 3-4 weeks) piglet mortality reported for Danish conventional indoor herds (Helveskov, 2017). The most frequent causes of mortality in the organic herds were stillbirth, crushing, starvation and infection (Rangstrup-Christensen et al., 2018). Dying from crushing, starvation or infection is associated with pain, hunger, fear and/or stress (as discussed by Pedersen et al., 2010). Therefore, the high mortality in organic production conflicts with the organic production striving to achieve high animal welfare and with the principle of health which refers to health as “*the maintenance of physical, mental, social and ecological well-being*” (IFOAM, 2005). Furthermore, the high mortality may be indicative of the system not providing sufficient living conditions for the animals, jeopardising the principle of fairness which “*insists that animals should be provided with the conditions and opportunities of life that accord with their physiology, natural behavior and well-being*” (IFOAM, 2005).

Studies on outdoor-housed pigs report varying piglet mortalities across the year with increases during winter (Berger et al., 1997; Randolph et al., 2005) and summer (Randolph et al., 2005; Rangstrup-Christensen et al., 2016). These fluctuations could be due to seasonality in hormones affecting parturition and lactation (Peltoniemi et al., 1997; Bassett et al., 2001; Peltoniemi and Virolainen, 2006) but could also reflect an insufficient thermal environment. For thermoregulation, the pig largely relies on behaviour. Insufficient thermal conditions, under which animals are unable to compensate for high or low temperature through thermoregulation, may both directly and indirectly affect piglet mortality. Low temperature increases the risk of piglets experiencing hypothermia and dying (Tuchscherer et al., 2000; Baxter et al., 2008) from for example crushing, disease or starvation (Baxter et al., 2009; Pedersen et al., 2011). High temperatures may indirectly increase mortality by causing hyperthermia in the sow. Hyperthermia can result in prolonged parturitions (Muns et al., 2016), a known risk factor for stillbirth (Borges et al., 2005; Canario et al., 2006; Baxter et al., 2009; Mainau et al., 2010), and lowered postnatal viability (Herpin et al., 1996). Furthermore, hyperthermia may reduce sow lactation performance (Black et al., 1993; Prunier et al., 1997; Quiniou and Noblet,

1999; Renaudeau and Noblet, 2001), thereby increasing the risk of starving piglets. Thus, the causes of mortality reported for organic pig production by Rangstrup-Christensen et al. (2018) correspond to the causes of mortality, which may be expected when parturient and lactating sows and suckling piglets are housed under insufficient thermal conditions. Therefore, the overall aim of the current PhD project was to quantify the thermal conditions inside the farrowing hut and to obtain knowledge on how these affect the course of parturition, thermoregulation in lactating sows and early piglet mortality.





## **2. ‘STATE-OF-THE-ART’**

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### **2.1 BACKGROUND: DANISH ORGANIC PIG PRODUCTION**

In Denmark, the first national association for organic agriculture [Landsforeningen Økologisk Jordbrug], a predecessor for today’s Organic National [Økologisk Landsforening], was founded in 1981. The first legal regulation concerning organic production in Denmark was proposed in 1986 and adopted on 14 May 1987 (1986/1 LSF 75). Yet, it was not until the year 2000 that a legal regulation on outdoor housing of pigs was proposed. This law was adopted in 2001 (LOV nr 173 af 19/03/2001 Historisk, 2001) and has been modified since then, the latest modification being published in 2017 (LBK nr 51 af 11/01/2017).

Sixty-one per cent of the Danish land is cultivated and of this land, 6.6% is farmed organically (Jensen and Pedersen, 2015) with 3.2% (5.559 ha) of the organic land being used for organic pig production (Jensen and Pedersen, 2015) which has been growing. Around 51,000 organic pigs were raised and slaughtered in 2007 compared to approximately 180,000 in 2017; the number is estimated to reach 230,000 by 2020 (The Danish Agricultural Agency, 2018). From 2015 to 2016, the sale of organic pig meat increased by 28% (Seges, 2017), and the increased public demand for organic pig meat is accompanied by a high pay-off. This is illustrated by organic farmers being payed DKK 29.40 per kg pig meat (2016/2017, Friland, 2017), which is almost three times the pay-off given for conventional pig meat (DKK 10.64 per kg meat in 2016/2017 (Danish Crown, 2017)).

This PhD project focussed on parturient and lactating sows and their piglets. Thus, an overview of the legal requirements (Danish conventional, EU organic and Danish organic) for housing in the farrowing section is provided in Table 1.

**Table 1** Overview of the housing and handling conditions of Danish conventional (BEK nr 17 af 07/01/2016; BEK nr 1324 af 29/11/2017), European organic (Commission Regulation (EC) No 889/2008; Council Regulation (EC) No 834/2007) and Danish organic (LBK nr 51 af 11/01/2017; Anonymous, 2017b) parturient and lactating sows and their suckling piglets.

	Danish conventional	European organic	Danish organic <sup>a</sup>
<b>Sows</b>			
Housing	Indoors (about 90% fixated)	Indoors with access to an outdoor run	In farrowing huts on pasture
Flooring	Not specified	Half the floor area must be solid	Outdoors on pasture
Space allowance	Fixated	Indoor area 7.5 m <sup>2</sup> Outdoor area 2.5 m <sup>2</sup>	Paddock size at least 300 m <sup>2</sup> per sow
Lactation period	Minimum 28 days <sup>b</sup>	Minimum 40 days	Average at least 49 days
Synthetic amino acids, GMO	Permitted	Prohibited	Prohibited
Occupational & nest building material	Suitable nesting material in a sufficient quantity	<i>Ad libitum</i> Straw bedding	<i>Ad libitum</i> Straw bedding, grass
Roughage	Not required	<i>Ad libitum</i>	<i>Ad libitum</i>
Shade	Not relevant	Not specified	All animals must have access to shade during the summer month <sup>c</sup>
Means for temperature regulation	None	Not specified	Access to a wallow <sup>d</sup>
Snout ringing	Not specified	Not specified	Permitted
<b>Suckling piglets</b>			
Access to feed	Not specified	Not specified	From 4 weeks of age
Tail docking	Permitted <sup>e</sup>	Prohibited	Prohibited
Teeth grinding	Permitted	Prohibited	Prohibited
Castration	Permitted, within 2-7 days after birth, use of analgesic required	Permitted, within the most appropriate age, use of anesthetic and/or analgesic required	Permitted, within 2-7 days after birth, use of anesthetic and analgesic required

<sup>a</sup> Includes the parts of the updated code of conduct that apply from 1 May 2018

<sup>b</sup> Piglets may be weaned at 21 days if they are moved to specialised farm sections

<sup>c</sup> The farrowing hut can constitute the shaded area, provided it has an additional opening (i.e. an opening besides the sow entrance) that is the size of or larger than the sow entrance

<sup>d</sup> When mean ambient temperature, recorded in the shade, exceeds 15°C

<sup>e</sup> Pigs should not be tail docked routinely. Tail docking is permitted within 2-4 days after birth, no use of anesthetic or analgesic required.

*Housing in the farrowing field.* The Danish organic code of conduct states that all pigs must be born on pasture (Friland A/S, 2015; Anonymous, 2017b), and organic parturient and lactating sows are housed on pasture all year round (Figure 1 shows examples of farrowing fields). Most producers keep lactating sows in individual paddocks, but some producers prefer communal paddocks with two or more sows. No later than 7 days prior to parturition, pregnant sows must be relocated to the farrowing field (LBK nr 51 af 11/01/2017). From 1 May 2018, each parturient sow must have access to at least 300 m<sup>2</sup> of paddock (Anonymous, 2017b). If the average daily temperature exceeds 15°C (recorded in the shade), it is required by law that a wallow is created to allow animals a mean for thermoregulation (LBK nr 51 af 11/01/2017). Previously, and during the conduct of the studies described in this thesis, the only requirement with respect to provision of shade in the farrowing field was: “*All pigs must have access to shelter and shade in farrowing huts, tin huts, tents or similar housing. It may also be trees, hedge etc.*” (Anonymous, 2017c). According to the updated code of conduct, from May 2018 both sows and piglets in the farrowing field must have access to shade (during the summer month) in addition to that provided by the hut (Anonymous, 2017b).

In every paddock, a farrowing hut must be placed (commonly an insulated A-frame hut, Figure 1) with a ventilation opening in the back. According to §6 in the Danish legislation (LBK nr 51 af 11/01/2017) concerning outdoor-housed pigs: “*The huts must be insulated or arranged so that the temperature requirement of the pig can be met under all weather conditions. During the arrangement of the farrowing hut both the temperature requirements of the sow, gilt and piglets must be taken into account*”. Management attempts to adjust hut climate according to weather conditions and meet the needs of the animals are typically: regulation of the amount of straw provided, opening/closing of the hut ventilation window, use of plastic curtains and facing the sow entrance with respect to season (e.g. wind direction).

*Management in the farrowing field.* Sows used in the outdoor production are highly prolific, as they are of the same genetic material as conventional sows. Thus, large litters are born, and the number of piglets often exceeds the number of teats on the sow. It is therefore common practise to conduct cross-fostering in the first days *postpartum*, and an increased use of two step nursing sows (Baxter et al., 2013) is also seen.



**Figure 1** Two pictures of farrowing fields with individual paddocks and A-frame huts. In the lower picture paddocks include an area with poplar trees and the huts are provided with fenders.

The first days *postpartum*, male piglets are castrated. Teeth clipping/grinding and tail docking are not permitted.

Just before parturition, a fender, board or roller is placed at the sow entrance to the farrowing hut, aiming at restricting the piglets to the hut. Sows can cross the devices and still have access to the entire paddock. When the piglets start to jump the devices (usually around 10 days of age), the restriction is removed, and piglets thereby have access to the entire farrowing field. Weaning is allowed from 7 weeks *postpartum*.

Within Danish organic pig production, parturient and lactating sows and their suckling piglets are housed outdoors on pasture. Thus, the animals are exposed to varying weather conditions. Whether the outdoor conditions meet the thermal requirements of the animals is unknown. Securing a proper thermal climate is imperative, as insufficient thermal conditions can have negative consequences for both the welfare of the sow and her piglets. Since the temperature requirements of the sow and the neonatal piglet differ, securing a proper thermal climate may not easily be achieved. However, the animals have evolved means of thermoregulation allowing them to exploit the resources provided by the farmer for thermoregulation.

## 2.2 THERMOREGULATION

Animals able to maintain a relatively constant internal body temperature, despite environmental fluctuations, are referred to as homeotherms (Mount, 1968; 1979). This is a characteristic of both mammals and birds. The processes by which homeotherms retain a constant body temperature involve both metabolism and behaviour. The thermal neutral zone states the ambient temperature range in which the metabolic costs of upholding a more or less constant body temperature are at a minimum (Mount, 1968; 1979; Randall et al., 2002). Within the thermal neutral zone, animals may still use metabolic inexpensive measures (such as changing posture, vasomotor response and piloerection) to adjust body temperature (Mount, 1979; Randall et al., 2002). The thermal neutral zone is delimited by the lower and upper critical temperatures (**LCT** and **UCT**, respectively). These critical temperatures vary with species but also within species, as there are individual variations. For example, the LCT of a newborn calf is 13°C (Gonzalez-Jimenez and Blaxter, 1962) as opposed to an adult lactating dairy cow where the LCT has been estimated to vary from -16°C to -37°C (Hamada, 1971). The LCT is 29°C in a newborn

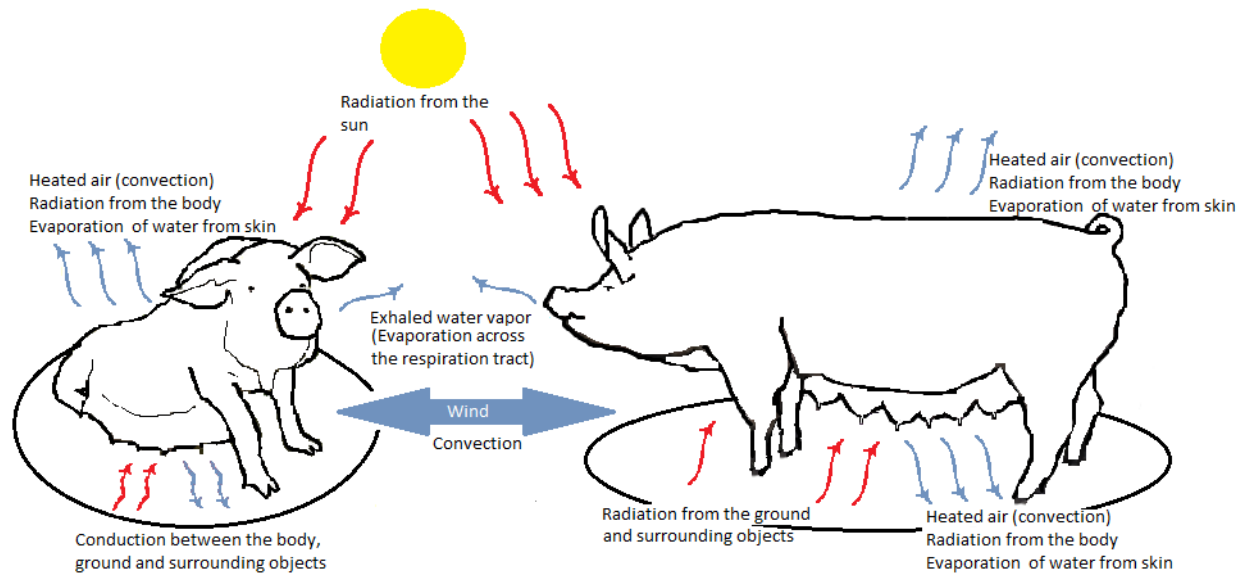
lamb (Alexander, 1961), whereas that of the unshorn adult sheep is estimated to vary from  $-20^{\circ}\text{C}$  (Mount, 1979) to  $-30^{\circ}\text{C}$  (Webster et al., 1969). The LCT of the neonatal piglets is  $34-35^{\circ}\text{C}$  (Mount, 1959), whereas that of the pregnant sow (at low feeding level) is around  $21^{\circ}\text{C}$  (Verhagen et al., 1986).

When faced with temperatures below the LCT or above the UCT, the metabolic costs of maintaining a constant body temperature will increase. Eventually, if temperature is consistently below the LCT, it may lead to a decrease in body temperature below the normal lower range (hypothermia). Ultimately, if this condition is prolonged, hypothermia will be fatal to the animal. Contrarily, temperatures above the UCT may result in an increased body temperature above the normal upper range (hyperthermia), which may accordingly be fatal.

Homeotherms may use a variety of mechanisms for thermoregulation to avoid the above fatal situations. One is metabolism which may be increased to generate heat (Mount, 1979). Through circulatory mechanisms, homeotherms can attempt to control heat exchange between their body and the environment (Mount, 1979; Randall et al., 2002; Sjaastad et al., 2016). For example, animals may cool peripheral tissues while maintaining core temperature through vasoconstriction (constriction of the blood vessels). By vasoconstriction, peripheral and cutaneous circulation may be reduced whereby peripheral insulation is increased and heat loss to the surroundings reduced. Contrarily, by using peripheral vasodilation (dilation of the blood vessels), blood flow to the body surface is increased and heat dissipation to the surroundings may thereby be increased, causing a reduction in body temperature. Finally, animals may conserve heat through counter-current heat exchange. This is achieved by the chilled venous blood returning from the body surface absorbing heat from the warm arterial blood (reviewed by Blix, 2016). Counter-current heat exchange is for example seen in the legs of reindeer, in the flippers of seals and in the nasal mucosa of for example reindeer (reviewed by Blix, 2016).

Insulation (fur, plumage, fleece, fat) and the use of circulatory mechanisms may decrease heat exchange between an animal and its environment, but, still, heat exchange takes place through four physiological processes: evaporation, radiation, conduction and convection (Porter and Gates, 1969; Mount, 1979; Randall et al., 2002; Sjaastad et al., 2016) (Figure 2).





**Figure 2** The mechanisms of heat exchange between an animal and its environment. Red arrows illustrate routes of heat transfer from the surroundings to the animal, whereas blue arrows demonstrate routes of heat loss from the animal.

### 2.2.1 Evaporative heat exchange

Evaporation occurs when water changes from its liquid state and becomes a gas. This process can be utilised by homeotherms for cooling. Evaporation requires heat which may be provided by an animal or its surroundings. Provision of heat from the surroundings is least efficient for increasing evaporative heat loss. Evaporative heat exchange can take place across the body surface of an animal or across the respiration tract (Figure 2). In animals with a dense fur (e.g. a dog wet from rain), the heat needed for evaporation of water from the body surface is mainly provided by the surroundings (due to the fur insulating heat loss from the body surface) why this form of heat exchange results in little heat loss for the animal. The majority of evaporative heat loss in animals with dense fur therefore takes place across the respiration tract. In dogs, for example, panting is an efficient mean of cooling (Hammel et al., 1958). In bare-skinned animals, like for example humans, heat for evaporation is provided across the entire body surface (the same is true for the pig as illustrated by the blue arrows in Figure 2). This makes evaporative heat loss a powerful mean of cooling, and for bare-skinned species

evaporation is crucial for survival in warm environments (e.g. in humans: Shibasaki and Crandall (2010) and pigs: Ingram (1965)).

Evaporative cooling may also be increased by wetting of the skin; the higher the proportion of wetted skin, the higher the level of evaporative heat exchange. In humans, sweat, which aids evaporative heat loss, is produced by eccrine sweat glands, which are distributed all over the body surface, and by some of the apocrine glands (so-called large sweat glands) (Kuno, 1934), and man can secrete several litres of sweat per hour (Rehrer and Burke, 1996; Sjaastad et al., 2016). Buffalos use wallowing for evaporative cooling (Marai and Haebe, 2010), and savannah elephants display more skin wetting (swimming, wallowing, spurting water on the skin) when ambient temperature is high (Mole et al., 2016).

In summary, evaporative heat exchange takes place across the respiration tract and body surface of an animal. Skin wetting may be used to increase heat loss across the body surface.

### *2.2.2 Radiation heat exchange*

Heat transfer by radiation happens as electromagnetic waves. When radiation (from the sun or the surroundings) hits an animal, it is reflected, absorbed or transmitted to the skin surface (Cena and Monteith, 1975). The structure of the hair coat (e.g. colour, length, density and angle of hairs) (Cena and Clark, 1973; Cena and Monteith, 1975; Monteith and Unsworth, 2013) or plumage (e.g. colour and whether erected or not) (Walsberg et al., 1978) will affect radiative heat transfer to the body. For example, Cena and Monteith (1975) found that, due to a lower transmission in (sheep) fleece with dark hair, black Welsh Mountain sheep fleece absorbs less radiation than white Dorset Down sheep fleece.

Radiative heat loss from an animal to its surroundings depends on the animal's surface temperature (Porter and Gates, 1969; Sjaastad et al., 2016), as both the intensity (energy per unit time) and the wave length of the emitted radiation are related to surface temperature (Sjaastad et al., 2016). The reflection, absorption and emission of thermal radiation by the surface are affected by a factor between 0 and 1, termed the emissivity. When emissivity is 0, all electromagnetic radiation is reflected, and no radiation is



emitted. On the contrary, when emissivity is 1, no radiation is reflected, all is absorbed (Soerensen, 2014). For animals, emissivity of a body area is also influenced by blood perfusion (Gärtner et al., 1964; Soerensen et al., 2014) and hair density (Soerensen, 2014).

Radiant heat transfer also depends on the surface area available for radiative heat exchange (Mount, 1979; Maloney et al., 2005) and the direction of the exchange on a temperature gradient. For example black wildebeests will face in a direction exposing the least proportion of their body surface to radiation from the sun when ambient temperature or solar radiation intensity is high (Maloney et al., 2005). Animals may also seek shade to lower heat load from solar radiation, and a variety of animals seek shade when ambient temperature increases (e.g. cattle: Bennett et al. (1985); Schütz et al. (2008), savannah elephants: Mole et al. (2016) and pigs: Heitman et al. (1962); Blackshaw and Blackshaw (1994)).

To sum up, radiative heat may be reflected, absorbed or transmitted to the skin surface, and animals may seek shade to lower radiative heat load from the sun.

### *2.2.3 Convective and conductive heat exchange*

The transfer of heat between the body and moving air (or water) is termed convection (Sjaastad et al., 2016), which can be both free and forced. Free convection describes the process by which heat transfer occurs due to a temperature gradient. Thus, when the body surface of an animal has a higher temperature than the surrounding air (or water, further only air will be discussed but the mechanism is the same for water), heat will be transferred from the animal to the air and, oppositely, if body temperature is lower, heat is transferred from the air to the animal (Mount, 1966). Forced convection is when heat exchange occurs due to movement of the surrounding air. Forced convection is dominant when wind speed is high, whereas when wind speed is low, free convection will be the main cause of heat transfer (McArthur, 1981). As high wind speed increases the level of forced convection, a wind chill index is commonly used when evaluating cold stress in animals (housed outdoors) to account for the influence of air movement (Tucker et al., 2007; Mader et al., 2010). Heat loss by convection can be affected by animal shape, size and posture; the higher the proportion of exposed body surface, the higher the heat

loss by convection. For instance, in Figure 2, the sitting sow will have a lower level of convection when compared to the standing sow, who exposes her udder for convection with the surrounding air.

The exchange of heat between objects that are in physical contact with one another is termed conductive heat exchange (Sjaastad et al., 2016). As for convection, the level of conduction depends on a temperature gradient between the surface of the animal and the surface of the object. Heat transfer from the animal to the object happens when the surface temperature of the animal is higher than that of the object and vice versa when the object has a higher surface temperature than the animal. The level of conduction will depend on the proportion of body surface available. Again referring to Figure 2, as the proportion of body surface in contact with the ground is higher in the sitting sow, conductive heat exchange between her body and the ground will be higher compared to that of the standing sow.

To increase heat loss by conduction, animals may adopt a posture which increases their contact with for example a cool ground surface (e.g. lying in lateral position). Contrary, to decrease conduction, animals decrease the proportion of body surface in contact with the cool surface (e.g. lying in sternal position). Furthermore, to conserve heat, several animals use huddling, and for example house mice display increased levels of huddling when ambient temperature is decreased (Batchelder et al., 1983). Huddling increases the insulation of the animals participating by decreasing the exposed body surface area of the participants (available for both convective and conductive heat exchange) whereby heat loss is diminished.

To sum up, convective and conductive heat exchange depend on a temperature gradient, and animals may change posture to affect these routes of heat exchange.

### 2.3 THERMAL IMPACT ON THE PIG

In the last part of the ‘State-of-the-Art’, the means for thermoregulation used by the pig are discussed along with the consequences of when the animals are exposed to an insufficient thermal climate. The thermal requirements of the lactating (and parturient) sow and her piglets are far apart. Lactating sows are susceptible to hyperthermia, and

their upper critical temperature (recorded under indoor, confined conditions) is between 25°C and 27°C (Prunier et al., 1997; Quiniou and Noblet, 1999). Sows are less sensitive to low temperatures. The lower critical temperature of pregnant sows (at low feeding level) is around 21°C (Verhagen et al., 1986) and has been suggested to be around 12°C in lactating sows (Black et al., 1993). In contrast to the sow, newborn pigs are prone to hypothermia. The lower critical temperature of the neonatal piglet is as high as 34-35°C (Mount, 1959), and it may be even higher in the first few hours after birth (Kammersgaard, 2013). Thus, in the following, sows are discussed concerning consequences of high ambient temperature, whereas neonatal piglets are in focus concerning consequences of low ambient temperature.

### *2.3.1 Parturient and lactating sows*

*Thermoregulation at increasing temperature.* The pig's ability to sweat is very limited (Ingram, 1967), as the skin of the pig is poorly vascularised and contains only apocrine sweat glands with limited response to elevated temperatures (Montagna and Yun, 1964; Ingram, 1965; 1967). Eccrine sweat glands are found only on the snout, lips and carpal organ of the pig (Montagna and Yun, 1964). Thus, increasing evaporative heat loss across the body surface through sweating, like seen in man, is not possible for the pig. Evaporation across the lung surface is also limited. Although pigs increase their respiration frequency in response to elevated temperatures (Mount, 1962; Ingram and Legge, 1969), the change in tidal volume is limited. Therefore, heat loss across the respiration tract is considered insufficient as a stand-alone mean to avoid hyperthermia (Ingram and Legge, 1969). Thus, the sows' ability to thermoregulate through physiological means is limited. To regulate their body temperature, pigs largely rely on behaviour. White breeds of pigs are close to bare skinned, and heat for evaporation is provided across the entire body surface. Therefore, evaporative heat exchange has the potential to constitute a powerful mean of cooling (Ingram, 1965). To exploit this mean for cooling, the pig uses the behaviour termed wallowing (Ingram, 1965; Fraser, 1970; Steinbach, 1970; Fialho et al., 2004; and reviewed by Bracke, 2011) (Figure 3).



**Figure 3** Sow lying in lateral position (thereby increasing the proportion of body surface available for convection with the water and for conduction with the bottom of the wallow) in a man-made wallow and a sow covered in mud after performing wallowing behaviour.

Such thermoregulatory behaviour appears well adapted to the swamps, marshes and riverine forests where pigs are naturally found (Graves, 1984) and corresponds well to the findings that wild pigs seek areas with year-round access to water (Graves, 1984; Abaigar et al., 1994; Thurfjell et al., 2009). Sows removed from this environment, and thus from the possibility of thermoregulating through wallowing, are susceptible to hyperthermia.

Depending on the environment they are offered, wallowing behaviour may be performed in holes created by the pigs through rooting (Horrell et al., 2001) in naturally occurring or man-made puddles (Fraser, 1970), in man-made concrete (Garrett et al., 1960; Steinbach, 1970) or steel (Heitman, 1959) wallows or even in the animals' own faeces (e.g. Huynh et al., 2007), underlining the innate motivation for wallowing. Wallowing may involve several types of behaviour, such as rooting, lying (Figure 3) and wriggling, and, as reviewed by Bracke (2011), wallowing may serve other functions besides thermoregulation (e.g. related to skin care). Wallowing behaviour is, however, more common at elevated temperatures (Heitman et al., 1962; Fraser, 1970; Huynh et al., 2005; Huynh et al., 2007).

The temperature-regulating effectiveness of wallowing behaviour depends on whether the pig wallows in a waterhole or a muddy puddle. Authors have reported that wallowing in mud prolongs the evaporation process with approximately 2 hours

compared to wallowing in clean water (1 hour in clean water vs 3 hours in mud) (Ingram, 1965; Gannon, 1996).

Wallowing is the most efficient mean of cooling in pigs. However, other types of behaviour are also involved in thermoregulation; for example, pigs may seek shade to lower heat transfer from solar radiation (Figure 4). Studies have shown that pigs seek shade when ambient temperature increases (Heitman et al., 1962; Blackshaw and Blackshaw, 1994). At increased temperatures, pigs will also increase their time spent in lateral position (Huynh et al., 2005), as this posture increases the proportion of body exposed to the cooler ground and surroundings thereby aiding heat loss by conduction (Sjaastad et al., 2016).

In the first week after parturition sows are likely to decrease the expression of wallowing behaviour as sows are motivated to stay with their piglets (Jensen, 1986) and wallowing would require the sows to leave the nest. Thus, during this week, sows may be particularly susceptible to hyperthermia.



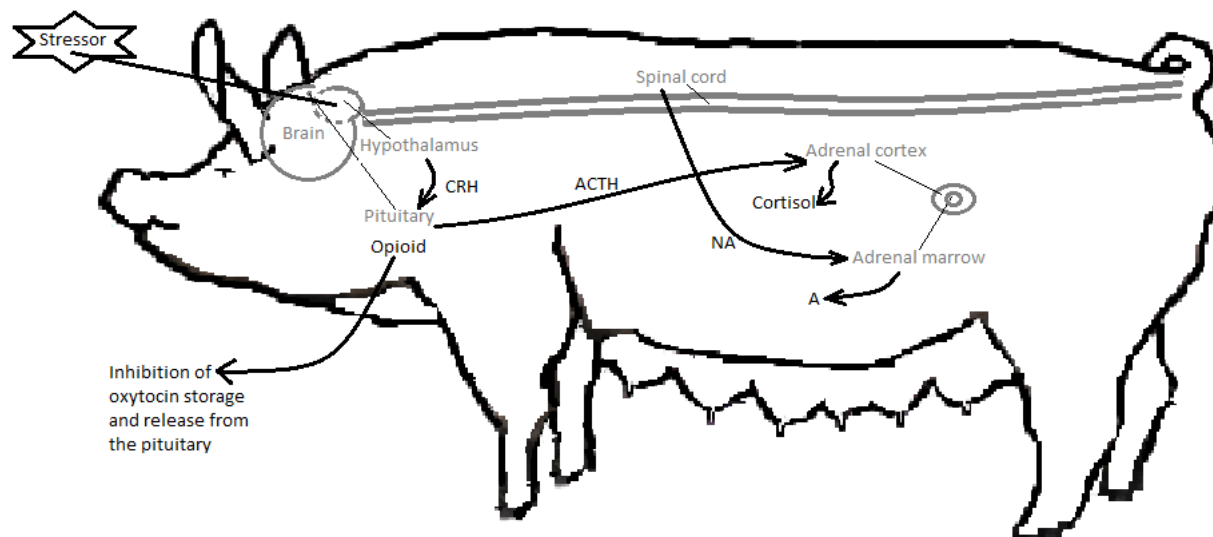
**Figure 4** Pigs seeking shade in an area with poplar trees.

*The stress response.* If the thermoregulative means of the sow fail to sustain her body temperature, sows may experience hyperthermia. Hyperthermia can have detrimental effects for the welfare of both the sow and her piglets.

During hyperthermia, the thermal conditions act as a stressor to the sow. A stressor is defined as an event, internal or external to the animal body, which involves a real or potential challenge to the maintenance of homeostasis (internal balance) (Sapolsky,



2002). The stress response then refers to the behavioural and/or the physiological responses elicited to re-establish homeostasis (Sapolsky, 2002). Both the physiological and behavioural stress responses may indirectly or directly affect piglet survival. Stress is associated with activation of the hypothalamic-pituitary-adrenal axis (Sapolsky, 2002) (Figure 5).



**Figure 5** A sketch of the stress response. The stressor is perceived by the hypothalamus, and the hypothalamic-pituitary-adrenal axis is activated as well as the sympathetic nervous system (Sapolsky, 2002). Most central to parturition and lactation is the inhibition of oxytocin release at the level of the pituitary. Abbreviations: CRH corticotrophin-releasing hormone; ACTH adrenocorticotrophic hormone; NA noradrenaline; A adrenaline.

When the brain perceives a stressor, the hypothalamus will secrete corticotrophin-releasing hormone, which affects the pituitary, stimulating the release of opioids and adrenocorticotrophic hormone. Adrenocorticotrophic hormone then stimulates the release of cortisol from the adrenal cortex. Concurrently, after perception of the stressor by the brain, the sympathetic nervous system is activated, and the spinal cord releases noradrenaline, which stimulates the release of adrenalin from the adrenal marrow. The purpose of these responses is to prepare the animal for the so-called ‘fight or flight’ response by mobilising energy, increasing blood oxygen levels and transporting both to the muscles. However, activation of the stress response is associated with inhibition of several other bodily functions. Firstly, activation of the sympathetic nervous system inhibits the parasympathetic nervous system, resulting in an inhibition of activity in the

gastrointestinal tract. The secretion of corticotrophin-releasing hormone inhibits the secretion of growth hormone-releasing hormone from the hypothalamus and growth hormone from the pituitary, which decreases growth of the individual. Stress also inhibits reproduction in several ways, and for example ovulation and implantation are inhibited when females are in a state of stress (Sapolsky, 2002). However, with respect to the parturition process and lactation, the most central effect of stress is the inhibition of the steroid hormone oxytocin through the secretion of opioids (Clarke et al., 1979; Bicknell et al., 1985).

*Parturition and stress in the parturient sow.* Opioids are involved in the storage of oxytocin in the pituitary prior to parturition and in the release and regulation of oxytocin during parturition (reviewed by Lawrence et al., 1997). Parturition onset is stimulated by foetal cortisol (reviewed by Whittle et al., 2001), which initiates synthesis of placental enzymes that metabolise progesterone to oestrogen thereby removing the progesterone blocking of uterine contractions. The shift in the oestrogen to progesterone ratio initiates and stimulates coordinated contractions of the myometrium (the uterine smooth muscle layer; by stimulating syntheses of myofilaments in the myometrium cells, expression of uterine oxytocin and prostaglandin receptors, the number of gap junctions between cells (Bazer et al., 2001; Kota et al., 2013; Sjaastad et al., 2016), and by activation of prostaglandin synthesis (Whittle et al., 2001)). The myometrium contractions result in dilatation of the cervix and stimulate oxytocin release from the pituitary (Sjaastad et al., 2016). Oxytocin stimulates uterine contractions directly on the myometrium and indirectly by stimulating prostaglandin synthesis (Kota et al., 2013; Vannuccini et al., 2016). During parturition, oxytocin secretion is pulsatile (reviewed by Russell et al., 2003) and, for example in the pig (Gilbert et al., 1994) and rat (Summerlee, 1981; Higuchi et al., 1986), additional pulses of oxytocin are seen after the birth of each offspring. As stress is associated with an elevated opioid tone, it may block the release of oxytocin thereby affecting the course of parturition. Accordingly, environmental stress affects oxytocin levels during parturition (Lawrence et al., 1992; Oliviero et al., 2008). In their study, Lawrence et al. (1992) found lower levels of circulating oxytocin in sows that were disturbed during parturition compared to undisturbed sows. Furthermore, the authors showed that injection with an opioid antagonist (naloxone), compared to a saline

injection, increased oxytocin secretion in the disturbed sows. Together these findings suggest that the disturbance (the stressor) acted through opioid pathways to inhibit oxytocin release, as an opioid antagonist could reverse the effect of the stressor. In another study on the effects of environmental stress, Oliviero et al. (2008) found lower post-expulsion pulses of oxytocin and longer parturition durations in crated v. non-crated sows. The authors' *post hoc* analysis further showed that sows with prolonged parturitions (parturitions lasting >4 h) exhibited lower post-expulsion oxytocin pulses compared to sows with normal parturitions (<4 h). This suggests that a prolonged parturition can constitute a stressor by itself. Prolonged parturitions may be associated with more pain (reviewed by Mainau and Manteca, 2011) and could therefore be more stressful. In crated sows, Muns et al. (2016) showed a trend towards a longer parturition when sows were housed at 25°C at the time of parturition compared to sows housed at 20°C, indicating that the high temperature may have acted as a stressor. Besides imposing a welfare challenge for the sow, a prolonged parturition has negative consequences for piglet welfare. Prolonged parturitions increase the risk of piglets experiencing hypoxia during birth, a condition which increases the risk of stillbirth (Pedersen et al., 2011) and reduces postnatal viability (Herpin et al., 1996). Furthermore, both indoor (Borges et al., 2005; Canario et al., 2006; Mainau et al., 2010) and outdoor (Baxter et al., 2009) prolonged parturitions have been identified as risk factors to stillborn piglets.

*Lactation and stress.* Oxytocin is not only important to the parturition process but also crucial to milk ejection. During lactation, the pulsatile release of oxytocin seen during suckling (reviewed by Russell et al., 2003) stimulates contraction of the myoepithelial cells of the mammary gland, which results in milk ejection from the alveoli. Thus, oxytocin is crucial to achieve milk ejection, and offspring of oxytocin-deficient females will starve (Nishimori et al., 1996). Stress (caused by forceful restraint: Cross (1955); Chaudhury et al. (1961); Lau (1991), auditory, olfactory or visual stimuli: Grosvenor and Mena (1967) or novelty: Lau (1991)) lowers or prevents milk ejection in rabbits (Cross, 1955), guinea pigs (Chaudhury et al., 1961) and rats (Grosvenor and Mena, 1967; Lau, 1991). When females subjected to stress are injected with oxytocin, offspring weight gain/female milk yield will be re-established, suggesting that stress inhibits oxytocin release whereby milk ejection is affected (Chaudhury et al., 1961; Grosvenor and Mena, 1967). In support of this stress-



mediated opioid inhibition, a study showed that an opioid inhibition on oxytocin release could be reversed by use of an opioid antagonist (naloxone) (Clarke and Wright, 1984). Clarke and Wright (1984) discuss that opioids likely exert their inhibitory effects on oxytocin release at the level of the pituitary gland.

In addition to affecting milk ejection, stress may also affect milk yield in sows. Studies show that sows housed at temperatures above their upper critical temperature have a lower lactation performance compared to sows housed within their thermal neutral zone (Black et al., 1993; Prunier et al., 1997; Quiniou and Noblet, 1999; Renaudeau and Noblet, 2001). Part of the explanation for the reduction in milk yield may likely be a decrease in feed intake, as sows housed at high temperatures lower their feed intake (Stansbury et al., 1987; Black et al., 1993; Prunier et al., 1997; Quiniou and Noblet, 1999; Renaudeau et al., 2002). The lower feed intake may be caused by the animals attempting to reduce their internal heat production when housed at high temperatures. However, Black et al. (1993) also suggest that high temperature may directly affect milk yield by redirecting blood flow away from the mammary glands.

Hence, if the thermal climate under outdoor conditions is insufficient to meet the animal's requirements, and the means for aiding the animal's thermoregulation are inadequate, then the thermal conditions may constitute a stressor to the animal. In that case, the thermal conditions (now being the stressor) may prolong the parturition process and inhibit milk-ejection through opioid inhibition of oxytocin release. Additionally, insufficient thermal conditions may lower the milk yield of the sow. These responses would have adverse consequences for the welfare of the sow in terms of the parturition process being prolonged. Moreover, a prolonged parturition increases the risk of piglet mortality, as it constitutes a risk factor for stillbirth and birth of less viable piglets. Finally, a lower milk ejection and milk yield would further result in higher postnatal mortality, as it would increase the risk of starving piglets.

### *2.3.2 Neonatal piglets*

*Insulation and metabolic thermoregulation at birth.* Piglets are born precocial, which means that they are at a relatively advanced developmental stage at birth. In many

respects this is true, as piglets are able to see, hear and walk at birth. In terms of thermoregulation, however, it may be misleading to describe the piglet as precocial. The piglet is born with minimal brown adipose tissue (Trayhurn et al., 1989; Berthon et al., 1994) which has important heat generative characteristics (Cannon and Nedergaard, 2004). Furthermore, the piglet's glycogen (Herpin et al., 2002a) and fat (McCance and Widdowson, 1959; Herpin et al., 2002a) reserves are limited at birth, which further limits the possibility of metabolic heat production and insulation capabilities. Mount (1963) suggested that neonatal piglets use vasoconstriction to increase insulation and thereby reduce heat loss to the surroundings. A later study was, nevertheless, unable to verify peripheral vasoconstriction in day-old piglets by measures of blood flow to the skin during cold exposure (Herpin et al., 2002a). Also, the neonatal piglet, in particular the low-birth-weight piglet, has a high surface to body mass ratio making it prone to heat loss (Herpin et al., 2002a). A reason why evolution may not have favoured well-developed thermal insulation and heat generation properties in the newborn piglet may be that under natural conditions, piglets are born in an extensive nest built by the sow (Stolba and Wood-Gush, 1981; Jensen, 1986).

*Nest microclimate.* About 2 days before parturition, the sow will isolate herself from the group and seek out a suitable nest location (Jensen, 1986; Stolba and Wood-Gush, 1989) such as an area with forest or bushes (Stolba and Wood-Gush, 1989). The actual nest building behaviour begins 3-7 hours *pre-partum*. During this period, the sow digs a hole in the ground which she fills with nesting materials such as grass and branches (Stolba and Wood-Gush, 1981; Jensen, 1986) (Figure 6).



**Figure 6** Sows collecting nesting materials (poplar branches and grass) prior to parturition.

Studies on indoor-housed sows show that sows are highly motivated to perform nest building behaviour (Widowski and Curtis, 1990; Arey et al., 1991; Castrén et al., 1993; Lawrence et al., 1994). The nest is thought to serve multiple purposes; one is to ensure a suitable microclimate for the piglets. The average temperature in nests built by free-ranging sows is around 22°C higher than the average ambient air temperature (Algers and Jensen, 1990). Furthermore, loose-housed indoor sows have decreased nest building activity when housed at high ambient temperature (Malmkvist et al., 2012), which could suggest a lower motivation for an extensive nest.

*Hypothermia and active means of thermoregulation.* At birth, neonatal piglets experience a drastic decrease in ambient temperature (15-20°C drop (Curtis, 1970; Herpin et al., 2002a); sow body temperature is ~38.5-39°C), which is accompanied by a drop in rectal temperature (Malmkvist et al., 2006; Pedersen et al., 2013). The piglets will use shivering thermogenesis to generate heat after birth (Mount, 1964; Berthon et al., 1994; Lossec et al., 1998; Herpin et al., 2002a; Herpin et al., 2002b). They may also increase their time spent in sternal position to decrease radiative, conductive and convective heat loss (Mount, 1964) and display huddling to conserve heat (Hrupka et al., 2000; Huynh et al., 2005) (Figure 7). Still, hypothermia occurs naturally after birth. The scope and duration of the drop in rectal temperature after birth is influenced by several factors. For instance, low birth weight (Stanton et al., 1973; Herpin et al., 2004; Baxter et al., 2008; Baxter et al., 2009; Kammergaard et al., 2011), low ambient temperature (Kammergaard, 2013) and asphyxia during birth (Stanton et al., 1973; Herpin et al., 1996) have been shown to increase the drop in rectal temperature and prolong the severity of hypothermia.

