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Swedish University of Agricultural Sciences

Faculty of Veterinary Medicine and
Animal Science

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– Depending on the measuring method and location of the measuring

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– Beroende på mätmetod och mätplats

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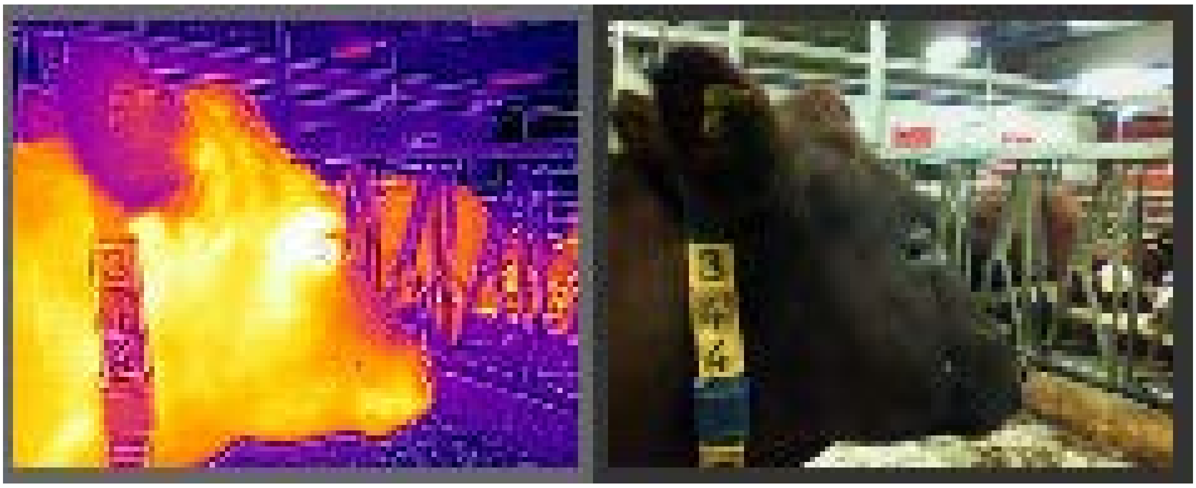

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Förändringar i mjölkkors temperatur – Beroende på mätmetod och mätplats –

Jessica Isaksson

Supervisor: Birgitta Staaf Larsson
Department: Department of Anatomy, Physiology and Biochemistry

Examiner: Kristina Dahlborn
Department: Department of Anatomy, Physiology and Biochemistry

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Abstract

Lactating cows have a higher heat production due to the milk synthesis compared to dry cows. In the regulation and general advice regarding animal husbandry (SJVFS 2010:15) it is stated that animals should be kept in thermal comfort. Animals have thermal comfort within the thermoneutral zone, where the animals can maintain their heat balance without any difficulty. The thermoneutral zone is restricted by the lower and upper critical temperature. When the temperature in the environment is lower than the lower critical temperature, the animal needs to increase their metabolism to maintain their body temperature. When the temperature in the environment instead is higher than the upper critical temperature the animals will start to sweat or pant, in an attempt to lower the body temperature. If they cannot get rid of the excess heat the body temperature will increase. No measurement of the thermal comfort is made in Sweden today, during the official dairy farm inspections. The aim of this study was therefore to examine if it is possible to measure cows' thermal comfort by measuring their heat loss.

Temperature measurements were collected from 20 dairy cows (eleven Swedish Red and White cattle and nine Swedish Holstein), at Lövsta the Swedish Lifestock Research Centre at SLU, Uppsala. The temperature measurement methods examined, were one rectal thermometer (Microlife AG, model MT20RA), one skin temperature meter (DM852), one IR meter (TN1) and two IR cameras (FLIR E8 and FLIR C2). The skin temperature meter and the IR meter were used to measure the temperature both ten centimeters below the hip bump and at the neck, while the IR meter also were used to measure the temperature at the vulva. The rectal thermometer was used to measure the temperature seven to eight centimeters into the rectum and photos were taken with both IR cameras at the eye, udder and vulva. The measurements were conducted monthly during the study period (6th February, 8th February, 10th February, 9th March, 19th April, 17th May, 21th June, 18th July, 30th August, 27th September, 13th October, 7th November, 13th December and 18th January). A weather station (Nexus prologue, model: IW004/36-5136) was used to measure the temperature and relative humidity in the middle of the stable. The mean temperatures and variance calculated for the lactating- and dry cows were used to make charts that evaluated and compared the measurement methods. The cows' milk yield was also obtained and compared to the mean udder temperature.

The conclusion was that the IR meter was most suitable to measure the cows' thermal comfort, because the mean temperature followed the housing temperature the most and the variance was low even if the housing temperature increased. The skin temperature meter and the IR camera FLIR C2 was after the IR meter the measuring methods that were most suitable to measure the cows' thermal comfort. These measuring methods was less suitable compared to the IR meter because they followed the housing temperature less and generated a larger variance. The measuring methods that was the least suitable to measure the cows' thermal comfort were the rectal thermometer and the IR camera FLIR E8. It is however important to remember that the result for the IR cameras could have been different if different measuring locations would have been chosen. More research is needed to construct the most effective method to measure cows' thermal comfort. It is also important to look at the farmers' perspective and generate a method that they practically can use to improve the cows' thermal comfort.

Sammanfattning

Mjölkkor har en högre värmeproduktion på grund av deras mjölkproduktion jämfört med sinkor. I Statens jordbruksverks föreskrifter och allmänna råd (SJVFS 2010:15) om djurhållning inom lantbruket m.m. (saknr. L100) står det att djurens behov av termisk komfort ska tillgodoses. Djur har termisk komfort inom den termoneutrala zonen, där djuren kan behålla sin värmebalans utan några svårigheter. Den termoneutrala zonen begränsas av den nedre och övre kritiska temperaturen. När temperaturen i miljön är lägre än den lägre kritiska temperaturen, måste djuret öka sin ämnesomsättning för att bibehålla sin kroppstemperatur. När temperaturen i miljön istället är högre än den övre kritiska temperaturen kommer djuren börja svettas eller hässja i ett försök att minska sin kroppstemperatur. Om de inte kan bli av med överskottsvärmen kommer deras kroppstemperatur att öka. Inga mätningar görs dock idag i Sverige gällande den termiska komforten vid offentliga djurskyddskontroller. Syftet med denna studie var därför att undersöka om det går att mäta mjölkkors termiska komfort genom att mäta deras värmeavgivning.

Temperaturmätningar togs från 20 mjölkkor (elva Svensk röd och vit boskap och nio Svensk Holstein) på Lövsta forskningscentrum, SLU, Uppsala. Temperaturmätnings-metoderna som undersöktes var en rektaltermometer (Microlife AG, modell: MT20RA), en hudtemperaturmätare (DM852), en IR-mätare (TN1) och två IR-kameror (FLIR E8 och FLIR C2). Hudtemperaturmätaren och IR-mätaren användes båda tio centimeter nedanför sittknölen och vid nacken, medan IR-mätaren också mätte temperaturen vid vulvan. Rektaltermometern mätte temperaturen sju till åtta centimeter in i rektum och foton togs med båda IR-kamerorna vid ögat, juvret och vulvan. Mätningarna utfördes en gång per månad under studieperioden (6 februari, 8 februari, 10 februari, 9 mars, 19 april, 17 maj, 21 juni, 18 juli, 30 augusti, 27 september, 13 oktober, 7 november, 13 december och 18 januari). En fuktighetsmätare (Nexus prologue, modell: IW004/36-5136) användes också för att mäta temperaturen och luftfuktigheten i mitten av stallet. Medelvärdena och variansen för de lakterande- och sinkorna beräknades och användes för att göra grafer, vilka utvärderade och jämförde mätmetoderna. Kornas mjölkavkastning jämfördes även med juvrets medeltemperatur.

Slutsatserna är att IR-mätaren är mest anpassad för att mäta kornas termiska komfort eftersom medeltemperaturen följde stalltemperaturen mest och för att variansen var låg även om stalltemperaturen ökade. Hudtemperaturmätaren och IR-kameran FLIR C2 var efter IR-mätaren mest anpassad att mäta kornas termiska komfort. Dessa mätmetoder var mindre anpassade jämfört med IR-mätaren eftersom de följde stalltemperaturen mindre och genererade en större varians. Mätmetoderna som var minst anpassade att mäta kornas termiska komfort var rektaltermometern och IR-kameran FLIR E8. Det är dock viktigt att komma ihåg att resultatet för IR-kamerorna kunde ha blivit annorlunda om andra mätplatser hade valts. Mer forskning behövs för att konstruera den mest effektiva metoden för att mäta kors termiska komfort. Det är också viktigt att studera det ur bönders perspektiv och generera en metod som de praktiskt kan använda för att öka kors termiska komfort.

Introduction

In today's dairy production it is important that each dairy cow (*Bos taurus*) gets the opportunities needed so they can have an optimal milk production. The milk production is for example affected by the breed of the cow (Sjaastad *et al*., 2010), the lactation state (Phillips, 2010) and the feed and water intake (Sjaastad *et al*., 2010). The temperature in the body are influenced by the management, the environment and physiological factors. These physiological factors may for example be the overall health of the animal, the reproduction state and the level of activity and excitement (Bewley *et al*., 2008b).