The lower rectal temperature limit, where the thermoregulatory heat metabolism is impaired in neonatal piglets, is around 34°C (normal temperature for suckling piglets around 39.5°C) (Lossec et al., 1998). However, the thermal tolerance of piglets depends on breed (Foley et al., 1971; Herpin et al., 2004), and partly due to their “*extra pelage and more mature metabolic response to cold*” (higher oxygen-consumption rate) wild boar piglets are more cold-resistant than domestic piglets (Foley et al., 1971). Intense selection for lean tissue growth in the conventional breeds may have affected both body composition and lowered physical maturity at birth (in terms of for example muscle

rotein, haematocrit level and levels of glucose, cortisol and lipid metabolism) (Herpin et al., 1993; Miles et al., 2012). Furthermore, selection for large litters may also have resulted in less viable piglets, as large litters are associated with for example lower birth weight (Roehe, 1999). This has a consequence for the piglet's ability to heat conserve. Consequences of hypothermia in piglets include lowered daily weight gain (Herpin et al., 1996) and increased risk of dying (Tuchscherer et al., 2000; Baxter et al., 2008) from causes such as crushing, disease and starvation (Baxter et al., 2009; Pedersen et al., 2011).



**Figure 7** Piglets huddling to conserve heat.

Neonatal piglets, in particular low-birth-weight piglets, are vulnerable to low temperatures, and hypothermia increases the risk of piglets dying. Since piglets are confined to huts during the first days of life, a sufficient thermal climate inside the hut is, therefore, imperative to piglet survival.

### **3. OVERALL AIM**

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The overall aim of this thesis was to quantify the thermal conditions inside the farrowing hut and to obtain knowledge on how these affect the course of parturition, thermoregulation in lactating sows and early piglet mortality.

#### **3.1 RESEARCH QUESTIONS FOLLOWED BY THEIR RELATED HYPOTHESES**

- 1) How does hut climate affect the course of parturition and early mortality? (Studies 1 and 3)
  - a. High hut temperature will result in more stillbirths and higher postnatal mortality (Study 1)
  - b. Low hut temperature will increase postnatal mortality (Study 1)
  - c. High hut temperature will increase parturition duration and the frequency of posture changes during parturition (Study 3)
  
- 2) How does the course of parturition affect early piglet mortality? (Study 2)
  - a. Prolonged parturitions will result in more stillbirths and higher postnatal mortality (Study 2)
  - b. A higher frequency of posture changes during parturition will increase postnatal mortality (Study 2)
  
- 3) How does hut climate affect physiological and behavioural thermoregulation in parturient and lactating sows? (Studies 3 and 4)
  - a. Sow surface temperature will increase with increasing hut temperature (Studies 3 and 4)
  - b. Respiration frequency of the sow will increase with increasing hut temperature (Study 3)
  - c. Sows with access to poplars will seek the shaded area with trees at increasing hut temperature (Study 4)



## 4. LIST OF INCLUDED PAPERS

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### Paper I

**Schild, S.-L.A.**, Foldager, L., Bonde, M.K., Andersen, H.M.-L., Pedersen, L.J. 2018. *Does hut climate matter for piglet survival in organic production?* Animal, doi:10.1017/S175173111800201X.

### Paper II

**Schild, S.-L.A.**, Rangstrup-Christensen, L., Thorsen, C.K. Bonde, M.K., Pedersen, L.J. *The course of parturition and consequences for piglet mortality in outdoor production.* Submitted to Applied Animal Behaviour Science August 2018.

### Paper III

**Schild, S.-L.A.**, Bonde, M.K., Pedersen, L.J. *Impact of hut temperature on the parturition process and level of thermoregulation in sows housed outdoors.* Submitted to Animal August 2018.

### Paper IV

**Schild, S.-L.A.**, Rangstrup-Christensen, L., Bonde, M.K., Pedersen, L.J. 2018. *The use of a shaded area during farrowing and lactation in sows kept outdoors.* Applied Animal Behaviour Science, doi.org/10.1016/j.applanim.2018.08.019.

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## 5. MATERIALS AND METHODS

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### 5.1 STUDY POPULATION

This thesis consists of four studies where Studies 1 and 3 investigate research question 1, Study 2 investigates research question 2, and lastly Studies 3 and 4 investigate research question 3. A brief description of each of the four studies is provided below. A more detailed description and discussion of the data collection methods and chosen study designs are provided later in this chapter.

The data sources (animals) for the four studies originated from two sources: five commercial herds (**Herd A-E**) and the experimental herd at the Department of Animal Science, Aarhus University (**AU Herd**). Figure 8 provides an overview of the herds from which animals were included in the different studies.

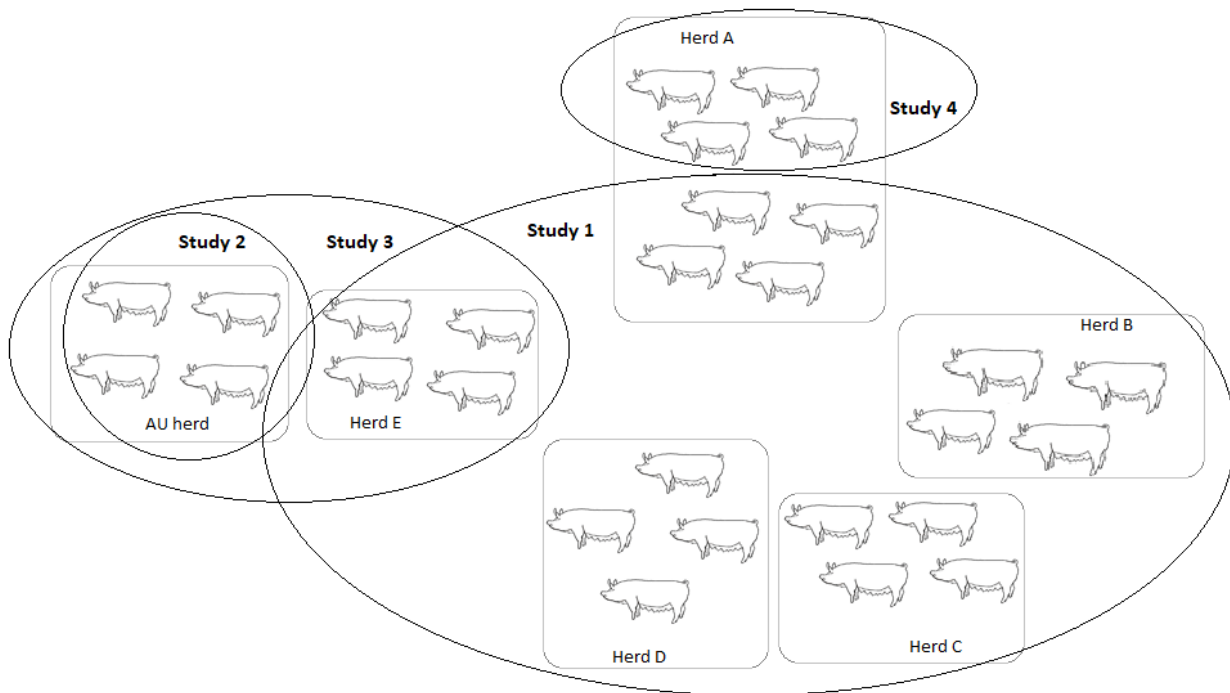
Study 1 investigated hypothesis 1a and 1b and was a large-scale study including 730 parturitions. Data were collected at five commercial organic pig-producing herds across a one-year period. Temperature and humidity were recorded and stored by data loggers placed inside 30 A-frame huts at each herd (20 in herd E). Data from seven sow batches in four of the herds and five batches in the fifth herd were collected. Furthermore, producers recorded information about each parturition (date of parturition, litter results etc.).

Study 2 investigated hypothesis 2a and 2b and was conducted at the experimental farm at the Department of Animal Science, Aarhus University. As a larger study was running at the experimental farm, sows (1) belonged to one of two sow genotypes: Topigs Norsvin TN70 (N=45) or Danbred Landrace × Yorkshire crossbreds (N=42), (2) had access to one of two hut types: communal hut (N=48) or A-frame hut (N=39) and (3) were fed one of two protein levels in the diet: normal protein diet (N=42) or low protein diet (N=45). The parturitions of these animals were video filmed, and the birth of each piglet and sow posture during parturition were recorded. Furthermore, all dead piglets were stored in a freezer and necropsied to verify cause of death as either stillborn before parturition, stillborn during parturition or dead after having been born.

The animals from one of the commercial herds and from the experimental herd at Aarhus University were also included in Study 3 which investigated hypothesis 1c, 3a and 3b. In this study, data loggers were again placed inside the farrowing huts and recorded hut temperature during parturition. Furthermore, video cameras were mounted in all huts, and the parturition

processes were recorded (birth of each piglet and sow postures during parturition). On a subset of the sows (sows at the AU herd), sow surface temperature, respiration frequency and willingness to eat were recorded between 24 and 48 hours after birth of the first piglet.

Study 4 investigated hypothesis 3a and 3c and was also conducted at a commercial organic pig-producing herd. In this herd, some of the animals had access to poplar trees in the farrowing field (57 with access, 14 without). Data loggers were placed inside every second A-frame hut to record hut temperature. Sow surface temperature was recorded in the first 3 days after parturition, and the behaviour of the sows was recorded by direct observations. Behavioural observations of sows' use of the farrowing paddock (14 sows with access to poplars, 14 without access) and sows' use of the area with poplar trees (57 sows with access to poplars) were conducted.



**Figure 8** A sketch illustrating from which herds animals were used for which studies. Herd A to E refer to commercial organic pig-producing herds and AU herd to the experimental farm at the Department of Animal Science, Aarhus University.

## 5.2 HOUSING AND ANIMALS FROM THE TWO DATA SOURCES

### 5.2.1 Commercial herds

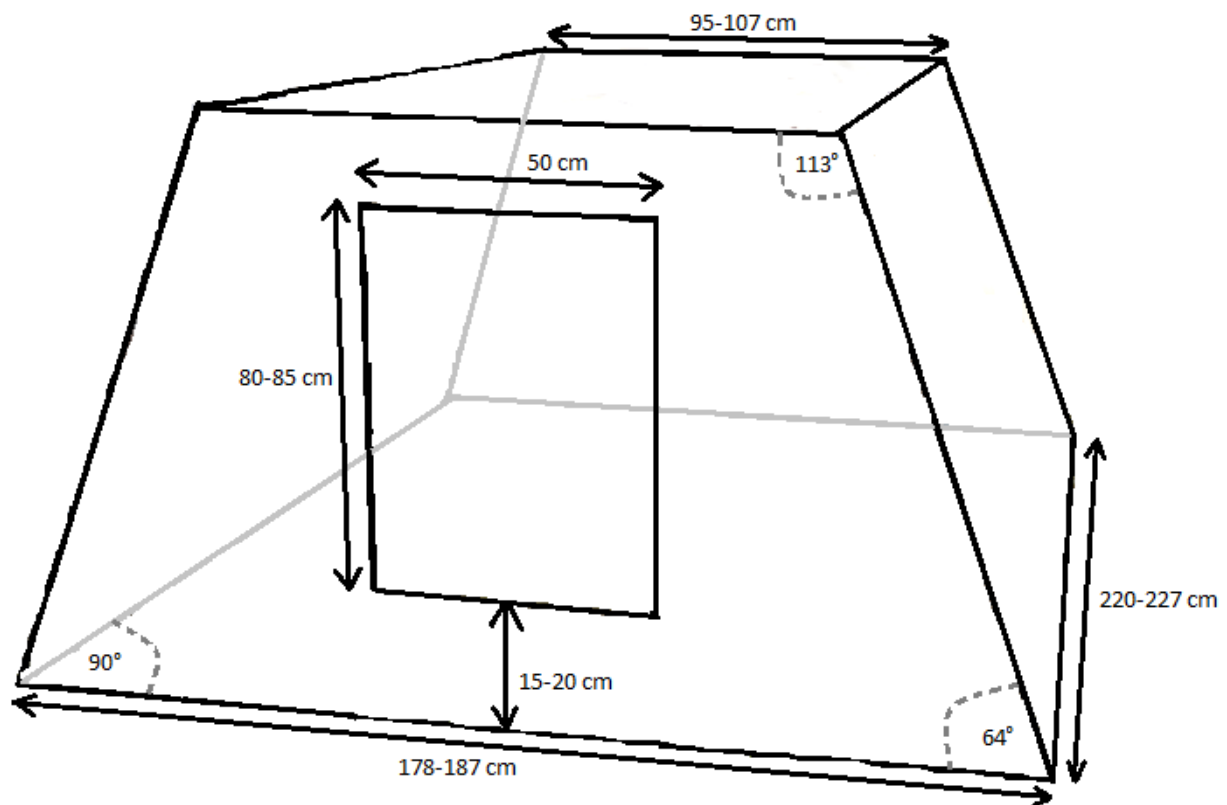
All five commercial, organic certified pig-producing herds housed their parturient and lactating sows (all nose ringed, common practise to reduce damage to paddock grass cover) in individual paddocks (size approximately 250-600 m<sup>2</sup>). Information regarding the size of each herd (number of year sows) and their production results is provided in Table 2.

**Table 2** Descriptive information about each of the commercial, organic pig-producing herds included in Studies 1, 3 and 4. Parity 1 refers to first parity sows and 2+ to multiparous sows (parity refers to the parity distribution of sows included in Study 1).

Herd	No. of year sows	Parity (%)		Litter size (no)	
		1	2+	Total born	Weaned <sup>a</sup>
A	550	29.7	70.3	17.7	11.4
B	360	15.1	84.9	17.4	11.5
C	910	30.6	69.4	17.0	12.5
D	345	22.2	77.8	17.9	11.9
E	360	0	100	18.0	-
Mean	-	19.5	80.5	17.6	11.8

<sup>a</sup> Weaned herd litter size at herd A to D after Rangstrup-Christensen et al. (2018)

The sows (Danbred Landrace × Yorkshire crossbreds) were introduced to the farrowing field 7-10 days prior to expected parturition. Within their respective paddocks, sows had access to an insulated (40-45 mm Styrofoam in roof, sides and end walls) A-frame hut (Figure 9) which had a ventilation window in the roof (measuring 25 × 25 cm) or back wall (measuring 15 × 25 cm, 16 × 34 cm, 25 × 34 cm or 30 × 30 cm) and a sow entrance in the front (50 × 80-85 cm). During the cold part of the year (winter and, depending on the weather conditions and temperature, part of autumn and spring), a plastic curtain was hung in the sow entrance to lower draught and keep the warmth in and the cold out of the hut. The ventilation window was opened according to herd routines. At parturition, a fender (length: 125 cm, width: 125 cm, height: 30 cm) was placed in front of each hut to prevent piglets from leaving the hut. The fender was removed again around day 10 *postpartum* when piglets started to jump across it.



**Figure 9** A sketch showing the design of the standard A-frame huts used in the study (reproduced from Paper I).

Huts were supplied with straw prior to parturition. The amount and type of straw used were according to herd routines and weather conditions (rainfall and temperature). *Postpartum* additional straw was supplied when needed, and the individual stockmen decided the need.

Within all paddocks, sows had access to an individual feeding trough, *ad libitum* access to water and, when mean ambient temperature exceeded 15°C, access to a man-made wallow (the wallow was created by the farmer digging a sow-sized hole in the ground which was then daily supplied with water, Figure 10). Additionally, in Study 4, 57 sows had access to fifth season poplar trees. Sows were fed according to the routines in each herd, and the sows had access to roughage (e.g. grass, hay or silage) as is specified in the Danish guidelines (Anonymous, 2018). Detailed information about the feed used in Herd A and E is available in manuscript 4 and 3, respectively.

In all herds, cross-fostering was performed *post* farrowing to even out litters – most commonly within the first week *postpartum*. Male piglets were castrated with pain relief within

their first week of life (day 2-7 *postpartum* according to Danish legislation (Anonymous, 2017a)). Piglets were weaned at 49 days *postpartum*. Post weaning, remaining bedding was removed (or burned), and the huts were relocated within paddock before new sows were introduced. Additionally, during spring, all herds changed farrowing fields, and thus new paddocks were created.



**Figure 10** Sow lying in a man-made wallow. The wallow was made by the farmer digging a sow-sized hole in the ground which was then supplied with water daily.

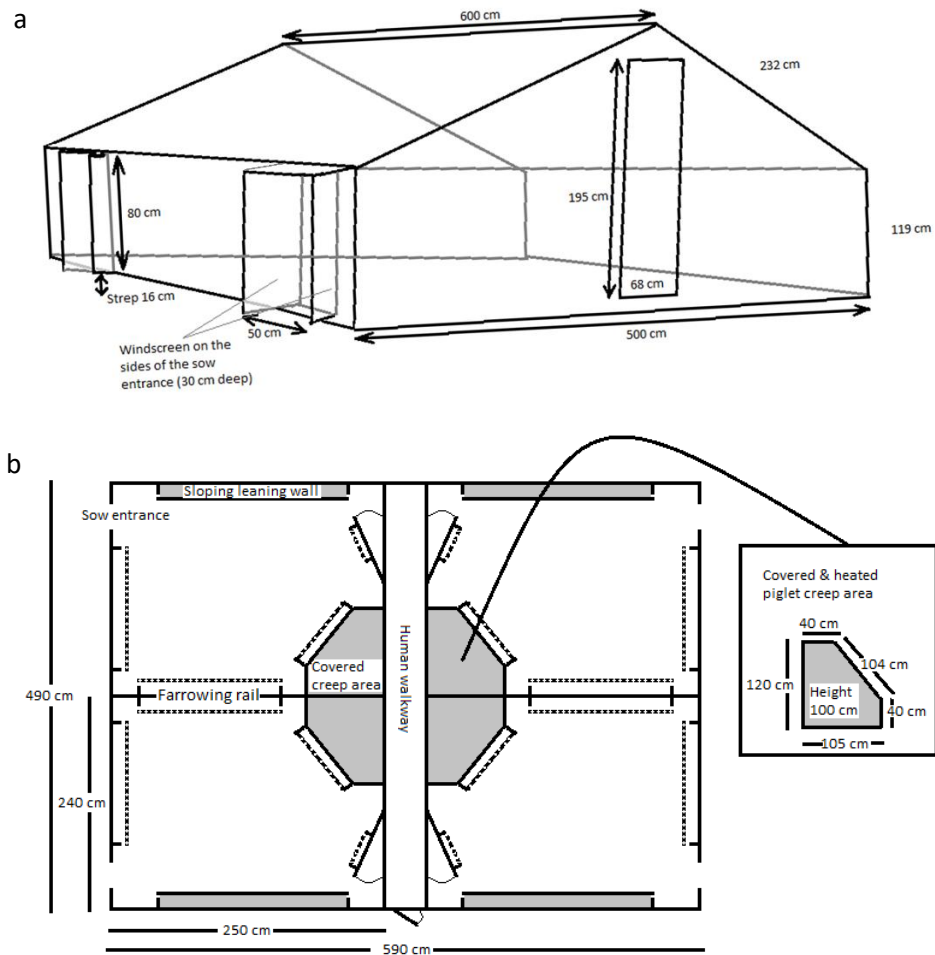
### 5.2.2 AU herd

Animals at the AU herd were all part of a larger study focussing on protein level in the feed, sow genetics and test of a newly developed communal hut. Thus, at this herd, sows belonged to one of two genotypes: Topigs Norsvin TN70 (N=45) or Danbred Landrace × Yorkshire crossbreds (N=42) which were evenly distributed on one of two hut types: communal hut (N=48, Figure 11) or A-frame hut (N=39) and one of two dietary protein levels: normal protein diet (N=42) or low protein diet (N=45). As in the commercial herds, all sows (nose ringed) were housed in individual paddocks (450 m<sup>2</sup>).



**Figure 11** A picture of two of the three communal huts at the experimental herd. In the distance some of A-frame huts can be seen.

Sows were moved to the farrowing field 10 days prior to expected parturition of the first sow of each batch. Within its paddock, each sow had access to a hut. Twelve sows per batch had access to a communal hut (air insulation: roof 20 mm, side and gables 50 mm) housing four sows individually (Figure 12). The communal hut had a ventilation window in the front ( $43 \times 43$  cm) and back ( $84 \times 56$  cm) gables, and windscreens (30 cm deep) around (top and sides) each sow entrance ( $50 \times 80$  cm). The remaining sows in each batch were housed in insulated (40 mm mineral wool in roof, sides and gables) A-frame huts with a ventilation window ( $16 \times 20$  cm) in the back wall. In both hut types, plastic curtains were placed in the sow entrance during the winter and spring sow batches. Ventilation windows were opened according to weather conditions. A roller (16 cm high, communal hut) or board (15 cm high, A-frame hut) was placed at the sow entrance of each hut at parturition and removed again day 10 *postpartum*.



**Figure 12** A sketch of the communal hut (Center of Development for Outdoor Livestock Production [Udviklingscenter for Husdyr på Friland], web page: [www.udviklingscenter.com](http://www.udviklingscenter.com)) a) seen from outside and b) arrangement inside the communal hut (Reproduced from paper II).

Huts were supplied with barley straw prior to parturition (7.6 kg/m<sup>2</sup> during summer, 10 kg/m<sup>2</sup> during autumn and spring, and 12.6 kg/m<sup>2</sup> during winter). Additional straw was supplied after parturition if needed (the need depended on weather conditions and temperature and was evaluated by stockmen and research technicians). Within all paddocks, sows had access to an individual feeding trough and *ad libitum* access to water in a trough, and man-made wallows, created by the stockmen digging a hole and supplying it with water daily, were created when ambient mean temperature exceeded 15°C. Sows were fed either a normal protein (7623 kJ/kg, raw protein 14.4%) or low protein (7554 kJ/kg, raw protein 12.5%; Vestjyllands Andel A.m.b.a., Ringkjøbing, Denmark) dry feed for lactating sows. Furthermore, from 1 December until 1 May, when the grass cover in the paddocks was sparse, sows had *ad libitum* access to clover grass silage.

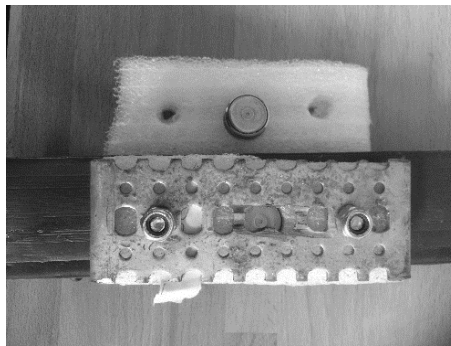
Cross-fostering was done once within 3 days of parturition and within genotype. Cross-fostering was only done when a litter had surplus piglets (more piglets than teats on the sow) and a sow with spare teats (more teats than piglets) was available. When no spare teats were available, surplus piglets were euthanised by blunt force trauma (starting with the smallest piglets in the litter) for ethical reasons. Male piglets were castrated with pain relief on day 3 *postpartum*. Weaning was done between  $48 \pm 4.9$  (mean  $\pm$  standard deviation) days *postpartum* after which remaining bedding was removed, and huts were moved to a farrowing field that had been without sows for at least 5 months.

### 5.3 DATA SAMPLING AND METHODS: ARGUMENTS FOR CHOICES

#### 5.3.1 *Environmental recordings*

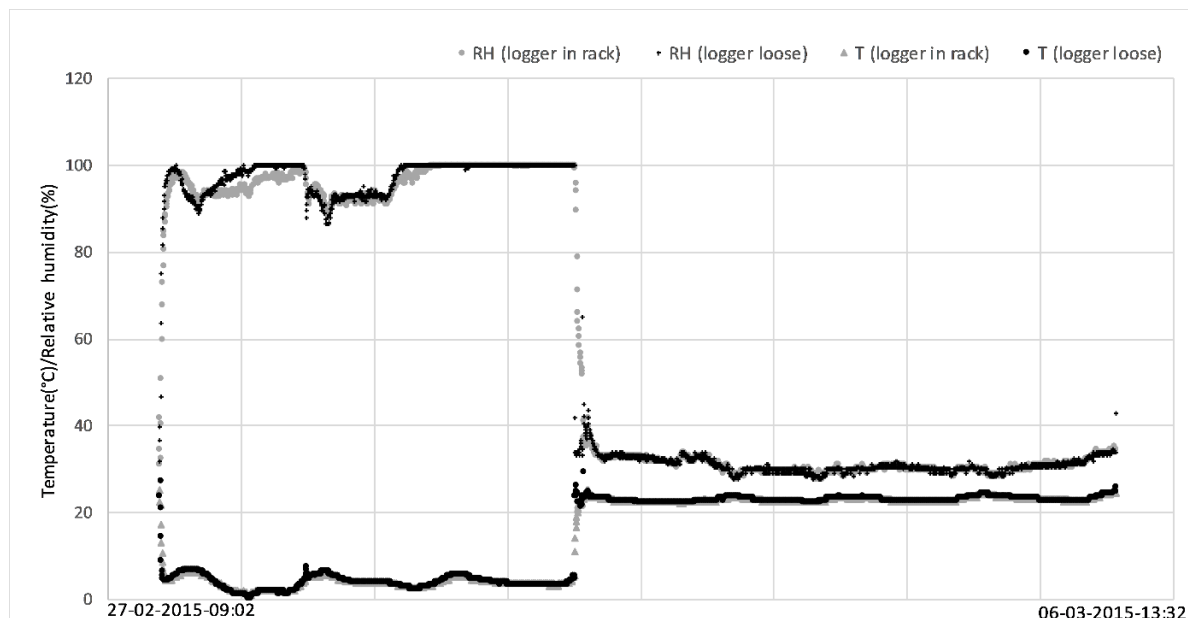
In Studies 1, 3 and 4, all huts (approximately every second hut in Study 4) had a data logger (Hygrochron™ iButton (DS1923), Stockholm, Sweden) mounted inside a logger rack (see Schild et al. (2018) for a detailed description) in the north-eastern or north-western corner (A-frame huts) or in the corner facing the aisle and away from the piglet creep area (communal huts, Study 3). The loggers were placed in the north-eastern or north-western corners inside A-frame huts, as these corners received the least amount of direct sunlight (on the outside surface of the hut), thus the risk of heat conduction from the hut surface was reduced. In the communal huts, the corners facing towards the aisle and away from the heated piglet creep area were also chosen to reduce the risk of heat conduction. Pilot studies were conducted to determine the effect of the logger rack and the effect of the height in which the logger was mounted. To test the effect of the logger rack, two data loggers were used: one was placed on a piece of backing foam, and another logger was placed inside a logger rack next to it. Both loggers (the one on backing foam and the one inside the rack) were then first placed on the ground inside an empty A-frame hut for 4 days and then moved inside and placed on a desk for another 4 days (Figure 13).





**Figure 13** The pilot set-up used to test the effect of placing the data logger inside the rack. On the picture, the top logger is placed on a piece of backing foam and the bottom logger inside the logger rack.

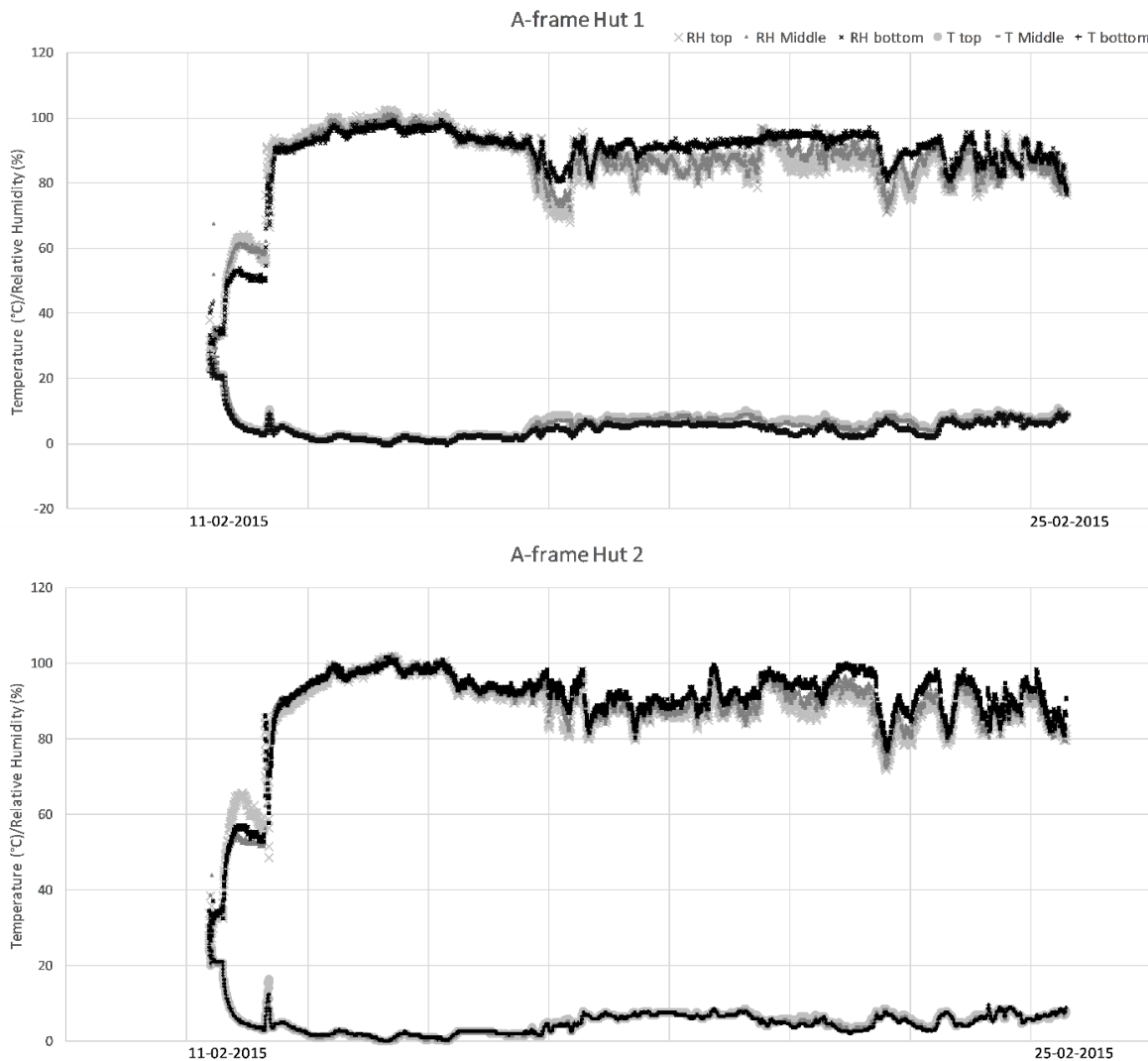
As can be seen from Figure 14, the logger rack did not appear to influence the recordings made. The drop seen on the figure corresponds with the time when loggers were moved from the A-frame hut and indoors.



**Figure 14** The effect of placing the logger inside the logger rack on the temperature (T, bottom graphs) and relative humidity recordings (RH, top graphs). Recordings were made every fifth minute from 27 February 2015 until 6 March 2015.

To test the effect of the height in which the loggers were placed, another pilot study was conducted. In Herd A, data loggers (in racks) were placed in three different heights (approximately 30 cm, 55 cm and 70 cm above the ground) inside two empty (no animals or bedding) A-frame huts. Figure 15 shows the recordings from each of the two huts. As can be seen, the temperature and relative humidity in the three locations followed each other although humidity in the middle and top loggers appeared to follow each other more closely than the

bottom location. The choice of the middle location was based on 1) lower risk of the data logger being covered by bedding (this could have become a problem for the bottom location) 2) being thought to represent the climate experienced by the sow and piglets more closely than the top location (as the middle location was closer to animal level).



**Figure 15** The effect of the height of the logger location on the recordings of temperature (T, bottom graphs, for both huts) and relative humidity (RH, top graphs, for both huts). Recordings were made every fifth minute from 11 February 2015 until 25 February 2015.

During Study 3 (after completion of Studies 1 and 4), the effect of the location of the data loggers inside the A-frame huts was tested at the AU herd. This was done by placing loggers inside three different locations in every third A-frame hut 1) in the north-eastern corner, 2) in the centre of the eastern wall, 3) next to the ventilation opening in the back wall. In Table 3, the average of the 10% highest and the 10% lowest hut temperatures and relative humidity recorded during the first 12 hours after birth of the first piglet are shown along with the mean and

variation in hut temperature and relative humidity (variation calculated as the difference between the average of the 10% highest and the average of the 10% lowest hut temperatures and relative humidity during this period).

**Table 3** The mean of the average temperature and relative humidity during the first 12 hours after birth of first piglet. Furthermore, the average of the 10% lowest (Lowest) and 10% highest (Highest) hut temperatures and relative humidity along with the variation (Var, calculated as the difference between Lowest and Highest temperature and relative humidity) in temperature and relative humidity for this period are shown.

	Temperature (°C)				Relative humidity (%)			
	Mean	Lowest	Highest	Var	Mean	Lowest	Highest	Var
Corner	15.6	13.7	17.3	3.6	88.9	76.2	89.1	12.9
Eastern wall	17.8	15.6	19.6	4.0	71.4	64.5	78.8	14.4
Back wall	16.1	14.3	18.2	3.8	80.3	70.9	88.3	17.4

Both the temperature and relative humidity recordings seemed to be affected by the logger location (Table 3). Temperature appears to be lower, relative humidity higher and the variation in both temperature and relative humidity smaller in the corner compared to the other two locations. Since this test of location of the loggers was done during Study 3, and after completion of both Studies 1 and 4, it was not possible to adjust the logger location during this project. However, the information given in Table 3 shows that the location did impact the recordings. In Figure 16, the locations are illustrated. As can be seen, the logger in location 2 (the eastern wall) was closer to the centre of the hut and nest, and therefore the recordings of temperature and relative humidity in location 2 may better represent those, which the animals experienced compared to the corner location chosen in Studies 1, 3 and 4.

During all studies, loggers were set at a low resolution and recorded (and stored) temperature (accuracy  $\pm 0.5^{\circ}\text{C}$ ) and relative humidity (accuracy  $\pm 0.6\%$ ) every tenth minute. The loggers were placed in the huts *pre-partum* and left until weaning. At low resolution, each data logger could store approximately 8,192 recordings, corresponding to about 28 days of recordings (when recording both temperature and relative humidity every tenth minute).



**Figure 16** A screenshot from the video recordings performed during Study 3. The red “circles” indicate the three locations of the data loggers (1: corner, 2: eastern wall and 3: back wall).

In Study 1, both temperature and relative humidity was used in the statistical analyses. The thought behind including relative humidity was that the discomfort experienced by an animal at a certain temperature could be affected by humidity. For instance, a high temperature and low humidity may affect the animal differently compared to both a high temperature and high humidity. However, no effect of humidity was found, and as the two variables were highly confounded for Studies 3 and 4, only temperature was included in the statistical analysis for these studies.

*Considerations regarding other climate descriptors.* It was considered whether a Temperature-Humidity Index (THI) could be used to account for the combined effects of temperature and relative humidity. The THI was first developed by Thom (1959) for studies into heat stress in humans. Since then, it has undergone several modifications; especially, the index has been adapted for use in studies into cattle comfort (e.g. Bianca, 1962; Berry et al., 1964; Hammami et al., 2013), and more elaborate indices, also accounting for solar radiation and wind speed, have been developed (Mader and Davies, 2002; Davis and Mader, 2003; Hahn et al., 2003; Mader et al., 2006; Gaughan et al., 2008; Mader et al., 2010). The THIs have, so far, been used for studies into the risk of hyperthermia. When investigating risk of hypothermia, a wind chill index is more commonly used. The wind chill index was originally developed by Siple and Passel (1945) and as for the THI, modifications have since been made to the wind chill index (Ames and Insley, 1975; Hahn et al., 2003; Tucker et al., 2007).

In the present studies, neither a THI nor a wind chill index was used. During most of the project, attention was paid to the time around parturition when animals are more or less confined (sows due to their maternal motivation and piglets physically by a barrier) to the hut. Thus, animals were sheltered from both solar radiation and wind. Solar radiation was expected primarily to influence the animals indirectly by affecting the temperature of the hut, which was recorded. Additionally, stockmen were thorough in filling up cracks at the base of the hut to lower the risk of draught, and, when temperatures were low, stockmen kept the ventilation window in the back of the hut shut, or left only a small crack open, and placed plastic curtains in the sow entrance. All these initiatives lowered the risk of draught and thus the effect of wind chill. Therefore, temperature and relative humidity were likely to be sufficient for describing the thermal climate experienced by the animals. However, it cannot be completely excluded that solar radiation and wind speed may have affected the animals.

With regards to why not a “simple” THI, accounting only for temperature and humidity in combination, was used. The THI is useful for assessing the risk of hyperthermia under warm conditions. However, as indicated in the study by Anderson et al. (2013), it may not be suited for testing the risk of hypothermia under cold conditions. Thus, to be able to account for the temperature and humidity across a whole year, temperature and relative humidity were chosen as categorical independent variables in Study 1.

### *5.3.2 Production records*

Both at the commercial herds and at the AU herd, information was collected regarding: sow identity, parity, date of insertion to the farrowing field, date of parturition, number of stillborn piglets, number of liveborn piglets, number of piglets euthanised and cross-fostered, number of piglets alive at castration and number of piglets alive at weaning. At the AU herd, research technicians were responsible for the day-to-day recordings, and the quality of the collected data was highly prioritised (i.e. time of farrowing was recorded precisely via video, all piglets were collected for counting of litter size on day 1 and 3 *postpartum*, check for/collection of dead piglets was done at least once daily, and the straw was checked for dead piglets at least on day 1 and 3 *postpartum*. Furthermore, notes made in the field were typed into an Excel sheet within one day of collection, making it possible to check for and correct erroneous recordings). At the commercial herds, farmers and their stockmen were responsible for carrying out the production recordings. Therefore, the quality of the data depended on the ability and

willingness of the staff to carry out the recordings correctly. During the meeting where host farms were recruited, several of the farmers expressed interest in gaining knowledge about the temperature inside their farrowing huts and its consequences for the sow and piglet mortality. Some farmers were particularly interested in the study, as they experienced high mortalities during summer and wondered if an insufficient hut climate was the cause. Thus, the motivation of the farmers was considered high, and farmers were therefore expected to be willing to make thorough data recordings throughout the whole study period. Four (herd A-D) of the five host farms had participated in a one-year study (part of another PhD project (Rangstrup-Christensen, 2017)) preceding the current project. For the preceding study, a pocket-sized booklet had been developed (in both English and Danish) for production recordings. During the preceding PhD study, herd A-D had been thoroughly instructed in carrying out the recordings (instructed in the importance of data quality), and regular evaluations of booklet recordings were made (filled booklets were checked and evaluations done by phone or during herd visits where recordings were discussed in farmers' and stockmen's coffee breaks). At these herds, both herd owners and stock personnel were therefore familiar with the booklet and the importance of the quality of the recordings made (a detailed description of the booklet and farmer training can be found in Rangstrup-Christensen, 2017). Still, during Study 1, booklets were checked upon receipt and during herd visits (when putting up or collecting data loggers). Building a good relationship with the farmers and the stockmen was prioritised to assure they would feel comfortable to reach out, should uncertainties arise with respect to production recordings. Herd E had not previously been trained in recording of production information using the booklet. Therefore, particular attention was paid to this farm. The farmer was instructed in the advantages of keeping thorough production records, in how to make the records, and follow-ups on booklet recordings were made regularly on this farm, primarily during visits but also by phone, to assure recordings were made correctly.

### *5.3.3 Behavioural recordings*

*Video recordings.* In Studies 2 and 3, parturitions were monitored by use of cameras (IPC-HDBW4100EP-0360B, Dahua Technology Co., Queen Anne House, 25-27 Broadway, UK) fitted with wide-angle lenses. Recordings were saved digitally and analysed using S-VIDIA Client MegaPixel (M. Shafro & Co., Riga, Latvia).

During parturition (from birth of the first until birth of the last piglet in the litter, irrespective of whether the piglet was born alive or not), sow location and posture were recorded (Table 4). Sows were recorded as being in a new posture when they rested in a posture for more than 2 seconds. Furthermore, for each piglet, the time of birth was recorded. Six observers were involved in the observation of the video data. Even though the recordings were relatively simple, and the observers were trained (I watched part of the videos with each observer before recordings were started), both some inter and intra observer variation may have occurred. The inter observer reliability could perhaps have been further improved by allowing observers to all watch the same parturition video and afterwards calibrate their recordings according to one another. Additionally, after more video observations, observers could again be exposed to the parturition video to test their intra observer reliability. Time did, however, not allow for this. In an attempt to test the data for observer reliability, I randomly selected some of the parturition recordings made by each of the observers to check the quality of the recordings. Furthermore, prior to analyses, the effect of observer was tested and found statistically insignificant ( $P > 0.05$ ).

**Table 4** Sow postures recorded during parturition (reproduced from Thorsen et al., 2017).

Posture	Definition
Standing/walking	Maintaining an upright position on extended legs
Sitting	Body weight supported by hind quarters, front legs are stretched and both front hoofs in the ground
Lateral position	Lying on one side with the udder exposed and with one shoulder touching the ground, head raised or resting
Sternal position	Lying on the belly with the udder hidden and without a shoulder touching the ground, head raised or resting
Outside	The sow is not in the hut

*Direct observations.* In Study 4, the behaviour of the sows was observed by direct focal animal scan sampling (Martin and Bateson, 2007). Observations were made from 2 days before until 8 days after expected parturition of the first sow in the batch and again on day 13 and 28 after expected parturition of the first sow in the batch. The behaviour was observed simultaneously for both part 1 (experimental study on the effect of poplar tree access on sow behaviour; 14 sows with no access to poplars and 14 sows with poplar access) and part 2 (testing hypothesis 3c: *sows with access to poplars will seek the shaded area with trees at increasing*

*hut temperature*, 57 sows with access to poplars, including the 14 used in part 1). It was recorded where in the paddock each sow was located and whether she was inactive (laying down) or active (not lying). The location of the sows could be (1) in the hut, (2) in the wallow, (3) in the poplar tree area (only sows with access to poplars) or (4) elsewhere in the paddock. On days 13 and 28 after expected parturition, the location of the piglets was also recorded. The piglets were recorded as being in the place (hut, wallow, poplar area, elsewhere in the paddock or unknown) where more than half the litter was located.

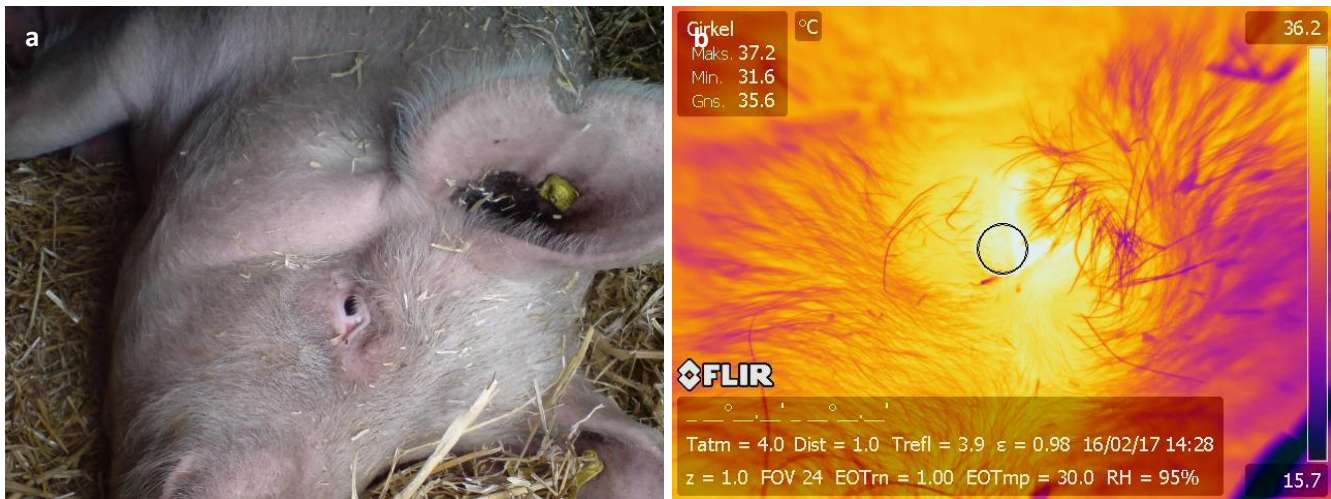
The behaviour of the animals was recorded every 30 minutes from 06:00 to 08:00, 09:00 to 11:00, 13:30 to 16:00 and 20:00 to 22:00. Several trained observers (six until day 8 after expected parturition and four on days 13 and 28 after expected parturition) were involved in the direct behavioural recordings. A randomisation test was conducted prior to data collection to increase inter observer reliability (see manuscript 4 for a detailed description).

#### 5.3.4 *Clinical recordings*

*Surface temperature.* In Study 3 (between 11:00 and 16:00, 24-48 hours after birth of the first piglet) and Study 4 (between 11:00 and 19:00, days 1, 2 and 3 *postpartum*), the surface temperature of the sows was recorded in the canthus of the eye by use of a thermographic camera (model FLIR P660, with SC660 software installed, FLIR Systems., Wilsonville, Oregon, USA). Recordings were only made when sows were lying inside their hut. An example of the photos taken is shown in Figure 17. The camera was turned on at least 45 minutes prior to recordings in order for it to calibrate. Before each recording, the emissivity was set to 1, and reflected temperature was then recorded by the observer pointing the camera lens in the opposite direction of the sow entrance (for recordings of sows in A-frame huts) or towards the hut ceiling (for recordings of sows in communal huts). Afterwards, the reflected temperature was adjusted in the camera settings and emissivity set to 0.98 (Soerensen et al., 2014). At the time of each recording, the ambient temperature and humidity were recorded and corrected in the camera settings. The distance between the camera and the sow eye was between 1 and 2 metres; in the camera settings, distance was set to 2 m. After photographing the surface temperature in the cornea of the eye, the maximum surface temperature (**MST**) was identified for each sow using the software ThermaCAM(TM) Researcher Pro 2.9 (FLIR Systems., Wilsonville, Oregon, USA). The maximum recorded temperature was preferred over the average to minimise uncertainty related to the pictures not being identical (e.g. if the sow tilted



her head a little, and the angle therefore was a bit off). The sow's body temperature was expected to represent the warmest heat source, and thus to minimise noise the maximum temperature was chosen for analysis (e.g in Figure 17, the straw near the cornea of the sow's eye has a considerable lower temperature and would affect the average surface temperature but does not affect the maximum temperature).



**Figure 17** Example of the pictures taken with the FLIR camera: a) is the reference picture and b) shows the corresponding infrared photo. The circle on picture b is a set-point used during photographing and does not refer to the later identification of the area in the cornea used for estimating the maximum surface temperature.

Surface temperature was chosen as one of the measures to evaluate the level of thermoregulation. The conditions were not optimal for thermographic recordings of surface temperature, as factors such as dust in the air and moisture on the skin and in the air constituted sources of uncontrolled variability (Sorensen et al., 2011). The eye has been identified as one of the most promising locations for measuring body temperature in sows by use of infra-red thermography (Schmidt et al., 2013). Furthermore, the eye is rather easy to photograph under outdoor conditions, as sows often face the sow entrance of the hut. Additionally, by selecting the cornea of the eye, the effect of dirt and moisture on the skin was sought to be minimised. Due to the outdoor conditions lowering the reliability of the infra-red recordings, measurements using a rectal thermometer would have been preferred. However, as the sows lay inside the farrowing huts during recordings, measuring rectal temperature was impossible due to the risk of sow aggression.

*Respiration frequency.* In Study 3, also between 11:00 and 16:00 at 24-48 hours after birth of first piglet, sow respiration frequency (**RF**) was recorded when sows lay inside their huts without nursing their piglets. The number of breaths was identified by the sound of the sow breathing and movement of her chest.

*Feeding test.* In Study 3, the sows' willingness to eat was recorded and expected to constitute an indicator of disease (potentially mastitis-metritis-agalactica (**MMA**) syndrome). Feeding activity may be reduced in sick animals (reviewed by Weary et al., 2009), and reduced appetite is a symptom of MMA (Martin and Mc Dowell, 1978; Larsen and Bækbo, 1997). Therefore, on day 1 *postpartum* (24-48 h after birth of first piglet), a feeding test was conducted for sows that had not been to their feeding trough (the feed had not been touched and appeared as a smooth heap) within 4 hours after feeding. The test was performed by the observer taking a handful of feed from the sow's feeding trough and throwing it in front of the snout of the sow through the sow entrance. Subsequently, the sow was observed for about 1 minute, and it was recorded whether (no sign of disease) or not (sign of disease) she began eating (sniff, collect and then chew the feed). The feeding test was not an optimal method to determine whether sows suffered from MMA. This could have been done more thoroughly by testing the milk production (may be reduced/halted in sows suffering from MMA), measuring the rectal temperature (may be increased) or checking for swollen mammary glands and vaginal discharge which are all symptoms of MMA (Martin and Mc Dowell, 1978; Larsen and Bækbo, 1997). However, none of these measures could be taken without serious disturbance of the sow and a consequently high risk of piglet crushing. Therefore, the feeding test was done as a supplement to the recordings of MST and respiration frequency, despite its limitations.

*Necropsies.* In Study 2, piglets that died within the first week after parturition were collected and kept frozen until necropsy could be performed. All necropsies were done by the same, trained veterinarian who determined the ultimate cause of death for each piglet (Rangstrup-Christensen et al., 2018). Stillborn piglets were identified by suspending lung tissue in water and observing whether (stillborn) or not (not stillborn) the tissue sank. Furthermore, by observing the internal organs of the stillborn piglets it could be determined whether the piglets had died prior to (organs a homogeneous brick-red colour) or during (organs with distinctively different colours) the parturition process. Presence of subcutaneous oedema, lacerations and/or fractures was used for identifying crushed piglets. Piglets euthanised were

noted by the stockmen. Remaining piglets were grouped as dying from a cause other than stillbirth, crushing or euthanasia. For the analyses, the necropsied piglets were split into two groups: (1) stillborn or (2) liveborn piglets dying of own accord (not euthanised).

#### 5.4 STUDY DESIGNS: ARGUMENTS FOR CHOICES

Two study designs were used during the current PhD project. For the main part of the studies (Studies 1, 2, 3 and the second part of Study 4), an observational study design was used, whereas an experimental design was used for the first part of Study 4.

An observational study is defined as a study in which the independent variables are not under the control of the researcher, such as weather conditions, and where the study aims at drawing inferences from a sample to the entire population. This type of study usually has a high external validity as it is commonly conducted in practice (on farm) and allows for a large sample size (Ersbøll and Toft, 2004).

Observational studies can be used when the experimenter cannot control the independent variable. When investigating the effect of hut temperature under outdoor conditions or parturition duration, it is not feasible to conduct a randomised controlled study design. It may be argued that in Study 3, where the relation between ambient temperature and the level of thermoregulation and course of parturition was investigated, it would have been more reliable to apply a controlled setting. This could be done by housing one group of sows inside a barn section at a temperature within their thermal neutral zone and another group of confined sows in a neighbouring section at a temperature above their upper critical temperature (resembling the design used in Muns et al. (2016)). The confined conditions would allow recording of for example rectal temperature, palpation of the udder (for recording of swollen and/or sore mammary glands). The controlled ambient temperatures would allow conclusions to be drawn regarding the course of parturition and level of thermoregulation of sows housed above their upper critical temperature compared to sows housed within their thermal neutral zone. However, under these settings, the effects of the diurnal variation in temperature, the effect of wind and the sow's ability to thermoregulate through behaviour (leave the hut, wallow etc.) would then have been lost, and the external validity would be low. Thus, such a controlled design would not reliably reflect how temperature affects thermoregulation and parturition when sows are housed under extensive outdoor conditions. The choice of observational design did have some consequences for the studies. This was particularly evident in Study 3 where

ambient temperature was actually quite low, and the median of the average 10% highest hut temperatures, in the 12 hours after birth of first piglet in each litter, was only 15.1°C. Consequently, the sows were likely not challenged by hut temperature, and the results (level of thermoregulation and consequences for the course of parturition) may have looked quite different at temperatures above the upper critical temperature of 25-27°C.

In an experimental study, more factors can be controlled whereby the variation within the study can be reduced (Ersbøll and Toft, 2004) (e.g. only including sows of the same parity reduces the variation between the animals). This is one of the main advantages of the experimental study design. Study 4 represents an experimental study conducted on farm. To avoid problems when conducting experimental studies on farms, good communication with the farmer and his stockmen is crucial. This was evident in Study 4. Only 14 of the agreed 25 control animals were put into control paddocks, and some of these 14 animals included first parity sows which were not supposed to be included, illustrating that, somewhere along the line, proper communication had failed. Conducting the study on farm of course reduced the costs associated with purchase of animals, stockmen salary etc. but also limited the control over the study set-up; for example, the parity of the animals was limited to what was available at the farm. Furthermore, the farmer decided for instance which animals should go into which paddocks and when and where wallows should be created. However, the study would not have been possible to conduct at the experimental AU herd, as this would have required the planting of poplar trees for which it takes 4-5 years to reach an age to survive the damage caused by sows. Also fewer animals would have been available, as the AU herd is smaller, and since the herd consisted of only two sow batches having parturitions at the right time (during Summer), would require much planning. Despite the study being an experimental study, it was conducted under outdoor conditions under which the weather and ambient temperature were out of the experimenter's control. The summer during which Study 4 was conducted was rather cold, in particular at the time of parturition. The mean hut temperature in the first week *postpartum* was 20.3°C, thus the animals may not have been so motivated to seek shade for thermoregulation in this week compared to in a warmer summer. Therefore, the value of the shade as a mean for thermoregulation under warm conditions may have been underestimated.

## 6. SYNOPSIS OF RESULTS

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### 6.1 HUT CLIMATE AND ITS EFFECT ON PIGLET MORTALITY

Study 1 aimed at quantifying the effect of temperature and humidity inside the hut at the time of parturition on stillbirth and liveborn mortality. It was expected that the risk of stillborn piglets and postnatal mortality (until castration) would be higher when hut temperature increased due to an expected risk of sow hyperthermia and consequently increased risk of piglet hypoxia during birth caused by prolonged birth intervals. Furthermore, low temperatures were expected to increase the risk of piglet hypothermia and thus the risk of liveborn mortality (until castration). Humidity at the level of water condensation (100%) was further expected to decrease the effectiveness of evaporative cooling, thereby increasing the risk of hyperthermia in the sows during hot temperatures. Contrary to this, a high humidity (100%) during cold temperatures was expected to prolong the evaporation of placental fluids and thus increase the risk of hypothermia in the piglets.

The study was conducted across a one-year period at five commercial organic pig-producing herds. Descriptive information about each herd is shown in Table 5.

**Table 5** Descriptive information about the five herds (reproduced from Paper I). Values are presented as raw means with standard error. Total mortality is reproduced from Rangstrup-Christensen et al. (2018) and may not represent all of the same animals as those included in the present study.

Herd	N <sup>a</sup>	Mortality		
		Stillborn	Liveborn mortality (until castration)	Total mortality (%)
1	148	1.0±0.1	3.0±0.2	31.8
2	152	2.0±0.2	2.4±0.2	33.3
3	134	1.4±0.2	1.5±0.1	21.4
4	158	1.6±0.2	2.7±0.3	29.7
5	54	2.3±0.3	NA	NA
Mean	-	1.7	2.4	29.1

<sup>a</sup>Total number of litters (observations) included in the analysis of year variation in stillbirth.

Time of year influenced both the risk of stillbirth ( $F_{3,635}=4.40$ ,  $P=0.004$ ) and liveborn mortality ( $F_{3,561}=3.86$ ,  $P=0.009$ ). The risk of stillborn piglets was lowest during winter (December, January, February), whereas the risk of liveborn mortality was lower during spring (March, April, May). During winter, there was an average of  $1.1\pm 0.2$  ( $\pm$ standard error) stillborn piglets compared to  $2.9\pm 0.2$  during autumn (September, October, November),  $1.6\pm 0.2$  during spring and  $1.5\pm 0.1$  during Summer (June, July, August). The average number of liveborn piglets that died before castration was  $1.8\pm 0.2$  during spring,  $2.3\pm 0.2$  during autumn,  $2.9\pm 0.3$  during winter and  $2.5\pm 0.2$  during summer. Hut temperature explained some of the yearly variation in the stillborn rate. During the cold part of the year (December, January and February), a large positive difference in the daily average of the 10% highest temperature between day 1 *pre-partum* and the day of parturition increased the risk of stillborn piglets ( $F_{1,99}=6.39$ ,  $P=0.013$ ), whereas the actual temperature during parturition did not affect risk of stillborn piglets. During these months, a  $5^{\circ}\text{C}$  increase in hut temperature difference (meaning a  $5^{\circ}\text{C}$  higher temperature on day 1 *pre-partum*) between the day 1 *pre-partum* and the day of parturitions days increased the rate of stillborn piglets with 58%, corresponding to a rate ratio of 1.58. The median difference in hut temperature between these 2 days was -1.7 (lower 10 percentile -5.3 and upper 90 percentile 1.1). During the remaining part of the year, the median variation was -1.3 (lower 10 percentile -6.0 and upper 90 percentile 3.1).

In the remaining part of the year, stillbirth rate depended on hut temperature category (low  $T\leq 22^{\circ}\text{C}$ , medium  $22^{\circ}\text{C}<T<27^{\circ}\text{C}$ , high  $T\geq 27^{\circ}\text{C}$ ) ( $F_{2,511}=6.46$ ,  $P=0.002$ ). The risk of stillborn piglet was 30% higher when temperatures were within category high compared to category medium. No relation between hut temperature and liveborn mortality was found.

Neither stillbirth nor postnatal mortality depended on hut humidity. The temperature and humidity recorded across the year are presented in Table 6. Temperature was highest during summer (June, July, August), lowest during winter (December, January, February), and temperature variation (within 24 hours) was highest during summer and spring (March, April, May).

**Table 6** Yearly variation (summer (Jun, Jul, Aug), autumn (Sep, Oct, Nov), winter (Dec, Jan, Feb) and spring (Mar, Apr, May) in the daily average of the 10% highest and the 10% lowest hut temperatures ( $T_{top10}$  and  $T_{bot10}$ , respectively) and relative humidity ( $RH_{top10}$  and  $RH_{bot10}$ , respectively).  $T_{diff}$  refers to the difference between  $T_{top10}$  and  $T_{bot10}$  (reproduced from Paper I). Temperatures are presented as least square means  $\pm$  standard error.

	Day zero <i>postpartum</i>			
	Summer	Autumn	Winter	Spring
$T_{top10}$	24.2 $\pm$ 0.5 <sup>a</sup>	16.5 $\pm$ 0.6 <sup>b</sup>	9.0 $\pm$ 0.6 <sup>c</sup>	16.6 $\pm$ 0.6 <sup>b</sup>
$T_{bot10}$	13.7 $\pm$ 0.4 <sup>a</sup>	9.1 $\pm$ 0.4 <sup>b</sup>	2.7 $\pm$ 0.5 <sup>c</sup>	6.1 $\pm$ 0.4 <sup>d</sup>
$T_{diff}$	10.5 $\pm$ 0.3 <sup>a</sup>	7.4 $\pm$ 0.3 <sup>b</sup>	6.3 $\pm$ 0.4 <sup>c</sup>	10.5 $\pm$ 0.3 <sup>a</sup>
$RH_{top10}$	93.6 $\pm$ 0.5 <sup>a</sup>	98.3 $\pm$ 0.6 <sup>b</sup>	99.7 $\pm$ 0.7 <sup>c</sup>	96.3 $\pm$ 0.6 <sup>d</sup>
$RH_{bot10}$	63.4 $\pm$ 1.3 <sup>a</sup>	76.8 $\pm$ 1.4 <sup>b</sup>	86.3 $\pm$ 1.6 <sup>c</sup>	66.6 $\pm$ 1.5 <sup>d</sup>

a, b, c, d refers to significant differences ( $P < 0.05$ ) within row.

Since there was no effect of temperature on postnatal mortality despite the fact that hut temperature dropped to levels far below the lower critical temperature of the neonatal piglet, the thermal climate inside the parturition nest, as opposed to the hut climate, was further investigated during Study 3 (at the AU herd). The outdoor temperature (recorded approximately 1 m above the ground), hut temperature (recorded approximately 50 cm above the location of the piglets) and nest temperature (recorded about 1 cm into the nest (straw) between the huddling piglets (where more than half the litter was located, irrespective of whether the piglets were next to the sow or not)) were recorded using an RS-1314 Thermometer with free probes (RS Components, Corby, UK). The thermometer was not in direct contact with the animals during recordings. The results of the recordings showed that nest temperature was in average 12.0°C higher in the nest compared to the ambient temperature inside the hut and in average 19.8°C higher in the nest compared to outdoors (Table 7).

**Table 7** Temperatures were recorded outside the hut, inside the hut (recorded ~50 cm above the huddling piglets) and in the nest (recorded 1 cm into the straw in-between the huddling piglets but without direct contact to these). No refers to the number of observations and Hut to the type of hut in which recordings were made (A is A-frame, C is communal hut). Day refers to day *postpartum*. Recordings were made during November, December and February, and temperatures are presented as means with range (in brackets).

No	Hut	Day	Temperature (°C)		
			Outdoors	Hut	Nest
18	A	1	4.8 (-1.0-11.2)	12.8 (6.4-24.1)	24.9 (20.1-34.1)
22	C	1	3.4 (-3.0-10.1)	9.3 (2.2-15.7)	23.6 (16.9-29.1)
16	A	2	3.3 (-2.0-10.5)	13.0 (6.6-19.08)	22.6 (13.0-29.2)
24	C	2	2.9 (-3.0-9.3)	9.8 (3.6-19.4)	23.4 (16.8-33.3)
16	A	3	4.1 <sup>a</sup> (0.0-10.4)	11.9 (5.8-17.8)	21.0 (13.4-30.3)
24	C	3	3.1 (-3.0-10.7)	10.3 (3.6-16.4)	24.1 (15.1-34.2)
14	A	7	5.2 <sup>a</sup> (-3.0-10.8)	13.4 (7.7-18.2)	24.2 (14.5-30.7)
16	C	7	4.1 (-2.0-10.3)	13.1 (8.3-18.4)	25.7 (19.8-32.7)
Mean			3.9 (-3.0-11.2)	11.7 (2.2-24.1)	23.7 (13.0-34.2)

<sup>a</sup>One observation is missing.

## 6.2 THE COURSE OF PARTURITION AND ITS EFFECT ON PIGLET MORTALITY

The aim of Study 2 was to investigate how the course of parturition (parturition duration and frequency of posture changes) affected the risk of stillbirth and liveborn mortality when sows give birth in outdoor huts. Eighty-seven sows gave birth during this study to a median litter size of 17.0 (range 6-27) totalborn piglets. On average 0.6 piglets were stillborn per litter (range 0-7). Of the stillborn piglets 71% died during parturition. Liveborn mortality until day 4 *postpartum* was 2.4 piglets (raw mean, range 0-8). Parturition duration was 4.3 hours (median) and ranged from 66 minutes to 35 hours. The risk of having stillborn piglets in a litter increased with a longer parturition duration ( $X^2(1df)=8.7$ ,  $P=0.003$ ) and so did the odds of liveborn piglets dying ( $F_{1,35}=4.1$ ,  $P=0.051$ ). When parturition duration increased by 60 minutes, the risk of having litters with stillborn piglets increased by 29% (odds ratio 1.29; 95% confidence



interval [1.05;1.57]), whereas the risk of liveborn mortality increased slightly (odds ratio 1.05; 95% confidence interval [1.00;1.11]). Contrary to the expected, the hourly number of posture changes during parturition had no significant impact on liveborn mortality. The main cause of death during the study was crushing. One hundred and fifty-four piglets died from crushing, 14 died from other causes, and for 24 piglets the cause of death was unknown (results excluding 111 euthanised piglets). The exact time of crushing is unknown, but of the crushed piglets 85 were collected within 48 hours of parturition (days 0 and 1 *postpartum*), 25 were found on day 2 *postpartum*, 38 on day 3 *postpartum*, and 6 were found 4 days *postpartum*.

During the first 3 hours of parturition, sows spent about two-thirds of their time lying in lateral position (120.0 minutes (median), range 0-180) and displayed 23 posture changes (median, range 0-110) during the 3 hours. The hourly rate of posture changes during the first 3 hours of parturition depended on hour of parturition (1, 2, 3;  $X^2$  (2df)=30.6,  $P<0.001$ ), parity (1, 2;  $X^2$  (1df)=5.9,  $P=0.015$ ) and genotype (Danbred, Topigs Norsvin;  $X^2$  (1df)=21.5,  $P<0.001$ ). The hourly rate of posture changes was higher in the first hour compared to the second and third hour, was higher in first parity sows irrespective of hour and sow genotype and for Topigs Norsvin sows irrespective of parity and hour (Table 8).

**Table 8** The number of posture changes for each sow genotype (Danbred, Topigs Norsvin) and parity for each of the first 3 hours of parturition (Hour) (reproduced from Paper II). Values are presented as medians with range (in brackets).

Hour	Danbred		Topigs Norsvin	
	1 <sup>st</sup> parity	2 <sup>nd</sup> parity	1 <sup>st</sup> parity	2 <sup>nd</sup> parity
1	8.0 (0-26)	5.0 (0-20)	18.5 (3-59)	14.0 (1-28)
2	1.0 (0-21)	0.0 (0-10)	12.0 (0-32)	5.5 (0-22)
3	0.0 (0-14)	0.5 (0-17)	9.0 (0-27)	2.0 (0-21)

Sows that had parturitions lasting longer than 4 hours spent 86% of the last 2 hours of their parturition lying in lateral position (median 115 minutes, range 0-120) and changed posture an average of 1.5 times (range 0-34) during these hours. Numerically, both sow genotypes spent more time lying in lateral position in first (120 minutes (range 117-120) and 112 minutes (range 102-120) for Danbred and Topigs Norsvin, respectively) compared to

second parity (115 minutes (range 0-120) and 102 minutes (range 67-120), respectively, for Danbred and Topigs Norsvin) during these 2 hours. In particular Topigs Norsvin sows had a high number of posture changes in first compared to second parity: 1 (mean, range 0-6) and 13.5 (range 0-34) posture changes for first and second parity (for first and second parity Danbred sows, respectively, 0 (range 0-4) and 1.5 (range 0-6) posture changes).

### 6.3 HUT CLIMATE AND ITS EFFECT ON THE COURSE OF PARTURITION

Study 1 showed that the risk of stillbirth was higher at high hut temperatures, and Study 2 identified a long parturition as a risk factor for both stillbirth and postnatal mortality. Thus, one of the aims of Study 3 was to investigate how hut temperature affected the course of parturition (parturition duration and frequency of posture changes).

The median of the average 10% highest hut temperatures, in the 12 hours after birth of first piglet in each litter, was 15.1°C (range 2-34°C), and the difference between the 10% highest and 10% lowest hut temperatures during this period was 4.0°C (range 0-17°C).

The course of parturition was unaffected by hut temperature. The median parturition duration was 266.8 minutes (63-1417 minutes), and during parturition sows changed posture 4.2 times per hour (median, range 0-25). In Table 9 below, farrowing duration and hourly frequency of posture changes are shown at the lower 10 percentile and upper 90 percentile of the hut temperature. Sows gave birth to 17.5 totalborn piglets (range 6-27).

**Table 9.** Distribution of parturition duration and the frequency of posture changes at the lower 10 percentile and upper 90 percentile of  $T_{10}$ .  $T_{10}$  are calculated as the average of the 10% highest hut temperatures during 12 hours after birth of first piglet in the litter. Values are presented as medians with range (in brackets) (reproduced from Paper III).

$T_{10}$	Parturition duration (min)	Posture changes (number/hour)
Lower quartile ( $\leq 6.6$ C)	340 (107-833)	3.7 (0-24)
Upper quartile ( $\geq 29.1$ °C)	398 (231-670)	1.9 (0-15)

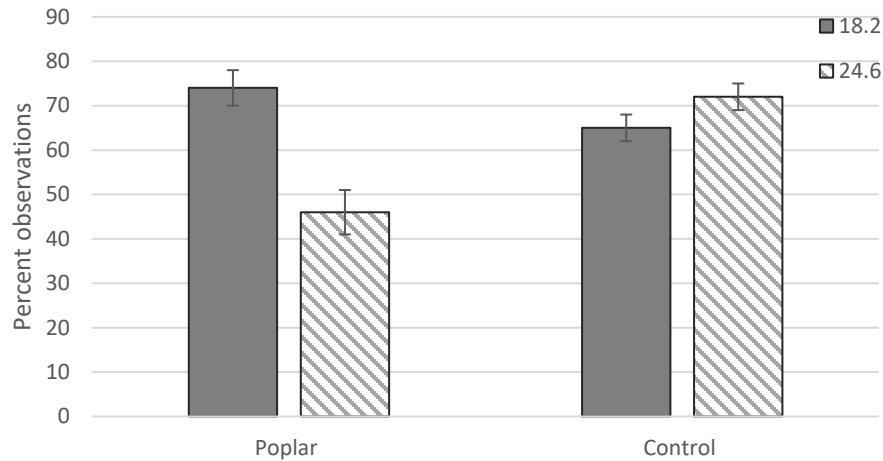
## 6.4 PHYSIOLOGICAL AND BEHAVIOURAL THERMOREGULATION IN THE FARROWING FIELD

Based on Study 1, it was concluded that high hut temperature might challenge the thermoregulatory abilities of the sows. Thus, sows' level of physiological thermoregulation was expected to depend on hut temperature. In accordance with the expected, the level of thermoregulation, as reflected by an increase in maximum surface temperature ( $F_{1,46}=58.9$ ,  $P<0.001$ ) and respiration frequency ( $F_{2,46}=11.0$ ,  $P<0.001$ ), on day 1 *postpartum* increased with increasing hut temperature. At lower 10 percentile ( $T_{10}\leq 6.1^{\circ}\text{C}$ ) and upper 90 percentile ( $T_{10}\geq 28.1^{\circ}\text{C}$ ) of the hut temperature maximum surface temperature was respectively  $34.0^{\circ}\text{C}$  (median, range  $32\text{-}35^{\circ}\text{C}$ ) and  $37.8^{\circ}\text{C}$  ( $36\text{-}39^{\circ}\text{C}$ ). Respiration frequency was affected by temperature category and was 36.12 breaths/min (back transformed LS mean), 18.95 breaths/min and 16.58 breaths/min for category 'high' ( $T_{10}\geq 27^{\circ}\text{C}$ ), 'medium' ( $12^{\circ}\text{C} < T_{10} < 27^{\circ}\text{C}$ ) and 'low' ( $T_{10}\leq 12^{\circ}\text{C}$ ), respectively.

Seeking a shaded area or wallowing are part of pigs' behavioural thermoregulation and may be early signs of thermoregulation in pigs. However, in Study 1 and 3, sows were not given access to a shaded area besides what was constituted and cast by the hut. In Study 4, it was therefore investigated how access to an alternative shaded area, constituted by an area of poplar trees, affected sows' use of their paddock resources (hut, wallow, open field). Secondly, it was investigated whether the sows would use the shade of trees for thermoregulation as indicated by sows being inside the poplar tree area when hut temperature increased.

The mean temperature inside the farrowing hut was  $20.4^{\circ}\text{C}$  (raw mean), in the poplar tree area mean temperature was  $16.2^{\circ}\text{C}$ , and in the open part of the farrowing field mean temperature was  $18.4^{\circ}\text{C}$ .

In interaction with hut temperature, access to poplars affected the sows' use of their hut ( $F_{1,85}=10.9$ ,  $P=0.001$ ). When hut temperature increased, sows with access to poplars decreased their use of hut, whereas this could not be seen for sows that did not have access to trees in the farrowing field (Figure 18). Hut temperature did not affect the sows' use of the wallow. However, wallows were only present when mean outdoor temperature exceeded  $15^{\circ}\text{C}$ .



**Figure 18** The percentage of observations where sows were inside their farrowing hut estimated at two different hut temperatures: 18.2 (lower 10 percentile) and 24.6°C (upper 90 percentile) recorded across the entire observation period. Values are LS means  $\pm$  standard error, provided for sows that had (poplars) or did not have (control) access to poplar trees in their paddock (reproduced from Paper IV).

Hut temperature affected sow surface temperature recorded on day 1 to 3 *postpartum* ( $F_{1,61}=6.1$ ,  $P=0.016$ ), which increased with increasing hut temperature. A 5-°C increase in hut temperature was accompanied by a  $0.82\pm 0.3$ -°C increase in maximum sow surface temperature. The development in sow surface temperature and hut temperature on days 1 to 3 *postpartum* is presented in Table 10.

**Table 10** Maximum sow surface temperature (MST) and corresponding hut temperature recorded on days 1 to 3 *postpartum* (Day *pp*) (reproduced from Paper IV). Temperatures are presented as medians with range (in brackets).

Day <i>pp</i>	MST (°C)	Hut temperature (°C)
1	37.2 (33.9-38.5)	19.6 (16.9-23.8)
2	36.9 (35.1-38.7)	19.7 (17.7-22.8)
3	36.8 (35.5-37.8)	21.6 (18.2-23.0)

The odds of observing sows inside the poplar tree area was independent of hut temperature. However, once sows were located inside the poplar area, the odds of the sows lying down increased with increasing hut temperature ( $F_{1,105}=25.2$ ,  $P<0.001$ ). At hut temperatures  $\leq 18.8$ °C (the lower 10-% quartile), sows lay down in  $16.5\pm 11\%$  of the observations, whereas at

temperatures  $\geq 24.8^{\circ}\text{C}$  (the upper 90-% quartile) sows lay down in  $68.8 \pm 5.8\%$  of the observations.

To summarise, the results of the four studies showed that prenatal mortality was affected by hut temperature; however, the effect depended on time of year. The rate of stillbirth increased during winter when temperature variations between day 1 *pre-partum* and the day of parturition increased. During the remaining part of the year, stillbirth rate was higher at increasing hut temperatures ( $\geq 27^{\circ}\text{C}$ ). Postnatal mortality was unaffected by temperature. Nest temperature was considerably higher than ambient hut temperature.

Both prenatal and postnatal mortality increased with increasing parturition duration, but postnatal mortality was unaffected by the hourly number of posture changes during parturition. Even though sows displayed increased signs of thermoregulation (increased maximum surface temperature and respiration frequency) at increasing hut temperatures, parturition duration and the frequency of posture changes were unaffected by hut temperature.

Access to shade affected the sows' use of their paddock, and sows with poplars in the farrowing field were observed less inside the hut at increasing temperatures compared to sows with no alternative shade. Yet, sows' total use (active and inactive) of the shade, constituted by an area of poplar trees, did not depend on hut temperature. However, once inside the poplar tree area, sows were more often observed lying in the shade when hut temperature increased.



## 7. GENERAL DISCUSSION

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### 7.1 THERMAL CONDITIONS AND RISK OF NEONATAL MORTALITY

#### 7.1.1 Stillbirth

*High temperature.* In accordance with hypothesis 1.a (*High hut temperature will result in more stillbirths*), high hut temperature ( $\geq 27^{\circ}\text{C}$ ) during the warmer part of the year (March to November) resulted in an increased risk of stillborn piglets. It was expected that the causal relationship would be high hut temperature constituting a stressor to the sows, resulting in a prolonged parturition and thereby more stillborn piglets. Corresponding to the current result, in conventional indoor herds, Vanderhaeghe et al. (2010) and Odehnalová et al. (2008) found increased risk of stillbirth for temperatures  $\geq 22^{\circ}\text{C}$  and  $\geq 28^{\circ}\text{C}$ , respectively. The effect of hut temperature on piglet mortality in outdoor herds is less studied. However, during summer, Randolph et al. (2005) (August, study from southern England) and Rangstrup-Christensen et al. (2016) (May to August, study from Denmark) found increased risk of mortality within 24 hours of birth and stillbirth (visual estimation), respectively, for the two studies, suggesting that high temperatures could be the underlying cause of mortality.

One way to bring down hut temperature could be by use of insulation (Randolph et al., 2005). However, the current finding suggests that even in insulated huts, high hut temperature constitutes a risk factor for stillbirth, and future studies into how the hut temperature can be improved are needed. Johnson and McGlone (2003) (study from Texas) found no difference in average daily temperature (or relative humidity) between insulated and uninsulated huts, thus other means to reduce hut temperature may be needed. In Australia, painting huts with solar reflective white paint is a commonly used mean to reduce hut temperature. As part of this PhD study, a pilot study was performed during a stay abroad, in Australia. In the study, one hut was painted white (solar reflective paint) and another metal grey. The study showed a lower temperature in the white-painted hut (average  $30.1^{\circ}\text{C}$ , range  $19.6\text{--}41.6^{\circ}\text{C}$ ) compared to the metal grey hut (average  $32.2^{\circ}\text{C}$ , range  $20.1\text{--}46.0^{\circ}\text{C}$ , unpublished data). Thus, painting huts white could be one way to reduce hut temperature.

*Diurnal temperature variation.* During winter (December-February), stillbirth risk was unaffected by the actual hut temperature while influenced by changes in hut temperature. The

risk of stillborn piglets increased when the daily average of the 10% highest hut temperatures was higher day 1 *pre-partum* compared to the day of parturition (Study 1). Only little is known about the impact of temperature fluctuations on the pig. Yet the increased mortality observed at large variations in temperature between days during winter could reflect sows having difficulties adapting the level of thermoregulation (physiologically and/or behaviourally) to changes in temperature. In this context, it is surprising then that sows in the present study seemed able to cope with large fluctuations in temperature within the 24-hour cycle (this variable had no significant impact on stillbirth risk) as opposed to temperature changes between days. Edwards et al. (1995) found indications of reduced diurnal temperature fluctuation in insulated compared to uninsulated huts, but this was not reflected in piglet mortality or growth rate. This could indicate that sows and piglets were unaffected by the fluctuations in hut temperature. Furthermore, a study of three diurnal air temperature cycles found no effect of temperature range (constant temperature or temperature cycle (with maximum temperature at 16:00 and minimum temperature at 04:00 and a temperature range between maximum and minimum of 10°C or 20°C)) on growth rate in growing pigs (housed in insulated vans; Morrison et al., 1975). This suggests that at least young pigs can adapt to even large diurnal temperature fluctuations. Temperature variation between day 1 *pre-partum* and the day of parturition did not affect stillbirth during the warmer part of the year (March-November). Lack of variation in temperature was not the reason for the missing effect. Instead, in the warmer part of the year, high hut temperature could have obscured the effect of temperature variation on the sows. The effect of temperature variation between day 1 *pre-partum* and the day of parturition was unlikely to be caused by extreme temperatures during winter. The daily average of the 10% lowest and highest hut temperatures measured during winter ranged from -8.4 to 11.8°C and from -1.4 to 16.2°C, respectively, on day 1 *pre-partum* and from -5.7 to 13.9°C and from -0.2 to 18.4°C, respectively, on the day of parturition. It is possible that the effect of temperature fluctuations between the two days may reflect another aspect of the weather conditions, which impacted the sow and hence the risk of stillbirth. During the conductance of the four studies included in this PhD project, factors such as heavy rain, strong wind and frozen ground were observed to affect the sows' willingness to leave the hut. It may be relevant to further investigate whether such factors have impact on the risk of stillbirth and thus could explain the effect of temperature fluctuation on the risk of stillborn piglets.



*Time of year.* During Study 1, there appeared to be a yearly variation, not explained by hut temperature, in the risk of stillbirth, with a lowered risk during winter (December to February). Accordingly, others (also during a one-year study period) have found increased risk of stillbirth during summer (Randolph et al. (2005) (mortality within 24 hours *postpartum*) and Rangstrup-Christensen et al. (2016)). The present Study 1 suggests that, when sows are housed outdoors, there may be a seasonal fluctuation in stillbirth beyond what is explained by hut temperature. However, a longer study period is required in order to confirm whether the present finding was random to the year of study or reflected a seasonal pattern. Hut temperature explained some of the yearly variation in stillbirth. Though, some variation may also be caused by the seasonal reproduction pattern in sows. Bassett et al. (2001) found seasonal fluctuations in plasma luteinising hormone and prolactin concentrations in domestic sows housed outdoors. Circulating prolactin and oxytocin may be positively correlated (Yun et al., 2013). Oxytocin stimulates myometrial contractions and is thus central to the parturition process. Seasonal changes in oxytocin could therefore result in seasonal changes in the course of parturition, which would impact the risk of stillbirth.

#### 7.1.2 *Postnatal mortality (until castration)*

*High temperature and possibility for thermoregulation.* High temperature was expected to impact liveborn mortality by affecting the course of parturition, resulting in the birth of less viable piglets. Furthermore, increased hut temperature was expected to increase the risk of postnatal death by affecting milk ejection and milk yield of the sows, thus increasing the risk of piglets starving and subsequently dying. However, contrary to the expected, postnatal mortality was unaffected by hut temperature (Study 1, rejecting the last part of hypothesis 1a *High hut temperature will result in higher postnatal mortality*). High temperatures occurred during Study 1 and likely affected the parturition process since the risk of stillborn piglets increased at temperatures  $\geq 27^{\circ}\text{C}$ . Therefore, it is reasonable to assume that prolonged parturitions did occur and also resulted in the birth of less viable piglets during this study. Contrary to the hypothesis *High hut temperature will increase parturition duration and the frequency of posture changes during parturition* (hypothesis 1.c), no relation between hut temperature and the course of parturition was found (Study 3). Likely, the reason for the missing effect is that hut

temperatures in Study 3 were too low to act as a stressor to the sows (median of the 10% highest hut temperatures was 15.1°C). Therefore, during Study 3, sows may have been able to prevent hyperthermia through thermoregulation. In a study on indoor loose-housed sows, parturition duration was unaffected at temperatures between 15 and 25°C, and the authors suggested that this was likely due to the sows being able to perform thermoregulatory behaviour (Malmkvist et al., 2012). Under outdoor conditions, sows have even more improved opportunities for performing thermoregulatory behaviour (e.g. increasing forced convection by lying in the hut entrance, wallowing, shade seeking). Thus, the ambient temperature where the thermal climate starts to act as a stressor to the sows, thereby impacting parturition, could be even higher under these conditions compared to both indoor-confined and loose-housed sows. Due to the improved possibility of thermoregulating, sows may therefore also have been able to reduce, or even avoid, hyperthermia and its negative consequences for milk ejection and milk yield *postpartum*. Access to milk, of course, has a positive impact on piglet weight gain and lowers the risk of starvation, thereby increasing the survival chances of the piglets. Accordingly, Randolph et al. (2005) discuss that high temperatures may have had a minimal effect on sow milk yield in their study due to wallow access in the paddocks. Hence, the present results, along with those by Randolph et al. (2005), emphasise the importance of providing outdoor sows with a mean for thermoregulation.