The body temperature is often measured when cows' thermal status is determined (Hicks *et al*., 2001). The main goals are to identify any change that occurs from what is considered a normal state and to prevent disease. This makes it possible to make an early detection of sick cows, which ensures quick treatment and a higher profitability for the dairy producers (Smith & Risco, 2005). Some locations for measuring the temperature is for example the rectum, ear, udder, vagina, reticulorumen (Firk *et al*., 2002) and the skin (DiGiacomo *et al*., 2014). Measuring the rectal temperature (Hicks *et al*., 2001) with a digital thermometer (Simmons *et al*., 1965) is however the most common measuring method. The rectal thermometer is cheap and easy to use (Hicks *et al*., 2001), but it requires direct contact between the investigator and the animals (Hicks *et al*., 2001). This can make the cows nervous and alter the body temperature (Simmons *et al*., 1965).

In the regulation and general advice regarding animal husbandry (SJVFS 2010:15) it is stated that animals should be kept in thermal comfort. No measurement of the thermal comfort is however made today in Sweden, during the official dairy farm inspections. The aim of this study was therefore to examine if it is possible to measure cows' thermal comfort by measuring their heat loss. The regulation and general advice regarding animal husbandry (SJVFS 2010:15) explains that animals have thermal comfort within the thermoneutral zone, where the animals can maintain their heat balance without any difficulty. The thermoneutral zone is restricted by the lower- and upper critical temperature. When the temperature in the environment is lower than the lower critical temperature, the animal needs to increase their metabolism and eat more to maintain their body temperature. When the temperature in the environment instead is higher than the upper critical temperature the animals will start to sweat or pant in an attempt to lower their body temperature. The temperature measurement methods that were examined were one skin temperature meter, one infrared (IR) meter, one rectal thermometer and two IR cameras, FLIR E8 and FLIR C2. This study is a part of Birgitta Staaf Larsson a doctor in philosophy (PhD) student at Swedish University of Agricultural Sciences (SLU) study, which is funded by the Swedish Animal Welfare Society.

Background

Regulation of the body temperature

The thermoregulatory system consists of a sensory component, a thermoregulatory centre and a motor component. The sensory component consists of neurons, which are called thermosensors. These thermosensors are nerve endings that are located in both the skin and the core of the body. The thermosensors monitor the temperature and transmit information to the thermoregulatory centre. The thermoregulatory centre is located in hypothalamus and it determines when the body is to warm, to cold or at an appropriate temperature. The motor component consists of neurons that sends command signals which regulate the heat production and heat loss in the body (Sjaastad *et al*., 2010).

The core body temperature

The core body temperature is the body's inner temperature and it is located in the central nervous system, the organs, the thorax, the abdomen and in the limbs. Mammals have a core body temperature between 36.5^{o}C to 39.5^{o}C and the temperature is relative constant. The core body temperature is regulated mainly by reflexes in the body, which is an impulsive motor pattern that the spinal cord or the extended marrow triggers as a respond to a specific sensory stimulus. The core body temperature is often measured in the rectum in domestic animal. The temperature can vary 0.5^{o}C to 1.0^{o}C over a period of 24 hours. If the core body temperature is as high as 44.0^{o}C or as low as 25.0^{o}C it is fatal or can give irreversible brain damage (Sjaastad *et al*., 2010).

When animals are kept in a temperature which is in their thermoneutral zone, no adjustment of the heat production is needed to keep the optimal core body temperature (Sjaastad *et al*., 2010). Water evaporates from the body all the time in an attempt to regulate the body temperature, except when the relative humidity (RH) is 100 percent (Kadzere *et al*., 2002). RH is defined as the ratio between the current partial pressure of the steam in the air and the maximum partial pressure in the current air temperature. This means that the value of RH changes depending on the air temperature because air can carry different amounts of water in different temperatures (Sällvik & Ehrlemark, 2007). If the air temperature drops below the lower limit of the thermoneutral zone cows will increase their heat production to keep a stable core body temperature. If the air temperature instead rises, cows will start to sweat or pant, in an attempt to lower the body temperature (Sjaastad *et al*., 2010). Thermal sweating (Kadzere *et al*., 2002) and panting (Sjaastad *et al*., 2010) occurs when the ambient temperature rises (Kadzere *et al*., 2002). Panting is a rapid and shallow breathing which increases the water evaporation in both the mouth and airway (Sjaastad *et al*., 2010).

The body surface temperature

The temperature of the outer shell of the body is called the skin temperature and consists of the skin and subcutaneous adipose tissue. The skin temperature can vary very much because it is the body's most efficient tool for keeping a nearly constant body temperature. If animals need to lower their temperature, heat is transported by the blood from the core of the body, to the skin. The temperature of the skin is therefore depending on the peripheral blood flow. When the body temperature increase, the impulse in the sympathetic nerve fibres to the blood vessels in the skin will decrease. As a result, the blood vessels will dilate and the flow of blood to the skin will rise, which increase the skin temperature (Sjaastad *et al*., 2010).

Thermoregulation

Thermoregulation consists of both heat gain and heat loss and the body temperature varies due to both internal and external factors (Figure 1). Heat gain is influenced by both the metabolism and the environment. The metabolism is an internal factor and cows have feed requirements for maintenance and an increased feed requirement for exercise, growth, lactation, gestation and feeding. If a cow for example has a high milk production, the heat gain will increase and in order to keep a constant body temperature the heat loss must increase as well, through thermoregulation. The environment is an external factor and it influences the cows' heat gain through radiation, conduction and convection. Almost all heat gained during daytime, comes direct or indirect from solar radiation. Heat gain from conduction occurs only if the cow is laying or standing on a surface that is warmer than the skin temperature, while heat gain from convection only occurs if the air temperature is higher than the skin temperature. Heat loss is also affected by both the metabolism and the environment. Heat loss occurs when milk, faeces and urine are removed from the body but also by radiation, conduction, convection and evaporation. Heat loss from radiation occurs all the time but it is higher during night when the ambient temperature is lower compared to the skin temperature. Conduction and convection generate heat loss when the surroundings are cooler than the body. Evaporation generates heat loss when the air temperature is lower than the temperature in the skin and respiratory passages (Fuquay, 1981). Other factors that also affect the body temperature are for example the cows' age, parity number, the production type, housing system, how often the cows are milked and which milking system the producers use (Smith & Risco, 2005).

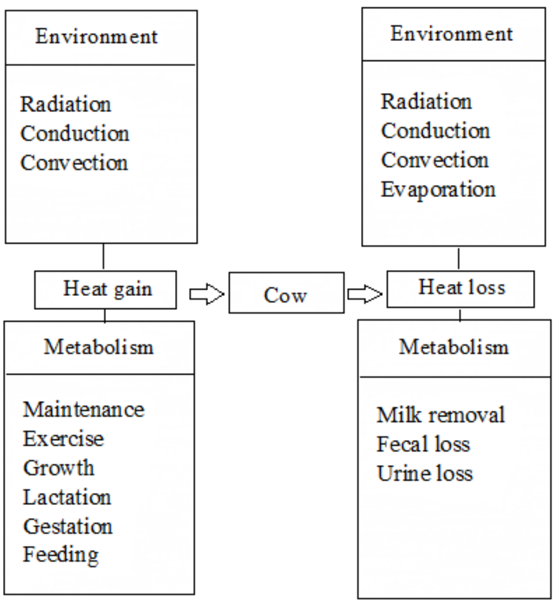

Figure 1: A modification from Fuquay, (1981). It shows that cows' body temperature is affected by internal (metabolism) and external (environmental) factors. These factors make the cows gain and lose heat, which helps them to maintain the body temperature.

External work and body mass affect heat production

When cows are on their dry period, the feed intake only needs to cover the maintenance requirement. During the lactation period the feed intake must increase because cows need three to four times more energy to support the milk production. The higher feed intake during the lactation period will result in a larger total heat production during this period. If cows do not have any production, like producing milk, growing or being pregnant, all the energy released from the nutrients will be converted to heat. If they instead produce milk and perform physical work approximately 20 percent of the released energy will be used for the production and the remaining 80 percent will be converted to heat (Sjaastad *et al*., 2010).

Heat production will increase with an increasing body mass and heat loss will increase relative to the body surface area. Large animals like cows have a smaller surface area relative to the body mass compared to smaller animals, while the body temperature between different mammals is almost the same. Cows will therefore have a lower heat loss per unit body mass compared to smaller animals. Large animals also have a lower metabolic rate and they may therefore have more difficulties too receive an optimal body temperature because they will store more heat in the body (Sjaastad *et al*., 2010).

Heat stress and its effect on the production

Heat stress is caused by a combination of different environmental factors like the ambient temperature, RH, wind, solar radiation and rainfall (Bohmanova *et al*., 2007). Heat stress can result in health problems like mastitis, poor reproduction or lameness and it can also reduce the milk production and the quality of the milk (Hicks *et al*., 2001).

Detection of heat stress

Heat stress and diseases are often detected by measuring the body temperature (Hicks *et al*., 2001). Animals have different sensitivity to the ambient temperature and RH, which means that their thermoneutral zone differs (Bohmanova *et al*., 2007). Cows have a normal body temperature between 38.3^{o}C to 39.4^{o}C (Hicks *et al*., 2001) and in order to keep a constant body temperature they need to be in equilibrium with the environment (Kadzere *et al*., 2002).