*Low temperature and a sufficient microclimate.* At low hut temperatures, piglet mortality was expected to increase due to piglets suffering from hypothermia. However, low temperature had no significant impact on postnatal mortality (Study 1, rejecting hypothesis 1.b *Low hut temperature will increase postnatal mortality*). Since the temperature inside the farrowing nest (mean 23.7°C) proved to be considerably higher than the recorded ambient hut temperature (mean 11.7°C), the microclimate in the nest was likely sufficient to prevent hypothermia among the piglets. Correspondingly, Berger et al. (1997) found a negative correlation between piglet loss and the amount of available straw (straw type not specified). Their results indicated a minimum requirement of 22 kg of straw in order to reduce piglet loss. This is less than the straw amount provided in both Herd A (~40 kg cut wheat and barley straw; during summer) and E (~20 kg during summer and ~40 kg during winter, cut rye straw). The amounts used in Herds B, C and D likely represented those used in Herds A and E. The average temperature of 23.7°C recorded in the nest (straw type: cut barley straw) during the present

PhD project resembles the average of 20.3°C recorded by Algers and Jensen (1990) in nests built by domestic sows under semi-natural conditions. The slightly higher temperature in the present project may be because recordings were made in the straw between the piglets, whereas Algers and Jensen (1990) recorded temperature in the straw in 5-cm distance to the piglets.

The result, showing no effect of low hut temperature on postnatal mortality in Study 1, illustrates the importance of ensuring a proper microclimate for the piglets. The lower critical temperature of the newborn piglet is 34-35°C (Mount, 1959) and may be even higher in the first few hours after birth (Kammersgaard, 2013), and a good microclimate should have a temperature above the lower critical temperature. However, Kammersgaard (2013) found indications that the upper critical temperature at birth is around 40°C, and temperature should not exceed this. As illustrated by the present results (straw nests) and those by Algers and Jensen (1990) (nests mainly consisting of straw, straw type not specified) straw may have sufficiently high insulating capabilities to provide a suitable microclimate. In support of this, heat loss to the floor was reduced to 41% when pigs (age 0-6 days) had 2.5 cm straw (type not specified) bedding as compared to no bedding (pigs housed directly on concrete) (Mount, 1967). Furthermore, Pedersen et al. (2016) showed a reduction in the immediate *postpartum* drop in rectal temperature when piglets were placed on a 30-cm layer of dry straw (type not specified). Likely, also the type of straw could impact the level of insulation. Concurrently, Moustsen (2003) suggested that rape and wheat straw may absorb less water from the ground as compared to barley straw.

A good microclimate should also be dry. Berger et al. (1997) and Kongsted and Larsen (1999) found a relation between grass cover and piglet mortality with higher piglet mortality when grass cover was poor. Berger et al. (1997) and Kongsted and Larsen (1999) suggest that when grass cover is poor, the sow may drag mud into the hut whereby hut humidity is increased and piglet mortality affected. Hut humidity did not impact liveborn mortality in Study 1. Thus, rather than an effect of humidity, the findings by Berger et al. (1997) and Kongsted and Larsen (1999) could reflect the effect of a wet microclimate. A wet nest would likely decrease the piglets' ability to dry after birth, and could increase the risk of humid piglets, which would result in piglets suffering from increased evaporative heat loss. Both these factors would increase the risk of piglets suffering hypothermia and thus increase the risk of dead piglets.

*Time of year.* The risk of postnatal mortality was lowest during spring (March, April, May). Accordingly, Berger et al. (1997) showed a seasonal pattern (French study, 4-year study

period) in mortality outdoors with higher piglet losses during late autumn and early winter, and a German study found higher mortality in outdoor herds during winter (January, February) (Spitschak, 1997). Furthermore, Randolph et al. (2005) found higher mortality (24 hours *postpartum* to weaning) during summer, irrespective of hut insulation. Contrary to this, Edwards et al. (1995) showed no significant effect of time of year (summer/winter; 22-month study period) on piglet mortality. In Study 1, the thermal conditions inside the hut could not explain the yearly fluctuations in liveborn mortality. Thus, as discussed for stillborn piglets, seasonality in hormones affecting reproduction could account for some of the variation in mortality. Concurrently, in the wild boar, Macchi et al. (2010) saw a seasonal birth pattern with a peak in spring. Furthermore, since lactation is affected by both prolactin and oxytocin, the seasonal changes in prolactin found by Bassett et al. (2001) may also reflect seasonal changes in sow lactation performance, which would also impact piglet survival.

*In summary.* The risk of stillbirth increased at high temperature. Hut temperature may thus have acted as a stressor on the sows during the warm part of the year. Future studies should explore ways to improve the thermal hut climate during this time of year. During winter temperature variation between day 1 *pre-partum* and the day of parturition resulted in an increased risk of stillbirth. This effect could reflect another aspect of the weather conditions, which affected stillbirth. The thermal conditions in the hut did not affect postnatal mortality or the course of parturition. Likely this was due to the outdoor sows having improved possibility for thermoregulating, whereby negative consequences of high temperature were reduced or even avoided. Additionally, a sufficient microclimate in the nest could reduce the risk of piglets becoming hypothermic. Time of year affected both the risk of stillbirth and postnatal mortality. Hut temperature explained some of the variation in stillbirth but could not explain the variation in postnatal mortality. Factors such as seasonal changes in hormones affecting sow reproduction and lactation may also impact the risk of both stillbirth and postnatal mortality. Further studies across more years are needed to confirm if there is a seasonal pattern in piglet mortality.

## 7.2 THE COURSE OF PARTURITION

### 7.2.1 *Consequences for stillbirth*

Although it was not possible to confirm the hypothesis that hut temperature affected the course of parturition and through that increased the risk of stillbirth, Study 2 showed that prolonged parturitions increased the risk of stillborn piglets (confirming part of hypothesis 2.a *Prolonged parturitions will result in more stillbirths*). This corresponds with a study on outdoor-housed sows (Baxter et al., 2009) and with findings from indoor conditions (e.g. Borges et al., 2005; Canario et al., 2006; Mainau et al., 2010). When parturition is prolonged, the risk of piglets experiencing hypoxia during birth is increased, which may occur due to damage to the umbilical cord as suggested by van Dijk et al. (2006).

Only few studies have investigated the duration of parturition under outdoor conditions (Wülbers-Mindermann et al., 2002; Baxter et al., 2009; Thorsen et al., 2017). The median parturition duration recorded during Study 2 (258 minutes) can be considered within the normal range (parturitions lasting <300 minutes) according to the definition by Oliviero et al. (2010) (parturition duration defined as from birth of first to last piglet). However, according to the definitions by Lucia Jr et al. (2002) (normal parturition duration <240 minutes, duration defined as from time of beginning to end of parturition) and Borges et al. (2005) (normal parturition duration <180 minutes, duration defined as birth from first to last piglet), the present duration would be categorised as longer than normal.

### 7.2.2 *Parturition duration*

Several factors influence the duration of parturition. For instance, in outdoor herds, parturition duration was found to be shorter in first parity sows (157±81.8 minutes) compared to in multiparous sows (235.4±104.6 minutes) (Wülbers-Mindermann et al., 2002). This is also true for sows housed indoors (Tummaruk and Sang-Gassanee, 2013; Hansen et al., 2017). Furthermore, it may explain the considerably shorter parturition duration found in the present study, where first and second parity sows were used, compared to the study by Thorsen et al. (2017) housing sows under similar conditions but using higher parity sows (mean parturition duration 450 minutes, parity 3 (median), range 1-6).

A factor known to increase parturition duration is confinement. Parturition seems to be longer for crated compared to loose-housed sows (Oliviero et al., 2008; Oliviero et al., 2010),

although some have not been able to confirm this (Hales et al., 2015; Hansen et al., 2017). In the latter studies, litter size was considerably larger than in Oliviero’s studies (Table 11). In addition, in the studies by Hales et al. (2015) and Hansen et al. (2017), crating was not until 2 days before expected parturition compared to 14-20 days before expected parturition in the former studies (Oliviero et al., 2008; Oliviero et al., 2010). Both factors may impact the results and explain the differences.

**Table 11** Overview of parturition duration reported for sows giving birth indoors in crates or pens or outdoors in huts.

	Parturition duration (min)			Parity	Total born		
	Crate	Pen	Outdoor		Crate	Pen	Outdoor
Wülbers-Mindermann et al. (2002)		243 <sup>1</sup>	157 <sup>1</sup> 235 <sup>2</sup>	1-2		11.7 <sup>1</sup>	10.2 <sup>1</sup> 12.2 <sup>2</sup>
Oliviero et al. (2008)	311	218		1-7	11.4 <sup>3</sup>	11.3 <sup>3</sup>	
Baxter et al. (2009)			128 <sup>4</sup> 229 <sup>5</sup>	5			14.0 <sup>4</sup> 15.0 <sup>5</sup>
Oliviero et al. (2010)	301	212		1-8	12.7		
Hales et al. (2015)	462	394		1-7	18.0	17.8	
Hansen et al. (2017)	199 <sup>1</sup> 324 <sup>2</sup>	241 <sup>1</sup> 328 <sup>2</sup>		1-3	15.8 <sup>1</sup> 19.3 <sup>2</sup>	16.11 <sup>1</sup> 18.7 <sup>2</sup>	
Thorsen et al. (2017)			450	1-6			18.4
Study 2			258	1-2			17.0

<sup>1</sup> First parity sows

<sup>2</sup> Second parity (Wülbers-Mindermann et al., 2002), second and third parity (Hansen et al., 2017)

<sup>3</sup> Liveborn

<sup>4</sup> Surviving piglets

<sup>5</sup> Stillborn piglets

Constipation and obesity may also result in prolonged parturitions (Oliviero et al., 2010). However, provision of plenty of nesting material prior to parturition increases sow plasma oxytocin concentrations (Yun et al., 2013), and an increased expression of nest building behaviour prior to parturition is associated with decreased parturition duration (Westin et al., 2015). Thus, organic housing provides conditions that all other matters equal have the potential to reduce the risk of prolonged parturitions. Sows are loose housed and therefore able to exercise; fed roughage, which may reduce the risk of constipation (Peltoniemi and Oliviero, 2015); and provided with plenty of nesting material and the opportunity to express nest

building behaviour. In support of this, one study compared the parturition duration between first parity sows housed outdoors ( $157 \pm 81.8$  minutes) and first parity sows loose housed indoors ( $243 \pm 77.5$  minutes) and found a shorter parturition duration for outdoor-housed sows (Wülbers-Mindermann et al., 2002). The parturition duration recorded in Study 2 was longer than that recorded for outdoor-housed sows in the study by Wülbers-Mindermann et al. (2002). The discrepancy between the studies could be due to differences in genetics. The sows in Wülbers-Mindermann et al. (2002) gave birth to an average of 10.2 (first parity outdoor), 11.7 (first parity confined) and 12.2 (multiparous outdoors) liveborn piglets per litter, whereas in the present study the average liveborn litter size was 16.5 piglets (range 6-26). In accordance, the parturition duration recorded in Study 2 was shorter than that reported for sows housed in pens in Hales et al. (2015) where the average total litter size resembled that of Study 2 (Table 11). It should be noted that providing birth assistance was part of the herd's normal handling and management routines in the study by Hales et al. (2015), whereas no birth assistance was provided during Study 2. In Denmark, systematic use of birth supervision and assistance is common practice in conventional indoor herds. It is not specified in the study by Hansen et al. (2017), whether birth assistance was used. However, as sows were managed according to herd routines, use of birth supervision and assistance could be part of the reason for the shorter parturition duration for first parity sows recorded by Hansen et al. (2017) compared to that of Study 2.

### *7.2.3 Pain and the need for birth assistance*

Despite the conditions provided, prolonged parturitions do occur in outdoor production, and longer parturitions were related to increased piglet mortality (Study 2). In indoor production, systematic birth supervision and birth assistance are widely used and may reduce total piglet mortality with as much as 50% (White et al., 1996; Christison et al., 1997; Andersen et al., 2009). Outdoors, these procedures have not been implemented, likely due to the hut designs (e.g. A-frame hut) making birth assistance impossible without jeopardising human safety and disturbing the sow to an extent that constitutes a risk for piglet crushing. However, new hut designs, for instance resembling the communal hut used in Study 2, would allow such procedures to be implemented in outdoor production, thereby providing a possible mean for lowering piglet mortality. Intervention during prolonged parturitions also reduces the risk of sows experiencing additional pain during a prolonged parturition. Parturition is associated with

pain in several animal species (for example in pigs: Mainau and Manteca (2011); Ison et al. (2016), rats: Cruz et al. (1996), mice: Mirza et al. (2013) and humans: Whipple et al. (1990); Brownridge (1995); Rowlands and Permezel (1998)). Since the pain experience is extended during long parturitions, these are likely to be associated with additional pain to the animal.

During human parturition pain stimuli arise from distention of the lower uterine segment, dilation of the cervix, uterine contractions and pressure caused by the foetus within the pelvis (Brownridge, 1995; Rowlands and Permezel, 1998). In the later part of parturition uterine activity increases (in humans: Gibb et al. (1984), in cows: Barrier et al. (2012)) and a longer parturition has been related with a higher frequency of uterine contractions (Barrier et al., 2012). Since uterine contractions are a source of pain the increased uterine activity suggests additional pain during prolonged parturitions. Although the pig gives birth to a litter of offspring, whereas humans and cattle most often give birth to only one offspring, prolonged parturitions could also result in more pain in a polytocous animal such as the pig.

Some animals, for example pigs (Jarvis et al., 1997), rats (Gintzler, 1980) and humans (Cogan and Spinnato, 1986; Whipple et al., 1990) display hyperalgesia during parturition. Studies suggest mechanical stimulation of the reproductive tract results in an elevated pain threshold (hyperalgesia) (reviewed by Rowlands and Permezel, 1998). In rats, pain threshold is higher during the passage of each pup compared to after the emergence of pups from the birth canal (reported after Toniolo et al. (1987) in Rowlands and Permezel (1998)). One may therefore speculate that in sows giving birth, the mechanical stimulation during parturition would be the same for equally sized litters, irrespective of parturition duration. In that context, the proportion of time during parturition with the sow experiencing an elevated pain threshold will, all things being equal, be lower when the parturition is prolonged. Parturition duration is related to litter size with longer parturitions for larger litters (Baxter et al., 2009) and larger litters are more heterogeneous and include a larger proportion of small and underweight piglets (Foxcroft et al., 2006; Quesnel et al., 2008). Thus, other factors, for example the mechanical stimulation during parturition, may also influence pain threshold; however, this is purely speculative. Knowledge on the relation between pain and parturition duration in the pig is very sparse. Nonetheless, as prolonged parturitions have negative consequences for piglet survival (Study 2), and since prolonged parturitions could likely be associated with an increased pain experience for the sows, some intervention is needed when using highly prolific sows outdoors. Therefore, it is suggested that implementation of systematic birth supervision and assistance could be beneficial. However, in crated sows, the fear of human handlers may increase the rate



of stillborn piglets (Hemsworth et al., 1999). Furthermore, Naaktgeboren (1979) described how fear may interrupt the course of parturition (suppress myometrical activity) in the ewe and miniature pig. Thus, studies that investigate whether birth supervision and assistance are favourable for piglet survival in an outdoor system, where sows are less accustomed to human presence, and the possibility of reducing sows fearfulness towards humans are needed. One study design could be to conduct an on farm experimental study where reduction of fear of humans and systematic birth supervision and assistance are investigated in a factorial design with suitable control groups.

During Study 2, two genotypes were used where one, Topigs Norsvin (totalborn (median) 16, range 6 to 21), gave birth to fewer piglets than the other, Danbred (totalborn 19, range 7 to 27). Median parturition duration was numerically, yet not significantly, lower for Topigs Norsvin sows (252 minutes, range 120-648 hours) compared to Danbred sows (276 hours, range 42-2102 minutes). Pedersen et al. (2006) showed that at increasing litter size, the inter birth interval between piglets becomes shorter. Thus, the around three piglets lower litter size for Topigs Norsvin sows may not be sufficient to impact the cumulative parturition duration, suggesting that an even lower litter size may be needed to achieve a shorter parturition duration. It could be relevant to investigate whether less prolific genotypes giving birth to a smaller number of piglets would be more suited for outdoor conditions. This could likely also alleviate the need for birth intervention.

#### *7.2.4 Consequences for postnatal mortality*

A prolonged parturition increased the risk of liveborn piglets dying before day 4 *postpartum*, confirming the last part of hypothesis 2.a *Prolonged parturitions will result in higher postnatal mortality* (Study 2). Baxter et al. (2009) showed no effect of parturition duration on postnatal mortality (liveborn that died before weaning) when sows gave birth outdoors in huts. In the study by Baxter et al. (2009), the cumulative parturition duration (128 minutes for surviving piglets and 229 minutes for stillborn piglets) and the litter size (13.95 for surviving piglets and 14.96 for stillborn piglets) were lower than those in the present study (median duration 258 minutes, median totalborn 17.0). This discrepancy may explain the lack of correspondence between the findings in the two studies. Parturition duration had a limited effect (odds ratio 1.05) on liveborn mortality in Study 2, which may be due the young age of the sows (first and second parity), as parturition duration increases with sow parity (e.g.

Tummaruk and Sang-Gassanee, 2013; Hansen et al., 2017). Hence, implications for liveborn mortality resulting from prolonged parturitions may be more pronounced in older sows. In addition to affecting the risk of hypoxia during birth, longer parturitions may also increase the risk of exhausted sows, which could increase the risk of piglet crushing due to risky behaviour such as flopping (Damm et al., 2005). However, outdoor sows have the opportunity to exercise and organic housed sows may walk between 1.1 km (in early lactation) and 3.4 km (in mid gestation) per day (Krogh et al., 2018). Thus, their stamina may be increased why the sows could be better able to cope with long parturitions. Furthermore, due to the opportunity to exercise, outdoor-housed sows likely have increased muscular control, which would result in more controlled lying-down movements and a decreased risk of piglet crushing. These factors could also explain the limited effect of parturition duration on liveborn mortality. In accordance with this reasoning, Thorsen et al. (2017) found no effect of parturition duration (average duration from first piglet till last liveborn 7.5 hours) on sow behaviour from birth of first piglets until 72 hours *postpartum* (time lying in lateral position, number of posture changes, time outside the hut, events of lying down preceded by pre-lying behaviour, the number of floppings (*after 'kneeling' a sow lets her hind quarters fall to one side* Wechsler and Hegglin (1997)) (except for a reduced latency to leave the hut when parturition was prolonged). After birth piglets may die as a result of prolonged parturitions due to the sow being weakened from the parturition, which could increase the risk of crushing due to reduced expression of pre-lying behaviour and/or more floppings. However, the results of Thorsen et al. (2017) could not confirm this hypothesis as parturition duration did not affect sow behaviour. Thus, more likely piglet mortality under outdoor conditions may be due to reduced viability when piglets are born during prolonged parturitions.

#### *7.2.5 Posture changes and piglet crushing*

In Study 2, the most frequent cause of death was piglet crushing, which corresponds with previous studies showing crushing as a main cause of liveborn death (indoors: e.g. Marchant et al. (2000); Pedersen et al. (2006) and outdoors e.g. Edwards et al. (1994); Baxter et al. (2009); KilBride et al. (2012); Rangstrup-Christensen et al. (2018)). Seventy-nine crushed piglets were collected within 48 hours (days 0 and 1 *postpartum*) of parturition and 69 on days 2 to 4 *postpartum*. Since the straw bedding was not thoroughly checked for dead piglets until day 1 *postpartum*, separating piglets crushed on days 0 and 1 *postpartum* was not possible. However,

as the frequency of posture changes (including rolling) during parturition did not influence piglet mortality (rejecting hypothesis 2.b *A higher frequency of posture changes during parturition will increase postnatal mortality*), it is more likely that crushing occurred either after the end of parturition or due to unviable piglets. Accordingly, Marchant et al. (2001) reported that the occurrence of crushing was particularly high within 24 hours after the end of parturition (posture changes recorded the first 7 days after parturition). Behaviour increasing risk of piglet crushing involves lying down from standing (Weary et al., 1996; Wechsler and Hegglin, 1997; Marchant et al., 2001), rolling (Weary et al., 1996; Wechsler and Hegglin, 1997; Marchant et al., 2001; Damm et al., 2005), lying down following limited expression of pre-lying behaviour (Marchant et al., 2001; Damm et al., 2005) and flopping (Wechsler and Hegglin, 1997; Damm et al., 2005). Correspondingly, for sows giving birth outdoors in huts, Vieuille et al. (2003) reported the majority of crushing occurring during the first 12 hours *postpartum* (crushing recorded the first 40 hours after parturition) and identified posture changes between lying, sitting and standing and rolling as the main causes of crushing. In Study 2, the hourly frequency of rolling between lateral and sternal (and sternal and lateral) position was 1.7 (range 0-9), with the total number of rolling ranging from 0-42 rolls per parturition. The display of pre-lying behaviour and flopping was not recorded. However, in outdoor-housed sows, Thorsen et al. (2017) reported only six incidences of flopping when sows lay down during the first 72 hours after birth of first piglet. The average hourly frequency of posture changes during Study 2 was 6.9 (range 0-36). This frequency is high when compared to the hourly frequency of posture changes recorded during the first 24 hours after birth of first piglet (2.5 changes per hour) in Thorsen et al. (2017). The frequency is also high compared to that recorded for loose-housed sows in the first 24 hours *postpartum* (approximately 3.0 changes per hour, Marchant et al., 2001). This is likely due to the age of the sows. First parity sows may be more responsive to their piglets and for example display more savaging than multiparous sows (Harris et al., 2003; Chen et al., 2008) and in Study 2 first parity sows displayed a higher frequency of posture changes than second parity sows (considering the first three hours of parturition). Half the observations in Study 2 were of first parity sows (the remaining were of sows in second parity) whereas the earlier studies included sows ranging from first to seventh parity (Marchant et al., 2001) and first to sixth parity (Thorsen et al., 2017). Furthermore, Study 2 suggested that Topigs Norsvin sows may display more posture changes during parturition (considering the first three hours of parturition), compared to Danbred sows. Thus, sow genotype could also

explain why a higher frequency of posture changes was seen. For example in Thorsen et al. (2017) only Danbred sows were included.

During parturition, sows may get up several times to sniff their piglets, particularly during the early phase of parturition (Jensen, 1986; Petersen et al., 1990). Correspondingly, the results of Study 2 showed that sows had a higher frequency of posture changes in the first compared to the second and third hours of parturition and the hourly number of posture changes was more than ten times higher in the first three compared to the last two hours of parturition. Thus, in Study 2, sows may mainly have gotten up during parturition to sniff their newborn piglets and therefore paid attention to the piglets also during the lying-down process.

Marchant et al. (2001) reported that expression of pre-lying behaviour was highest on the day of parturition and that laying down following limited piglet-directed pre-lying behaviour constituted a dangerous event with respect to piglet crushing. Consequently, posture changes during parturition may be less risky in relation to neonatal crushing than posture changes after the end of parturition where sows may be fatigued and energy depleted. This could explain the lacking effect of the frequency of posture changes during parturition on postnatal mortality. Yet, Weary et al. (1996) found the highest incidence of crushing and near crushing during parturition compared to after parturition. The difference between the studies could be caused by difference in housing (crates and pens in Weary et al. (1996) compared to huts and 450 m<sup>2</sup> paddocks in Study 2). Furthermore, litter size in the present study (17.10 median) was larger than that recorded in the study by Weary et al. (1996) (~10 totalborn, 197 piglet from 20 litters). Thus, due to the presence of a larger number of piglets in the present study compared to that by Weary et al. (1996), the risk of crushing may have been higher *postpartum* during Study 2 compared to *postpartum* in the study by Weary et al. (1996).

Based on Study 2, it is suggested that crushing, under outdoor conditions, mainly occurs after, and not during, parturition, which raises the questions 1) When does crushing occur under outdoor conditions during the *postpartum* period? 2) What are the risky types of behaviour resulting in crushed piglets when sows have the possibility of exercising prior to parturition and give birth in huts with deep bedding and space for performing pre-lying behaviour? 3) What is the impact of the viability of the piglets on the risk of crushing? It would be beneficial to answer these questions in future studies, as they could potentially provide information on how to reduce the risk of crushing in outdoor systems.

*In summary.* The parturition duration recorded during Study 2 may be considered in the upper end of what constitutes a normal parturition duration. Longer parturitions were associated with an increased risk of stillborn piglets, which could be due to an increased risk of the piglets experiencing hypoxia during birth. Outdoor housing provides conditions, which should decrease the risk of prolonged parturitions for example sows are able to exercise, fed roughage and provided with plenty of nesting material. Since prolonged parturitions do occur and are associated with increased risk of stillbirth and likely also additional pain for the sows some intervention is needed. Postnatal mortality also increased when parturition duration was prolonged. The effect of parturition duration on postnatal mortality was likely caused by a reduced viability of the piglets born during long parturitions. Crushing was the main cause of death yet posture changes during parturition had no significant effect on postnatal mortality. This suggests that crushing likely occurred after the course of parturition, and/or that crushing mainly occurred due to low viability of the piglets. More investigation into the timing of and behaviour (of both sow and piglets) resulting in piglet crushing under outdoor conditions are needed to identify ways of reducing the risk of crushing outdoors.

### 7.3 DO SOWS THERMOREGULATE SUFFICIENTLY?

When temperature increases above the thermal neutral zone, sows will thermoregulate through physiological means, e.g. by increasing blood flow to the periphery of the body (to aid convection) and increasing the respiration frequency (to increase evaporation across the respiration tract). Accordingly, Studies 3 and 4 showed an increase in sow surface temperature with increasing hut temperature (confirming hypothesis 3.a *Sow surface temperature will increase with increasing hut temperature*), and Study 3 showed an increase in sow respiration frequency when temperature increased (Study 3, confirming hypothesis 3.b *Respiration frequency of the sow will increase with increasing hut temperature*). The results correspond with findings for indoor-housed sows (e.g. Malmkvist et al., 2012; Muns et al., 2016) and Brown-Brandl et al. (2001), suggested respiration frequency could be used as an early indicator of heat stress.

For thermoregulation, sows also rely on thermoregulatory behaviour (e.g. wallowing and shade seeking). Concurrently, in Study 4, sows were more often observed lying when inside the poplar tree area when hut temperature increased, suggesting they used the shade of the trees for thermoregulation. However, the total percentage of observations in which sows were

recorded in the poplar tree area was unrelated to hut temperature (therefore hypothesis 3.c *Sows with access to poplars will seek the shaded area with trees at increasing hut temperature* could only be partly confirmed). Wallowing is an effective mean for thermoregulation in the pig, yet no effect of hut temperature could be shown for this behaviour in Study 4. Since wallows were only created when mean daily temperature exceeded 15°C, temperature and the possibility to wallow were confounded, which may explain the lacking effect of hut temperature.

Even though sows in Study 4 displayed signs of increased thermoregulation through physiological means, the sows remained in the hut during the first week *postpartum* and only rarely frequented the wallow and shade of the poplars in this period. In the first week *postpartum* (and during parturition), sows are motivated to remain in their nest (Jensen, 1986; Stolba and Wood-Gush, 1989). Thus, sows stay in the hut due to maternal motivations, which likely reflect an attempt to improve the fitness of the offspring. Calving females of the fallow deer seek safer, but less resource rich, habitats, thereby compromising own energy intake while increasing the fitness of the offspring (by reducing risk of predation, Ciuti et al., 2006). When temperature increases, sows increase physiological means of thermoregulation but may eventually experience a motivational conflict between remaining with the piglets (to optimise offspring fitness through nursing, provision of warmth and protection) and reducing the heat load through behavioural thermoregulation (unconsciously optimising the likelihood of having another litter by improving own fitness). During this period, sows may therefore be more susceptible to hyperthermia as they may be slower to start thermoregulating through behaviour due to their maternal motivation to remain by their offspring. The sow has invested time and energy in the existing offspring (Maternal expenditure (Smiseth et al., 2012)), for instance by gestation, nest building, parturition and, depending on offspring age, colostrum and milk production. Therefore, she will be highly motivated to keep the litter alive.

In Study 3, 13 sows gave birth when daily average of the 10% highest hut temperatures exceeded 27°C. These sows displayed a lower hourly number of posture changes (1.9 median) compared to sows giving birth at lower temperature (3.7). Movement of the body is associated with an increase in internal heat production (McDonald et al., 1988; Noblet et al., 1993; van Milgen et al., 1998). Sows giving birth at high hut temperature may thus have attempted to reduce own heat production by reducing their hourly number of posture changes. Additionally, three of the 13 sows giving birth at high temperatures left the hut during parturition (for comparison, only three of the 92 sows giving birth at lower temperatures left the hut). The daily

mean of the 10% highest temperatures on the day of parturition of these three sows were 29.1°C (left the hut five times), 29.6°C (left the hut two times) and 31.6°C (left the hut two times). This may suggest that at hut temperatures above 27-29°C, sows may no longer be able to sufficiently cope with the high temperature inside the hut through physiological means and decreased activity. Hence, the sows may have left the hut to try to decrease their body temperature, for example through wallowing. Sows leaving the huts during parturition could therefore be an indicator of an insufficient thermal hut climate. During Study 4, only one sow displaying nest building on a particularly warm day chose to give birth outside the hut (she built a nest in the outer row of poplartrees). This suggests that sows preferred the hut as their nesting location. Therefore, sows giving birth outside the hut could also be an indicator of the hut being too warm. Other factors may also be expected to cause sows to give birth outside the hut, for example if there is draft in the hut or a predator, for example a fox, visits the hut prior to onset of parturition. Furthermore, Study 4 showed that sows spent the vast majority of the observations inside the huts during the first week *postpartum*, implying they were motivated to remain with their piglets. Thus, if a sow remains outside the hut during this period, (apart from feeding, drinking and eliminating behaviour) it could indicate, for example, that the hut climate is too warm for the sow to cope or that the sow suffers from disease. For example, sows suffering from mastitis may try to avoid piglets massaging the udder. Indoors sows suffering from mastitis can be reluctant to allow nursing (Martin and Mc Dowell, 1978). Farmers could utilise this information to identify sows in need of attention.

Sows that had access to poplars were seen frequenting both the wallow and poplar tree area, suggesting that neither of these could replace the other. The wallow provides a quick and efficient mean for cooling, whereas the poplars likely provided a cool resting place. Furthermore, a shaded area may supplement the wallow, as resting in the shade post wallowing could extend the evaporation process and reduce the amount of heat for evaporation provided by solar radiation.

*To sum up.* Signs of an increased level of physiological thermoregulation were seen at increasing hut temperature, reflected by increased maximum surface temperature and respiration frequency. Behavioural thermoregulation was also indicated as sows lay more when inside the poplar area at increasing hut temperature. Sows mainly stayed in the hut the first week *postpartum*, thus sows staying outside the hut during this period could be a sign of an

inappropriate thermal climate in the hut. Sows giving birth at particularly high hut temperature reduced their frequency of posture changes during parturition and left the hut more often during parturition. It is therefore suggested that at hut temperatures exceeding 27-29°C sows may start to have difficulty coping inside the hut.

#### 7.4 ADVANTAGES OF TREES IN THE PADDOCK

Although the sows' total use of the poplar tree area was independent of hut temperature, the time sows spent lying once inside the tree area depended on hut temperature, which suggests that sows utilised the shade of the poplars for thermoregulation. Danish organic pig farmers and non-governmental organisations have recently acknowledged the importance of providing additional shade (in addition to the hut) in the farrowing field. The current PhD project along with Danish studies into agroforestry contributed in emphasising the importance of shade provision in the farrowing field, which added to the motivation for the inclusion of shade provision as a requirement in the updated code of conduct for organic pig production. Farmers use various solutions for shade provision, for example canopies, huts with two sow-sized openings and trees. By adding shade, farmers improve the animals' possibility of performing species-specific behaviour, as they allow sows (and piglets) to use shade-seeking behaviour as a mean for thermoregulation. Thereby, the 'naturalness' of the system is improved (according to the agroecological and the integrity approaches (Verhoog et al., 2003)).

During parturition, the sows will be motivated to remain in the nest, and both Study 1 and Study 3 indicate that particularly high hut temperatures on the day of parturition may be accompanied by negative consequences, such as the increased risk of stillborn piglets observed in Study 1, and behavioural changes as indicated in Study 3. To reduce the risk of these negative impacts it could be beneficial to attempt to reduce hut temperature. One way could be to paint the huts white with solar reflective paint as suggested in section 7.1.1. However, another suggestion is to move the hut into a shaded area, possibly constituted by an area of trees. When compared to other means of shade (for example canopies), planting trees may be argued to further improve the 'naturalness' of the organic system since pigs are naturally found in forest and scrub areas (Graves, 1984; Abaigar et al., 1994; Thurfjell et al., 2009), and trees may therefore contribute to further expression of behavioural needs (thereby also adding 'naturalness' according to the integrity approach (Verhoog et al., 2003)). When sows have access to trees in the farrowing field, they may use the tree area for example for grassing and rooting (Bonde, 2016), and the



trees to rub against (Jakobsen et al., In prep). Under natural and semi-natural conditions, tree areas serve a variety of functions to pigs. Pigs may use trees for foraging (for example acorn and nuts) (Barrett, 1982; Graves, 1984; Wilcox and Van Vuren, 2009), bedding and nesting material (leaves, twigs) (Graves, 1984; Jensen, 1986), shade and shelter (Graves, 1984; Rodríguez-Estévez et al., 2012), and the tree area as a resting location (Barrett, 1982; Graves, 1984; Stolba and Wood-Gush, 1984; Jensen, 1986). Trees therefore add heterogeneity to the environment. In addition to enriching the outdoor housing conditions, studies in agroforestry show that perennial crops such as poplars and willows are effective in taking up water and thereby nitrate (Jørgensen et al., 2005; Dimitriou et al., 2012; Pugesgaard et al., 2015). Hence, nitrate leaching is reduced, which is beneficial for the environment and contributes to the sustainability and to the ‘naturalness’ (according to the agroecological approach (Verhoog et al., 2003)) of the system. Furthermore, planting trees may help to visualise the ‘naturalness’ of the organic system to consumers, thereby aiding in branding organic pig production as an animal welfare friendly production form, which allows expressing species-specific behaviour, which consumers associate with good animal welfare (reviewed by Thorslund et al., 2017).



## 8. CONCLUSIONS

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This thesis aimed at quantifying the thermal conditions inside the farrowing hut and at obtaining knowledge on how these impact the course of parturition, thermoregulation in lactating sows and early piglet mortality. The collective findings of the studies show that temperatures inside insulated farrowing huts during the warm part of the year exceed the upper critical temperature recorded for lactating sows, and, during the cold part of the year, ambient hut temperature reaches levels far below the lower critical temperature of the neonatal piglet.

1. High hut temperature resulted in increased risk of stillborn piglets. However, neither high nor low hut temperatures affected postnatal mortality. The lacking effect of temperature on postnatal mortality could be due to 1) sows being able to thermoregulate through behaviour *postpartum*, thereby avoiding potentially negative impacts of high temperature on lactation performance and 2) a sufficient microclimate in the nest reducing negative impacts of low ambient temperature on the newborn piglets. Parturition duration and the frequency of posture changes during parturition were unaffected by hut temperature. Likely, this was due to relatively low temperatures during the warmest season of the study period and should not be interpreted as the course of parturition being unrelated to temperature.
2. A prolonged parturition increased stillbirth and postnatal mortality. Contrary to this, posture changes during parturition did not significantly affect postnatal mortality.
3. Increasing temperature resulted in increased thermoregulation through physiological means reflected as increased sow surface temperature and respiration frequency. Behavioural thermoregulation, in the form of shade seeking, was also indicated at higher temperatures.

Overall, the present results suggest that at low ambient temperature, the currently used management initiatives are sufficient to avoid negative impacts of the thermal climate in the hut on early piglet mortality. However, at high temperature, the results suggest a need for further development to reduce negative impacts of hut temperature on particularly prenatal piglet mortality. In the nestbound period, sows used physiological means for thermoregulation, but later, *postpartum*, they also appeared to utilise behavioural thermoregulation. However, as sows are nestbound in the first week *postpartum*, bringing down the hut temperature in the warm part of the year seems essential to reduce in particular stillbirth.

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## **PAPER I**

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Does hut climate matter for piglet survival in organic production?

S.-L.A. Schild, L. Foldager, M.K. Bonde, H.M.-L. Andersen, L.J. Pedersen  
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# Does hut climate matter for piglet survival in organic production?

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*Piglet mortality in outdoor production systems varies across the year, and a reason for this variation could be fluctuations in hut climate, as ambient temperature might influence piglet survival, both directly and indirectly. Therefore, the aim of the current study was to investigate the impact of farrowing hut climate and year variation on stillbirth and liveborn mortality. A large-scale observational study was conducted at five commercial organic pig-producing herds in Denmark from June 2015 to August 2016. Both year variation ( $F_{3,635} = 4.40$ ,  $P = 0.004$ ) and farrowing hut temperature ( $F_{2,511} = 6.46$ ,  $P = 0.002$ ) affected the rate of stillbirths. The risk of stillborn piglets was lowest in winter and during this season larger changes in hut temperature between day 1 parturition and the day of farrowing increased the risk of stillbirths ( $F_{1,99} = 6.39$ ,  $P = 0.013$ ). In addition, during the warm part of the year stillbirth rate increased at temperatures  $\geq 27^{\circ}\text{C}$ . Year variation also affected liveborn mortality ( $F_{3,561} = 3.86$ ,  $P = 0.009$ ) with a lower rate of liveborn deaths in spring. However, the hut climate did not influence liveborn deaths. Consequently, other factors than hut climate may explain the influence of year variation on liveborn mortality. These could be light differences causing seasonality in reproduction and lactation.*

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**Keywords:** neonatal piglet mortality, organic, outdoor pig production, temperature, humidity

## Implications

Piglet mortality constitutes a major challenge in organic production. Studies suggest that piglet mortality is higher during summer and winter. Yet, causes underlying these fluctuations have not been identified. The current study suggests hut climate as a risk factor for stillbirths during summer, *albeit*, at temperatures higher than the upper critical temperature (UCT) for confined sows. This is likely due to outdoor sows having improved opportunities for thermoregulation. Management initiatives counteracting the effects of low temperatures during the cold part of the year appear sufficient to reduce liveborn mortality. Consequently, other factors may explain yearly fluctuations in liveborn mortality.

## Introduction

Ambient temperature has a major impact on piglet survival either by acting directly on the piglets (low temperature) (Pedersen *et al.*, 2013) or by indirectly acting on the sows (high temperature), as shown for farrowing sows housed indoors (Vanderhaeghe *et al.*, 2010). The UCT of indoor-crated, lactating sows is around  $25^{\circ}\text{C}$  to  $27^{\circ}\text{C}$  (Prunier *et al.*, 1997;

Quiniou and Noblet, 1999). Thus, when a sow is exposed to higher temperatures, there is a risk that it cannot thermoregulate sufficiently, resulting in increased body temperature (hyperthermia). Under confined indoor conditions, the high environmental temperature can result in a longer farrowing duration and longer inter birth intervals between piglets (Oliviero *et al.*, 2008), more sick sows, reduced feed consumption and lowered milk production (Prunier *et al.*, 1997; Quiniou and Noblet, 1999). Therefore, results suggest that high temperatures affect piglet survival indirectly by changing the course of the farrowing, increasing the risk of stillbirths and non-viable piglets and by reducing milk production and consequently increasing the risk of piglets dying of starvation. When exposed to high temperatures, pigs will, if they have the opportunity, start to display wallowing (Heitman *et al.*, 1962; Fraser, 1970; Bracke, 2011) and the behaviour is an effective mean of cooling (as reviewed by Bracke, 2011).

Contrary to this, low ambient temperature directly influences piglet survival, as it may lead to low body temperature (hypothermia) in piglets (Pedersen *et al.*, 2011; Panzardi *et al.*, 2013). At birth, piglets experience a sudden decrease in ambient temperature, which is reflected by a drop in rectal temperature. In relation to birth weight, this temperature reduction has been identified as a factor influencing piglet

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survival (Baxter *et al.*, 2009; Pedersen *et al.*, 2011). Furthermore, piglets are born covered in placental fluids and this condition, combined with the exposure to a reduced ambient temperature, may result in rapid cooling of piglets (Baxter *et al.*, 2009), and consequently increase the risk of death due to hypothermia. The thermal comfort zone of a neonatal piglet at birth is 34°C to 35°C (Mount, 1959), and in particular small and underweight piglets are at risk of experiencing hypothermia (Kammersgaard *et al.*, 2011).

Under outdoor conditions, animals are exposed to more extreme thermal conditions than indoors, thus the risk of hyperthermia among sows and hypothermia among piglets is likely to be increased. Sudden changes in temperature could, in addition, reduce the ability of sows and piglets to adjust to the ambient temperature.

Studies on animals housed outdoors show changes in piglet mortality according to the season. Berger *et al.* (1997) found an increased mortality during autumn and winter (study conducted in France). In uninsulated huts in an outdoor pig unit in southern England, Randolph *et al.* (2005) saw indications of higher mortality during summer and a significant increase of early piglet mortality during winter. Rangstrup-Christensen *et al.* (2016) found more stillborn piglets during summer, even in insulated huts (in Denmark). Part of the explanation for seasonality in piglet mortality may be caused by seasonality in hormones affecting parturition and lactation (Bassett *et al.*, 2001; Macchi *et al.*, 2010). However, hut temperature and humidity may also play an important role as suggested above. None of the studies on yearly variations in mortality under outdoor conditions focus on the hut climate, and hence there is a need to clarify the impact of hut temperature and humidity on piglet mortality for animals housed outdoors in insulated huts. The overall aim of the current study was to quantify the effect of yearly variation, hut temperature and humidity at the time of farrowing on piglet mortality in commercial organic herds.