Temperature humidity index

When animals' thermal comfort is measured, the Temperature Humidity Index (THI) is used. This index measures the degree of heat stress the animals are under with help of the air temperature and RH (Sällvik & Ehrlemark, 2007). Bohmanova *et al.* (2007) concluded that cows are less affected by heat stress if they are exposed to hot but dry air, with a RH between 22 to 28 percent. When RH then rises, the cows' ability to cool down will decrease and their milk production will decline. Avendaño-Reyes (2012) explains the connection between the ambient temperature and RH (Figure 2). Dairy cows are not affected by heat stress if THI is below 72 units, with an ambient temperature of $\leq$ 25.0^{o}C and 50 percent RH. In these conditions lactating dairy cows will reach their optimal production. When dairy cows are affected by mild heat stress, THI is between 72 and 79 units. The ambient temperature is either 25.0^{o}C with RH above 50 percent or 30.0^{o}C with RH above 30 percent. In these conditions, dairy cows will start to look for shade and the respiration rate will increase. When dairy cows are affected by moderate heat stress the THI is between 80 to 89 units. The temperature is either 35.0ºC with RH of 40 percent or 40.0ºC with RH of 35 percent. In these conditions, dairy cows' body temperature and respiratory rate will increase even more, as well as the saliva production and water intake, while the food intake will decrease. The fertility and milk production will also be affected negatively. Dairy cows are affected by severe heat stress when THI is between 90 to 98 units. The temperature is either 40.0ºC with RH of 60 percent or 49.0ºC with RH of 35 percent. In these conditions, dairy cows will be very uncomfortable because the body temperature and respiration rate will increase very much. The milk production and fertility will decline even more and it may even lead to death.

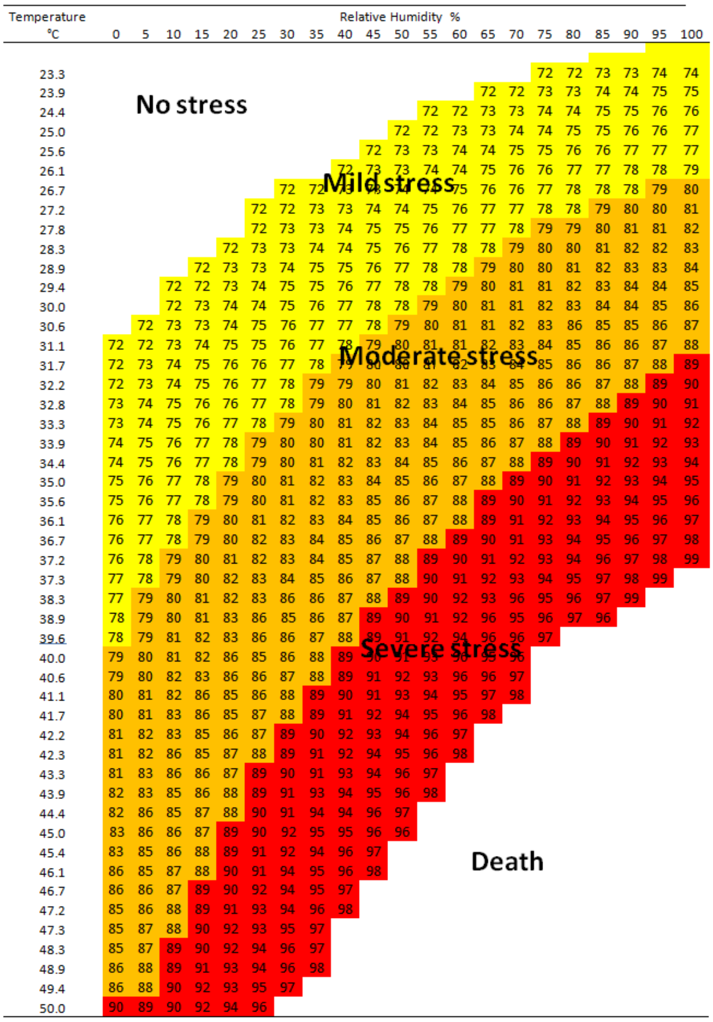

Figure 2: From the book: Milk Production - an up-to-date overview of animal nutrition, management and health (Avendaño-Reyes, 2012). It shows the connection between the ambient temperature and RH which makes up the THI. Different values of the THI gives dairy cows' different degree of heat stress.

How heat stress affect the rectal temperature and respiration rate

Dairy cows' thermal adaptability was investigated by Srikandakumar & Johnson (2004). The cows participating in the study were from the breeds Holstein, Jersey and American milking zebu. Blood samples were collected, the respiratory rate was measured and the rectal temperature was measured with a digital thermometer. The results showed that the rectal temperature and the respiratory rate increased in all the breeds when the cows were affected by heat stress. Cincović *et al.* (2011) and Lemerle & Goddard (1986) could also see that the rectal temperature and respiratory rate increased when cows were affected by heat stress. Lemerle & Goddard (1986) concluded however, that this happened when THI reached a certain value. The rectal temperature increased when THI was greater than 80 units and the respiratory rate increased when THI was approximately 73 units. The results from Lemerle & Goddard (1986) suggest that the increase in respiratory rate at a lower value of THI can prevent an increase in the rectal temperature until the THI reaches 80 units.

Dairy cows' milk production

Dairy cows today do not produce more milk per kilogram body weight than other mammals, but they have a longer lactation period which means that they produce a larger total amount of milk (Phillips, 2010). A dairy cow produces on average 25 to 30 litre milk every day but it varies between individuals and younger cows tend to have a lower milk production (McDonald *et al*., 2011).

Lactation curve

When dairy cows are milked, the lactation curve will start with an increase in the milk production from the time when the calf is born until 35 days postpartum (McDonald *et al.*, 2011). The cows will then reach the peak lactation and after that point the production will start to decline (Sjaastad *et al*., 2010). The reduction is on average 2.0 to 2.5 percent per week but for cows in their first lactation the reduction is 1.5 to 2.0 percent per week (McDonald *et al*., 2011). A graphic example on a lactation curve can be seen in Figure 3, where the peak lactation is 30 litre per day at week six and the reduction under the remaining lactation period is 2.0 percent per week.

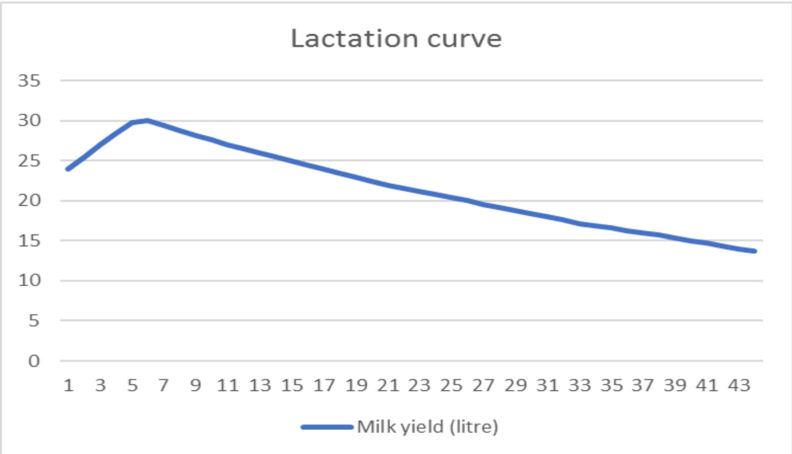

Figure 3: Graphic example of a lactation curve, where the peak lactation is 30 litres, six weeks into the lactation and the reduction under the remaining lactation period is 2.0 percent per week.

During the lactation period, dairy cows produce milk with an energy content that is three to four times higher than their maintenance requirement is under the dry period (Sjaastad *et al.*, 2010). Dairy cows should always have a dry period that last for six to eight weeks before the next calving (Sjaastad *et al*., 2010).

Lactating cow's temperature

Lactating dairy cows create much more metabolic heat due to their milk production compared to dry cows. The body temperature can be lowered if the cows are milked because heat is stored in the milk. The temperature can also be lowered if cows have access to shade in the milking parlour in the summer (Araki *et al*., 1984). Araki *et al.* (1984) measured the vaginal temperature on Holstein-Friesian cows and could see a large difference between cows in early and late lactation and all cows had a drop in their body temperature when they were milked. Araki *et al.* (1984) could also see a significant difference in the temperature between dry cows and lactating cows, where the difference was largest when the ambient temperature was high. The lactating cows were also more sensitive to different environmental factors, compared to the dry cows.

Monitoring the health of the animal

There are many different methods to measure dairy cow's health, for example, milk yield, general attitude, blood component analysis and the rectal temperature. Measuring the rectal temperature is today the most common method and it is often measured during the postpartum period to detect infection (Smith & Risco, 2005). When high producing dairy cows are in their postpartum period they undergo a time of physiological stress, which makes it important to detect illness early (Wagner *et al*., 2007). If dairy cows stay healthy in their postpartum period, they will later have an increase in their day-to-day milk production. Any deviation from what is considered a normal health status will cause a drop in the milk production, which lowers the producers' profits (Smith & Risco, 2005).

When cows get an infection and inflammation, trauma or both, the body temperature will increase above the optimal body temperature, which result in fever (Benzaquen *et al*., 2007). Fever helps the body to combat certain types of infections but the mechanism behind it is still unknown. When the temperature increases above what is optimal, the thermoregulatory center will interpret this and the heat production will exceed the heat loss (Sjaastad *et al*., 2010). Sheldon *et al*. (2004) measured the rectal temperature on Holstein-Friesian cows during ten days after parturition, to estimate if the cows had fever. The conclusion was that the cows had fever if they had a temperature $\geq 39.7^{o}$C. Burfeind *et al.* (2010) also studied the rectal temperature and a temperature of $\geq 39.4^{o}$C was used to define if the cows had fever.