It was hypothesised that more piglets would be stillborn during summer and at high hut temperature. It was also hypothesised that max humidity (100%), during high hut temperature, would result in more stillbirths due to an expected decrease in the effectiveness of evaporative cooling resulting in an increased risk of hyperthermia among the sows.

Furthermore, an increased liveborn mortality was expected during winter. It was hypothesised that at a low hut temperature and high humidity (at the level of water condensation, 100%), liveborn mortality would increase as the evaporation of placental fluids could be prolonged and death due to hypothermia increased.

## Material and methods

### Animals and housing

This study was conducted at five Danish commercial organic pig-producing herds from June 2015 to August 2016.

All farrowing sows were crosses of Danish Landrace and Yorkshire. Farmers introduced the sows to the farrowing field between 7 and 10 days *prepartum*. Sows and piglets were fed and managed according to the Danish legislation. All male piglets were castrated with pain relief; in addition, cross-fostering was conducted in all herds.

After relocation to the farrowing field, sows were housed in standard, individual grass-covered farrowing paddocks with access to individual farrowing huts. Huts were insulated (40 to 45 mm flanking in roof, sides and end walls) A-frame huts (Figure 1) with a ventilation window either through the roof (measuring 25 × 25 cm) or in the back (measuring 15 × 25, 16 × 34, 25 × 34 or 30 × 30 cm) and a sow entrance in the front. A fender was placed in front of all huts before farrowing and removed again after castration. The opening of the ventilation window and removal of the fender were

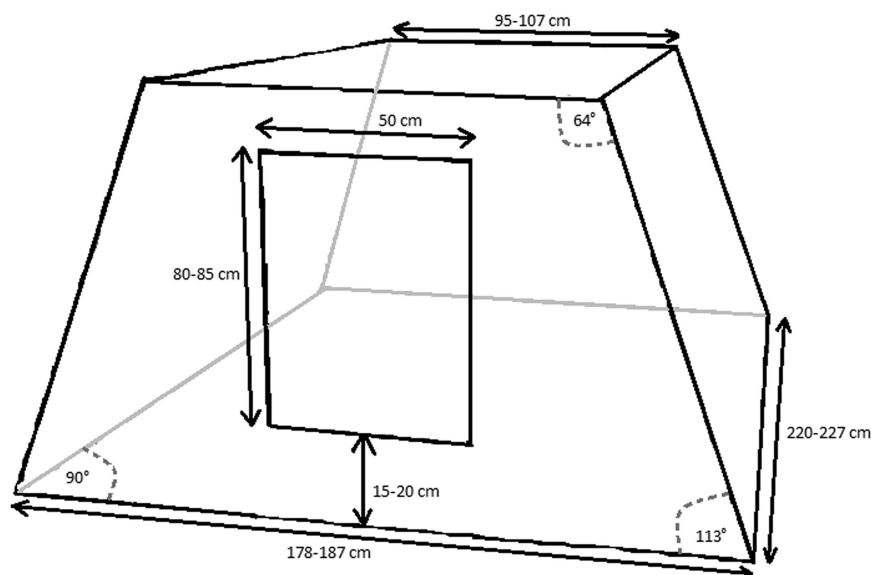


Figure 1 A sketch of the standard A-frame sow hut used in the current study.

according to herd routines. All huts were provided with straw before insertion of sows into the farrowing field. The amount of straw supplied before insertion and after farrowing depended on weather conditions (temperature and rainfall). Additional straw was supplied according to the individual stockman's decision.

When outdoor temperature increased above 15°C, a wallow was created in each farrowing paddock, as required according to the Danish legislation. In late autumn and during winter, curtains were placed in the sow entrance of each hut.

In all herds, the farrowing huts were relocated within the paddock between farrowing batches. After the hut was moved to its new location, the remaining bedding was burned.

### Study design

This was an observational study comprising seven farrowing batches of 30 farrowings in each of four herds (herd A to D), and five batches in the fifth herd (herd E). At herd E, batch one consisted of 30 farrowings, batch two and three of 10 farrowings and batch four and five of 20 farrowings.

Within herds A to D there were 8 weeks between farrowing batches, whereas in herd E data collection was distributed between two farrowing fields, thus there were ~4 weeks between farrowing batches in this herd.

### Data collection

**Environmental recordings.** At the initiation of the study, each herd was visited, and a logger rack (Supplementary Figure S1) was placed in the north-eastern or north-western corner of each hut. The rack was made by an 18-cm long, triangular and hollow plastic tube. The tube was filled with PU SKUM (polyurethane foam sealant) (SAM Partner A/S, Kolding, Denmark) to lower the conduction of heat/cold to/from the hut wall. Furthermore, the logger was placed about 5 mm into a 15-mm thick layer of backing foam upon the tube. Above the data logger, a steel grid was mounted to protect against damage. The logger was not in direct contact with the steel grid. The logger rack was glued to the hut wall 55 cm above the ground. One data logger, in a rack facing north-east, was placed outside in the farrowing field 55 cm above the ground.

During the study, each herd was visited about a week before the expected farrowing of each batch. A data logger (Hygrochron™ iButton (DS1923), Maxim Integrated Products, Inc., San Jose, CA, USA) was then placed inside each hut in the logger rack and left until weaning.

The loggers recorded temperature and humidity every 10<sup>th</sup> min from 1 to 7 days before and until 7 days after expected farrowing. Loggers recorded data at a low resolution (accuracy: ±0.5°C and ±0.6% relative humidity (RH)).

The daily (24 h) average (DA) of the 10% highest values for the ambient temperature ( $T$ ) and RH and correspondingly the DA of the 10% lowest  $T$  and RH were calculated for each farrowing on the day of farrowing (day 0, the 24 h leading up

to 1200 h (midday) on the day piglets were observed in the nest) and the 1<sup>st</sup> day *postpartum* (day 1). Hereafter, both  $T$  and RH were converted to categorical values.

With respect to stillborn piglets, the main cause of stillbirth was expected to be high temperatures causing hyperthermia in sows and so three  $T$  categories were created 'low<sub>st</sub>':  $T \leq 22^\circ\text{C}$ ; 'med<sub>st</sub>':  $22^\circ\text{C} < T < 27^\circ\text{C}$ ; and 'high<sub>st</sub>':  $T \geq 27^\circ\text{C}$ . These categories were based on the UCT for sows being 25°C to 27°C for lactating sows under indoor conditions (Prunier *et al.*, 1997; Quiniou and Noblet, 1999).

For liveborn mortality, both high and low temperatures were expected to influence mortality. Five temperature categories were made representing both critical values for low and high temperatures: 'low<sub>lb</sub>':  $T \leq 5^\circ\text{C}$ ; 'lom<sub>lb</sub>':  $5^\circ\text{C} < T < 11^\circ\text{C}$ ; 'med<sub>lb</sub>':  $11^\circ\text{C} \leq T < 22^\circ\text{C}$ ; 'him<sub>lb</sub>':  $22^\circ\text{C} \leq T < 27^\circ\text{C}$ ; and 'high<sub>lb</sub>':  $T \geq 27^\circ\text{C}$ . The choice of the lower temperature categories was based on the knowledge about temperature span between the surroundings and the farrowing nest (Algers and Jensen, 1990). This suggests the nest temperature may be around 25°C warmer than the surroundings at low ambient temperatures, under semi-natural conditions. Thus, temperatures below 5°C measured above the nest would represent the lower extreme under Danish weather conditions.

In addition, two categories for RH were made: 'normal':  $\text{RH} < 100\%$  or 'high':  $\text{RH} = 100\%$  (the level of condensation). When humidity reached 100%, the evaporation of placental fluids was expected to be prolonged, and thus newly born piglets may have increased risk of hypothermia due to prolonged period of drying up (Baxter *et al.*, 2009). In addition, when water condensed, it started dripping into the straw from the roof and sides of the hut thereby wetting the straw and affecting the piglets' ability to uphold a sufficient body temperature. Furthermore, at high  $T$ , a high RH was expected to reduce the efficiency of evaporative cooling in the sows. Relative humidity category 'high' was however rare in the higher  $T$  categories ( $n=4$  observations when  $T$  'high<sub>lb</sub>',  $n=4$  when  $T$  'him<sub>lb</sub>',  $n=8$  when  $T$  'med<sub>lb</sub>'), making it impossible to investigate an interaction between RH and  $T$  with the current data set.

Sudden and large fluctuations in  $T$  could be as important as the actual temperature for the thermal comfort of sows and piglets. Therefore, a variable describing hut  $T$  fluctuations was made. In the analysis of stillborn piglets, the difference between DA of the 10% highest  $T$  on day 1 *prepartum* (day -1) and day 0 was calculated ( $T_{\text{diff},1-0} = T_{10\%}(\text{day } -1) - T_{10\%}(\text{day } 0)$ ). These days were chosen as sudden increases in  $T$  were expected to reduce sows' ability to cope with high  $T$  and may thus affect the risk of stillbirths. In the analysis of liveborn mortality, the difference in the DA of the 10% highest  $T$  between days 0 and 1 was also calculated ( $T_{\text{diff},0-1} = T_{10\%}(\text{day } 0) - T_{10\%}(\text{day } 1)$ ).

The diurnal span in temperature for days 0 and 1 was also calculated as the difference between the DA of the 10% highest  $T$  and the DA of the 10% lowest  $T$  values ( $T_{\text{diff}} = T_{\text{highest}} - T_{\text{lowest}}$ ).  $T_{\text{diff}}$  was categorised into four based on its quartiles.

**Recording of production results.** All producers recorded production results and information about each sow in a booklet: sow parity, number of liveborn piglets, number of stillborn piglets, number of piglets euthanized at first inspection, number of piglets added to or removed from the litter at first inspection, number of piglets alive at castration and piglets weaned.

**Data editing.** All herds contributed with data for the analyses of stillborn piglets, and 646 farrowings were included. Herd A to D contributed with data to the analyses of liveborn deaths until castration (only litters where castration was performed on day 2 to 7 *postpartum* were included), and 568 farrowings were included.

Farrowings lacking production records were excluded from the analyses (84 excluded from the analyses of stillborn piglets and 162 excluded from the analyses of liveborn deaths). Furthermore, sows that had 10 or more piglets added to their litter were excluded as these sows were most likely used as nurse sows.

A total of 17 sows were recorded with two farrowings during the study period. Before final analysis, a sensitivity analysis was made by removal of the second farrowing for these sows. This did not change any results and therefore the litter in contrast to the sow was used as a statistical unit.

#### Statistical analyses

All statistical analyses were conducted with SAS (SAS 9.3; SAS Institute Inc., Cary, NC, USA). The effect of parity was included in the models as follows: sows in their first parity were assigned to parity group 1; sows in their second to fourth parity were assigned to parity group 2; sows in their later parities were assigned to parity group 3. The mean-centred count of total born piglets (litter size at farrowing (LF)) and quadratic of LF (LF<sup>2</sup>) were used to adjust for the effect of litter size in the analyses.

#### Effect of year variation on hut climate

The effect of year variation on the farrowing hut climate was analysed using linear mixed models:

$$Y_{ij} = V_i + \vartheta_j + \varepsilon_{ij} \quad (1)$$

where  $V$  refers to year variation ( $i = 1, 2, 3$  and  $4$  indicating spring (March, April and May), summer (June, July and August), autumn (September, October and November) and winter (December, January and February)),  $\vartheta$  is a normal distributed random effect to account for repeated measures (index  $j$ ) at herd level ( $h = 1, 2, 3, 4$  and  $5$ ) and  $\varepsilon$  refers to the normal distributed residual error. The continuous values for the DA of the 10% highest and the 10% lowest  $T$  and RH, and  $T_{\text{diff}}$  and  $\text{RH}_{\text{diff}}$  for both days 0 and 1 were used as response variables ( $Y$ ).

#### Stillborn piglets

First, the effect of year variation on the proportion of stillborn piglets was investigated by use of the following binomial generalised linear mixed model, omitting dispersion and

random effect parameters from the formula:

$$\text{logit}(\pi) = \beta_0 + \beta_1 \text{LF} + \beta_2 \text{Spr} + \beta_3 \text{Sum} + \beta_4 \text{Aut} + \sum_{i=1}^2 \alpha_i \text{Parity}_i$$

$\beta_0$  refers to the intercept for the combination: year variation in winter and parity group 3.  $\beta_1$  is the parameter describing the effect of LF. Spr, Sum and Aut are indicator functions (implying these sum to 0 (if year variation is in winter) or 1 (if year variation in Spr, Sum or Aut)).  $\beta_{2-4}$  describe the effect of Spr, Sum, Aut in relation to the reference, winter.  $\alpha_1$  and  $\alpha_2$  describe the effect of parity group 1 and 2 in relation to the reference (parity group 3). Parity<sub>1</sub> and Parity<sub>2</sub> are indicator functions. The herd was included as a random effect. In the full model, LF<sup>2</sup> was also included; however, this parameter was removed by backward model reduction of statistically non-significant effects ( $P > 0.05$ ).

For the analysis of the effect of hut climate on the proportion of stillborn piglets, only climate variables for days -1 and 0 were considered. Winter had a lower proportion of stillbirths compared with the remaining three seasons and was consequently analysed separately (model 3). As the categories 'med<sub>st</sub>' and 'high<sub>st</sub>' did not occur during winter, new categories were created: 'low<sub>st</sub>':  $T \leq 5^\circ\text{C}$ ; 'med<sub>st</sub>':  $5^\circ\text{C} < T \leq 21^\circ\text{C}$ . Data from spring, summer and autumn were merged and analysed by use of the original categories ('low<sub>st</sub>':  $T \leq 22^\circ\text{C}$ ; 'med<sub>st</sub>':  $22^\circ\text{C} < T < 27^\circ\text{C}$ ; 'high<sub>st</sub>':  $T \geq 27^\circ\text{C}$ ) (model 4).

For both analyses, a binomial generalised linear mixed model was used including herd as a random effect:

$$\text{logit}(\pi) = \beta_0 + \beta_1 \text{LF} + \beta_2 T_{\text{diff},1-0} + \sum_{i=1}^2 \alpha_i \text{Parity}_i \quad (3)$$

$\beta_0$  refers to Parity group 3,  $\beta_1$  is the parameter describing the effect of LF and  $\beta_2$  describes the effect of  $T_{\text{diff},1-0}$ .  $\alpha_1$  and  $\alpha_2$  describe the effect of parity group 1 and 2 in relation to the reference (parity group 3) and are indicator functions. LF<sup>2</sup>,  $T$ , RH and  $T_{\text{diff}}$  were not statistically significant, and so these parameters were not included in the final model (3).

Below model 4, used for the analysis of hut climate in the merged warm part of the year (spr, sum and aut), is shown:

$$\text{logit}(\pi) = \beta_0 + \beta_1 \text{LF} + \sum_{i=1}^2 \alpha_i \text{Parity}_i + \sum_{j=1}^4 \gamma_j T_j \quad (4)$$

$\beta_0$  refers to the intercept for the combination parity group 3 and  $T$  category 5 ('high').  $\beta_1$  is the parameter describing the effect of LF.  $\alpha_1$  and  $\alpha_2$  describe the effect of parity group 1 and 2 in relation to the reference (parity group 3). Parity<sub>1</sub> and Parity<sub>2</sub> are indicator functions.  $\gamma_{1-4}$  describe the effect of  $T$  category 'low<sub>st</sub>', 'lom<sub>st</sub>', 'med<sub>st</sub>' and 'him<sub>st</sub>' in relation to  $T$  category 'high<sub>st</sub>'.  $T_{1-4}$  are indicator functions. LF<sup>2</sup>, RH,  $T_{\text{diff},1-0}$  and  $T_{\text{diff}}$  were removed from this model (4) by backward elimination of statistically non-significant parameters.

### Mortality of liveborn piglets until castration

To account for the variation in days until castration between litters, the effect of year variation on postnatal mortality until castration was investigated using a negative binomial generalised linear mixed model. The response variable was the number of liveborn piglets that died before castration. As for the analyses of stillborn piglets, herd was included as random effect. Parity was included in the initial model, but was not statistically significant and is not included in the final model (5):

$$\log(\mu) = \log[L] + \beta_0 + \beta_1 LF + \beta_2 LF^2 + \beta_3 Spr + \beta_4 Sum + \beta_5 Aut \quad (5)$$

where  $\log[L]$  is the log-offset of number of liveborn piglets times days until castration ( $L$  days at risk).  $\beta_0$  refers to the intercept for year variation in winter.  $\beta_1$  is the parameter describing the effect of LF and  $\beta_2$  describes the effect of  $LF^2$ .  $\beta_{3-5}$  are the parameters describing the effect of year variation. Spr, Sum and Aut are again included as indicator functions, and  $\beta_{3-5}$  describe the effect of Spr, Sum, Aut in relation to winter.

Again, an effect of year variation was found, and so for the analyses of the effect of hut climate variables on liveborn mortality, data were split into data from spring (model 6) and data from winter, summer and autumn (model 6). A negative binomial generalised linear mixed model was used for both. The random effect of the herd was omitted in the analysis of the data from spring as it was so small that the procedure set it to zero. In the analysis of the merged winter, summer and spring data, the herd was included as a random effect in the model:

$$\log(\mu) = \log[L] + \beta_0 + \beta_1 LF \quad (6)$$

where  $\log[L]$  is the log-offset of days at risk ( $L$ ),  $\beta_0$  refers to the intercept and  $\beta_1$  is the parameter describing the effect of LF. No effects were found for  $LF^2$ , RH,  $T$ ,  $T_{diff,0-1}$  and  $T_{diff}$  and so these variables were removed by backward elimination of statistically non-significant effects.

### Results

The median number of total born piglets during the study period was 18 (range 5 to 29) ( $n = 646$  farrowings) of which one (median, range 0 to 20) was stillborn. At castration, two (median, range 0 to 21) ( $n = 568$  farrowings) of the liveborn piglets had died. Informations regarding each herd can be found in Table 1.

#### Effect of year variation on hut climate

As can be seen in Table 2, year variation significantly affected hut climate both on days 0 and 1. Year variation influenced the DA of the 10% lowest and highest temperatures recorded both on day 0 ( $F_{3,661} = 260.9$ ,  $P < 0.001$  and  $F_{3,657} = 239.2$ ,  $P < 0.001$  for the lowest and highest temperatures, respectively) and 1 ( $F_{3,549} = 288.5$ ,  $P < 0.001$  and  $F_{3,549} = 187.7$ ,  $P < 0.001$  respectively, for the lowest and highest temperatures). The highest temperatures were recorded in summer ( $24.2 \pm 0.5^\circ\text{C}$  and  $25.2 \pm 0.3^\circ\text{C}$  for days 0 and 1, respectively) and the lowest in winter ( $2.7 \pm 0.5^\circ\text{C}$  and  $6.1 \pm 0.4^\circ\text{C}$  for days 0 and 1, respectively).  $T_{diff}$  was also affected by year variation on both days 0 ( $F_{3,657} = 43.3$ ,  $P < 0.001$ ) and 1 ( $F_{3,549} = 71.1$ ,  $P < 0.001$ ).  $T_{diff}$  was largest in summer ( $10.5 \pm 0.3^\circ\text{C}$  and  $8.8 \pm 0.3^\circ\text{C}$  for days 0 and 1, respectively) and spring ( $10.5 \pm 0.3^\circ\text{C}$  and  $9.3 \pm 0.3^\circ\text{C}$  for days 0 and 1, respectively) and lowest during winter ( $6.3 \pm 0.4^\circ\text{C}$  and  $5.8 \pm 0.4^\circ\text{C}$ , respectively, for days 0 and 1).

Descriptive values of the outdoor temperature recordings made in the farrowing fields can be found in Table 3.

#### Stillborn piglets

Year variation affected the risk of stillborn piglets ( $F_{3,635} = 4.4$ ,  $P = 0.004$ , model 2), in that the risk was lowest in winter compared with the remaining part of the year (Table 4). In winter,  $T_{diff,1-0}$  affected the rate of stillbirths ( $F_{1,99} = 6.39$ ,  $P = 0.013$ , model 3) with a one unit increase in  $T_{diff,1-0}$  increasing the odds of stillborn piglets by 10%,

**Table 1** Descriptive information about the five pig-producing herds

Herds	Year sows <sup>b</sup>	Parity <sup>a</sup> (%)		Litters <sup>c</sup>	LS		Mortality		
		1	2		Total LS <sup>d</sup>	Weaned LS <sup>e</sup>	Stillborn <sup>f</sup>	Early mortality <sup>g</sup>	Total mortality <sup>e</sup>
1	550	29.7	70.3	148	17.7 ± 0.3	11.4	1.0 ± 0.1	3.0 ± 0.2	31.8
2	360	15.1	84.9	152	17.4 ± 0.3	11.5	2.0 ± 0.2	2.4 ± 0.2	33.3
3	910	30.6	69.4	134	17.0 ± 0.4	12.5	1.4 ± 0.2	1.5 ± 0.1	21.4
4	345	22.2	77.8	158	17.9 ± 0.3	11.9	1.6 ± 0.2	2.7 ± 0.3	29.7
5	360	0	100	54	18.0 ± 0.3	NA	2.3 ± 0.3	NA	NA
Mean <sup>h</sup>	2525	19.5	80.5	646	17.6	11.8	1.7	2.4	29.1

LS = litter size.

<sup>a</sup>Percentages of sows included in the analysis of year variation in stillbirth. Grouped according to parity where 1 = first parity sows and 2 = multiparous sows.

<sup>b</sup>Number of productive sows per year.

<sup>c</sup>Total number of litters included in the analysis of year variation in stillbirth.

<sup>d</sup>Average number of total born piglets per litter (± standard error).

<sup>e</sup>Weaned herd LS and total mortality (in%) after Rangstrup-Christensen *et al.* (2018).

<sup>f</sup>Average number of stillborn piglets (± standard error) per litter.

<sup>g</sup>Average number of liveborn piglets dying before castration (± standard error).

<sup>h</sup>Year sows and litters are given as totals.



**Table 2** The influence of year variation (summer, autumn, winter and spring) on the daily average of the 10% highest sow farrowing hut temperatures ( $T_{top10}$ ) and relative humidity ( $RH_{top10}$ ) and correspondingly the daily average of the 10% lowest sow hut temperatures ( $T_{bot10}$ ) and relative humidity ( $RH_{bot10}$ )

	Day 0				<i>F</i>	<i>P</i>	Day 1				<i>F</i>	<i>P</i>
	Summer	Autumn	Winter	Spring			Summer	Autumn	Winter	Spring		
$T_{top10}$	24.2 ± 0.5 <sup>a</sup>	16.5 ± 0.6 <sup>b</sup>	9.0 ± 0.6 <sup>c</sup>	16.6 ± 0.6 <sup>b</sup>	$F_{3,657} = 239.2$	***	25.2 ± 0.3 <sup>a</sup>	19.6 ± 0.4 <sup>b</sup>	12.1 ± 0.5 <sup>c</sup>	18.4 ± 0.4 <sup>d</sup>	$F_{3,549} = 187.7$	***
$T_{bot10}$	13.7 ± 0.4 <sup>a</sup>	9.1 ± 0.4 <sup>b</sup>	2.7 ± 0.5 <sup>c</sup>	6.1 ± 0.4 <sup>d</sup>	$F_{3,661} = 260.9$	***	16.1 ± 0.3 <sup>a</sup>	12.5 ± 0.3 <sup>b</sup>	6.1 ± 0.4 <sup>c</sup>	8.8 ± 0.4 <sup>d</sup>	$F_{3,549} = 288.5$	***
$T_{diff}$	10.5 ± 0.3 <sup>a</sup>	7.4 ± 0.3 <sup>b</sup>	6.3 ± 0.4 <sup>c</sup>	10.5 ± 0.3 <sup>a</sup>	$F_{3,657} = 43.3$	***	8.8 ± 0.3 <sup>a</sup>	6.8 ± 0.3 <sup>b</sup>	5.8 ± 0.4 <sup>c</sup>	9.3 ± 0.3 <sup>a</sup>	$F_{3,549} = 25.1$	***
$RH_{top10}$	93.6 ± 0.5 <sup>a</sup>	98.3 ± 0.6 <sup>b</sup>	99.7 ± 0.7 <sup>c</sup>	96.3 ± 0.6 <sup>d</sup>	$F_{3,657} = 43.3$	***	91.6 ± 0.6 <sup>a</sup>	96.7 ± 0.7 <sup>b</sup>	100.3 ± 0.7 <sup>c</sup>	97.6 ± 0.6 <sup>b</sup>	$F_{3,549} = 71.1$	***
$RH_{bot10}$	63.4 ± 1.3 <sup>a</sup>	76.8 ± 1.4 <sup>b</sup>	86.3 ± 1.6 <sup>c</sup>	66.6 ± 1.5 <sup>d</sup>	$F_{3,669} = 43.3$	***	62.5 ± 1.3 <sup>a</sup>	72.4 ± 1.5 <sup>b</sup>	83.4 ± 1.6 <sup>c</sup>	64.4 ± 1.5 <sup>b</sup>	$F_{3,549} = 79.5$	***

$T_{diff}$  is the difference between  $T_{top10}$  and  $T_{bot10}$ . Day 0 refers to the day of farrowing and day 1 to day 1 *postpartum*. Least square means ± standard error are given for each variable within each combination of season and day.

<sup>a,b,c,d</sup>Significant differences ( $P < 0.05$ ) within row for each day.

\*\*\*  $P < 0.001$ .

**Table 3** Outdoor temperatures for unshaded loggers placed outside the hut

	Winter	Spring	Summer	Autumn
Average (°C)	1.7	11.0	17.8	9.8
10% highest DA temperatures	8.5	22.1	30.8	17.3
10% lowest DA temperatures	-6.6	4.3	9.6	1.9

DA = daily average.

Recordings from all five pig-producing herds are included for winter (December to February), spring (March to May), summer (June to August) and autumn (September to November).

corresponding to an OR of 1.1. During winter,  $T_{diff,1-0}$  had a median of -1.9°C (range -9.3°C to 7.5°C).

In the remaining part of the year,  $T$  category affected the risk of stillbirths ( $F_{2,511} = 6.46$ ,  $P = 0.002$ , model 4). Farrowings on days with  $T$  in category 'high<sub>st</sub>' had a higher risk of stillbirths compared with farrowing days with temperatures in category 'med<sub>st</sub>'. There was a 30% increased risk of stillbirths in category 'high<sub>st</sub>' compared with category 'med<sub>st</sub>', corresponding to an OR of 0.77 CI [0.60, 0.99].

No significant effects of RH category or  $T_{diff}$  were found. Across the year,  $T_{diff}$  had a median of 8.4°C (range 0°C to 28.5°C).

**Table 4** Summary of the output from the final models of stillborn piglets

Models	Variables	Levels	No. of litters	OR	95% CI	<i>F</i>	<i>P</i>
2	Litter size	Continuous	646	1.12	1.10; 1.14	$F_{1,635} = 133.7$	<0.001
		1	143	0.49	0.38; 0.63	$F_{2,635} = 18.3$	<0.001
	Parity group	2	375	0.67	0.57; 0.79		
		3	128	1			
		Autumn	151	1.48	1.18; 1.86	$F_{3,635} = 4.4$	0.004
		Spring	139	1.45	1.14; 1.84		
3	Year variation	Summer	247	1.27	1.02; 1.59		
		Winter	109	1			
	Litter size	Continuous	108	1.16	1.10; 1.22	$F_{1,99} = 31.5$	<0.001
		1	30	0.38	0.17; 0.83	$F_{2,99} = 4.12$	0.019
	Parity group	2	51	0.56	0.34; 0.92		
3		27	1				
$T_{diff,1-0}$		Continuous	108	1.10	1.02; 1.18	$F_{1,99} = 6.39$	0.013
4	Litter size	Continuous	521	1.11	1.09; 1.14	$F_{1,511} = 100.5$	<0.001
		1	112	0.47	0.36; 0.62	$F_{2,511} = 18.8$	<0.001
	Parity group	2	313	0.65	0.55; 0.77		
		3	96	1			
		$T$ category	low	280	1.07	0.89; 1.29	$F_{2,511} = 6.46$
	med		128	0.77	0.61; 0.96		
	high	113	1	1			

OR = odds ratio; CI = confidence intervals.

First output is from the final model 2 (effect of year variation), second output is from the final model 3 (effect of hut climate during winter) and third output is from the final model 4 (effect of hut climate during the remaining three seasons).

'Parity group' '1' included sows in their first parity, '2' sows in their second, third and fourth parity, '3' sows in their later parities; 'Year variation' refers to the part of the year in which the farrowing occurred (autumn: September, October and November; spring: March, April and May; summer: June, July and August; winter: December, January and February). ' $T_{diff,1-0}$ ' is the difference in the daily average of the 10% highest temperatures between day 1 *prepartum* and the day of farrowing; ' $T$  category' refers to the temperature ( $T$ ) on the day of farrowing, 'low'  $T \leq 21^\circ\text{C}$ ; 'med'  $T = 22^\circ\text{C}$  to  $26^\circ\text{C}$ ; 'high'  $T \geq 27^\circ\text{C}$ .

OR for each variable (and level) with corresponding 95% CI,  $F$  and  $P$  values are presented for the overall effect of each variable.

**Table 5** Summary of the output from the final models of liveborn piglets that were found dead before the time of castration

Models	Variables	Levels	No. of litters	RR	95% CI	F	P
5	Litter size	Continuous	568	1.04	1.02; 1.07	$F_{1,561} = 16.8$	<0.001
	Litter size sq	Continuous	568	1.00	1.00; 1.01	$F_{1,561} = 4.3$	0.039
	Year variation	Summer	216	1.28	1.03; 1.60	$F_{3,561} = 3.9$	0.009
		Autumn	146	1.39	1.10; 1.76		
		Winter	94	1.51	1.17; 1.94		
Spring		112	1				
6s	Litter size	Continuous	112	1.08	1.03; 1.13	$F_{1,110} = 9.2$	0.003
6r	Litter size	Continuous	456	1.05	1.03; 1.07	$F_{1,453} = 18.3$	<0.001

RR = rate ratio; CI = confidence intervals.

First output is from the final model 5 (effect of year variation); second output (6s) is from the final model 6 for the effect of hut climate in the remaining three seasons.

'Litter size sq' refers to the square of the mean-centred litter size; 'Year variation', the part of the year in which the farrowing occurred (autumn: September, October and November; spring: March, April and May; summer: June, July and August; winter: December, January and February).

RR for each variable (and level) with corresponding 95% CI, F and P values are presented for the overall effect of each variable.

### Mortality of liveborn piglets until castration

The median number of days until castration was 5 (range 3 to 8). There was an effect of year variation ( $F_{3,561} = 3.9$ ,  $P = 0.009$ , model 5) with spring having a lower rate of postnatal mortality compared with the remaining part of the year (Table 5). With respect to the impact of hut climate, no significant effects of T or RH category,  $T_{diff,0-1}$  or  $T_{diff}$  were found for mortality of liveborn piglets.  $T_{diff,0-1}$  had a median of  $-0.8^{\circ}\text{C}$  (range  $-11.6^{\circ}\text{C}$  to  $14.5^{\circ}\text{C}$ ) and  $T_{diff}$  a median of  $6.8^{\circ}\text{C}$  (range  $0.0^{\circ}\text{C}$  to  $29.7^{\circ}\text{C}$ ).

## Discussion

### Stillborn piglets

The risk of stillborn piglets was lowest in winter, which is in accordance with Rangstrup-Christensen *et al.* (2016) who found a lower risk of stillborn piglets during winter compared with summer (May to August). Still, a larger data set involving recordings across at least 4 years is needed in order to confirm a seasonal fluctuation in the rate of stillbirths. During summer, it was expected that a high T would increase the sows' risk of hyperthermia resulting in more stillborn piglets (Vanderhaeghe *et al.*, 2010). In accordance, an effect of T was found. The risk of stillbirths was increased at high compared with middle-high temperatures, suggesting sows were heat stressed at high hut T. In category 'high<sub>st</sub>', T was  $\geq 27^{\circ}\text{C}$  whereas the middle-high ('med<sub>st</sub>') category was for T between  $22^{\circ}\text{C}$  and  $26^{\circ}\text{C}$ , corresponding to the UCT measured for sows under indoor confined conditions (Quiniou and Noblet, 1999). The current results could, therefore, indicate a higher UCT for outdoor sows, which is likely due to the improved possibility for thermoregulation outdoors; however, more detailed animal level recordings are required to confirm this hypothesis. In particular, evaporative cooling is an important mean for thermoregulation in the pig (Lucas *et al.*, 2000; Vanderhaeghe *et al.*, 2010) and Vanderhaeghe *et al.* (2010) found fewer stillbirths in confined sows that were showered before parturition. The sows in the current

study had the opportunity to regulate their body temperature through behaviour – for instance through wallowing. It is therefore likely that the problem with increased temperatures is not as great outdoors as for crated sows. It may first arise at higher temperatures than the UCT recorded in crated sows. In addition, hyperthermia may mainly occur during periods where sows are bound to the nest such as during farrowing. Our results suggest that initiatives for reducing hut temperature around farrowing in outdoor production may increase piglet survival.

It was expected that high farrowing hut humidity would decrease the effectiveness of evaporative cooling in hot periods, thereby increasing the risk of hyperthermia and consequently also stillbirths. However, this expectation could not be confirmed. A reason for the lack of effect of RH could be that sows may have remained outside the hut after wallowing. In addition, hut RH only rarely reached 100% in the warm periods likely due to the increased ventilation of the hut (open ventilation window and no curtain in front of the hut). This suggests that RH under outdoor conditions is not important to consider in relation to hyperthermia during summer in a temperate climate like that of Denmark. The mean hut humidity during summer was  $90.1 \pm 0.4\%$  (range 73.2% to 100%).

It was expected that sudden changes in hut temperature would reduce the sows' ability to adapt to a high T thereby increasing the risk of hyperthermia, but this hypothesis was not confirmed. Nevertheless, during winter larger changes in  $T_{diff,1-0}$  increased the risk of stillbirths. Pigs may adapt when exposed to long-term high or low temperatures and have difficulties adjusting when the temperature suddenly changes. This may be part of the explanation for the effect of  $T_{diff,1-0}$ . It remains unknown, however, why this effect was only seen during winter and why no effect of within-day temperature changes ( $T_{diff}$ ) was found.

In accordance with previous studies conducted both in outdoor production systems (KilBride *et al.*, 2012; Rangstrup-Christensen *et al.*, 2016) and in the indoor loose housing

(KilBride *et al.*, 2012; Hales *et al.*, 2014), an increase in litter size was accompanied by more stillborn piglets. Furthermore, higher parities were also associated with more stillborn piglets. This may be caused by larger litter sizes in older sows, which corresponds with previous studies (Hales *et al.*, 2014), but it may also be due to the weakening of high parity production sows.

#### *Mortality of liveborn piglets until castration*

Hypothermia is a known cause of piglet mortality (Pedersen *et al.*, 2011; Panzardi *et al.*, 2013), and organic piglets are kept outdoors where the influence of the thermal climate is likely to be even more pronounced than in indoor systems. Hypothermia was therefore expected to be reflected in the piglet mortality by higher mortality during winter compared with the remaining part of the year as well as at a low  $T$  particularly if RH was high. This could not be confirmed by the current study.

In accordance with Randolph *et al.* (2005), no increase in liveborn deaths was found during winter in the current study. Contrary, Berger *et al.* (1997) showed increased mortality during autumn and winter but did not specify whether the farrowing huts studied were insulated or not. Randolph *et al.* (2005) showed that in uninsulated huts early mortality increases during winter and so the discrepancy between the study by Berger *et al.* (1997) and the current study could be differences in hut insulation. The DA of the 10% lowest temperatures inside the farrowing hut during winter was  $4.6 \pm 0.5^\circ\text{C}$ , whereas the DA of the 10% lowest outdoor temperatures was  $-6.6 \pm 0.8^\circ\text{C}$ , indicating that hut insulation protected the animals against the more extreme  $T$  outside the hut and allowed sows to warm up the farrowing hut. In addition, all farrowing huts were supplied with plenty of straw during winter. The study by Algers and Jensen (1990) showed that the temperature in a sow-built farrowing nest, composed mostly of straw, was on average  $20.3^\circ\text{C}$ . Temperature was recorded in 5 cm distance to the piglets and was reported not to be correlated with weather or ambient temperature. Thus, it is likely that in the current study nest temperature inside the farrowing hut was sufficiently high to prevent hypothermia. This is supported by Pedersen *et al.* (2016) who showed that a 30-cm layer of dry straw strongly reduced the immediate *postpartum* drop in rectal temperature under indoor conditions.

Daily average of the 10% highest hut humidity during winter was  $96.3 \pm 0.5\%$ . High humidity and low temperature were expected to prolong the evaporation of placental fluids, thereby increasing the risk of hypothermia (McGinnis *et al.*, 1981; Baxter *et al.*, 2009). This could not be confirmed and may again be caused by the microclimate in the nest being sufficient for drying of piglets and prevention of hypothermia.

Mortality was lowest during spring. A more comprehensive data set is needed to confirm whether this was merely due to a random yearly fluctuation during the current study period or whether it reflects a seasonal pattern in outdoor

liveborn mortality. The year variation seen could be due to the seasonal reproduction pattern in sows. Macchi *et al.* (2010) found a seasonality in sow birth patterns with a peak in the spring related to the seasonality in the timing of oestrus hormones. Bassett *et al.* (2001) showed seasonal changes in plasma luteinizing hormone and prolactin concentrations, suggesting a seasonal reproduction. These seasonal changes may be part of the reason for the reduction in stillbirths during winter and reduction in postnatal deaths during spring. Based on their results, Yun *et al.* (2013) suggested a positive correlation between circulating prolactin and oxytocin. Thus, the seasonal changes in prolactin may correlate with changes in oxytocin concentration affecting parturition. Oxytocin is well known for influencing the course of farrowing, and a low oxytocin level has been related to prolonged farrowings (Lawrence *et al.*, 1992; Oliviero *et al.*, 2008), which may increase the risk of stillborn and weak-born piglets. In addition, in their review, Peltoniemi and Virolainen (2006) propose that the trend towards an increased weaning weight in piglets weaned from January to June (reported after Peltoniemi *et al.* (1997) in Peltoniemi and Virolainen (2006)), and the seasonal changes in prolactin found by Bassett *et al.* (2001) suggest a changed lactational performance of sows across the year. This could be part of why fewer postnatal deaths were seen during spring in the present study.

The current results showed litter size as a risk factor for liveborn mortality, which corresponds with previous findings (Pedersen *et al.*, 2011; Panzardi *et al.*, 2013).

#### **Conclusion**

An increased risk of stillbirths was seen at high hut temperature during the warm part of the year. The lowest risk of stillbirths was seen in winter and the lowest rate of liveborn mortality in spring. This could be due to seasonality in hormones affecting parturition and lactation. In addition, the present results indicate that, in insulated farrowing huts and under careful management practices, sows are able to maintain a sufficient microclimate in the farrowing nest preventing hypothermia among piglets when hut temperature is low. Humidity did not appear to prevent evaporative cooling during summer or increase hypothermia in winter. Thus, humidity may not be relevant when considering piglet mortality in outdoor systems in a temperate climate.

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### Declaration of interest

The authors have no conflicts of interest.

### Ethics statement

Animal housing and handling complied with Danish legislation and the study conformed to the Guidelines for Ethical Treatment of Animals in Applied Animal Behaviour and Welfare Research by the ethics board of the International Society of Applied Ethology (Olsson *et al.*, 2017).

### Software and data repository resources

None of the data and models are deposited in an official repository.

### Supplementary material

To view supplementary material for this article, please visit <https://doi.org/10.1017/S175173111800201X>

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## **PAPER II**

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The course of parturition and consequences for piglet survival in outdoor production

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Applied Animal Behaviour Science, Submitted August 2018

# The course of parturition and consequences for piglet survival in outdoor production

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## Abstract

High piglet mortality remains a major challenge in organic pig production. The use of hyper prolific genotypes giving birth to large litters may prolong parturition and cause parturition-related problems under outdoor conditions where birth assistance cannot easily be provided. The aims of the current study were therefore to investigate the effects of the course of parturition (duration and hourly number of posture changes during parturition) on stillbirth and early postnatal mortality and further to investigate whether the course of parturition was affected by hut type and sow genotype. Lastly, the behaviour of the sows was studied for the first 3 hours after birth of first piglet. Sows gave birth in four batches of 10 to 11 Danbred Landrace × Yorkshire crossbred sows (in first and then second parity) and 10 to 12 Topigs Norsvin TN70 sows (in first and then second parity). Within batch, six sows of each line gave birth in a communal hut, and the remaining sows in each batch in standard A-frame huts. Irrespective of genotype and hut type, a longer parturition increased the risk of having at least one stillborn piglet in the litter ( $P=0.003$ ) and the risk of postnatal mortality ( $P=0.051$ ). A 60-minute increase in parturition duration increased the risk of litters with stillborn piglets by 29% and postnatal deaths by 5%. This indicates that birth assistance may be needed also under outdoor conditions in order to reduce neonatal mortality. The hourly number of posture changes during parturition did, however, not influence postnatal mortality, and was not influenced by the duration of parturition. Sows spent the majority of time lying in lateral position during the first 3 hours of parturition (median 120.0 min, range 0-180 min) although they changed posture 23 times (median, range 0-110) during these three hours. The behaviour (time spent in lateral and sternal position, standing and number of posture changes) of the sows during the first 3 hours of parturition, among others, depended on genotype and parity.

## Highlights

- Duration of parturition affected stillbirth and postnatal mortality
- Genotype and parity affected behaviour during parturition but not parturition duration
- Number of posture changes during parturition did not affect postnatal mortality

*Keywords: outdoor pig production, piglet mortality, genotype, behaviour during parturition*

## 1 Introduction

Across Europe, organic pig production is growing (Früh et al., 2014). Despite the growth within this production system, a recent Danish study showed that piglet mortality remains a challenge (Rangstrup-Christensen et al., 2018). In for example Denmark, France, Sweden and Germany, the genetics used in the organic production are the same hyper prolific genotypes as those used in conventional pig production (Früh et al., 2014). Therefore, prolonged parturitions occurring in indoor systems due to birth of large litters likely exist outdoors as well. In countries such as Denmark and the UK, free-range and organic parturient and lactating sows are housed on pasture and give birth in huts. Only limited knowledge concerns what happens inside the hut during parturition. Some of the few studies done, monitoring sows giving birth in outdoor systems, showed that traits such as prolonged parturitions (Baxter et al., 2009; Thorsen et al., 2017) and longer inter birth intervals between piglets (Baxter et al., 2009) were related to an increased risk of stillbirth. These traits are also known risk factors for piglet mortality in conventional indoor production (Borges et al., 2005; Canario et al., 2006; Mainau et al., 2010). Furthermore, a recent study found that 82% of the stillborn piglets in nine organic pig-producing herds died during parturition (Rangstrup-Christensen et al., 2018), suggesting prolonged parturitions as a main cause of stillbirths.

Long parturitions may also affect postnatal mortality as they increase the risk of piglets experiencing hypoxia during birth, a condition related to reduced postnatal viability (Herpin et al., 1996). Additionally, parturition causes pain in sows (reviewed by Mainau and Manteca (2011); Rutherford et al. (2013); Ison et al. (2016b)), and, as reviewed by Ison et al. (2016a), pain may result in behavioural changes such as more frequent posture changes, which constitutes a risk factor for piglet crushing (Damm et al., 2005).

The first aim of the current study was to investigate how the course of parturition (parturition duration and hourly number of posture changes during parturition) affected

stillbirth and early postnatal mortality in piglets from sows housed outdoors. Additionally, the course of parturition was studied in two genotypes (Danbred and Topigs Norsvin), both bred for indoor production conditions but with different breeding goals for maternal traits. The effect of two hut types on the course of parturition was also investigated. The two hut types represented a traditional A-frame hut for housing a single sow and a communal hut with improved opportunities for supervision, housing four sows individually but under the same roof. Finally, sow behaviour was studied as parturition progressed.

It was hypothesised that for both genotypes and hut types, a prolonged parturition would result in more litters with stillborn piglets and a higher postnatal mortality. Additionally, a higher number of posture changes were expected to increase postnatal mortality.

## **2 Materials and methods**

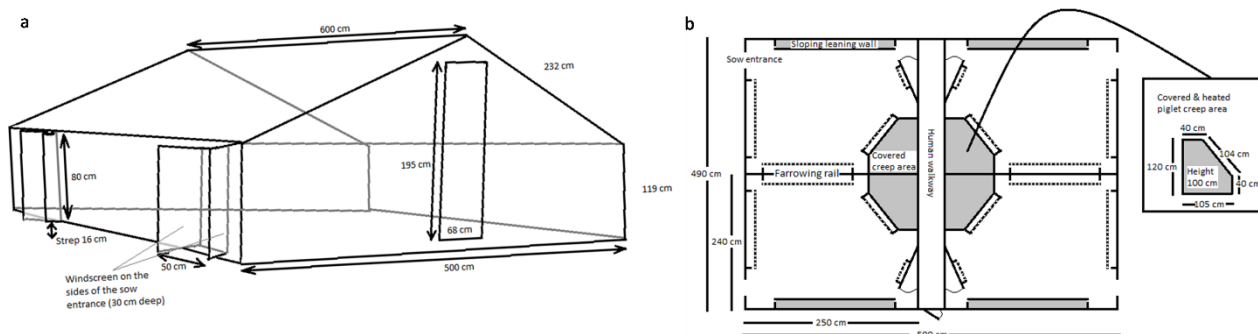
### **2.1 Animals and housing**

The study was conducted at the experimental herd at the Department of Animal Science, Aarhus University from November 2016 to August 2017. In total, the study comprised 87 parturitions from 48 sows followed during their first and second parity. The parturitions took place in four batches of 10 to 11 Danbred Landrace Yorkshire crossbred sows and 10 to 12 Topigs Norsvin TN70 sows. Batches 1 and 2 represented sows during first parity, while batches 3 and 4 represented second parity. The sows were housed outdoors in paddocks throughout the entire project period, and no birth assistance was provided.

Sows were moved to the farrowing field 10 days prior to expected parturition of the first sow per batch where they were kept in individual paddocks (18 × 25 m) with access to a hut, and, in the warm season (batches 3 and 4), sows had access to a wallow.

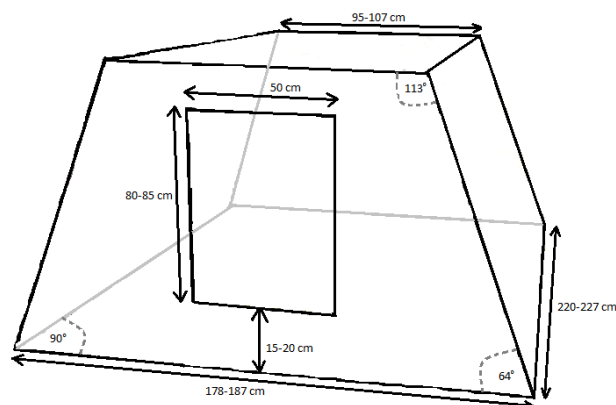
Twelve sows per batch (six of each genotype) had access to a communal hut (Center of Development for Outdoor Livestock Production, Marsvej 43, DK-8960 Randers, Denmark; Figure 1). Each communal hut had four pens for individually housed sows, and each of the four compartments housing one sow measured L:240 cm, W:250 cm. The remaining sows in the batch were housed in standard A-frame huts with room for only one sow (L:230 cm, W<sub>bottom</sub>:190 cm, W<sub>top</sub>:110 cm, H:110 cm). In the sow entrance to each A-frame hut (Figure 2), a board, and in the entrance to the communal hut a roller, prevented piglets from leaving the hut during the first 10 days after birth. Additionally, plastic curtains were placed in the sow entrance of both hut types during autumn and winter (batches 1 and 2).





**Figure 1.** Sketch of the communal hut (Center of Development for Outdoor Livestock Production, Marsvej 43, DK-8960 Randers, Denmark). a) seen from the outside and b) seen from the inside. Each hut had room for four individually housed sows. From the human walkway in the centre of the hut, a view of each sow compartment was available, and gates allowed access to each compartment from the walkway. Dotted lines show where farrowing rails were located. Each piglet creep area was heated with an eHEAT PLUS Heater version 1.0 (Orbital A/S, Trykkerivej 5, 6900 Skjern, Denmark). There was no flooring in the farrowing hut or in the covered piglet creep area.

All huts were supplied with barley straw prior to sow relocation to the farrowing field. In summer, approximately 7.6 kg of straw per square metre was provided, in autumn and spring approximately 10 kg/m<sup>2</sup> and in winter 12.6 kg/m<sup>2</sup>. Between parturition batches, huts were relocated to new paddocks that had been without sows for at about 5 months.



**Figure 2** A sketch of the A-frame hut that housed one sow per hut (after Schild et al., 2018).

Sows were fed once daily in the morning, and, as part of another study not reported further here, the sows were fed different protein levels (normal or low) balanced within genotype and hut type. Pregnant sows on normal protein diet were fed a dry feed for gestating sows (diet gestating: 7315kJ/kg, raw protein 11.1%; Green So Drægtig, Vestjyllands Andel A.m.b.a., Ringkjøbing, Denmark) and those on low protein diet, a diluted dry feed (diluted gestating 7338kJ/kg, raw protein 10.2%; Vestjyllands Andel A.m.b.a., Ringkjøbing, Denmark). From the sows entered the farrowing field, they were fed a dry feed for lactating sows (sows on normal protein: 7623kJ/kg, raw protein 14.4%; sows on low protein: 7554kJ/kg, raw protein 12.5%; Vestjyllands Andel A.m.b.a., Ringkjøbing, Denmark). During

spring and summer (batches 3 and 4), the clover grass cover on the paddocks constituted *ad libitum* roughage, whereas in autumn and winter (batches 1 and 2), when the grass cover was sparse, sows were provided *ad libitum* clover grass silage. Sows had *ad libitum* access to water from a large trough.

## 2.2 Data collection

### 2.2.1 Video recordings

All parturitions were monitored by use of video cameras (IPC-HDBW4100EP-0360B, Dahua Technology Co., Queen Anne House, 25-27 Broadway, UK) with a fitted wide-angle lens. Video recordings were saved digitally and analysed by use of S-VIDIA Client MegaPixel (M. Shafro & Co., Riga, Latvia). Recordings were made from birth of first until birth of last piglet in the litter (defined as the parturition duration), irrespective of whether the pigs were stillborn or liveborn. Additionally, the time of birth of each piglet and sow posture were recorded (ethogram described in Table 1).

**Table 1** List of sow postures recorded during farrowing (after Thorsen et al. (2017)). To be scored in a posture, a sow had to rest in the given posture for more than 2 seconds.

Posture	Definition
Standing/walking	Maintaining an upright position on extended legs
Sitting	Body weight supported by hind quarters and both front legs stretched and front hoofs in the ground
Lateral position	Lying on one side with the udder exposed and with one shoulder touching the ground, her head raised or resting
Sternal position	Lying on the belly with the udder hidden, or partly hidden, and without a shoulder touching the ground, her head raised or resting
Outside	The sow is not in the hut

### 2.3.2 Piglet recordings

The day after parturition (24 to 36 hours after birth of first piglet), all piglets were counted, inspected, weighed and ear tagged for individual recognition. Piglets weighing less than 700 g were considered non-viable and euthanised by blunt force trauma. At 3 days of age, piglets were once again weighed and inspected. Furthermore, male piglets received 0.04 to 0.05 mL Flunixin 50 mg and were castrated. Cross-fostering was done within genotype once within 3 days of parturition when sows gave birth to a surplus of piglets (more piglets than available

teats). Piglets were always added to an evenly aged or younger litter. In cases where cross-fostering was not possible (no sows with spare teats), the smallest of the surplus piglets were euthanised.

Humane endpoints for both sows and piglets during the study were defined as follows: unable to stand on own accord, severe injury (broken bone, deep wound). An additional humane endpoint for piglets was emaciated (conspicuous ribs, backbone and hip bones).

### 2.3.3 Necropsies

Dead piglets from each litter were collected from parturition until day 4 *postpartum* (**pp**). The date of collection and the sow from which they were taken were recorded. In addition, it was recorded whether piglets were euthanised or died of their own accord. The collected piglets were kept frozen and subsequently thawed at room temperature prior to necropsy. At necropsy, the ultimate cause of death of each piglet was recorded. The cause of death was divided into five categories: stillborn, crushed, euthanised, other and unknown. Stillborn piglets were identified by testing whether lung tissue sank when suspended in water. In addition, stillborn piglets were examined to determine whether time of death occurred before the onset of parturition or during parturition. Stillborn piglets with general autolysis of internal organs (rendering all organs a homogeneous brick-red colour) were classified as having died prior to onset of parturition. Stillborn piglets presenting internal organs with distinctively different colours (a brown/reddish liver, white and pale stomach and small intestines, and greenish large intestines) with no sign of autolysis were classified as having died during parturition. Crushed piglets were identified by subcutaneous oedema, internal and/or external lacerations and/or fractures. At necropsy, euthanised piglets were identified by the cause of death noted during collection. Piglets for which the cause of death could not be determined were categorised as unknown. Piglets diagnosed with a cause of death other than stillborn, crushed or euthanised were grouped together as “other”. This category included piglets dying from infection, starvation and malformation.

## 2.4 Statistical analysis

For the statistical analyses, SAS (SAS 9.3, SAS Institute Inc., Cary, NC, USA) was used.

### 2.4.1 Piglet mortality

Parturition duration was calculated as the time interval between birth of first and last piglet in the litter. The inter birth interval between birth of piglets was calculated as the mean

duration between the birth of two consecutive piglets, and afterwards the standard deviation of the mean inter birth interval was calculated.

Of the 87 parturitions, 55 were without stillbirths, 20 with one stillborn in the litter and 9 with two, while 3 had more than two stillborn piglets. The variable “stillbirth” was converted to a binomial variable given a value of 0 to litters with no stillborn and the value of 1 to litters with one or more stillborn piglets (model 1). For the analysis of postnatal mortality (model 2), no euthanised piglets were included; only piglets dying of their own accord were considered. Cross-fostered piglets (N=10) that died (N=1) were counted as dead by their genetic mother – not the foster mother.

The frequency of posture changes per hour was calculated as the number of posture changes (including rolling between sternal and lateral position) divided by parturition duration.

The continuous variables (parturition duration, inter birth interval, standard deviation of the inter birth interval, and litter size) were tested for correlation, and as parturition duration, inter birth interval and standard deviation of the inter birth interval correlated significantly with each other, only parturition duration and litter size were included in the analyses.

One parturition was an outlier in the dataset and lasted 35 hours, a sensitivity analysis was conducted by removing this parturition. This did not change any results, thus the parturition was included in the analyses.

#### 2.4.1.1 Stillborn piglets

The odds of having litters with at least one stillborn piglet were analysed by use of the following binomial generalised linear model.

$$\text{logit}(\pi_i) = \beta_0 + \beta_1 PD \quad (\text{model 1})$$

$\beta_0$  refers to the intercept, and  $\beta_1$  is the parameter describing the effect of parturition duration (PD). The initial model also included, birth litter size (L), parity (P), hut type (HT), genotype (G), protein level in the diet and their possible two-way interactions (including with PD), but these effects were all removed by elimination of statistically non-significant ( $P > 0.05$ ) effects.

#### 2.4.1.2 Early mortality of liveborn piglets

The proportion of piglets dying until day 4 *pp* (postnatal deaths / (live) litter size on day 1 *pp* (after euthanasia of non-viable piglets)) was analysed by a binomial generalised linear mixed model with sow number as random effect.

$$\text{logit}(\pi_{ij}) = \beta_0 + \beta_1 PD + \beta_2 L + \beta_3 P \quad (\text{model 2})$$

$\beta_0$  refers to the intercept for parity 2.  $\beta_1$  is the parameter describing the effect of parturition duration (PD), and  $\beta_2$  is the parameter describing the effect of birth litter size (L).  $\beta_3$  describes the effect of parity 1 (P) in relation to the reference (parity 2). Parity was included as an indicator function, implying P is 1 (if parity in 1) or 0 (if parity in 2). The initial model also included hut type (HT), genotype (G), protein level in the diet and hourly number of posture changes and the two-way interactions P\*PD, PD\*L, P\*L, PD\*G, L\*G.

Results of the analyses are presented as odds ratio (**OR**) with 95% confidence intervals (**CI**).

#### 2.4.2 The duration of parturition

Parturition duration was square root transformed to achieve normally distributed residuals. The following final linear mixed model was used,

$$Y_{ijk} = L_{ijk} + \delta_{ijk} + \varepsilon_{ijk} \quad (\text{model 3})$$

L is the parameter describing the effect of litter size at birth (i in Danbred, Topigs Norsvin, j in parity 1 and 2, and k refers to sow identity).  $\delta$  and  $\varepsilon$  are normal distributed.  $\delta$  is the effect of (index i, j, k) of sow identity, and  $\varepsilon$  is the residual error term. The initial model also included the variables parity (P), hut type (HT), genotype (G), protein level and the two-way interactions P\*G, G\*HT, G\*L, but these were removed by elimination of statistically non-significant effects ( $P > 0.05$ ). Results of the analysis are presented as LS means  $\pm$  Standard error.

#### 2.4.3 Behaviour during parturition

##### 2.4.3.1 Behaviour during the first 3 hours of parturition

For the description of sow behaviour during the first 3 hours of parturition, the categorical variable hour of parturition was created where 1 referred to the first hour after birth of first piglet, 2 referred to the second hour after birth of first piglet, and 3, to the third hour after birth of first piglet. The variable total parturition duration was also created and referred to the total duration of parturition in whole hours. The last commenced hour of each parturition was removed from the data set, as this was never a complete hour, and so total parturition duration was a variable from 1 to 11 (excluding one parturition that lasted 35 hours). In model 4 to 7 compound symmetry was used to account for correlation between repeated observations within parturition.

Below, the final models, after elimination of statistically non-significant effects ( $P > 0.05$ ), are shown.

As most sows spent the majority of the parturition lying in lateral position, data were left skewed and had a large proportion at or near the right limit of 3600 seconds per hour. The response was therefore converted to the duration per hour, in minutes, not spent lying in lateral position calculated as  $3600 - \text{time spent lying in lateral position} / 60$ . This response was analysed by the following final negative binomial generalised linear model

$$\log(\mu) = \beta_0 + \beta_1 HP_1 + \beta_2 HP_2 + \beta_3 G + \beta_4 P + \beta_5 G * P \quad (\text{model 4})$$

$\beta_0$  is the intercept referring to the reference combination of parturition hour 3, Topigs Norsvin genotype and parity 2. The effect of hour of parturition (HP) was modelled by two indicator functions  $HP_1$  and  $HP_2$  being one for parturition hour 1 and 2, respectively, and zero for hour 3. The corresponding two coefficients are  $\beta_1$  and  $\beta_2$ . The parameters  $\beta_3$ ,  $\beta_4$  and  $\beta_5$  describe the effects of genotype (G), parity (P) and their interaction ( $G * P$ ), where G and P are indicator functions being 1 for Danbred and parity 1, respectively, and 0 otherwise. The initial model also included the variables hut type (HT), total parturition duration (PD), protein level in the diet and the two-way interactions  $HP * G$ ,  $HP * P$ , and  $HT * P$ .

The time spent lying in sternal position was analysed by the following final zero-inflated negative binomial generalised linear model. The zero-inflation part of the model included hour of parturition, genotype, parity and hut type.

$$\log(\mu) = \beta_0 + \beta_1 HP_1 + \beta_2 HP_2 + \beta_3 G + \beta_4 P \quad (\text{model 5})$$

$\beta_0$  refers to the intercept for the combination of parturition hour 3, genotype in Topigs Norsvin and parity 2. Hour of parturition (HP) was again modelled by the two indicator functions  $HP_1$  and  $HP_2$  being 1 for parturition hour 1 and 2, respectively, and 0 elsewhere. The corresponding two coefficients are  $\beta_1$  and  $\beta_2$ . The parameters  $\beta_3$  and  $\beta_4$  describe the effects of genotype (G) and parity (P), where G and P are indicator functions being 1 for Danbred and parity 1, respectively, and 0 otherwise. The initial model also included the variables hut type (HT), total parturition duration (PD), protein level in the diet and the two-way interactions  $HP * G$ ,  $HP * P$ ,  $G * P$  and  $HT * P$ .

The time sows spent standing during parturition was analysed by the following zero-inflated negative binomial generalised linear model. The zero-inflation part of the model included hour of parturition, genotype, parity and hut type.

$$\log(\mu) = \beta_0 + \beta_1HP_1 + \beta_2HP_2 + \beta_3G + \beta_4P + \beta_5HT + \beta_6G * P \quad (\text{model 6})$$

$\beta_0$  refers to the intercept for hour of parturition in 3, genotype in Topigs Norsvin, parity in 2 and hut type in communal hut.  $\beta_1$  and  $\beta_2$  are the parameters describing the effect of hour of parturition (HP) in 1 and 2, respectively, in relation to the reference (HP in 3).  $HP_1$  and  $HP_2$  were again modelled as indicator functions. The parameters  $\beta_3$ ,  $\beta_4$ ,  $\beta_5$  and  $\beta_6$  describe the effects of genotype (G), parity (P), hut type (HT) and the G\*P interaction. G, P and HT are indicator functions being 1 for Danbred, parity 1 and A-frame hut, respectively, and 0 otherwise. The initial model also included the variable total parturition duration (PD), protein level in the diet and the two-way interactions HP\*G, HP\*P, and HT\*P.

For the analysis of the number of posture changes during parturition, the following final negative binomial generalised linear model was used.

$$\log(\mu) = \beta_0 + \beta_1HP_1 + \beta_2HP_2 + \beta_3G + \beta_4P \quad (\text{model 7})$$

$\beta_0$  is the intercept referring to the reference combination of parturition hour 3, Topigs Norsvin genotype and parity 2. The effect of the three levelled categorical variable hour of parturition (HP) was again modelled by the two indicator functions  $HP_1$  and  $HP_2$ , and the corresponding two coefficients were  $\beta_1$  and  $\beta_2$ . The parameters  $\beta_3$  and  $\beta_4$  describe the effects of genotype (G) and parity (P) where G and P are indicator functions being 1 for Danbred and parity 1, and 0 otherwise. The initial model also included the variables hut type (HT), total parturition duration (PD), protein level in the diet and the two-way interactions HP\*G, HP\*P, G\*P and HT\*P.

Results of the analyses are presented as rate ratio with 95% CI.

### 3 Results

#### 3.1 Piglet mortality

Forty-six sows gave birth in first parity (22 Danbred and 24 Topigs Norsvin) and 41 of these again in their second parity (20 Danbred and 21 Topigs Norsvin). The median total litter size was 17.0 (range 6-27) piglets; 16 (range 6-23) for first-parity sows and 19 (range 8-27) for second-parity sows, and 19 (median, range 7-27) for Danbred and 16 (range 6-21) for Topigs Norsvin.

### 3.1.1 Stillborn piglets

Thirty-two litters included stillborn piglets, and 55 did not. On average,  $0.6 \pm 0.1$  (raw mean  $\pm$  standard error, range 0-7) piglets per litter were stillborn. In total, 356 piglets were necropsied, and the necropsies showed that approximately 71% of the stillborn piglets died during parturition.

The odds of litters with stillborn piglets significantly increased with increasing duration of parturition ( $X^2$  (2df)=8.7,  $P=0.003$ , Table 2). A 60-minute increase in parturition increased the risk of litters with stillbirths by 29%, corresponding to an odds ratio (**OR**) of 1.29 (95% CI[1.05;1.57]).

Neither litter size, parity, hut type, genotype, protein level in the diet, nor the two-way interactions significantly influenced the risk of stillbirth within litters. The mean number of stillborn piglets per litter was  $0.43 \pm 0.1$  (raw mean  $\pm$  standard error, range 0-4) for first-parity sows and  $0.78 \pm 0.2$  (range 0-7) for second-parity sows,  $0.76 \pm 0.2$  (range 0-7) for Danbred and  $0.44 \pm 0.1$  (range 0-2) for Topigs Norsvin sows, and  $0.48 \pm 0.1$  (range 0-2) in communal huts and  $0.74 \pm 0.2$  (range 0-7) in A-frame huts.

**Table 2** Summary of the output from the final models of piglet mortality and the duration of parturition. First output is from the final model 1 (stillbirth). Second output is from the final model 2 (postnatal mortality). Third output is from the final model 3 (parturition duration). F and p values are presented for the overall effect of each variable. OR refers to odds ratio and 95% CI to the 95% confidence interval.

Model	Variable	Levels	No. of observations	OR	95% CI	$X^2$	p
1	Parturition duration	Continuous	86	1.29	1.05;1.57	(1df)=8.7	0.003
Model	Variable	Levels	No. of observations	OR	95% CI	F	p
2	Parturition duration	Continuous	86	1.05	1.00;1.11	$F_{1,35}=4.1$	0.051
	Litter size	Continuous	86	1.07	1.01;1.14	$F_{1,35}=5.2$	0.028
	Parity	1	45	2.15	1.44;3.21	$F_{1,35}=15.1$	<0.001
		2	41	1			
3	Litter size	Continuous	86			$F_{1,37}=3.9$	0.055

### 3.1.2 Early mortality of liveborn piglets

Within 4 days *pp*,  $2.4 \pm 0.2$  (raw mean  $\pm$  standard error, range 0-8) liveborn piglets died (154 crushed, 14 other causes and 24 unknown) (not including euthanised piglets (N=112)).

The odds of early mortality increased slightly with increasing duration of parturition (OR 1.05 95% CI[1.00-1.11],  $F_{1,35}=4.1$ ,  $P=0.051$ , Table 2). Both litter size ( $F_{1,35}=5.2$ ,  $P=0.028$ ) and



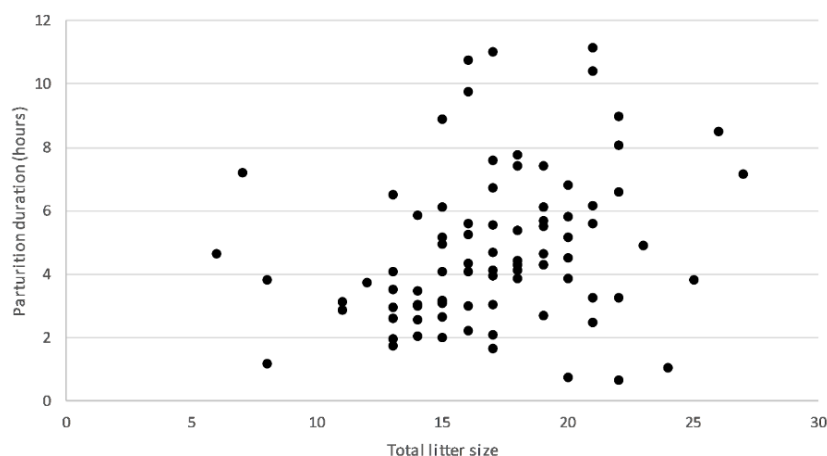
parity ( $F_{1,35}=15.1$   $P<0.001$ ) affected the risk of postnatal deaths. First-parity sows had 115% higher odds of postnatal mortality compared to sows in their second parity (CI [1.44;3.21]). Within the two parities, the mean number of postnatal deaths was  $2.5\pm 0.3$  (raw mean $\pm$ standarderror, range 0-8) in first parity and  $2.2\pm 0.3$  (range 0-7) for second-parity sows. The odds of liveborn piglets dying increased with 7% for every extra piglet in the litter, corresponding to an OR of 1.07 (CI[1.01-1.14]). Hut type, genotype, hourly number of posture changes and protein level in the diet did not influence the risk of liveborn piglets dying within 4 days *pp*, taking into account that non-viable and surplus piglets had been euthanised. The mean number of postnatal deaths was  $2.6\pm 0.3$  (range 0-8) in the communal huts and  $2.1\pm 0.3$  (range 0-7) in A-frame huts, and  $2.1\pm 0.3$  (range 0-8) for Topigs Norsvin sows and  $2.6\pm 0.3$  (range 0-8) for Danbred sows.

### 3.2 The duration of parturition

The median parturition duration was 4.3 h and ranged from 66 minutes to 35 hours.

The parturition duration increased slightly with increasing litter size ( $F_{1,37}=3.9$ ,  $P=0.055$ , Table 2) but was not significantly affected by genotype, hut type, parity or protein level in the diet. Figure 3 shows a scatter plot of the parturition duration against the litter size (totalborn).

The median duration of parturition for Danbred was 3.2 h (range 0.8-11) and 4.2 h (range 2.0-10.8) for Topigs Norsvin in first parity, and 6.4 hours (range 0.7-35) and 4.7 hours (range 2.0-8.9) for the two lines in second parity, respectively.



**Figure 3** The parturition duration plotted against the total litter size at birth (including stillborn).

### 3.3 Behaviour during parturition

#### 3.3.1 Behaviour during the first 3 hours of parturition

Seventy-six of the 83 sows had a parturition duration lasting at least 3 hours. During the first 3 hours of parturition, these sows spent two-thirds of the time lying in lateral position (median 120 minutes, range 0-180). The rate ratio sows spent lying in lateral position depended on hour of parturition ( $X^2$  (2df)=26.7,  $P<0.001$ , Table 3), and sows lay more in this posture the further the parturition progressed. Sows spent 37.4 minutes (median, range 0-60) lying in lateral position in the first hour of parturition, 53.5 minutes (range 0-60) in the second hour and 56.7 minutes (range 0-60) in the third hour of parturition. Lateral position also depended on an interaction between parity and genotype ( $X^2$  (1df)=5.7,  $P=0.017$ ). The time spent in lateral position for each genotype within each parity and hour after birth of first piglet is shown in Table 4.

Sows spent only a median of 10.1 minutes (range 0-99) of the first 3 hours of parturition in sternal position. The rate ratio of sternal position depended on hour of parturition ( $X^2$  (2df)=7.0,  $P=0.030$ ), parity ( $X^2$  (1df)=7.4,  $P=0.007$ ) and genotype ( $X^2$  (1df)=29.9,  $P<0.001$ ) (Table 3). The zero-inflation model showed that the zero-inflation depended on hour of parturition ( $X^2$  (2df)=11.3,  $P=0.004$ ), parity ( $X^2$  (1df)=4.6,  $P=0.032$ ) and genotype ( $X^2$  (1df)=31.8,  $P<0.001$ ).

The rate ratio of standing during parturition depended on the hour of parturition ( $X^2$  (2df)=15.7,  $P<0.001$ ), hut type ( $X^2$  (1df)=7.6,  $P=0.006$ ) and an interaction between parity and genotype ( $X^2$  (1df)=5.9,  $P=0.015$ , Table 3). Sows stood more in the first hour of parturition (7.9 minutes, range 0-43) compared to the second (0 minutes, range 0-60) and third hour (0 minutes, 0-21), and during all 3 hours sows stood more in the communal huts (2.2 minutes, range 0-60) compared to the A-frame (0 minutes, range 0-26) huts. Time not spent lying (in lateral or sternal position) or standing, sows spent either sitting or outside the hut.

During the first 3 hours of parturition, sows changed posture 23 times (median, range 0-110). The rate of posture changes during these hours depended on hour of parturition ( $X^2$  (2df)=30.6,  $P<0.001$ ), parity ( $X^2$  (1df)=5.9,  $P=0.015$ ) and genotype ( $X^2$  (1df)=21.5,  $P<0.001$ ) (Table 3). The rate was higher in hour 1 compared to hours 2 and 3, higher for first parity sows compared to second parity sows (irrespective of hour and genotype), and higher for Topigs Norsvin compared to Danbred sows (irrespective of parity and hour). The hourly number of posture changes for each parity with respect to genotype is provided in Table 4.

**Table 3** Summary of the output from the final models of behaviour during the first 3 hours of parturition. First output is from the final model 4 (not lateral position). Second output is from the final model 5 (sternal position). Third output is from the final model 6 (standing). Fourth output is from the final model 7 (posture changes). Rate ratio (RR) for each variable (and level) with corresponding 95% confidence intervals (CI),  $X^2$  and  $p$  values are presented for the overall effect of each variable.

Model	Variable	Levels	No. of observations	RR	95% CI	$X^2$	$p$
	Hour of parturition	1	83	2.55	1.8; 3.6	(2df)=26.7	<0.001
		2	78	1.43	1.0; 2.0		
		3	67	1			
	4	Parity*Genotype <sup>1</sup>	DB 1 v. 2		0.53	0.3; 1.1	(1df)=5.7
		TN 1 v. 2		1.75	1.1; 2.9		
		1 DB v. TN		0.28	0.2; 0.5		
		2 DB v. TN		0.91	0.4; 1.9		
5	Hour of parturition	1	83	1.82	1.9; 2.8	(2df)=7.0	0.030
		2	78	1.42	0.9; 2.2		
		3	67	1			
	Parity	1	120	1.63	1.2; 2.3	(1df)=7.4	0.007
2		108	1				
Genotype	Danbred	101	0.32	0.2;0.5	(1df)=29.9	<0.001	
	Topigs	127	1				
	Norsvin						
6	Hour of parturition	1	83	2.02	1.4;3.0	(2df)=15.7	<0.001
		2	78	1.14	0.7; 1.8		
		3	67	1			
	Hut type	A-frame	99	0.63	0.5; 0.9	(1df)=7.6	0.006
Communal		129	1				
Parity*Genotype <sup>1</sup>	DB 1 v. 2		0.78	0.5; 1.3	(1df)=5.9	0.015	
	TN 1 v. 2		1.71	1.2; 2.5			
	1 DB v. TN		0.82	0.6; 1.2			
	2 DB v. TN		1.80	1.1; 3.0			
7	Hour of parturition	1	83	2.19	1.7; 2.9	(2df)=30.6	<0.001
		2	78	1.25	0.9; 1.7		
		3	67	1			
	Parity	1	120	1.53	1.1; 2.1	(1df)=5.9	0.015
2		108	1				
Genotype	Danbred	101	0.42	0.3;0.6	(1df)=21.5	<0.001	
	Topigs	127	1				
	Norsvin						

<sup>1</sup> DB refers to Danbred, TN to Topigs Norsvin, and 1 and 2 to first and second parity, respectively.

**Table 4** The duration of lateral position and number of posture changes for sows belonging to each genotype (Danbred, Topigs Norsvin) within each of the two parities for each of the first 3 hours of parturition (HP). Values are presented as raw medians with range (in brackets).

	HP	Danbred		Topigs Norsvin	
		1 <sup>st</sup> parity	2 <sup>nd</sup> parity	1 <sup>st</sup> parity	2 <sup>nd</sup> parity
Lateral position (minutes)	1	49.8 (12-60)	47.5 (0-60)	24.8 (1-58)	41.6 (0-57)
	2	58.1 (31-60)	25.1 (0-60)	38.4 (0-60)	53.0 (0-60)
	3	54.8 (29-60)	57.7 (0-60)	47.8 (6-60)	58.3 (0-60)
Posture changes (number)	1	8.0 (0-26)	5.0 (0-20)	18.5 (3-59)	14.0 (1-28)
	2	1.0 (0-21)	0.0 (0-10)	12.0 (0-32)	5.5 (0-22)
	3	0.0 (0-14)	0.5 (0-17)	9.0 (0-27)	2.0 (0-21)

### 3.2.2 Behaviour during the last 2 hours of parturition

Twenty-two sows had a parturition lasting more than 4 hours. Of and of these sows 13 were Danbred, and 9 were Topigs Norsvin. Descriptive results of sow behaviour during the last 2 hours of parturition for the 22 sows are presented here as medians with range.

In the last 2 hours of parturition, the sows spent 86% of the time lying in lateral position (median 115.0 minutes, range 0-120). Danbred sows lay in lateral position for 120.0 minutes (range 117-120) in first parity and 114.9 minutes (range 0-120) in second parity, and Topigs Norsvin 112.0 minutes (range 102-120) and 102.4 minutes (range 67-120) in first and second parity, respectively.

Altogether, the sows spent a median of 0 minutes (range 0-47) lying in sternal position and stood for 0 minutes (median, range 0-10.6) during the last 2 hours of parturition. During these hours, sows changed posture 1.5 times (median, range 0-34). Danbred sows changed posture 0 (median, range 0-4) and 1.5 (median, range 0-6) times in first and second parity, respectively, and Topigs Norsvin sows 1.0 (range 0-6) and 13.5 (range 0-34) posture changes, respectively, for first and second parity.

## **4 Discussion**

### **4.1 Piglet mortality**

#### **4.1.1 Stillborn piglets**

The results showed higher odds of litters with stillborn piglets when parturition duration increased, which is in accordance with previous findings for both indoor (Pedersen et al., 2011; Panzardi et al., 2013) and outdoor-housed (Baxter et al., 2009; Thorsen et al., 2017) parturient sows. A prolonged parturition will increase the risk of piglets experiencing, or even dying from, hypoxia during birth, and studies have shown that 78-88% of stillborn piglets die during, and not before, parturition when identified by necropsy (mixed parity including first-parity sows: Edwards et al. (1994), sow parity 3.6-3.7: Marchant et al. (2000), 71% multiparous sows: Rangstrup-Christensen et al. (2018)). The 78-88% dying during parturition is a little higher than the present results (71%); the difference may be explained by the young sows used in the current study.

Studies have also shown increased risk of stillbirth with increasing litter size (median liveborn: 11 KilBride et al. (2012), average totalborn: 15.4 Rangstrup-Christensen et al. (2016), average totalborn 17.6: Schild et al. (2018)). Thus, it is surprising that this variable did not affect the odds of having litters with stillborn piglets in the current study. This could be due to a correlation between parturition duration, litter size and parity. Previously, a larger litter size has been related to a longer parturition (Baxter et al., 2009) and higher parity sows give birth to larger litters (Koketsu et al., 1999; Quesnel et al., 2008; Hales et al., 2014). Consequently, some of the variation caused by litter size and parity may be explained by parturition duration in the current study, which could also explain the lacking effect of parity in the present study. In accordance, the present results showed a relation between the duration of parturition and litter size with longer parturitions for larger litters.

#### **4.1.2 Postnatal mortality**

Postnatal mortality increased with increasing parturition duration, litter size and parity. Hypoxia during birth results in the birth of less viable piglets (Herpin et al., 1996), and thus prolonged parturitions, were expected to increase postnatal mortality. This is in accordance with the present findings, although postnatal mortality increased only slightly with parturition duration. Baxter et al. (2009) did not find an effect of parturition duration on postnatal mortality when parturient sows gave birth in huts outdoors. The cumulative parturition duration (2 hours (surviving) and 3.8 hours (stillborn)) and the litter sizes (13.95 (surviving) and 14.96 (stillborn)) recorded in Baxter et al. (2009) are both low compared to those found in the current study, which may explain the differences in results between the

studies. In the present study surplus piglets were euthanized starting with the smallest piglets and piglets that appeared weak or were injured. Thus, if parturition duration affects piglet viability, in that piglets are weaker and therefore also easier get injured after birth, then the effect of parturition duration on postnatal mortality may have been underestimated.

The present results showed an increasing postnatal mortality with increasing litter size at birth. Litter size is a well-known risk factor for liveborn mortality, and the result of more postnatal deaths when litter size increased corresponds with previous findings

(birth litter size: Baxter et al. (2009), number of piglets in the litter: KilBride et al. (2012)).

In accordance with KilBride et al. (2012), the current results showed a higher liveborn mortality in litters from first compared to second-parity sows when litter size was accounted for as a covariate in its own. However, in the present study parity was confounded with season, as first-parity sows gave birth during winter, and second-parity sows gave birth during spring/summer. Some studies on outdoor-housed sows have indicated higher postnatal mortality during winter (Berger et al., 1997; Randolph et al., 2005), although this could not be confirmed when sows gave birth in insulated huts (Randolph et al., 2005). Still, it cannot be excluded that, for the current study, time of parturition (winter or spring/summer) may explain some of the parity variation seen in postnatal mortality.

Contrary to the expected, postnatal mortality was unaffected by the rate of posture changes during parturition despite the main cause of mortality being crushing. As reviewed by Damm et al. (2005), sows' lying-down behaviour can constitute a risk factor for piglet crushing, which is one of the main causes for postnatal mortality (indoors for example: Marchant et al. (2000); Pedersen et al. (2006), outdoors for example: Baxter et al. (2009); KilBride et al. (2012); Rangstrup-Christensen et al. (2018)). Particularly during and immediately after parturition, piglets may be in risk of crushing as the vigilance or mobility of the piglets is limited (English and Smith, 1975). One reason for the lacking effect of posture changes on mortality may be that sows during parturition mainly got up to sniff their newborn piglets. Sows are known to raise during parturition to sniff their piglets (Jensen, 1986; Petersen et al., 1990). Thus, when sows raised during parturition, they may have focused on the piglets and therefore paid attention to these also during the lying-down movement. The present results suggest that crushing within the first 4 days *pp* mainly occurs due to lowered piglet viability and/or after parturition is completed. This, however, contrasts with Weary et al. (1996) who found the highest rate of crushing and near-crushing during parturition. The reason for the discrepancy may be caused by differences in housing and/or litter size. In the study by Weary et al. (1996), sows were housed indoors in crates and pens and gave birth to

around 10 totalborn piglets (197 piglet from 20 litters) whereas in the present study sows were housed in huts with access to 450 m<sup>2</sup> of paddock and gave birth to an average of 17.1 piglets.

The maximum parturition duration recorded in the present study was 35.0 hours, while Thorsen et al. (2017) reported a maximum parturition duration of 28.9 hours (for sows housed outdoors in insulated A-frame huts). Both durations clearly show that prolonged parturitions do occur in modern outdoor production and that, in some cases, birth assistance could be beneficial in order to increase piglet survival. In support of this, the negative effects of a prolonged parturition on postnatal piglet survival, and the fact that the majority of stillborn piglets die during parturition (Leenhouders et al., 1999; Marchant et al., 2000; Rangstrup-Christensen et al., 2018), suggest an opportunity to save viable piglets suffering from hypoxia during prolonged parturitions by providing birth assistance. Within the indoor pig production, initiatives are taken in order to assist sows with prolonged parturitions, and studies have shown that total mortality can be lowered with as much as 50% (White et al., 1996; Christison et al., 1997; Andersen et al., 2009) by implementing systematic birth supervision and caretaking of less viable piglets. Furthermore, White et al. (1996) showed that the proportion of stillborn piglets was 15.6% and 32.1% of the total piglet mortality for indoor-housed sows subjected to or not subjected to birth assistance, respectively. It may therefore be possible to improve both human safety and animal welfare in outdoor production by introduction of huts with improved management possibilities. The communal hut used in the current study allowed supervision and access for caretakers to each sow from a sow-protected aisle dividing the pens on each side. These hut features would make it possible to perform both birth supervision and assistance, without jeopardising the safety of stockmen. However, outdoor-housed sows are not as habituated to the presence of humans as sows housed indoors. Therefore, birth supervision and assistance could cause disturbance, increasing the risk of piglet mortality; for example, if sows get up, it will increase the risk of piglet crushing. Thus, whether birth assistance could be beneficial outdoors needs further investigation.