Rectal temperature

Using the rectal temperature to measure the temperature is a proven method and lot of research has been done on its usability (Bewley *et al*., 2008a; Burfeind *et al*., 2010; Naylor *et al*., 2012; Sheldon *et al*., 2004; Smith & Risco, 2005; Wagner *et al*., 2007). Veterinarians, researcher and producers also agree that the use of the rectal temperature is a great tool for detection of disease five to ten days after delivery (Smith & Risco, 2005).

Variation of the rectal temperature

Using rectal temperature as the main measuring method can result in a variation of the temperature between individual cows. This variation could be between 101^{o}F to 103^{o}F, which correspond to 38.6^{o}C to 39.4^{o}C. Healthy cows have however a narrower variety of the rectal temperature than sick cows and the temperature is normally ≤ 102ºF, which corresponds to ≤ 38.9ºC (Smith & Risco, 2005). The rectal temperature varies during the day regardless if the cows are affected by heat stress or not. This variation arises due to seasonal changes and physiological factors. When cows are affected by heat stress, this variation helps them to cope because they can store heat in the body during the day and use it during night (Lemerle & Goddard, 1986).

The rectal temperature is directly affected by the ambient temperature and when the ambient temperature rises the rectal temperature will increase as well (Bewley *et al*., 2008b). Other factors that also affects the rectal temperature are the housing system, how often the cows are milked and which milking system the producers use (Smith & Risco, 2005). Bewley *et al.* (2008a) also concluded that the rectal temperature is affected by the depth and duration of the probe inserted, and the presence of air or feces in the rectum.

The method used to measure the rectal temperature

A digital thermometer is often used to measure the rectal temperature. No general method on how to use the rectal thermometer (penetration depth and angle) is however available today which can lead to inaccurate results. Naylor *et al.* (2012) made therefore a study with the aim to determine an appropriate method for using digital thermometers on cattle. The rectal temperature was measured on cows that were a cross between Holstein, Brahman and Red and Black Angus, by students. The students used their own digital thermometers and inserted the thermometer less than five centimetres into the rectum, twice. The rectal temperature was also measured with a Cornell mercury thermometer that was inserted twelve centimetres into the rectum by a trained clinician. The result showed that the rectal temperature was significantly different between the cows and the thermometer that were used. The rectal temperature varied also depending on whether it was a student or a trained clinician who measured the temperature. When a student measured the rectal temperature, it could be as much as 0.94ºC lower, but the mean difference between the students and the trained clinician was 0.50ºC.

The effect the investigator has on the measured rectal temperature was investigated by Burfeind *et al.* (2010). The rectal temperature was first measured with a digital thermometer (GLA M750) by the same investigator and then by two investigators. Burfeind *et al.* (2010) also investigated the difference between four digital thermometers (GLA M750, MTI8101, Domotherm TH1 and MT1831) when the same investigator measured the rectal temperature. The result showed that the measurements taken by the same investigator had a higher repeatability and that the choice of thermometer can influence the measured rectal temperature up to 0.30ºC.

Penetration angel

The penetration angel used to insert the thermometer and its effect on the measured rectal temperature has been investigated by Naylor *et al*. (2012). A trained veterinarian inserted a digital thermometer differently, three times into the rectum on ten different cows. The digital thermometer was first inserted in a neutral angel, the second time with the tip pointed down so it touched the ventral mucosa and the third time with the tip pointed upwards so it touched the dorsal mucosa. The result showed that the rectal temperature varied less than 0.10°C depending on the penetration angel.

Penetration depth

The penetration depth used when the rectal temperature is measured has been investigated by Burfeind *et al.* (2010). Two different penetration depths, 6.0 or 11.5 centimeter into the rectum were examined with a digital thermometer (MTI8101). The result showed that the penetration depth had an impact on the measured rectal temperature. When the thermometer was inserted 11.5 centimeter into the rectum it generated a higher rectal temperature compared to the rectal temperature measured on the penetration depth of 6.0 centimeter. The choice of penetration depth influences the measured rectal temperature up to 0.40°C.

The mean rectal temperature

The mean rectal temperature has been measured in many studies with different types of thermometers (Bewley *et al*., 2008a; Naylor *et al*., 2012; Sheldon *et al*., 2004; Simmons *et al*. 1965). Bewley *et al.* (2008a) measured the rectal temperature with a digital thermometer (GLA M750) and the mean rectal temperature was 38.8°C. Naylor *et al*. (2012) also measured the rectal temperature with a digital thermometer. The mean rectal temperature was 38.5°C if an untrained student took the temperature and if the thermometer was inserted to the beginning of the display window the mean rectal temperature became instead 38.8°C. Naylor *et al*. (2012) also used a Cornell mercury thermometer to measure the rectal temperature and the mean rectal temperature became then 38.9°C. The rectal temperature has also been measured with an electronic thermometer by Sheldon *et al.* (2004) and the mean rectal temperature was 38.6°C. Sheldon *et al.* (2004) could also see that the mean rectal temperature was highest two days after parturition, 38.8°C and that the temperature then decreased to the lowest value of 38.3°C on day ten.

The mean pararectal temperature, which is near the rectum or the rectum muscle has been investigated by Simmons *et al*. (1965). This was done with radio telemetry, where the signal was picked up by a commercial radio receiver. Temperature sensitive transmitters were surgically implanted in the crop, rumen and near the rectum in each cow and the mean pararectal temperature was 37.9°C ± 0.47°C.

How the health affects the rectal temperature

A critical period for cows is five to ten days after calving (Smith & Risco, 2005) and Wagner *et al*. (2007) evaluated therefore the rectal thermometer as a diagnostic tool. Some cows were removed during the study because they were categorized as sick, when their rectal temperature was above 40.3°C. It was therefore only possible to make a meaningful comparison of the cows' rectal temperature up to five days after calving. The result showed that the healthy cows had a lower rectal temperature at 8 am compared to 4 pm. The measurements taken 8 am shows that 26 percent of the healthy cows had at least one observation were the rectal temperature was ≥ 39.5°C and nine percent had a at least one observation were the rectal temperature was ≥ 39.7°C, the first ten days in milk (DIM). The sick cows had no significant difference in their rectal temperature before they were removed from the study, but they were more likely to have one observed temperature above 39.5ºC, the first three DIM.

Body surface temperature

The temperature in the skin varies due to environmental and physiological factors, but also depending on where the temperature is measured on the body (Zygmunt *et al*., 2013). The impact the stable temperature had on the skin temperature has been investigated by Zygmunt *et al.* (2013). The skin temperature was measured at eight different locations with a non-contact thermometer (Fluke 572 pyrometer) on hybrid cattle with at least 50 percent Holstein-Friesian breed. The measurements were taken two times every day during four days in September and eight days in October. The skin temperature was measured on the left and right side of the chest behind the shoulder, on the front and back of the udder, on the rump at the level of the hip joint and the hock joint. The result showed that the skin temperature, on all the measuring locations except for the right hock joint was higher in warmer stables. In both the cold and the warm stables the skin temperature was highest in the udder and lowest in the hock joint. The temperature was also higher in the evening for all the eight measuring locations, where the smallest difference was in the udder skin.

Measuring the skin temperature with infrared thermography

Infrared thermography (IRT) can be used to measure the skin temperature. This is a fast, easy, non-invasive method that does not require any direct contact between the investigator and the animals (Johnson *et al*., 2011). IRT measures the radiant energy from a surface (Berry *et al*., 2003) and the results are given as a thermogram. In these thermograms, every pixel represents a temperature (Metzner *et al*., 2014) and based on these thermograms conclusions can be drawn about the body- and skin temperature (Berry *et al*., 2003).

Using IRT can be of interest when cows have an inflammatory process in their body, like mastitis, which changes the peripheral blood circulation (Metzner *et al*., 2014). IRT is however a relatively new method and not many studies have investigated if IRT can be used to measure animals' body temperature. Metzner *et al*. (2014) mentions that one problem with thermography is to determine the area on the animals' where the photos should be taken. Another problem is that the tools available on the market for analysing the photos are designed for buildings and industrial constructions and are not designed to analyse live animals. Using this method at farms could also be difficult if the hygiene is poor, because this makes the cows dirtier. If the cows are dirty it is hard to get a reliable skin temperature, because the dirt can make the temperature lower. Removing the dirt with water could change the skin temperature depending on the temperature on the water and rubbing the dirt of makes the skin temperature higher because the blood circulation in the area will increase (Metzner *et al*., 2014).

The measurement location

It is important to find the hottest point in the area of interest when using IRT. If the temperature at the vulva is of interest it is hard to measure the hottest point because the tail is in the way. It is therefore easier to find the hottest point in locations like the eye or the back of the ear (Hoffmann *et al*., 2013). Hoffmann *et al.* (2013) studied if an IRT camera could be used to detect the body temperature in different parts of the body. The study was divided into two experiments, performed at two different locations. In the first experiment, cows with the breeds Holstein-Friesian, Jersey and cross breeds were used and data were collected during two days. The rectal temperature was measured eight centimetres into the rectum by the same investigator in the beginning of every thermography recording with a digital thermometer (Microlife VT 1831). Another investigator made the recordings with the infrared thermography video using a portable IR camera (OPTRIS PI 160). The recordings were taken on a distance of 30 to 40 centimetres on four different regions (the eye, back of the ear, shoulder and vulva), always on the cows' right side. In the second experiment, cows and calves with the breed Holstein-Friesian was used. As in the first experiment the rectal temperature was taken with a digital thermometer in the beginning of every thermography recording. The infrared temperature was measured at two places, the eye and back of the ear. The body temperature was used as a reference value and was measured with loggers in the vagina and with a digital thermometer in the rectum. The result from the first experiment showed that the body regions eye, back of the ear and vulva is more consistent with the body temperature than the shoulder region. The results from the second experiment with the IR camera showed that the temperature on both the body and the head rises when the rectal temperature increased up to 38.7^{o}C. It was also visible that the temperature on the body always was higher than the temperature on the head.