## 4.2 Behaviour during parturition

### 4.2.1 Description of behaviour

In accordance with previous studies, the results showed that sows spent the majority of the parturition process lying in lateral position; although only considering the first 3 and the last 2 hours after birth of first piglet (indoors 50-100% of the first 3 hours depending on farrowing duration (Jarvis et al., 1999), semi-natural conditions, duration not specified

(Jensen, 1986; Petersen et al., 1990)). In the first 3 hours after birth of first piglet, sows in general displayed an increased rate of lateral lying and a decrease in all other observed behaviour (sternal position, standing, changing posture) the further parturition progressed. Accordingly, findings for indoor loose-housed sows (Jarvis et al., 1999; Thodberg et al., 1999) and free-ranging sows (Petersen et al., 1990) show that sows are more active in the initial period after birth of first piglet after which the majority of time is spent lying in lateral position. The number of posture changes was highest in the initial hour of parturition compared to the second and third hour, and the mean hourly number of posture changes was more than ten times higher in the first 3 compared to the last 2 hours after birth of first piglet. Correspondingly, for indoor loose-housed sows, Pedersen et al. (2003) found more posture changes in the first 3 hours of parturition compared to the later hours.

#### 4.2.2 Factors influencing behaviour

During the first 3 hours of parturition, all types of behaviour (lateral position, sternal position, standing and the number of posture changes) were affected by genotype and parity or an interaction between the two. The influence of parity was likely caused by the sows' experience with the birthing process and presence of piglets. First-parity sows may have reacted more strongly to the parturition process and been more responsive to the newborn piglets, and for example got up more to sniff their piglets. First parity sows are known to react more strongly to the presence of their piglets and studies show more savaging in gilts compared to sows (Harris et al., 2003; Chen et al., 2008).

In general, Topigs Norsvin sows displayed more lying in sternal position, standing (depended on an interaction between parity and genotype) and posture changes compared to Danbred sows. Lying in lateral position was affected by an interaction between genotype and parity. The first 3 hours of lying in lateral position depended on parity for the Topigs Norsvin sows which lay less in lateral position in the first compared to the second parity. Danbred sows did not change their lateral position between parities. In first parity, the rate of lying in lateral position was lower for Topigs Norsvin than for Danbred sows. These differences in behaviour could suggest that the Topigs Norsvin sows are more restless or perhaps more responsive to their piglets during parturition, particularly in first parity. Although the genotype-parity interaction did not impact parturition duration significantly, numerically parturition duration was higher for second parity Danbred sows compared to both first and second parity Topigs Norsvin sows. Furthermore, the Danbred sows gave birth to, numerically, larger litters than Topigs Norsvin sows. Thus, the increased duration of



lateral lying for Danbred sows could also indicate that these sows were exhausted from giving birth.

During the first 3 hours of parturition, sows housed in communal huts had a higher rate of standing compared to those housed in A-frame huts. In the A-frame huts, sows had less floor space available compared to sows in communal huts. However, Cronin et al. (1998) showed that sows housed indoors in pens (total area 9.1 m<sup>2</sup>) with a small nesting area (3.4 m<sup>2</sup>) spent more time standing compared to sows housed in pens (total area 9.1 m<sup>2</sup>) with a larger nesting area (4.3 m<sup>2</sup>), which is opposite to the current findings. Thus, something besides floor space availability could be the cause of reduced standing in A-frame huts. In these huts, the inward sloping side walls restricted sow movement and might have affected the sows' willingness/motivation to spend time standing. The increased standing in the communal huts could also be caused by the sows reacting to the presence of neighbouring sows, as sows seek isolation prior to (and during) parturition (Jensen, 1986). Thus, the increased rate of standing could reflect the presence of other sows causing disturbance.

### *Conclusion*

This study showed that prolonged parturitions do occur in outdoor housing and that long parturitions are related both to increased risk of stillbirth and increased risk of postnatal death. Therefore, management initiatives in terms of birth assistance could be a solution to alleviate consequences of long parturitions in outdoor systems, although studies are needed to confirm this. Contrary to the expected, postnatal mortality was unaffected by posture changes during parturition, suggesting that crushing occurs *postpartum*.

All behaviour displayed (lying in lateral position, lying in sternal position, standing and changing posture) during parturition was affected by genotype, parity or both these factors, which could be a sign of varying responsiveness to the parturition process and presence of piglets between first and second parity sows and Topigs Norsvin and Danbred sows. In general, within the first 3 hours of parturition, sows increased their lateral position and decreased all other behaviour as parturition progressed.

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## **PAPER III**

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Impact of hut temperature on the parturition process and level of thermoregulation in sows housed outdoors

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# Impact of hut temperature on the parturition process and level of thermoregulation in sows housed outdoors

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Short title: Impact of hut temperature on sows housed outdoors

## Abstract

Farrowing hut temperatures during summer may exceed the upper critical temperature recorded for lactating sows housed indoors in crates. This could result in the sows experiencing hyperthermia, a condition, which can cause a prolonged parturition. Fifty-five sows were observed for signs of thermoregulation (elevated surface temperature and respiration frequency) the day after parturition and the ambient temperature inside their farrowing huts was recorded. One hundred and five parturitions were video recorded and the hut temperature during parturition was recorded. Sow maximum surface temperature ( $P < 0.001$ ) and respiration frequency ( $P < 0.001$ ) measured day one *postpartum* increased with increasing hut temperature. Furthermore, maximum surface temperature on day one *pp* increased with increasing parturition duration ( $P = 0.026$ ). Hut temperature affected neither the duration of parturition nor the hourly number of posture changes during parturition. Parturition duration increased with increasing litter size ( $P < 0.001$ ) whereas the hourly number of posture changes decreased with increasing litter size ( $P = 0.003$ ). In conclusion, when temperature increased sows increased their level of thermoregulation by physiological means as indicated by an increase in maximum surface temperature and respiration frequency. The parturition process was unaffected by hut temperature suggesting sows were able to thermoregulate sufficiently to avoid negative consequences of hut temperature.

**Keywords:** outdoor pig production, thermoregulation, temperature, parturition, posture changes

## **Implications**

Outdoor kept sows are, during summer months, frequently exposed to high environmental temperatures that may challenge thermoregulation with potential negative impacts on the course of parturition.

This study showed that the level of thermoregulation in outdoor kept sows increased with increasing hut temperature as reflected by increased surface temperature and respiration frequency even during mild temperatures. However, the study suggests that, at mild temperatures, outdoor kept sows with access to a wallow appear able to thermoregulate sufficiently to avoid negative impacts of temperature on the course of parturition.

## **1 Introduction**

The upper critical temperature of crated lactating sows indoors is around 25 to 27°C (Prunier et al., 1997; Quiniou and Noblet, 1999), although a recent study suggested that outdoor kept sows may be more tolerant to high ambient temperatures due to improved possibilities for thermoregulation (Schild et al., 2018). If sows are unable to compensate for increasing temperatures, they may experience hyperthermia. Environmental stress can inhibit the release of oxytocin, as shown both for pigs (Lawrence et al., 1992) and rodents (Leng et al., 1988). Since oxytocin controls contractions of the myometrium during parturition (reviewed by Lawrence et al., 1997), then stress caused by hyperthermia may be a risk factor for prolonged parturitions. Accordingly, Muns et al. (2016) found a trend towards longer parturitions in crated sows housed at 25°C compared to sows housed at 20°C. Several studies show increased risk of stillborn piglets when parturition is prolonged (Canario et al., 2006; Baxter et al., 2009; Mainau et al., 2010). In addition to affecting prenatal mortality a prolonged parturition may also affect postnatal mortality as hypoxia during birth reduces piglet viability (Herpin et al., 1996).

For thermoregulation, pigs rely largely on behaviour and increased ambient temperature has been associated with more wallowing (reviewed by Bracke, 2011), shade seeking (Heitman et al., 1962; Blackshaw and Blackshaw, 1994) and lateral lying (Huynh et al., 2005). In the present study, sows were observed during parturition and thus motivated to remain in the nest. Therefore, an increase in ambient temperature could be expected to create a motivational conflict between lying in the nest and displaying thermoregulatory behaviour (e.g. leave the hut to wallow or seek shade or a cooler spot inside the hut). Such a motivational conflict may be reflected in an increased number of posture changes, which could influence postnatal mortality (increased risk of crushing). Thus, high temperature may

have several negative impacts on piglet survival, which has recently been shown to be high in organic production (Rangstrup-Christensen et al., 2018).

Both Randolph et al. (2005) and Schild et al. (2018) recorded temperatures above the upper critical temperature of crated lactating sows inside insulated farrowing huts, and in insulated huts Schild et al. (2018) found an increased risk of stillbirths when hut temperature was  $\geq 27^{\circ}\text{C}$ . Randolph et al. (2005) showed that piglet mortality was increased during summer and, in insulated huts, Rangstrup-Christensen et al. (2016) found an increased risk of stillbirth during summer. Together these results support the hypothesis that high temperature could be a risk factor for prolonged parturitions in outdoor systems. The aims of the current study were therefore to investigate the impact of hut temperature on the level of thermoregulation in outdoor housed sows, and to investigate if hut temperature affected the parturition process (parturition duration and frequency of postural changes). It was hypothesised that 1) the level of thermoregulation (maximum surface temperature and respiration frequency) would increase with increasing hut temperature 2) parturition would be prolonged and posture changes more frequent when hut temperature increased.

## **2 Material and methods**

### *2.1 Animals and housing*

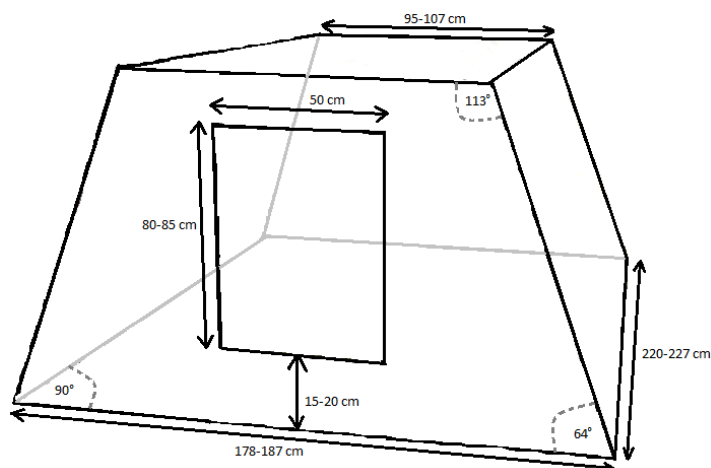
This study was divided into two parts.

*Part 1* studied hypothesis 1 (the level of thermoregulation would increase with increasing hut temperature) at the experimental herd at the Department of Animal Science, Aarhus University (AU herd), Denmark. The study included 55 parturitions divided on three batches. Batch 1 (parturitions in November and December 2016) included 16 parturitions by first parity sows, batch two (parturitions in January 2017) included 19 parturitions by first parity sows, while batch 3 (parturitions in May 2017) included 20 second parity sows (including the 16 animals from batch 1). No birth assistance was provided during the study. All sows were inserted into individual paddocks (18x25 m) ten days before expected parturition of the first sow per batch. When the average daily environmental temperature exceeded  $15^{\circ}\text{C}$  a wallow was created (necessary during spring (batch 3) and summer (batch 4, included in part 2 of the study)), and in winter and autumn plastic curtains were used at the sow entrance in all huts.

The animals were part of a larger study investigating differences between sows of two different genotypes (Danbred Landrace Yorkshire crossbreds and Topigs Norsvin TN70 ),



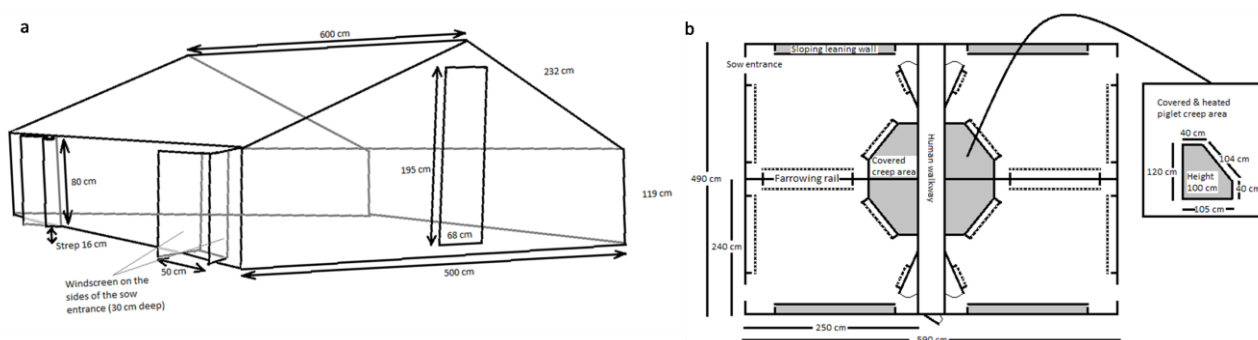
two levels of protein content in the diet (standard versus low), and two different hut types (A-frame hut Figure 1 and communal hut Figure 2).



**Figure 1** A sketch of each of the A-frame hut (after Schild et al., 2018).

Within each batch sows were randomly distributed in a balanced design to each level of genotype, protein and hut type. The communal huts had a ventilation window in each gable (43x43 cm in the front gable and 84x56 cm in the end gable) and 20 mm air insulation in the roof and 50 mm air in the sides and gables. The A-frame huts were fully insulated (40 mm mineral wool in the roof, sides and gables) and had a ventilation window (16x20 cm) in the back wall.

Before sows were inserted in their paddocks all huts were provided with barley straw (7.6 kg/m<sup>2</sup> in summer, 10 kg/m<sup>2</sup> in autumn and spring, and 12.6 kg/m<sup>2</sup> in winter).



**Figure 2** A sketch of the communal hut (Center of Development for Outdoor Livestock Production, Marsvej 43, DK-8960 Randers, Denmark) seen from the outside (a) and the indoor arrangement of the communal hut (b) where four sows were housed individually and piglets had access to a heated (eHEAT PLUS Heater version 1.0, Orbital A/S, Trykkerivej 5, 6900 Skjern, Denmark) creep area. There was no flooring in the hut or in the covered piglet creep area. (after Schild et al., In prep).

From sows entered the farrowing field they were fed a dry feed for lactating sows (sows on standard protein: 7623 kJ/kg, raw protein 14.4%; sows on low protein: 7554 kJ/kg, raw

protein 12.5%; Vestjyllands Andel A.m.b.a., Ringkøbing, Denmark). Additionally, from 1<sup>st</sup> December until 1<sup>st</sup> of May, where grass cover in the paddocks was sparse, sows had *ad libitum* access to clover grass silage. Sows were fed manually once daily in the morning. All sows had *ad libitum* access to water.

Between batches remaining straw bedding was removed and huts were moved to paddocks that had been without sows for about five months.

*Part 2* studied the second hypothesis (parturition duration would be prolonged and posture changes more frequent when hut temperature increased) and included a total of 105 parturitions of which 73 were from the AU herd (including parturitions from *Part 1*) and 32 were from a private, organic, pig-producing herd (**PP** herd).

Besides the three batches described under *Part 1* of the study a fourth batch (giving birth in June 2017) including 18 sows giving birth in their second parity was included from the AU herd.

The 32 parturitions from the PP herd were by Danbred Landrace x Yorkshire crossbred sows divided between 5 batches (6, 9, 5, 7, and 5 sows for block 1 to 5). Parturitions took place from November 2015 to August 2016. No birth assistance was provided during the study period. Sows were housed in standard individual paddocks (20x30 m) with access to an insulated A-frame hut (40 mm flamingo in roof, sides and gables, Figure 1) with a ventilation window in the roof (measuring 25x25 cm) or in the back (measuring 33x16 cm)). The ventilation window was adjusted according to herd routines. A wallow was manually created when outdoor temperatures exceeded 15°C. Prior to sow insertion to the farrowing field, 10 days before expected parturition, huts were provided with chopped rye straw (5-8 kg/m<sup>2</sup> in summer and spring; 8-10 kg/m<sup>2</sup> in autumn and winter). In the farrowing field sows were fed a ration of 3.5 kg dry feed for gestating sows daily (Green So Drægtig Cobs, Vestjyllands Andel A.m.b.a., Ringkøbing, Denmark) (DE: 7315 kJ/kg =1748.29 kcal/kg, crude fiber: 7.6%). At parturition the feed was changed and sows were fed a dry feed for lactating sows (Green So energi, Vestjyllands Andel A.m.b.a., Ringkøbing, Denmark) (DE: 7931 kJ/kg = 1895.51 kcal/kg, crude fiber: 4.3%). Sows were fed manually once daily in the morning. All sows had access to fresh clover grass in the paddocks. From October to mid-May, where grass cover was sparse sows were provided with barley and clover grass wholecrop silage. All sows had *ad libitum* access to water.

Between batches remaining straw bedding was removed and within each paddock the huts were moved to a new location.

## 2.2 Data collection

### 2.2.1 Behavioural observations

All parturitions in both herds were recorded with video cameras (IPC-HDBW4100EP-0360B, Dahua Technology Co., Queen Anne House, 25-27 Broadway, UK) fitted with wide angle lenses. The recordings were saved and analysed using S-VIDIA Client MegaPixel (M. Shafro & Co., Riga, Latvia).

The time of birth of all piglets (not separating live and stillborn) was recorded along with sow posture during parturition (Table 1). Descriptive information about sow behaviour during parturition (e.g. time spent in each posture) is reported elsewhere (Schild et al., In prep).

**Table 1** Sow postures recorded during parturition (after Thorsen et al. (2017)). Sows were recorded in a posture when they had spent at least 2 seconds in the respective posture.

Posture	Definition
Standing/walking	Maintaining an upright position on extended legs
Sitting	Body weight supported by hind quarters and both front legs stretched with the hoofs in the ground
Lateral position	Lying on one side with the udder exposed and with one shoulder touching the ground, her head raised or resting
Sternal position	Lying on the belly with the udder hidden, or partly hidden, and without a shoulder touching the ground, her head raised or resting
Outside	The sow is not in the hut

### 2.2.2 Temperature

Inside every A-frame hut (at both the AU and the PP herd) and every compartment of the communal huts data loggers (Hygrochron™ iButton (DS1923), Maxim Integrated Products, Inc, San Jose, CA 95134 USA) were placed in the north-eastern corner (A-frame hut) or in the corner facing towards the aisle (communal hut) inside logger racks (for a description see Schild et al. (2018)). The loggers recorded data every tenth minute from day seven *pre-partum* until seven days *postpartum* (**pp**). Loggers recorded temperature at a low resolution (accuracy  $\pm 0.5^{\circ}\text{C}$ ).

The average of the 10% highest hut temperatures ( $T_{10}$ ) during 12 h after the birth of the first piglet was calculated and used in the statistical analyses. The temperature variation ( $T_{diff}$ ) was calculated as the difference between the average of the 10% highest and the DA of the 10% lowest hut temperatures during the same time period.

### 2.4.3 Signs of thermoregulation and disease

The following data were collected in *Part 1* of the study (including the first three of the four batches at the AU herd). Three infra-red pictures of the canthus of the eye were taken of each sow between 11:00 and 16:00 on day one *pp* (defined as 24-48 h after birth of first piglet). Recordings were made only when sows were lying inside their hut. The best picture was chosen for further analysis. The maximum surface temperature (**MST**) of the sows was defined as the highest measured temperature in the canthus of the eye. The infra-red pictures were taken using a thermographic camera (model FLIR P660, with SC660 software installed, FLIR Systems., Wilsonville, Oregon, USA). Emissivity ( $\epsilon$ ) was set to 1.0 and reflected temperature recorded. Reflected temperature was then adjusted in the camera settings and  $\epsilon$  set to 0.98 (Soerensen et al., 2014). The distance between the camera and the canthus was kept around 1 m (set to 2 m in the camera settings). The surrounding temperature and humidity were recorded and corrected in the settings of the thermographic camera before measurement. The camera was allowed to calibrate for at least 45 minutes before recordings were started.

Respiration frequency was measured as number of breaths per minute (**RF**) where each breath was identified by the sound of the sows breathing and the movement of her chest. RF was recorded when sows' were lying down in their hut. Signs of disease were observed at the same time by a feeding test conducted on sows that had not been to their feeding trough (feed was in a smooth pile that appeared untouched by the sow) within approximately 4 hours after feeding. The test was performed by the observer taking a handful of feed from the sows feeding trough and throwing it, through the sow entrance, in front of the snout of the sow. It was noted whether or not the sow began eating (sniffing, rooting and chewing the feed). All tested sows were observed for one minute after the presentation of feed. The variable 'loss of appetite' was created as a binomial variable where "0" referred to sows that had been to their feed (feeding trough was empty or the feed no longer gathered in a smooth pile) or ate during the feeding test (considered no sign of disease) and "1" was given to sows that neither ate from the feeding trough nor in the test (considered a sign of disease). Lastly, all treatments of sows were recorded by the stockmen.

### 2.5 Statistical analysis

The statistical analyses were made in SAS (SAS 9.3, SAS Institute Inc., Cary, NC, USA). Parturition duration was calculated as the time interval between birth of the first and last piglet in the litter; irrespective of whether the piglet was born alive or not.

### 2.5.1 Part 1. Level of thermoregulation

MST was log transformed to improve normality of the residuals. For the final analyses the following generalized linear model was used after removal of statistically non-significant effects ( $P > 0.05$ ),

$$Y_{ij} = \alpha T_{10ij} + \beta PD_{ij} + \varepsilon_{ij} \quad (\text{model 1})$$

where  $\alpha$  is the parameter describing the effect of  $T_{10}$  (i in sow identity and j in parity 1,2) and  $\beta$  is the parameter describing the effect of parturition duration (PD) (index ij).  $\varepsilon$  is the normal distributed residual error. The initial model used for the analysis of maximum surface temperature included the effects  $T_{10}$ ,  $T_{\text{diff}}$ , parity (1,2), parturition duration, sow genotype (Danbred, Topigs Norsvin), protein level in the diet (standard, low), and hut type (communal hut, A-frame hut).

For the analysis of the respiration frequency  $T_{10}$  was converted to a categorical value since a visual inspection of the data showed no linear correlation between respiration frequency and  $T_{10}$ . The categorical variable of  $T_{10}$  ( $T_{\text{cat}}$ ) was based on the lower thermal comfort temperature of lactating sows (approximately  $12^{\circ}\text{C}$  suggested by Black et al. (1993)) and the upper critical temperature of lactating sows (approximately  $25\text{-}27^{\circ}\text{C}$  (Prunier et al., 1997; Quiniou and Noblet, 1999)). Thus, the category 'low' included  $T_{10} \leq 12^{\circ}\text{C}$ , 'medium' was for  $12^{\circ}\text{C} < T_{10} < 27^{\circ}\text{C}$  and category 'high' included  $T_{10} \geq 27^{\circ}\text{C}$ . A generalized linear model was again used for the analysis,

$$Y_i = T_{\text{cat},i} + \varepsilon_i \quad (\text{model 2})$$

where  $T_{\text{cat}}$  refers to the categorical  $T_{10}$  (i in low, middle, high) and  $\varepsilon$  is the normal distributed residual error. To improve normality the respiration frequency was log transformed. The initial model also included the variables  $T_{\text{diff}}$ , parity, parturition duration, sow genotype, protein level, and hut type, but these were removed by elimination of statistically non-significant effects ( $P > 0.05$ ).

One parturition was clearly an outlier in the dataset (lasted longer than 35 h). A sensitivity analysis was conducted by removing this parturition. This result improved normality of the residuals and so the parturition was removed from the analyses. 'Loss of appetite' was analysed using mixed logistic regression with sow identity included as a random effect. The initial model included the variables  $T_{10}$ ,  $T_{\text{diff}}$ , parity, parturition duration, sow genotype, protein level, and hut type. However, none of these statistically affected the response ( $P > 0.05$ ) and thus no final model is shown.

### 2.5.2 Part 2. Parturition duration and postural changes

In the study herd and parity were confounded in that at the PP herd only had multiparous sows (median parity 2.5 range 2 to 6) whereas the sows at the AU herd were used in 1<sup>st</sup> and 2<sup>nd</sup> parity. Due to these limitations of the study design, repeated measures on the same sow were not possible to include in the analyses and therefore parturition was considered the statistical unit. It is emphasized that what is termed parity in *Part 2* in reality also covers both variation between herds.

For the analyses, the variable parity group was created so that first parity sows were considered parity group 1 and multiparous sows as parity group 2.

Parturition duration was log transformed to improve normality of the residuals. The following final generalized linear model, after removal of statistically non-significant effects, was used for the analysis of farrowing duration,

$$Y_{ij} = \beta L_{ij} + \varepsilon_{ij} \quad (\text{model 3})$$

where  $\beta$  is the parameter describing the effect of litter size (L) (i in sow identity and j in parity group 1,2) and  $\varepsilon$  is the normal distributed residual error. The initial model included the variables hut temperature ( $T_{10}$  and  $T_{diff}$ ), parity group and litter size (total born).

To improve normality of the residuals the hourly number of posture changes was squareroot transformed. The hourly number of posture changes was analysed by the following final generalized linear model, after removal of statistically non-significant effects.

$$Y_{ij} = P_j + \beta L_{ij} + \varepsilon_{ij} \quad (\text{model 4})$$

P refers to parity group (j in 1,2) and  $\beta$  is the parameter describing the effect of litter size (L) (i in sow identity, j) and  $\varepsilon$  is the normal distributed residual error. The initial model included the variables  $T_{cat}$  and  $T_{diff}$ , where  $T_{cat}$  referred to the categorical variable where 'low'  $T_{10} \leq 12^\circ\text{C}$ , 'middle'  $12 < T_{10} < 27^\circ\text{C}$ , and 'high'  $T_{10} \geq 27^\circ\text{C}$ .

Four parturitions lasting longer than 24 h were clearly outliers. Since the normality of the residuals was improved when the parturitions were excluded from the dataset, a sensitivity analysis was conducted by removing these parturitions. This did not change the results. The four parturitions were therefore not included in the final analyses of data from *Part 2*.

### 3 Results

#### 3.1 Part 1

The average of the 10% highest hut temperatures ( $T_{10}$ ) during 12 h after the birth of the first piglet influenced sow maximum surface temperature (MST) ( $F_{1,46}=58.9$ ,  $P<0.001$ , Table 2). A  $10^{\circ}\text{C}$  increase in  $T_{10}$  was accompanied by a  $1.5^{\circ}\text{C}$  (back transformed model estimate) increase in MST ( $0.038\pm 0.005$  model estimate  $\pm$  standard error). For the upper 90% quartile of  $T_{10}$  ( $\geq 28.1^{\circ}\text{C}$ ) the MST was  $37.8$  (median, range  $36\text{-}39^{\circ}\text{C}$ ) whereas at the lower 10% quartile of  $T_{10}$  ( $\leq 6.1^{\circ}\text{C}$ ) mean MST was  $34.0^{\circ}\text{C}$  (range  $32\text{-}35^{\circ}\text{C}$ ). The respiration frequency (RF) was affected by  $T_{\text{cat}}$  ( $F_{2,46}=11.0$ ,  $P<0.001$ , Table 2). Respiration frequency for  $T_{\text{cat}}$  ‘high’ ( $T_{10}\geq 27^{\circ}\text{C}$ ) was higher than  $T_{\text{cat}}$  ‘low’ ( $T_{10}\leq 12^{\circ}\text{C}$ ) and ‘medium’ ( $12^{\circ}\text{C}< T_{10}< 27^{\circ}\text{C}$ ), whereas the latter did not differ statistically. For  $T_{\text{cat}}$  ‘high’ RF was  $36.12$  breaths/min (back transformed LS mean) whereas RF was  $16.58$  breaths/min and  $18.95$  breaths/min for category ‘low’ and ‘medium’, respectively.

**Table 2** Summary of the output from the final models. First output is from the final model 1 (MST). Second output is from the final model 2 (Respiration frequency). Third output is from the final model 3 (parturition duration) and the fourth output is from model 4 (posture changes).  $T_{10}$  refers to the average of the 10% highest hut temperatures during the first 12 h after the birth of the first piglet.  $T_{\text{cat}}$  is the categorical variable where “low” refers to  $T_{10}\leq 12^{\circ}\text{C}$ , “med” to  $12<T_{10}< 27^{\circ}\text{C}$ , and “high” to  $T_{10}\geq 27^{\circ}\text{C}$ . F and p values are presented for the overall effect of each variable.

Model	Variable	Levels	No. of observations	F	p
1	$T_{10}$	Continuous	49	$F_{1,46}=58.9$	$<0.001$
	Parturition duration	Continuous	49	$F_{1,46}=5.3$	0.026
2	$T_{\text{cat}}$	Low Med High		$F_{2,46}=11.0$	$<0.001$
3	Litter size	Continuous	100	$F_{1,98}=14.8$	$<0.001$
4	Litter size	Continuous	100	$F_{1,97}=9.6$	0.003
	Parity group	1 2	35 65	$F_{1,97}=8.8$	0.004

MST also depended on parturition duration ( $F_{1,46}=5.3$ ,  $P=0.026$ ). For the upper 90% quartile of parturition duration (468 min) the mean MST was  $38.7^{\circ}\text{C}$  (median, range  $34\text{-}39^{\circ}\text{C}$ ) whereas at the lower 10% quartile (124 min) mean MST was  $36.8^{\circ}\text{C}$  (range  $34\text{-}37^{\circ}\text{C}$ ). Contrary, RF was unaffected by parturition duration ( $P>0.05$ ). Neither MST nor RF was affected by  $T_{\text{diff}}$ , parity, sow genotype, protein level in the diet or hut type. Descriptive information on the hut climate, temperature regulation and course of parturition is provided in Table 3.

None of the investigated variables ( $T_{10}$ ,  $T_{diff}$ , parturition duration, parity, sow genotype, protein level in the diet, or hut type) influenced the variable 'loss of appetite'. Twenty-four sows did not eat on day one *pp* whereas 31 sows ate either in the feeding test or at the feeding trough. In the farrowing field two sows were treated for mastitis within four days *pp*. One of the sows (treated 4 days *pp*) did not eat during the feeding test or at the feeding trough on day 1, 2 or 3 *pp*, whereas the other sow (treated 2 days *pp*) ate on day 1 and 2 but not on day 3 *pp*. Eleven sows were treated for worms, one for a hoof abscess and one sow for inflammation of the bladder.

### 3.2 Study part 2

Hut climate ( $T_{10}$  and  $T_{diff}$ ) affected neither parturition duration ( $T_{10}$   $P=0.31$ ;  $T_{diff}$   $P=0.43$ ) nor the hourly number of posture changes during parturition ( $T_{10}$   $P=0.79$ ;  $T_{diff}$   $P=0.30$ ). Median parturition duration at the upper 90% quartile of  $T_{10}$  ( $\geq 29.1^{\circ}\text{C}$ ) was 398 min (median, range 231-670) and 340 min (range 107-833) at the lower 10% quartile of  $T_{10}$  ( $\leq 6.6^{\circ}\text{C}$ ). The mean hourly number of posture changes during parturition at  $T_{10} \geq 29.1^{\circ}\text{C}$  and  $T_{10} \leq 6.6^{\circ}\text{C}$  was respectively, 1.9 (0-15 changes/hour) and 3.7 (0-24 changes/hour). Thirteen sows gave birth when daily average of the 10% highest temperatures exceeded  $27^{\circ}\text{C}$ . Numerically these sows displayed a lower hourly number of posture changes (median 1.9, range 0-15) compared to the remaining sows that gave birth at lower temperatures (4.2, 0-25). Three of the sows furthermore gave birth when the mean of the 10% highest temperatures exceeded  $29.1^{\circ}\text{C}$  and these sows, numerically, left the hut more frequently compared to the remaining sows. One sow left the hut five times, the other two sows left the hut two times whereas of the remaining 92 sows, giving birth at lower hut temperatures, three sows left the hut a total of five times.

Parturition duration increased with increasing litter size ( $F_{1,98}=14.8$ ,  $P<0.001$ , Table 2) whereas the rate of posture changes decreased with increasing litter size ( $F_{1,97}=9.6$ ,  $P=0.003$ , Table 2). Parity group also impacted the hourly number of posture changes ( $F_{1,97}=8.8$ ,  $P=0.004$ ). First parity sows displayed a hourly number of 5.1 (back transformed LSmean) posture changes ( $2.5 \pm 0.2$  LSmean  $\pm$  Standard error) whereas multiparous sows displayed 3.4 (back transformed LSmean) posture changes per hour ( $1.8 \pm 0.1$  LSmean  $\pm$  Standard error).



**Table 3** Descriptive data from each of the two study parts (Part 1 investigating the level of thermoregulation; Part 2 investigating the effects of hut temperature on the course of parturition).  $T_{10}$  is the average of the 10% highest hut temperatures during 12 hours after the birth of the first piglet and  $T_{diff}$  is the difference between the average of the 10% highest and the average of the 10% lowest hut temperatures during the same time period. Values are given as medians with range (in brackets).

	Part 1	Part 2
Number of observations	55	105
Hut climate		
$T_{10}$ (°C)	15.5 (2-31)	15.1 (2-34)
$T_{diff}$ (°C)	3.5 (1-16)	4.0 (0-17)
Temperature regulation		
MST (°C)	35.8 (32-39)	-
RF (breaths/min)	18 (10-96)	-
Parturition traits		
Total litter size (no of piglets)	17.0 (6-26)	17.5 (6-27)
Parturition duration (min)	250.0 (73-670)	266.8 (63-1417)
Posture changes per hour	5.4 (0-25)	4.2 (0-25)

## 4 Discussion

### 4.1 Study Part 1

As expected both maximum surface temperature and respiration frequency increased with increasing hut temperature ( $T_{10}$ ), which is in accordance with previous studies done on indoor (e.g. Malmkvist et al., 2012; Muns et al., 2016) and outdoor housed sows (only considering MST, Schild et al. (Accepted)). Brown-Brandl et al. (2001), found an increase in rectal temperature of castrated male pigs housed at 32°C compared to castrates housed at 18, 24 and 28°C. Respiration frequency was highest for castrates housed at 32°C and higher at 28°C compared to 24 and 18°C and the authors suggested respiration frequency could be an early indicator of heat stress. Accordingly, increases in MST and respiration frequency are considered indicators of an elevated level of thermoregulation in terms of increased blood flow to the skin and a corresponding increased heat loss across the body surface and increased evaporative heat loss across the lung surface (Mount, 1962; Ingram and Legge, 1969). At higher temperatures, MST increased with increasing parturition duration, which

may be caused by increased energy expenditure during parturition resulting in an elevated heat production. Therefore, prolonged parturitions may challenge sows more thermally compared to shorter parturitions. Yet, contrary to MST, respiration frequency was not affected by the duration of parturition.

Parturition related diseases such as mastitis-metritis-agalactica syndrome are related to lowered milk production (Martin and Mc Dowell, 1978; Larsen and Bækbo, 1997), increased rectal temperature (Martin and Mc Dowell, 1978; Larsen and Bækbo, 1997), increased surface temperature (Soerensen, 2014), increased respiration frequency (Martin and Mc Dowell, 1978), swollen and sore mammary glands and vaginal discharge (Martin and Mc Dowell, 1978; Larsen and Bækbo, 1997) and decreased feeding activity (Larsen and Bækbo, 1997). Therefore, in the present study, a combination of 'loss of appetite', increased MST and increased respiration frequency was considered an indicator of sick sows. Including recordings such as swollen mammary glands, vaginal discharge and rectal temperature could have made the test more reliable. However, using such measures in an outdoor system would result in serious disturbances of the sow and consequently a high risk of piglet crushing. Therefore, despite its limitations, 'loss of appetite' was used as a supplement to MST and respiration frequency. The occurrence of disease based on 'loss of appetite' was low during the present study and only two sows were treated for mastitis.

Incidence of disease was expected to be more pronounced at high hut temperatures (due to an expected risk of hyperthermia) and prolonged parturitions. However, no effect of hut temperature or parturition duration was found for 'loss of appetite', maybe due to that outdoor kept sows during warm periods are able to thermoregulate by wallowing and seeking shade.

Together the results of *Part 1* show that parturient and lactating sows housed in huts outdoors do show increased signs of thermoregulation when hut temperature increases even at relatively low temperature.

#### *4.2 Study part 2*

The current study showed that temperatures above the upper critical temperature of 25 to 27°C for indoor crated sows (Prunier et al., 1997; Quiniou and Noblet, 1999) do occur inside insulated sow huts even during relative mild summers. This corresponds with previous findings (Randolph et al., 2005; Schild et al., 2018). Contrary to the expected, hut temperature did not affect parturition duration or the frequency of posture changes during parturition. Correspondingly, Malmkvist et al. (2012) found no effect of room temperature (15 to 25°C) on the parturition duration of loose-housed sows. The authors suggest this could

be due to sows being loose-housed and therefore having the opportunity to display thermoregulatory behaviour. Accordingly, for crated sows, that are less able to display thermoregulatory behaviour, Muns et al. (2016) saw a trend towards a longer parturition when sows were housed at high room temperature (20 vs 25°C). Compared to indoor loose-housed sows, outdoor housed sows have even better opportunity for displaying thermoregulatory behaviour (e.g. increasing forced convection by lying in the hut entrance, wallowing, shade seeking), which could explain the lacking effect of hut temperature on parturition duration and posture changes in the present study. During the nestbuilding period sow activity level is high, which will result in an increased internal heat production (Feyera and Theil, 2017). Access to a wallow during this period could therefore allow the sows to avoid hyperthermia prior to the onset of parturition. During parturition sows are motivated to remain in the hut (nest) and thus less likely to display wallowing. However, due to the relatively low temperatures during the warmest part of the study period, it is likely that sows, even though they were (motivationally) restricted to the hut, may not have been thermally challenged during parturition. Thus, the sows may have been able to thermoregulate sufficiently by physiological means (increased respiration and MST). In accordance, signs of changed behaviour were indicated for the sub-set of sows giving birth when the daily average of the 10% highest temperatures exceeded 27°C. These sows displayed a numerically lower frequency of posture changes compared to the remaining sows. Since increased physical activity is associated with an increased heat production (McDonald et al., 1988; Noblet et al., 1993; van Milgen et al., 1998) the reduction in the hourly number of posture changes may reflect the sows attempting to reduce own heat production. This result could indicate that outdoor housed sows are not thermally challenged until temperatures exceed 27°C. In accordance Schild et al. (2018) reported increased risk of stillbirth for outdoor housed sows at temperatures  $\geq 27^{\circ}\text{C}$ . Furthermore, the present results indicated that the parturient sows were unable to cope with hut temperature (through decreased activity and increased level of physiological thermoregulation) when daily average of the 10% highest temperatures exceeded 29.1°C as sows giving birth above those temperatures left the hut more frequently during parturition compared to sows giving birth at lower hut temperatures. Thus, it appears that sows preferred to remain with their piglets during parturition. However, when hut temperature became too high, sows may have been thermally challenged to an extent where they had to leave the hut to avoid becoming hyperthermic. By doing so sows were able to thermoregulate and likely also able to avoid negative impacts of hyperthermia. However, sows leaving the hut during parturition could have negative consequences for piglet survival.

Temperature fluctuations ( $T_{\text{diff}}$ ) within the first 12 hours after birth of the first piglet did not affect parturition duration or the hourly number of posture changes in the current study suggesting, sows were able to adapt to the fluctuating temperatures. In accordance, Schild et al. (2018) found no effect of temperature fluctuations (within day) on the risk of stillbirth for sows housed outdoors. Furthermore, under outdoor conditions a reduced diurnal temperature fluctuation in insulated compared to uninsulated huts was not reflected in piglet mortality or growth rate (Edwards et al., 1995), and Morrison et al. (1975) found no effect of diurnal temperature cycle (constant, 10°C or 20°C) on growth rate in growing pigs (housed in insulated vans).

In accordance with previous studies parturition duration depended on litter size (average litter size 13.95 (surviving) to 14.96 (dying); Baxter et al., 2009) and the hourly number of posture changes was highest for first parity sows (Mainau et al., 2010). However, the variation of posture changes explained by parity group in the current study could also be caused by variation between the two herds as parity and herd to some extent were confounded. In accordance with Mainau et al. (2010), who found a negative correlation between litter size and activity, the present results showed a higher hourly number of posture changes with decreasing litter size. Large litters prolong the parturition process and thus it is likely that sows get fatigued, which may result in sows lying still. Also birth of many piglets may induce more oxytocin release, which could have a calming effect on the sows (reviewed by Uvnäs-Moberg and Petersson, 2005).

### *Conclusion*

Physiological signs of thermoregulation the day after parturition increased with increasing hut temperature. However, the course of parturition was unaffected by temperature suggesting, that under the current study conditions, the animals were able to compensate sufficiently for increasing hut temperature.

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### **Declaration of interest**

The authors have no conflicts of interest to declare.

### **Ethics statement**

Housing and handling of animals complied with the Danish legislation and the study conformed with the Guidelines for Ethical Treatment of Animals in Applied Animal Behaviour and Welfare Research (Sherwin et al., 2017).

### **Software and data repository resources**

Data and models are not deposited in an official repository.

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## **PAPER IV**

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The use of a shaded area during farrowing and lactation in sows kept outdoors

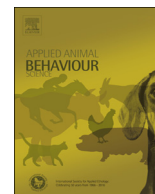
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## The use of a shaded area during farrowing and lactation in sows kept outdoors

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## ABSTRACT

The hut temperature in outdoor pig production during summer can exceed the upper critical temperature of lactating sows. Therefore, sows may experience hyperthermia, a condition which has several adverse consequences for the welfare of both sow and piglets. Thus, the aim of the current study was to investigate possible benefits of providing sows with access to an alternative shaded area, apart from the huts, constituted by an area with poplar trees within the farrowing paddock. The study consisted of two parts: Part one was an experimental study investigating the effects of providing sows with access to poplars. Fourteen sows with access to poplars and 14 sows without access to poplars were included. In the second part of the study, including 57 sows, the sows' use of the poplars was studied. In both study parts, sows were studied during four periods: *pre-partum* (day 2 *pre-partum* until, and including, the day of farrowing (day 0), early *postpartum* (day 1 to 4 *postpartum*), late *postpartum* (day 5 to 7 *postpartum*) and late lactation (two observation days, 13 and 28 days after expected farrowing, range day 11 to 31 *postpartum*). Access to poplars affected the sows' use of the farrowing hut, and an interaction was found between temperature and treatment (access to poplars or no access) so that access to poplars resulted in a decreased use of the hut at higher hut temperatures. No effect of temperature was seen for controls. Maximum surface temperature of sows was only affected by hut temperature and increased with increasing temperature, whereas wallowing was affected by parity group and period. The odds of wallowing were higher for parity group 1 and *pre-partum*. Whether the sows chose to enter the poplar area was unaffected by hut temperature but higher *pre-partum* and in late lactation compared to early and late *postpartum*. Once inside the poplars, sows lay more when hut temperature increased. Sow location had a major impact on the location of the piglets after removal of the fender, and the piglets followed the sow into the hut and the poplar tree area. In conclusion, sows lay more in the poplar area when hut temperature increased, but the sows total use of the poplars was unaffected by temperature, suggesting, poplars in the farrowing field may serve several purposes this could be as an area for thermoregulation, exploration and foraging.

### 1. Introduction

High ambient temperature increases the risk of stillborn piglets both when sows are housed outdoors (Schild et al., 2018) and indoors (Vanderhaeghe et al., 2010). Correspondingly, a large Danish study showed an increased risk of stillborn piglets during the warm season in organic sow herds (Rangstrup-Christensen et al., 2016). When sows are exposed to high ambient temperatures, there is a risk that they experience hyperthermia. Stress has been shown to have an inhibitory effect on oxytocin (Lawrence et al., 1992), and since a low level of oxytocin has been associated with prolonged farrowing (Oliviero et al., 2008), hyperthermia may have negative consequences for the course of farrowing by prolonging the parturition process. In accordance, Muns

et al. (2016) found a trend towards a longer farrowing when crated sows were housed at 25 °C compared to 20 °C. Prolonged farrowings have been identified as a risk factor for stillborn piglets, also when animals are housed outdoors (Baxter et al., 2009; Thorsen et al., 2017). A long farrowing increases the risk of piglets experiencing hypoxia during birth and hypoxia is associated with reduced postnatal viability (Herpin et al., 1996). Besides affecting the course of farrowing, exposure to high ambient temperature may result in increased sow body weight loss (Stansbury et al., 1987; Quiniou and Noblet, 1999; Renaudeau et al., 2002), reduced lactation performance (Prunier et al., 1997; Quiniou and Noblet, 1999; Renaudeau et al., 2001) and lowered piglet weight gain (Quiniou and Noblet, 1999; Renaudeau et al., 2002; Muns et al., 2016). Hence, high ambient temperature may have several

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adverse consequences for the welfare of both sow and piglets, and, consequently, also to farm economy. When animals are housed outdoors, they may be expected to experience more extreme ambient temperatures than indoor-housed animals, thus, it is important to ensure that sows have the possibility to thermoregulate sufficiently to avoid hyperthermia.

The farrowing hut may become very warm when ambient temperatures are high during summer (Randolph et al., 2005; Schild et al., 2018), reaching temperatures exceeding the upper critical temperature of 25–27 °C recorded for crated sows (Prunier et al., 1997; Quiniou and Noblet, 1999). Since studies have shown that pigs seek shade when ambient temperature increases (Heitman et al., 1962; Blackshaw and Blackshaw, 1994), one way to lower the risks associated with high temperatures could be to provide outdoor-housed sows with access to a shaded area other than inside the farrowing hut. Therefore, the aim of the current study was to investigate possible benefits of providing sows with access to an alternative shaded area constituted by an area with poplar trees. It was predicted that 1) sow surface temperature (as a symptom of increased thermoregulation) would increase with increasing hut temperature 2) in general, the use of the farrowing hut would decrease with increasing hut temperature, 3) access to poplars would decrease the sows' use of the farrowing hut, 4) use of the poplars would increase at increasing hut temperature, and 5) the piglets' use of the paddock would depend on the location of the sow.

## 2. Material and methods

### 2.1. Animals and husbandry procedures

The study was conducted at a commercial organic pig-producing herd located in the western part of Jutland, Denmark, from July to September 2015. The study comprised crossbred Danbred Landrace (L) x Yorkshire (Y) lactating sows, that were all nose-ringed (to reduce sow damage to the grass cover in the paddock), and their crossbred L x Y x Duroc piglets.

Cross-fostering was done on day 1 and 2 *postpartum* (*pp*) to even out litters. After day 2 *pp*, live piglets were only removed from their litter if they were not thriving. Male piglets were castrated with pain relief on day 4 *pp*, and all piglets were vaccinated against *Mycoplasma hyopneumonia* (enzootic pneumonia).

The grass cover in the farrowing field was rye grass, and sows had access to an insulated A-frame hut (L:220 cm,  $W_{\text{bottom}}$ :180 cm,  $W_{\text{top}}$ :105 cm, H:105 cm, Fig. 1) with a ventilation window in the back (30 × 30 cm). Opening of the ventilation window was done according to herd routines. Prior to farrowing, a fender was placed in front of all huts. The fender was removed 10 days *pp*. Prior to the sows' transfer to the farrowing field, all huts were provided with approximately 40 kg of

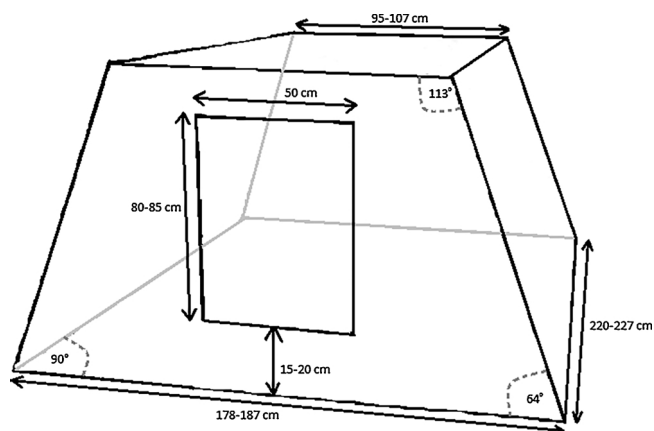


Fig. 1. A sketch of the insulated A-frame huts used in the farrowing field (after Schild et al., 2018).

cut wheat and barley straw. More straw (about 20 kg) was provided once, twice or thrice after castration (according to herd routines). From insertion to the farrowing field, each sow received approximately 3 kg of a complete dry feed for lactating sows daily (Green Die Hestbjerg, Vestjyllands Andel A.m.b.a., Ringkøbing, Denmark). At farrowing, the meal size was reduced to 1–2 kg per sow. After castration (median day 4), meal size was increased to 6–7 kg and then gradually increased until weaning where it reached about 12 kg per sow. From the removal of the fender, piglets also had access to feed (Green Start farefold, Vestjyllands Andel A.m.b.a., Ringkøbing, Denmark).

Water was available *ad libitum* in a water trough (each water trough was shared by two neighbouring sows). Furthermore, when day temperature exceeded 15°C in the shade, a wallow was manually created in each farrowing paddock as is required according to Danish legislation (Anon., 2017).

### 2.2. Study design

#### 2.2.1. Study 1: Effect of poplars v. No poplars

The first part of the study was an experimental study conducted as a balanced factorial study with two levels where sows (all belonging to the same farrowing batch) either had access to (N = 14) or did not have access to (N = 14) poplar trees in the farrowing field. The number of available control paddocks (no access to poplars) was limited to 14, whereas there were 57 test paddocks (access to poplars). Therefore, of the available test paddocks, 14 were randomly selected for the study, the only criterion being that the parity of the test sows should match the parity of the controls. The parity distribution of both test and control sows was: 4 first parity sows, 4 s parity, 1 fourth parity, 3 fifth parity, 1 seventh parity, and 1 sow in eighth parity.

#### 2.2.2. Experiment 2: use of poplars

This part of the study was an observational study of how the sows and piglets used the poplar tree area. For this study all 57 paddocks with access to poplars were included.

The parity distribution of the sows was as follows: 8 first parity sows, 11 s parity, 4 third parity, 12 fourth parity, 7 fifth parity, 2 sixth parity, 8 seventh parity and 5 sows in eighth parity.

### 2.3. Experimental procedures

After relocation to the farrowing field, control sows were placed in standard individual farrowing paddocks measuring 278 m<sup>2</sup> (14.4 × 19.3 m) (for a picture of control and test paddocks see Fig. 2). The test sows were given access to a similar paddock as the control sows with additional access to an area with 8 × 4 rows of poplars (three of the paddocks had 3 × 4 rows of poplars) (fifth season poplars approximately 6 m in height). The poplar tree area measured 212 m<sup>2</sup> (11 × 19.3 m).

### 2.4. Data collection

#### 2.4.1. Environmental recordings

Data loggers recording and storing temperature and humidity (Hygrochron™ iButton (DS1923), Stockholm, Sweden) were placed in logger racks (see Schild et al. (2018) for a description) inside the north-eastern corner of 34 of the 71 farrowing huts. Loggers were evenly distributed between the huts in the farrowing field. One logger facing northeast was placed in a logger rack outside in the farrowing field, 55 cm above the ground. Eight loggers (also in logger racks) were evenly distributed inside the poplars on the north-eastern side of selected trees. These loggers were placed 1 m above the ground. All loggers recorded and stored temperature and humidity every tenth minute from 3 days prior to expected farrowing until 25 days after expected farrowing. Both temperature and humidity were recorded at a low resolution (accuracy: temperature ± 0.5°C and humidity ± 0.6% RH).



**Fig. 2.** a) a picture of some of the control paddocks where sows did not have access to the poplar tree area (the young poplar trees about 1 m high can be seen behind the A-frame huts) and b) a picture of the paddocks where sows had access to an area with fifth season poplar trees (about 6 m high), which can be seen behind the A-frame huts.

For huts without loggers, temperature and humidity were calculated as the mean of the temperature and humidity in the two nearest neighbouring huts (with the sow entrance facing the same direction) containing data loggers.

#### 2.4.2. Study 1

**2.4.2.1. Behavioural recordings.** Due to the visual presence of the poplars, observers were not blinded for treatment.

The sows' behaviour was recorded by direct observation on a focal level by use of scan sampling (Martin and Bateson, 2007). The types of behaviour recorded were “inactive”: *lying on the belly or the side*; “active”: *sitting, standing or walking*; “unknown”: *it is not possible to record the sow's behaviour*. Sow location (hut, wallow or remaining paddock (including poplars for test sows) was also recorded. Whenever possible, behaviour and sow location were recorded at one paddock's distance to lower disturbance.

Each day from 2 days before until 8 days after expected farrowing of the farrowing batch, six trained observers recorded the sows' behaviour and location. On day 13 and 28 after expected farrowing, four trained observers conducted the recordings. Observers were dressed alike, and no bright colours were worn. Three observers (two on day 13 to 28 after expected farrowing) monitored the sows during mornings (from 06:00 to 11:00 h), and three observers (two on day 13 and 28 after expected farrowing) monitored the sows during afternoons (from 13:30 to 22:00 h). During mornings, all sows were observed (sow behaviour and location recorded) every half hour from 06:00 to 08:00 h (morning obs. 1) and again every half hour from 09:00 to 11:00 h (morning obs. 2). In the afternoon, sows were observed every half hour from 13:30 to 16:00 h (afternoon obs. 1), from 17:00 to 19:00 h (afternoon obs. 2) and from 20:00 to 22:00 h (afternoon obs. 3). To minimize the inter observer effect, a randomisation test was conducted in R (version 3.2.0, © The R Foundation) stating where each observer should record each day and at each observation round (morning obs. 1, 2 and afternoon obs. 1, 2, 3). This test also secured that within 2 days, each observer had monitored all sows at least once; all sows were observed by each observer as close to an equal amount of times as possible; within shift (morning or afternoon), observers monitored each sow at all observation periods (morning obs. 1, 2 or afternoon obs. 1, 2, 3) an equal amount of times within the observation days.

**2.4.2.2. Sow surface temperature.** Surface temperature was measured on day 1, 2 and 3 *pp* between 11:00 and 19:00 h on both control and test sows in the canthus of the eye using a thermographic camera (model FLIR P660, with SC660 software installed, FLIR Systems., Wilsonville, Oregon, USA). Reflected temperature was measured with the emissivity ( $\epsilon$ ) set to 1.0 after which reflected temperature was adjusted and  $\epsilon$  set to

0.98 (Soerensen et al., 2014). The distance between the camera and the sow's eye was kept between 1 and 2 m; in the camera settings, distance was set to 2 m. The surrounding temperature and humidity were measured daily (using a Wilfa HY-1, HydraTemp; Hygro- and thermometer, Wilfa Danmark A/S, Denmark) and corrected in the settings of the thermographic camera before each measurement. The camera was turned on at least 45 min prior to recording in order to allow it to calibrate. Recordings were only made when sows were lying inside their hut.

#### 2.4.3. Study 2

**2.4.3.1. Behavioural recordings.** While conducting the behavioural observations described above, the observers recorded additional information about all sows with access to poplars. It was recorded when the sows were within the poplar tree area and when inside the poplar area whether the sows were laying or not. Additionally, on days 13 and 28 after expected farrowing, the fenders confining the piglets to the farrowing huts were removed. Thus, piglets roamed freely in the farrowing field. Therefore, on these days, the location of the litter was recorded (defined as the location of more than half the piglets in the litter). The litter could be in the hut, poplar area, remaining paddock or out of sight.

#### 2.5. Statistical analyses

All data were analysed in SAS (SAS 9.3, SAS Institute Inc., Cary, NC, USA). Visual plots showed that hut temperature and humidity were strongly correlated, and thus only hut temperature was included in the statistical analysis. The effect of parity was included in the model as follows: Sows in their first parity were assigned to parity group 1; second to fourth parity sows to parity group 2 and sows above their fourth parity were assigned to parity group 3.

Furthermore, observation days were grouped in lactation periods. Days *pre-partum* (days 2 to 0 (where parturition took place)) were assigned period 1; days 1–4 *pp* were assigned period 2 (termed early *pp*); days 5–8 *pp* were assigned period 3 (termed late *pp*) and days 11 *pp* and above were assigned period 4 (termed late lactation) (days between day 8 and 11 were not included in the analyses). The hut temperature used in the analyses was the average for each lactation period (except for Model 3 where the daily average was used, see 2.5.1).

##### 2.5.1. Study 1

All initial models (except for the analysis of sow surface temperature, Model 3) included the variables: treatment (access to poplars v. no access to poplars), parity group, period, hut temperature and the two-way interactions treatment\*period, period\*hut temperature,



treatment\*hut temperature. The final models, after removal of statistically non-significant ( $P > 0.05$ ) effects, are shown below.

For the analysis of the average number of observations per period sows were in the hut, the following generalised linear model was used,

$$Y_{ijk} = T_i + O_j + \beta_1 t_{ijk} + T_i * O_j + \varepsilon_{ijk} \quad (\text{Model 1})$$

where  $T_i$  refers to the effect of treatment ( $i$ : in poplars or no poplars),  $O_j$  is the effect of period ( $j$ : *pre-partum*, early *pp*, late *pp* or late lactation),  $\beta_1$  is the effect of hut temperature in interaction with treatment,  $t$  describes the effect of hut temperature ( $t$ ) (index  $i,j,k$  where  $k$  refers to sow number).  $T_i * O_j$  refers to the effect of the interaction between treatment and period, and  $\varepsilon$  is the normal distributed residual error. *Post hoc* pairwise comparisons of LS means were made for the treatment-period interaction. Results of the model are provided as LS means with standard error.

Due to many zeroes in the dataset, the number of observations per period where sows chose to lie in the wallow (termed “wallowing”) was converted to a binomial variable by considering all means  $> 0$  as ones and all 0 as zeroes. The analysis was done by use of the following binomial generalised linear model.

$$\text{logit}(\pi) = \beta_0 + \sum_{i=1}^2 \alpha_i \text{Parity}_i + \sum_{j=1}^3 \gamma_j \text{Period}_j \quad (\text{Model 2})$$

$\beta_0$  refers to the intercept for the combination parity group 3 and period 4 (“late lactation”).  $\alpha_1$  and  $\alpha_2$  describe the effect of parity group 1 and 2 in relation to the reference (parity group 3).  $\text{Parity}_1$  and  $\text{Parity}_2$  are indicator functions implying these sum to 0 (if parity group is in 3) or 1 (if parity group is in 1 or 2).  $\gamma_1$ ,  $\gamma_2$ , and  $\gamma_3$  describe the effect of period 1 (“*pre-partum*”), period 2 (“early *pp*”) and period 3 (“late *pp*”) in relation to period 4 (“late lactation”).  $\text{Period}_{1-3}$  are indicator functions. Results of this model are presented as odds ratios (OR) with 95% confidence interval (CI).

For the analysis of average maximum sow surface temperature on day 1–3 *pp*, the following variables were included in the initial model: treatment, parity group, day *pp*, hut temperature (average temperature for each day) and the two-way interactions treatment\*parity, treatment\*day *pp*, treatment\*hut temperature, day *pp*\*hut temperature. The analysis was conducted using the following final generalised linear model,

$$Y_{ijk} = \beta t_{ijk} + \varepsilon_{ijk} \quad (\text{Model 3})$$

where  $\beta$  is the parameter describing the effect of hut temperature (index  $i$ : in poplars or no poplars;  $j$ : in day *pp*;  $k$ : in sow number), and  $\varepsilon$  is the normal distributed residual error. Results are provided as LS means with standard error.

### 2.5.2. Study 2

Due to many zeroes in the dataset (sows were only in the poplars 7% of the total number of observations) the average number of observations where sows were in the poplars per period (termed “poplar use”) was converted to a binomial variable by considering means  $> 0$  as ones and all 0 as zeroes. The following binomial generalised linear mixed model was used for the analyses.

$$\text{logit}(\pi) = \beta_0 + \sum_{j=1}^3 \gamma_j \text{Period}_j \quad (\text{Model 4})$$

$\beta_0$  refers to the intercept for period 4 (“late lactation”), and  $\gamma_{1-3}$  describe the effects of period $_{1-3}$  (“*pre-partum*”, “early *pp*”, “late *pp*”).  $\text{Period}_{1-3}$  are indicator functions. Sow number was included as a random effect to account for repeated measures within sow. The initial model also included the variables: parity, hut temperature and the two-way interaction period\*hut temperature, but these were removed by backward elimination of statistically non-significant effects ( $P > 0.05$ ). Results of Model 4 are presented as OR with CI.

The variable “lying in poplars” refers to the number of observations

sows were lying in the poplar area divided by the number of observations of sows in the poplar area for each period. For the analysis of this variable, a linear mixed model was used,

$$Y_{jk} = \beta t_{jk} + \vartheta_{jk} + \varepsilon_{jk} \quad (\text{Model 5})$$

where  $\beta$  is the parameter describing the effect of hut temperature ( $t$ , index  $j$  in period (“*pre-partum*”, “early *pp*”, “late *pp*”, “late lactation”);  $k$  in sow number), and  $\vartheta$  is the normal distributed random effect accounting for repeated measures within sow (index  $j,k$ ).  $\varepsilon$  is the normal distributed residual error. The initial model also included the variables: parity, period and the two-way interaction period\*hut temperature. The results of Model 5 are presented as LS means with standard error.

The binomial generalised linear mixed model shown below was used for the analysis of whether piglets were located in the poplar area, using each observation point as the statistical unit.

$$\text{logit}(\pi) = \beta_0 + \beta_1 \text{Sow location} \quad (\text{Model 6})$$

$\beta_0$  refers to the intercept Sow location in “not with piglets”.  $\beta_1$  is the parameter describing the effect of Sow location “same as piglets” in relation to Sow location “not with piglets”. Sow location “same as piglets” is included as an indicator function. Hut number was included as a random effect to account for repeated measures within hut. The initial model also included time of day and the interaction Time of day\*Sow location. Results are provided as OR with CI.

A binomial generalised linear mixed model was also used to analyse whether piglets were located in hut, again using each observation as the statistical unit.

$$\text{logit}(\pi) = \beta_0 + \beta_1 \text{Time of day} + \beta_2 \text{Sow location} \quad (\text{Model 7})$$

$\beta_0$  refers to the intercept for Time of day “not morning” and Sow location “not with piglets”.  $\beta_1$  is the parameter describing the effect of Time of day “morning” in relation to the reference Time of day “not morning”. Time of day is an indicator function.  $\beta_2$  describes the effect of Sow location “same as piglets” in relation to Sow location “not with piglets”. Sow location “same as piglets” is included as an indicator function. Hut number was included as a random effect. The interaction Time of day\*Sow location was also included in the initial model. Results are presented as OR with CI.

## 3. Results

The average hut temperature (for both treatment groups) during the observation period was  $19.5 \pm 4.1$  °C (raw mean  $\pm$  standard deviation, range 10.1–30.1 °C) *pre-partum*,  $20.3 \pm 3.2$  °C (range 11.0–32.5 °C) early *pp*,  $20.3 \pm 3.1$  °C (range 12.6–32.5 °C) late *pp*, and  $24.2 \pm 4.2$  °C (range 14.1–32.1 °C) in late lactation.

### 3.1. Study 1

The results showed an interaction between treatment and period ( $F_{3,85} = 4.2$ ,  $P = 0.008$ , Table 1) for the percentage of observations of sows inside the farrowing hut. The results of the interaction can be found in Fig. 3. Sows with access to poplars were observed fewer times inside the hut *pre-partum* ( $51 \pm 4\%$  of the observations LSmean  $\pm$  SE) compared to controls ( $74 \pm 3\%$  of the observations), whereas post farrowing no significant differences between the two treatment groups were found. Both control and poplar sows were observed less inside the hut during late lactation compared to all other periods.

There was an interaction between treatment and hut temperature ( $F_{1,85} = 10.9$ ,  $P = 0.001$ ) which showed that sows with access to poplars decreased their use of hut when temperature increased, whereas such a decrease could not be shown for control sows. At the lower 10 percentile of the hut temperature (18.2 °C) sows with access to poplars were inside the farrowing hut  $74 \pm 4\%$  (LS mean  $\pm$  SE) of the observations compared to  $46 \pm 5\%$  of the observations at the upper 90

**Table 1**

Summary of the output from the final models (Model 1: number of observations per period where sows were in the hut; Model 2: sows in wallow or not, Model 3: maximum sow surface temperature on day 1 to 3 *postpartum*) used in Study 1. Temperature refers to hut temperature and treatment refers to whether sows had access to poplars (P) or not (C). *Pre-partum* refers to days 2 to 0 (where parturition took place), *Early pp* is 1 to 4 *postpartum* (*pp*), *late pp* is days 5 to 8 *pp* and *late lac* days 11 *pp* and above (excluding days between day 8 and 11 *pp*). OR refers to odds ratio and 95% CI to the 95% confidence interval.

Model	Variable	Levels	F	p
1	Temperature* Treatment* Period	Continuous See Fig. 3	F <sub>1,85</sub> = 10.9 F <sub>3,85</sub> = 4.2	< 0.001 0.008

Model	Variable	Levels	No. of observations	OR	95% CI	X <sup>2</sup>	p	
2	Parity group	1	24	6.42	1.3:31.1	(2df) = 6.2	0.045	
		2	37	2.24	0.5:9.3			
		3	35	1				
	Period	<i>Pre-partum</i>	22	0.102	0.014	0.018;0.58	(3df) = 49.7	< 0.001
		<i>Early pp</i>	25	0.008		0.002;0.091		
		<i>Late pp</i>	22	1		0.001;0.061		
<i>Late lac</i>		27						

Model	Variable	Levels	No. of observations	F	p
3	Temperature	Continuous	63	F <sub>1,61</sub> = 6.1	0.016

percentile of hut temperature (24.6 °C). Contrary control sows were inside their hut 65 ± 3% and 72 ± 3% of the observations, respectively for the lower and upper percentile of hut temperature.

The use of the wallow did not depend on hut temperature or differ between the treatment groups but was affected by parity group (X<sup>2</sup> = (2df) = 6.2, P = 0.045, Table 1) and period (X<sup>2</sup> = (3df) = 49.7, P < 0.001). The percent of observations each group of sows were seen wallowing within each period is shown in Table 2. Sows in parity group 1 had higher odds of wallowing compared to sows in parity group 3 (parity group 1 in relation to parity group 3 odds ratio (OR) of 6.42, CI [1.3;31.1]). The odds of wallowing did not differ significantly between parity groups 1 and 2 or between groups 2 and 3.

The odds of sows wallowing were higher in late lactation compared to all other periods. The OR of wallowing *pre-partum* compared to late lactation was 0.102 (CI[0.018;0.58]) and in *early pp* OR 0.014 (CI [0.002;0.091]) and *late pp* OR 0.008 (CI[0.001;0.061]) compared to late lactation. The odds of wallowing were higher *pre-partum* compared to *early* and *late pp* but did not differ significantly between the latter two.

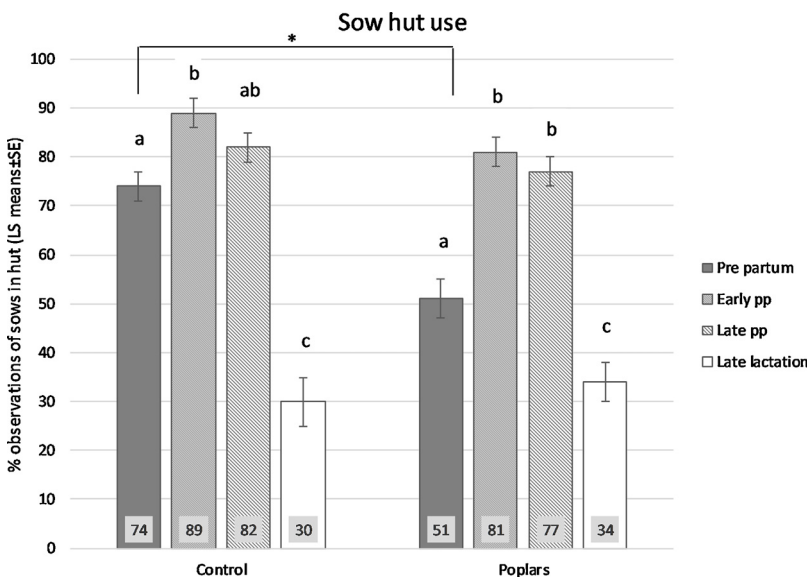
The only variable affecting sow surface temperature (when lying in the hut) was hut temperature (F<sub>1,61</sub> = 6.1, P = 0.016, Table 1), and a

**Table 2**

The percent observations sows in each parity group (parity group: 1) first parity sows, 2) sows in their 2nd to 4th parity, 3) sows above their 4th parity) were seen wallowing within each of the four lactation periods (*Pre-partum* including the day of farrowing); *Early postpartum* (*pp*) (days 1–4 *pp*); *Late postpartum* (days 5–7 *pp*); *Late lactation* (days 11 *pp* and above). Values are presented as medians with range (in brackets).

	Period	Observations of sows in the wallow (%)			
		<i>Pre-partum</i>	<i>Early pp</i>	<i>Late pp</i>	<i>Late lactation</i>
Parity group	1	4 (0-7)	0 (0-2)	0 (0-2)	12 (2-24)
	2	1 (0-21)	0 (0-4)	0 (0-3)	20 (2-31)
	3	2 (0-3)	0 (0-0)	0 (0-0)	18 (0-37)

five-degree increase in hut temperature increased maximum sow surface temperature by 0.82 ± 0.3 °C. The median hut temperature on days 1–3 *pp* was, respectively, 19.6 °C (range 16.9–23.8 °C), 19.7 °C (17.7–22.8 °C), and 21.6 °C (18.2–23.0 °C) and correspondingly the median of the maximum sow surface temperature on these days was, respectively, 37.2 °C (33.9–38.5 °C), 36.9 (35.1–38.7 °C), 36.8 (35.5–37.8 °C).



**Fig. 3.** LS Means and standard error are shown for the percent of observations where the sows were in the hut for each treatment group (access to poplars (Poplars) or not (Control)) and period (*Pre-partum* including the day of farrowing); *Early postpartum* (*pp*) (days 1–4 *pp*); *Late postpartum* (days 5–7 *pp*); *Late lactation* (days 11 *pp* and above).

a,b,c refer to statistical significant differences (P < 0.05) between periods within treatment group.

\* Refers to significant differences (P < 0.05) between treatment groups within periods.

**Table 3**

Summary of the output from the final models (Model 4: sows in the poplar area or not; Model 5: the number of observations sows were lying in the poplars/number of observations of sows in poplar for each period; Model 6: piglets in poplars (each observation point as statistical unit); Model 7 piglets in hut (each observation point as statistical unit) used in Study 2. *Pre-partum* refers to days 2 to 0 (where parturition took place), Early *pp* is 1 to 4 *postpartum* (*pp*), late *pp* is days 5 to 8 *pp* and late lac days 11 *pp* and above (excluding days between day 8 and 11 *pp*). OR refers to odds ratio and 95% CI to the 95% confidence interval.

Model	Variable	Levels	No. of observations	OR	95% CI	F	p
4	Period	<i>Pre-partum</i>	45	0.13	0.03;0.527	$F_{3,141} = 14.0$	< 0.001
		Early <i>pp</i>	50	0.02	0.01;0.08		
		Late <i>pp</i>	52	0.03	0.01;0.12		
		Late lac	54	1			
5	Temperature	Continuous	120			$F_{1,105} = 25.2$	0.030
6	Sow location	With piglets	514	82.7	59.7;114.6	$F_{1,2000} = 703.9$	< 0.001
		Not with piglets	1488	1			
7	Time of day	Morning	756	1.7	1.3;2.2	$F_{1,1999} = 14.6$	< 0.001
		Not morning	1246	1			
	Sow location	With piglets	453	158.9	92.8;272.1	$F_{1,1999} = 341.2$	< 0.001
Not with piglets	1549	1					

### 3.2. Study2

The odds of the sows being within the poplar tree area were not affected by hut temperature but depended on period ( $F_{3,141} = 14.0$ ,  $P < 0.001$ , Table 3). The odds were highest in late lactation and second highest *pre-partum* compared to early and late *pp*. *Pre-partum* sows were in the poplars 2% (median, range 0–30%) of the observations, early *pp* 0% (0–14%), late *pp* 0% (0–23%) and late lactation 22% (0–68%). The OR of sows being in the poplars was 0.13 (CI[0.03;0.53]) for *pre-partum* compared to late lactation, 0.02 (CI[0.01;0.08]) for early *pp* compared to late lactation and 0.03 (CI[0.01;0.12]) for late *pp* compared to late lactation. When inside the poplars, sows were more likely to lay when hut temperature increased ( $F_{1,105} = 25.2$ ,  $P < 0.001$ , Table 3). Once inside the poplar tree area sows were observed lying  $16.5 \pm 11\%$  of the observations when hut temperature was  $\leq 18.8^\circ\text{C}$  (the lower 10% quartile) compared to  $68.8 \pm 5.8\%$  of the observations when hut temperature was  $\geq 24.8^\circ\text{C}$  (the upper 90% quartile). The average, minimum and maximum temperature and humidity recorded within the farrowing hut, in the poplar area and in the open farrowing field are shown in Table 4.

The OR of the piglets being within the poplars was 82.7 (CI [59.7;114.6]) when the sow was also in the poplars ( $F_{1,2000} = 703.9$ ;  $P < 0.001$ ). Eighty-five percent of the piglets were observed in the poplars when the sows was also in the poplars compared to 6% when the sow was elsewhere in the paddock.

Whether piglets were in the hut or not also depended on the sow's location ( $F_{1,1999} = 341.2$ ;  $P < 0.001$ , Table 3), and the odds were higher when the sow was inside the hut (OR 158.9, CI[92.8;272.1]). Ninety-seven percent of the observations of piglets in the hut were when the sow was also in the hut whereas only 16% of the observations were of piglets in the hut when the sow was elsewhere in the paddock.

**Table 4**

Temperature and humidity recordings are given for recordings made inside the farrowing huts, in the poplar area and in the paddock (recorded in an open part of the farrowing field) throughout the experimental period. Values are given as means and range. Range refers to the minimum and maximum point recordings (recordings were made every ten minutes from 3 days prior to expected farrowing until 25 days after expected farrowing). N refers to the number of data loggers in each location.

		Location of logger		
		Hut (N = 71)	Poplars (N = 8)	Paddock (N = 1)
Temperature ( $^\circ\text{C}$ )	Mean	20.4	16.2	18.4
	Range	7.0 to 42.5	7.6 to 33.6	5.0 to 48.5
Relative humidity (%)	Mean	69.9	73.5	78.8
	Range	17.7 to 100	7.6 to 100	1.6 to 100

Furthermore, the odds of the piglets being inside the hut were higher in the morning (06:00 to 11:00 h) compared to the remaining part of the day (13:30 to 22:00 h) (OR 1.7, CI[1.3;2.2],  $F_{1,1999} = 14.6$ ;  $P < 0.001$ ) irrespective of sow location. In the morning, 41% of the observations of piglets were in the farrowing hut compared to 31% in the remaining part of the day. During morning 27% of the observations were of sows inside the hut, and the during the rest of the observation period sows were in the hut 24% of the observations.

## 4. Discussion

### 4.1. Study 1

Access to poplars was accompanied by a change in the sows' use of the farrowing hut. Sows with access to poplars markedly decreased their use of the hut when hut temperature increased, whereas this could not be shown for control sows. It was unexpected that sows without access to poplars did not decrease their use of the hut when hut temperature increased. Studies show that pigs seek shade when ambient temperature increases (e.g. growers compared at 21 v. 24  $^\circ\text{C}$  in Heitman et al. (1962) and weaners, growers, dry sows and boars observed at temperatures ranging from 15 to  $> 35^\circ\text{C}$  in Blackshaw and Blackshaw (1994)). The current result may therefore suggest that sows without alternative shade in the farrowing field seek shade inside the farrowing hut even at high hut temperatures. Furthermore, the temperature recordings in the present study showed that the maximum temperature recorded in the field is higher compared to that of the hut. Therefore, even though hut temperature was high, sows may have been more able to thermoregulate inside the shade of their huts. The observations in Study 2 of 57 sows with poplars did however, not show a relation between hut temperature and the use of poplar trees. Although, sows may have been able to seek shade and cooler temperature close to the poplars without being inside the tree area (for example when the sun was low in the west, poplars in east-facing paddocks would cast a small shadow along the outer line of trees).

Sows with access to poplars were less inside the hut *pre-partum* compared to control sows, whereas no difference in use of the hut was seen early and late *pp* where sows in general spent most of the observation period inside the farrowing hut. In agreement, Jensen (1986) found that sows spend most of their time in the nest during the first 9 days *pp*, Buckner et al. (1998) showed that newly farrowed sows spend most of their time inside the hut, and a Danish study (observing 167 sows with willows in the farrowing field) observed that sows with access to willows spend around 80% of their time in the farrowing hut in the first week after farrowing (Bonde, 2016), which is comparable to the results from this study. Since sows with access to poplars did not decrease their use of the hut during the nest bound period, access to poplars did not appear to reduce the sows' willingness to remain with

their piglets in the present study.

To improve the sows' opportunity to thermoregulate, Danish free-range and organic sows are provided with access to a wallow during the warm season (Anon., 2017). Surprisingly, no relation between hut temperature and wallowing was found. This contrasts with several other studies showing more wallowing in growing pigs (Heitman et al., 1962; Huynh et al., 2005) and gilts (Huynh et al., 2007) at increasing temperatures. The reason for the discrepancy between the present and previous studies may be that the current study focused on lactating sows, or the fact that the wallow was only present at temperatures above 15 °C. The presence of piglets and the motivation to remain in the nest may have suppressed the sows' motivation to leave the hut to wallow. However, it should be noted that hut temperature and period were confounded, as the temperature was higher in late lactation compared to the remaining three periods. Still, not only in late lactation but also *pre-partum* (where hut temperature was comparable to early and late *pp*) sows were more likely to use the wallow compared to during early and late *pp*.

The first parity sows had higher odds of wallowing than high parity sows (parity group 3). This could be due to multiparous sows being more experienced and having developed better maternal qualities. Thus, multiparous sows may be more reluctant to leave the nest and their piglets to wallow.

Maximum surface temperature clearly increased with increasing hut temperature. This is in accordance with results found under indoor conditions for loose-housed sows (Malmkvist et al., 2012) and confirms that increased signs of thermoregulation occur when hut temperature increases, also in a temperate climate with relatively low summer temperatures. Recordings of surface temperature were only made while sows were lying in the hut and it cannot be excluded that those sows, which were most thermally challenged, may have left the hut.

#### 4.2. Study2

Since studies have demonstrated that sows and pigs seek shade at increasing temperature (Heitman et al., 1962; Blackshaw and Blackshaw, 1994), pigs may use shade as a mean for thermoregulation. Contrary to the expected, the likelihood of the sows seeking the poplars was unaffected by hut temperature but depended on period and was higher *pre-partum* and in late lactation compared to early and late *pp*. This corresponds with Bonde (2016) who also found that sows preferred location was inside the hut in the week after farrowing. The effect of period may indicate that the sows were motivated to remain in the hut with their piglets during this period. However, no interaction between temperature and period was found for the total use of the poplars. Therefore, the increased use of the poplar area *pre-partum* and in late lactation suggests that the sows may have used the poplars for something besides thermoregulation. Only few sows were observed gathering poplar branches for nest building, consequently, the increased use of the poplars *pre-partum* was likely caused by another use of the tree area. Bonde (2016) observed that 19.4% of the sows with piglets of 1–4 weeks of age used willows for grassing, and 19.4% rooted in the willow area, whereas none of the sows with piglets younger than a week of age were observed using the willow area. Thus, the current results may reflect an increased motivation of the sows to explore and forage *pre-partum* and in late lactation. However, the results could also reflect varying needs for thermoregulation in the different periods of lactation. The need to thermoregulate *pre-partum* and in late lactation may be higher compared to early and late *pp*. In the *pre-partum* period sows are heavy and own heat production is increased (Feyera and Theil, 2017). Furthermore, day 0 was included in this period and thus the increased activity during nest building likely also added to the sows heat load. During the late lactation period, the temperature was generally high and also sows own heat production may have been high due to peak lactation (Feyera and Theil, 2017).

In the present study, when sows were inside the poplar area, sows

lay more when hut temperature increased, suggesting they preferred resting in the shade of the trees during high temperature. In accordance, the average and maximum temperatures recorded in the poplar tree area were lower than both the temperatures recorded in the hut and the open part of the farrowing field. Bonde (2016) also found that sows with older piglets (1 to 4 weeks of age) lay more in an area with willow trees at ambient temperatures above 15 °C, and at temperatures above 20 °C 26% of the observations were of sows lying in the willow area. The poplar area, in the current study, provided cover along with more space, compared to the hut, which could also make the poplar area an attractive resting place. This would also allow the piglets to lie more distributed and away from the sow, which would reduce heat load from the piglets onto the sow.

The piglets' main source of nourishment in the first weeks *post-partum* is milk from the sow (Damm et al., 2003). Piglet location was therefore expected to depend on the location of the sow. In accordance, the current study showed that, regardless of the location being in the hut or in the poplars, the major determiner for piglet location was the location of the sow. Additionally, the odds of finding piglets in the hut were higher in the morning compared to the remaining part of the day, irrespective of the sow's location, probably because piglets spent the night and early morning in their nest (hut). The sows' use of the farrowing hut did not appear to differ between the morning and the remaining part of the day, and in both these periods sows were most often observed outside the hut.

During the entire study period, sows spent time inside the poplar area, irrespective of the hut temperature. However, sows were more often observed lying in the poplars when hut temperature increased, suggesting they used the cool poplar tree area for thermoregulation.

#### 5. Conclusion

Together, the results of the study suggest that providing sows with access to an area with poplar trees could serve as a mean in the future to improve the welfare of sows kept in outdoor production systems. Providing the sows with alternative shade in the farrowing field allowed the animals to rest, and likely thermoregulate, in the shade of the trees. When sows were active, the poplars appeared to serve another purpose which could be as an area for exploration and foraging.

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