Measuring the eye temperature

Using IRT to measure the eye temperature is a fast and easy method which Church *et al*. (2014) investigated. Church *et al*. (2014) studied the relationship between the eye- and rectal temperature on Angus cross breed steers. Thermographic photos were taken with an IR camera (FLIR 140), at a distance of one meter. The rectal temperature was taken directly after the thermographic photos with a digital thermometer (GLA-M500). The result showed that the mean rectal temperature was 39.2^{o}C and the mean eye temperature was 37.5^{o}C. This means that the rectal temperature was on average 2.0^{o}C higher than the eye temperature.

How the environmental factor, solar loading affect the eye temperature was also investigated by Church *et al*. (2014). Thermographic photos were taken with an IR camera (E60) at the eyes on Holstein dairy cows, two times, 30 minutes apart from each other. When the first photo was taken, the left eye was exposed to sunlight, while the head of the cows provided shade for the right eye. The second time the photo were taken, both eyes were in the shade. The result showed that solar loading is strongly affected by the cows' hair colour. The IRT of the white part of the head had a temperature of approximately 35.0^{o}C while the black parts had a temperature of approximately 50.0^{o}C. Direct sunlight increased the eye temperature by 0.56^{o}C ± 0.36^{o}C, which means that exposure to direct sunlight can give false positive result. When the result becomes false positive it means that the temperature indicates that the cows have fever even if they do not. When the cows were in shade the temperature in the left and the right eye was almost the same (38.8^{o}C vs. 38.3^{o}C).

The effect the environmental factor, wind speed had on the eye temperature was also investigated by Church *et al*. (2014). Wind speeds of approximately seven and twelve kilometres per hour was used on dairy cows. The result was that the difference in the mean eye temperature was 0.43ºC and 0.78ºC, with the lower respective the higher wind speed. This means that the wind speed also has an effect on the eye temperature.

Measuring the udder temperature

The udder temperature can also be measured with IRT and Metzner *et al*. (2014) investigated if the skin temperature at the udder could detect acute mastitis and fever. First lactating Holstein-Friesian dairy cows were used and one day into the study the cows were injected with 2 ml of *Escherichia coli* in the teat cistern on the right side of the udder. The left side was injected with a placebo which consisted of 2 ml of sterile physiological saline. The thermography photos were taken, 1.8 meter from the rear of the cows, with a B20 HSV camera. The rectal temperature was also recorded with a digital thermometer. Before the cows were injected with *E.coli*, they had a rectal temperature < 39.5ºC and after the injection all the cows had a rectal temperature of ≥ 39.5ºC at least two times during the study. Before the study there were no difference in the skin temperature of the left and right side of the udder, but after the injection with *E.coli* a difference could be seen. After the injection, the skin temperature at the left side of the udder range from 34.1ºC to 37.7ºC and the right side range from 34.5ºC to 39.7ºC. Metzner *et al*. (2014) did also find a good correlation between the skin temperature of the udder and the rectal temperature in both parts of the udder. This shows that it is possible to monitor the cows' body temperature with thermography photos taken from the rear of the cows, at the udder.

The variation in the udder temperature was investigated by Berry *et al.* (2003) using IRT. The study was conducted during the summer on Holstein Friesian cows. The study was divided in two parts, where part one investigated how the udder and rectal temperature changed. Measurements of the rectal temperature and photos of the udder were taken twice every day. The first measurement was taken 30 minutes before the cows were released to an outdoor enclosure and the second measurement were taken two hours after they had returned indoors. Part two investigated how the udder temperature varied during 24 hours while the cows remained indoors. Measurements of the rectal temperature with a rectal thermometer (Pharmasystems LTD) and thermographic photos with a thermal scanner (FLIR Inframetrics 760) of the udder were taken every second hour during four days. The thermography photos were taken on the cows from a rear position at a distance of 2 to 2.5 meter when the cows were standing up with their tail held away. It was important that the udders were clean when the photos were taken. If the udders were dirty they were cleaned with warm water and then the photos were taken ten minutes after so the udders could regain their normal temperature. The udder temperature increased significantly after the cows had been in the outdoor enclosure, while the rectal temperature remained the same. The udder temperature was in general 3.0ºC to 5.0ºC colder compared to the rectal temperature. The udder temperature also varied during the day, where the temperature was lowest between 04:00 and 06:00 in the morning and highest during the afternoon/early evening. The smallest variability occurred between 14:00 and 18:00. This study shows that IRT is a promising method for early detection of mastitis if the environmental temperature also is monitored.

Material and method

Study design

Temperature measurements were taken from 20 dairy cows at Lövsta which is SLU's research facility outside Uppsala. The measurements were conducted four days in February (4th, 6th, 8th and 10th) and then monthly during the remaining study period (9th March, 19th April, 17th May, 21th June, 18th July, 30th August, 27th September, 13th October, 7th November, 13th December and 18th January). At the measurements taken between 17th May and 30th August the cows were held in an outdoor enclosure during night. The cows came in to the stable when it was time for the morning milking and were let out again after the evening milking. All the measurements were conducted around either the morning or evening milking and the time when the measurements were performed was written down for each cow. The measurements taken 6th, 8th and 10th February and 13th October were conducted around the morning milking and the remaining measurements were taken around the evening milking.

The participating cows

Lövsta manage their own recruitment, which means that no animal is bought in to the heard. The breeds used are Swedish Red and White cattle (SRB) and Swedish Holstein (SH) and eleven SRB and nine SH were used in this study. The stable accommodates 300 dairy cows and the cows' annual milk production 2015 was 2582 ton, while the average milk production per cow was 10120 kg energy-corrected milk (ECM). The cows are held in a warm loose house system, which are divided in three different sections (K1, K2 and K3). During the study period the cows were moved between these sections, depending on their lactation stage, health status and energy requirements. The cows are milked in an automatic milking rotary (AMR™) two times every day and they are inseminated approximately two months into their lactation period. The dry period begins approximately five to six weeks before parturition. When the cows start their dry period, they are moved to another part of the stable, which they share with heifers. Approximately four weeks before parturition the dry cows are moved to the calving area in the stable. After the delivery, the cows are moved to the part of the stable were the lactating cows are held (Lövsta research centre, 2016).

All the cows used in this study were newly calved and followed for one year. This includes their lactation period which lasts for approximately 305 days and their dry period which last approximately 40 days. The cows' parturition dates were between 15-12-22 to 16-02-05. The cow with the ID number 1581 calved first and the cow with the ID number 344 calved last. Information about the cows' ID number, breed, number of deliveries, parturition dates and when the cows started their dry period can be seen in Table 1. At the measurement 7th November, the cows with ID number 74, 83, 361, 367 and 375 had started their dry period. At the measurement 13th December, the cows with the ID number 74, 213, 344, 361, 375, 972 and 1581 were on their dry period while the cows with the ID number 83 and 367 were in the calving area in the stable. At the measurement 18th January, the cows with the ID number 213, 336, 360, 972, 1581 and 5357 were on their dry period, while the cows with the ID number 74, 83, 344, 361, 367 and 375 had started a new lactation period. No measurements were performed on the cows that had started a new lactation period because this study only follows the cows during one lactation and dry period.

The cow with the ID number 1475 was taken out of production 27th May due to complications at the calving. She was then replaced by the cow with the ID number 344 at the measurement 21th June. Both cows are of the breed SRB and they are treated as one cow in this study because it made future analysis easier. It is however important to remember that this can affect the results obtained because they are two different individuals with different genetics, age, parity number, personality and milk production. The cow with the ID number 961 did not want to do the measurement with the skin temperature meter at the neck, which can be due to a bad previous experience of syringes. This measuring method took approximately 72 seconds and at the first measure she shown apparent signs of stress and even left concentrate. This measurement was therefore marked as a missing value, at all the measurements except for the one taken 21th June, because at that measurement the skin temperature meter could be used on the neck.

Table 1: *Information about the cows' ID number, breed, parity number, calving dates and when the dry period begins*

ID number	Breed	Parity number	Parturition date	Drying of period	ID number	Breed	Parity number	Parturition date	Drying of period
47	SH	2	16-01-30	16-11-09	361	SRB	0	16-01-19	16-11-04
74	SH	2	16-01-23	16-10-28	363	SH	0	16-01-08	17-02-01
83	SRB	2	16-01-19	16-10-17	367	SH	0	16-01-12	16-10-23
90	SRB	2	16-01-10	16-10-03	370	SRB	0	16-01-13	16-11-17
213	SH	1	16-01-10	16-12-14	375	SRB	0	16-01-16	16-11-11
336	SRB	0	16-01-08	16-12-24	961	SH	4	16-01-09	16-02-28
344	SRB	0	16-02-05	16-11-20	972	SH	4	16-01-19	16-12-07
347	SRB	0	16-01-15	16-11-15	1475	SRB	5	15-12-22	16-05-27
352	SH	0	16-01-13	17-02-11	1581	SRB	4	16-01-25	17-01-26
358	SRB	0	16-01-04	16-11-04	5357	SRB	5	16-01-22	17-02-01
360	SH	0	16-01-28	17-01-03					

Temperature measurements

The cows' temperature was collected with five different temperature measurement methods by the same investigator. The measuring devices used was one rectal thermometer (Microlife AG, model MT20RA), one skin temperature meter (DM852), one IR meter (TN1) and two IR cameras (FLIR E8 and FLIR C2).

Rectal thermometer

The rectal temperature was measured with a digital thermometer (Figure 4), which use electronic heat sensors to record the body temperature (Mayo clinic, 2015). The temperature range is between + 32.0^{o}C to + 42.0^{o}C and the measurements were taken once at each measurement. The thermometer was inserted seven to eight centimeters into the rectum and therefore not all the way to the display window. When inserted the thermometer touched the intestinal wall and it took approximately 20 seconds to measure the temperature. It was important that the thermometer not only was held in the manure because then the thermometer would show a misleading temperature.

Skin temperature meter and IR meter

The skin temperature meter is a precision thermometer that measure the radiation (Figure 4). The thermometer has resistance temperature detectors and it is also temperature sensitive. The temperature detectors correlate the measured temperature to the resistance of a highly pure conductor. The resistance in the conductor increase when the temperature increase and decrease if the temperature decrease (Instrumart, 2017). The temperature range for the skin temperature meter is between – 1.0^{o}C to + 50^{o}C and the resolution is 0.10^{o}C (Ellab, 2017).

The IR meter is a non-contact infrared thermometer (Figure 4), but it should be positioned as close to the animal as possible (Ross Brown Sales Pty Ldt). The IR meter measure the infrared radiation. The infrared radiation is a type of electromagnetic radiation and the lens in the IR meter leads the thermal radiation onto a detector. The detector then converts the thermal radiation to an electrical signal (Azo sensors, 2015). The temperature range of the IR meter is between -32.9^{o}C to + 219.9°C, while the resolution is 0.1°C (Ross Brown Sales Pty Ldt).

The skin temperature meter and the IR meter were both used at the cow's neck and ten centimeters below the hip bump while the IR meter also was used to measure the temperature at the cow's vulva (Figure 5). The measurements taken with the skin temperature meter took approximately 72 seconds, while the measurement taken with the IR meter took approximately two seconds to perform. The measurements taken with the skin temperature meter was taken once at each visit, at each location. The part of the skin temperature meter that measured the temperature was placed under the hairs at the neck and hip bump so it had contact with the skin. The measurements taken with the IR meter was taken two times directly after each other at the same location, at each visit. The measurement with the highest value was then used. The IR meter measured the skin temperature on top of the hairs at the neck, hip bump and vulva.

Figure 4: Shows the rectal thermometer (Microlife AG, model MT20RA), the IR meter (TN1) and the skin temperature meter (DM852), in that order.

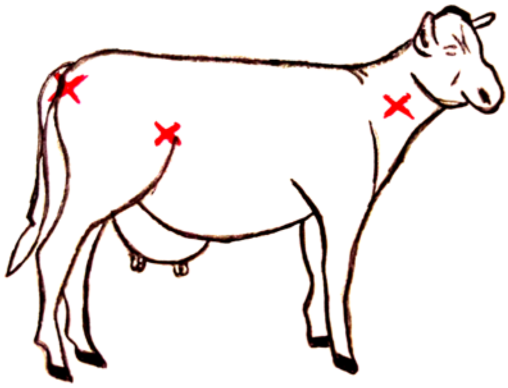

Figure 5: Shows were the measurements with the skin temperature meter and the IR meter was taken. Both measurement methods were used at the neck and ten centimetres below the hip bump, while the IR meter also was used at the vulva.

IR camera FLIR E8 and FLIR C2

The IR cameras measure infrared radiation and it is a non-contact measuring method. The infrared radiation is in fact heat radiation and the IR cameras converts the heat radiation into an electronic signal, which then is converted to a thermal photo. The thermal photo contains temperature data, which makes it possible to monitor thermal performance and to identify heat-related problems (FLIR, 2017).

The difference between the two IR cameras, FLIR E8 and FLIR C2 (Figure 6) is for instance that the temperature range and detector resolution differs. The temperature range for FLIR E8 is - 20.0^{o}C to + 250^{o}C, while the temperature range for FLIR C2 is -10.0^{o}C to +150^{o}C. The detector resolution for FLIR E8 is 320 X 240, while FLIR C2 has a detector resolution of 80 X 60 (ELFA DISTRELEC, 2016a, 2016b).

Photos were taken with both IR cameras at the cow's eye, udder and vulva (Figure 7). One photo was taken at each location from a maximum distance of one meter. The photos were always taken in the order eye, udder and vulva because it made the later analysis of the photos in the software FLIR tools easier. When the photos were analysed a circle was made around the area of interest. The software provided then automatically the highest (and lowest) value in that area and the highest value was used in further analyses.

Figure 6: Shows the IR cameras; FLIR E8 and FLIR C2, in that order.

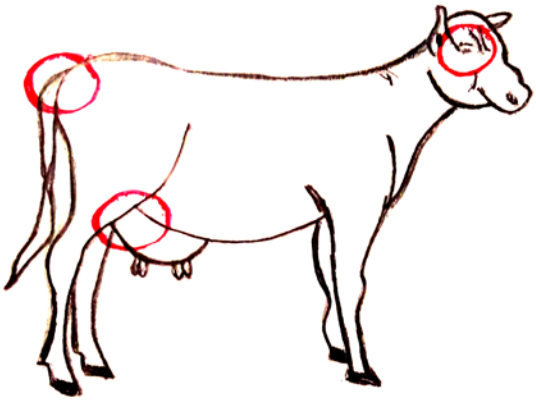

Figure 7: Shows were the measurements with the two IR cameras FLIR E8 and FLIR C2 were taken. The photos were always taken in the order eye, udder and vulva.

Record keeping of the measurements

The time when all the temperature measurements where taking place was recorded, as well as the time when the photos was taken with both IR cameras. The temperature obtained from the skin temperature meter, IR meter and rectal thermometer, was also recorded. Sometimes the cows did not want to be handled and then a rope was used to tie them up. But if the cows did too much resistance no measurement was taken and it became a missing value instead.

Calculations

The temperature measurements obtained 4th February were removed from future calculations because too few values were collected. All the other temperature values obtained from the other measurements were analysed in soft independent modelling of class analogy (SIMCA), which is a statistical method for classification of data. The temperature values within three standard deviations (SD) were used in future calculations because it includes 99.7 percent of the temperature values in a normal distribution. A total of 16 values were not within three SD and were therefore removed. Thirteen values were removed because they were too low and they were taken with the skin temperature meter, IR meter and both IR cameras. Three values were removed because they were too high and they were taken with the IR meter, IR camera FLIR E8 and the rectal thermometer (Appendix 1).

Mean values and variance

Mean values of the temperatures collected with the different measuring methods were calculated. Sometimes two measuring values were taken on the same cow with the same measuring method and then the highest value was used in the calculation. At the measurements 7th November, 13th December and 18th January, some cows had started their dry period and the mean values were therefore calculated separate for the lactating and dry cows. The mean values were used to make charts, which showed how the mean temperature changed over the study period in relation to the variance and housing temperature. The carts can be seen in the result part below.

The variance was calculated to see how much the temperature varied between cows. The variance was calculated separate for the lactating and dry cows because lactating cows produce much more heat, due to their milk production. If the temperature is similar between cows, there will be a smaller variance and if the temperature instead is more diverse there will be a larger variance.

The mean values and variance were calculated separate for the lactating and dry cows, based on all the remaining values obtained at each measurement (Appendix 2, Appendix 3 and Appendix 4). Different charts were then made based on the mean values and the variance.

Lactation curve

The participating cows' milk yield were registered and the data were used to make a lactation curve of the average milk production per cow and month. The cow with the ID number 1475 were replaced with the cow 344 at the measurement taken 21th June and the data on the cows' milk yield were only included when they were included in the study. The data used can be seen in Appendix 5. The average milk production for all the cows was also set in relation to the mean temperature obtained at the udder with the IR cameras FLIR E8 and FLIR C2.

Temperature and relative humidity in the stable

The temperature and RH was recorded with a weather station (Nexus prologue, model: IW004/36-5136) in the middle of the stable. The housing temperature was recorded at ten of the twelve measurements and the measurements that occurred 9th March and 21th June were not recorded. The RH in the stable was recorded at eleven of the twelve measurements and the measurement that occurred 9th March was not recorded. The measurements were not recorded at these measurement occasions because the batteries in the weather station run out of energy. At the measurement 7th November, cows had started their dry period and at the measurement 13th December, two cows were also held in the calving area of the stable. The housing temperature and RH was therefore also recorded in these sections of the stable.

Results

Calculation of the mean values and variance

Before the mean values were calculated, a total of 16 values were removed from future calculations. These values were either too low (< 3 SD) or too high (> 3 SD) in comparison to the other values taken with the same measuring method (Appendix 1). The number of values removed with each measuring method was, five values with the skin temperature meter, three values with the IR meter, one value with the rectal thermometer, three values with the IR camera FLIR E8 and four values with the IR camera FLIR C2.

Temperature measurements

A compilation of the five temperature measurement methods in relation to the housing temperature for both the lactating and dry cows, can be seen in Figure 8. The measuring method that followed the housing temperature the most was the IR meter, where the largest increase occurred during the summer measurements when the weather was warmer. The IR meter also obtained the lowest mean temperatures, compared with the other measuring methods, where the mean values at the hip bump and neck was lowest. The skin temperature meter was after the IR meter the measuring method that followed the housing temperature the most. The IR camera FLIR C2 had similar fluctuation during the study period as for the skin temperature meter, however no measurements were obtained at the measurements taken 17th May and 21th June, which made the analyse of this measuring method more difficult. The measurement methods that followed the housing temperature the least was the rectal thermometer and the IR camera FLIR E8 was after the rectal thermometer the measuring method that followed the housing temperature the least. Measurements at the udder and vulva with the IR camera FLIR E8 obtained the highest mean temperature during a large part of the study period compared to the other measuring methods.

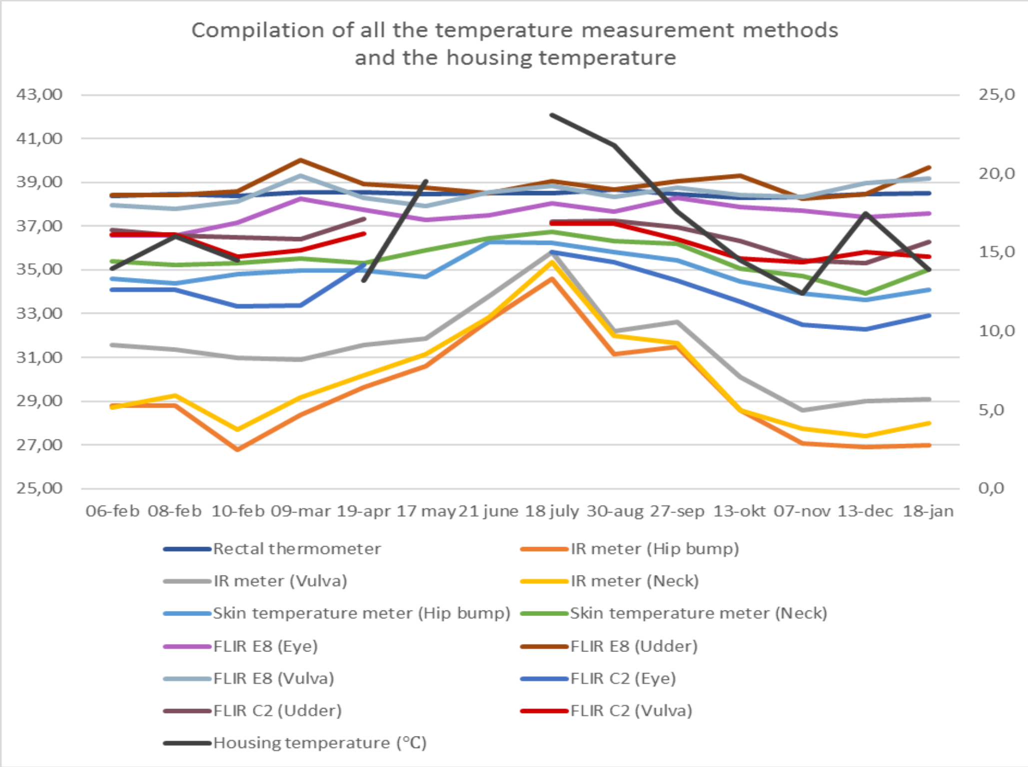

Figure 8: A compilation of the mean temperatures obtained with the five measurement methods (left axis) and the housing temperature (right axis) on both the lactating and dry cows during the whole study period.

Rectal thermometer

As expected, the dairy cows who participated in this study had a relatively constant mean rectal temperature and also a small variance, both on their lactation and dry period (Figure 9 and Figure 10). The mean rectal temperature was also not significantly affected by the housing temperature because the mean temperature remained almost the same during the measurements taken in the summer, even if the housing temperature increased.

The lactating cows obtained the highest mean rectal temperature, 38.7°C during the measurement taken 30th August, while the lowest mean rectal temperature, 38.3°C was obtained 13th October. The largest difference in the mean rectal temperature for the lactating cows was therefore only 0.40°C and throughout the whole study period the cows' overall mean rectal temperature was 38.5°C. The variance was largest in the beginning of the study period, at the measurement taken 6th and 8th February, but the variance was overall very low. The peak lactation occurred around the measurement taken 9th March, but the mean rectal temperature remained constant (Figure 9).

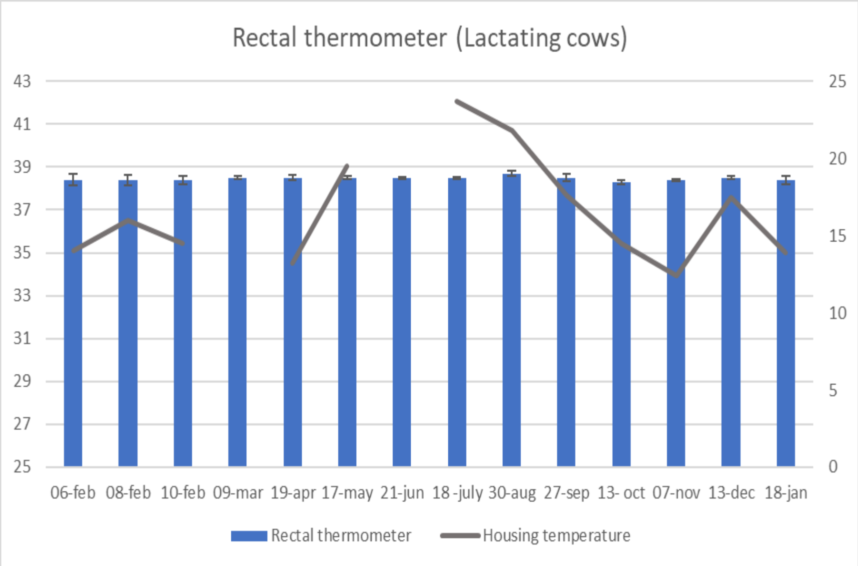

Figure 9: The lactating cows' mean rectal temperature (left axis) and the variance obtained with the rectal thermometer in comparison to the housing temperature (right axis).

The dry cows obtained the highest mean rectal temperature, 38.7°C during the measurement taken 18th January, while the lowest mean rectal temperature, 38.2°C was obtained 7th November. The largest difference in the mean rectal temperature for the dry cows was 0.50°C and the dry cows overall mean rectal temperature was as for the lactating cows, 38.5°C. The rectal temperature remained constant even if the housing temperature increases between the measurements taken 7th November and 13th December (Figure 10).

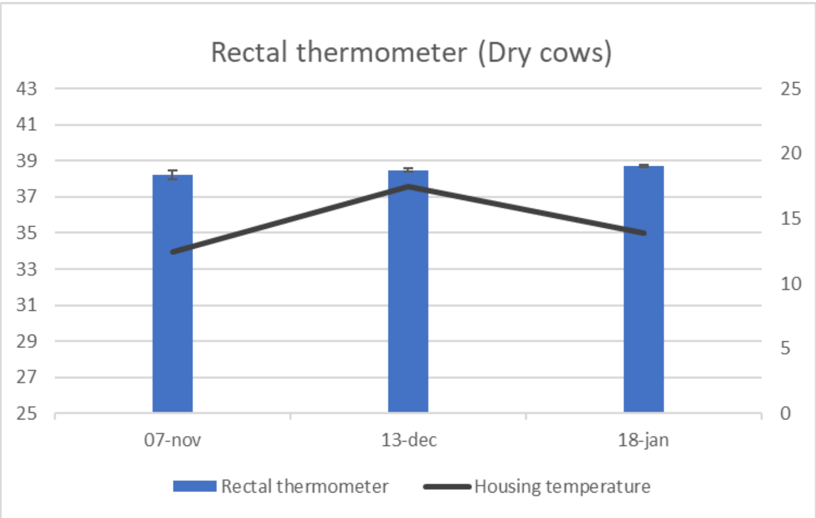

Figure 10: The dry cows' mean rectal temperature (left axis) and the variance obtained with the rectal thermometer in comparison to the housing temperature (right axis).

Skin temperature meter

The mean temperature and the variance obtained with the skin temperature meter, ten centimetres below the hip bump and at the neck is compared to the housing temperature for both the lactating and dry cows (Figure 11 and Figure 12).

The lactating cows' mean temperature obtained with the skin temperature meter is relatively constant in the beginning of the lactation period, between the measurements taken 6th February to 17th May. After that, there is an increase in the mean temperature taken on both locations, at the measurements taken during the summer, when the housing temperature increased. The highest mean temperature at the hip bump was 36.3°C 21th June, while the lowest mean temperature was 33.6°C 13th December. The highest mean temperature at the neck was instead 36.8°C 18th July, while the lowest mean temperature was 33.9°C 13th December. The largest difference in the mean temperature at the hip bump and at the neck was 2.7°C respective 2.8°C and throughout the whole study period the cows' overall mean temperature at the hip bump and neck was 34.9°C respective 35.5°C (Figure 11).

The lactating cows' variance at the neck is slightly larger compared to the variance at the hip bump during a large part of the study period. No variance was obtained at the measurement taken 17th May because the temperature was only measured on one cow (Figure 11). In the beginning of the study period the variance was larger on both measurement locations, and at the middle of the study period, when the housing temperature increased, the variance between the lactating cows were smaller. The smallest variance obtained at the hip bump was 0.26, 30th August, while the largest variance at the hip bump was 1.28, 6th February. The smallest variance at the neck was 0.1, 13th December, while the largest variance at the neck was 1.42, 13th October (Figure 11).

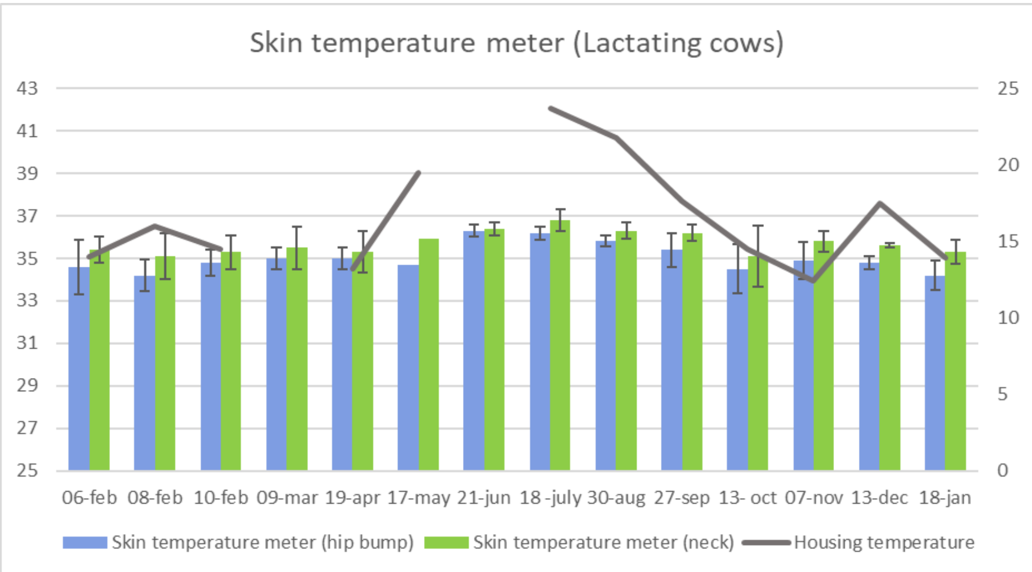

Figure 11: The lactating cows' mean temperature (left axis) and the variance obtained with the skin temperature meter, ten centimetres below the hip bump and at the neck, in comparison to the housing temperature (right axis).

The dry cows' mean temperatures measured with the skin temperature meter obtained the highest and lowest values at the same measurements at both the hip bump and neck. The highest mean temperatures at both the hip bump and neck was 34.0°C respective 34.6°C 18th January. The lowest mean temperature at both the hip bump and neck were 30.8°C respective 31.9°C 7th November. The largest difference in the mean temperature at the hip bump and neck was 3.2°C respective 2.7°C and throughout the dry period the cows' overall mean temperatures at the hip bump and neck was 32.3°C respective 32.9°C (Figure 12). In comparison to the lactating cows, the dry cows have a lower mean temperature at both measurement locations. The dry cows had also a larger difference in their overall mean temperature at both measurement locations compared to the lactating cows.

The largest and smallest variance at respective location occurs however at different measurement. The variance obtained at the neck was largest (5.24) 7th November and at the hip hump (2.64) 13th December. The smallest variance was instead obtained at the neck (0.06) 18th January and at the hip bump (1.05) 7th November (Figure 12).

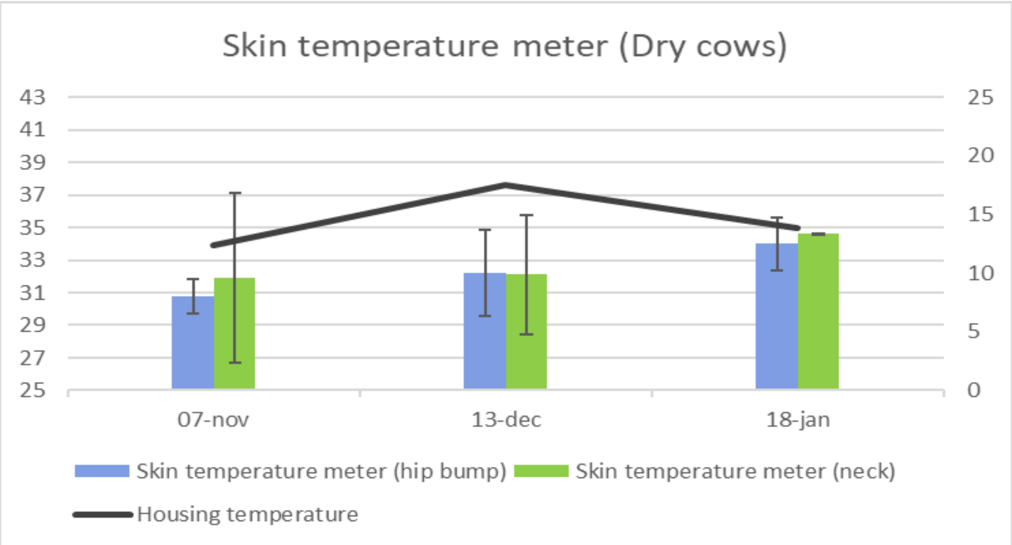

Figure 12: The dry cows' mean temperature (left axis) and the variance obtained with the skin temperature meter, ten centimetres below the hip bump and at the neck, in comparison to the housing temperature (right axis).

IR meter

The mean temperature and the variance obtained with the IR meter, ten centimetres below the hip bump, neck and vulva is compared to the housing temperature for both the lactating and dry cows (Figure 13 and Figure 14).

The lactating cows' mean temperature obtained with the IR meter at all the measured locations follow the housing temperature the most, compared to the other measuring methods. The highest mean temperatures were obtained at the vulva, while the mean temperatures at the hip bump and neck followed each other more. The highest mean temperature at the hip bump was 34.6°C 18th July, while the lowest mean temperature was 26.8°C 10th February. The highest mean temperature at the neck was 35.4°C 18th July, while the lowest mean temperature was 27.4°C 13th December. The highest mean temperature obtained at the vulva was 35.8°C 18th July, while the lowest mean temperature was 28.6°C 7th November. The largest difference in the mean temperature at the hip bump, neck and vulva was 7.8°C, 7.9°C respective 7.2°C. Throughout the whole study period the cows' overall mean temperature at the hip bump, neck and vulva was 29.3°C, 30.6°C and 31.4°C (Figure 13).

The variance obtained for the lactating cows was small even if the mean temperatures obtained with the IR meter increased with increasing housing temperature. The variance was larger in the beginning of the study period at the measurements taken 6th, 8th and 10th February, but also at the measurements taken 13th October. The largest variance at the hip bump (5.34), was obtained 13th October and the largest variance at the vulva (5.19) and neck (3.02) were instead obtained 6th February. The lowest variance at the hip bump (0.21) and neck (0.21) was obtained 17th May. The lowest variance at the vulva (0.14) was also obtained 17th May, but also 13th December. (Figure 13).

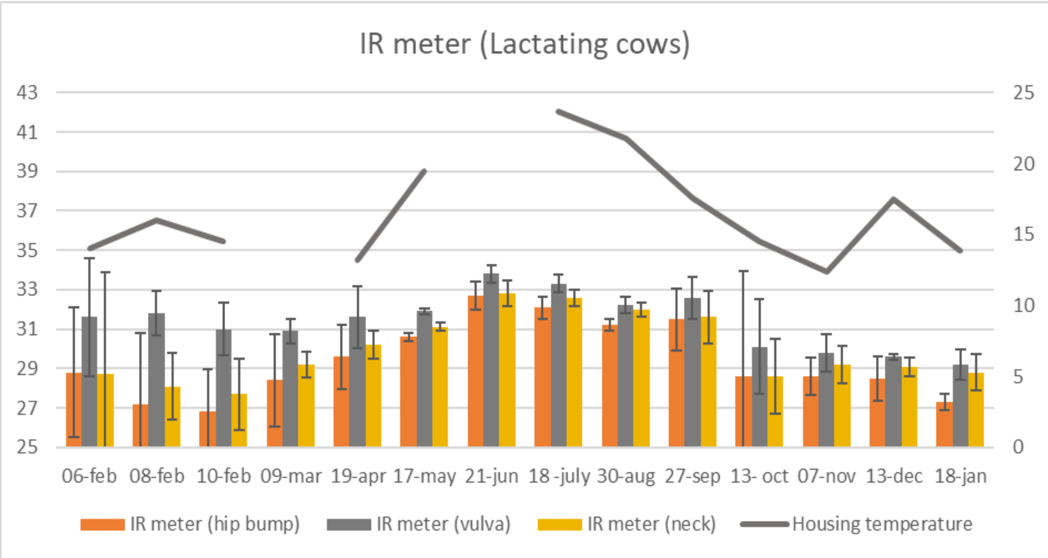

Figure 13: The lactating cows' mean temperature (left axis) and the variance obtained with the IR meter ten centimetres below the hip bump, neck and vulva, in comparison to the housing temperature (right axis).

The dry cows' mean temperature obtained with the IR meter had highest mean temperatures at the vulva and lowest at the neck. The highest mean temperature at all the measured locations was obtained 18th January and the lowest 7th November. The highest mean temperatures for the vulva, hip bump and neck was 29.1°C, 26.7°C respective 27.2°C. The lowest values obtained at the vulva, hip bump and neck was instead 25.0°C, 22.8°C respective 23.8°C. The largest difference in the mean temperature at the hip bump, neck and vulva was 3.9°C, 3.4°C and 4.1°C and throughout the dry period the cows' overall mean temperatures at the vulva, hip bump and neck was 27.7°C, 24.8°C and 25.5°C (Figure 14).

The dry cows had the largest variance at the vulva (2.99), 13th December, while the variance at the hip bump (1.28) and neck (2.53) was largest 18th January respective 13th December. The smallest variance was obtained at the neck (0.69) 18th January, while the variance at the hip bump (0.77) and vulva (0.96) was smallest at the measurements taken 13th December respective 18th January (Figure 14).

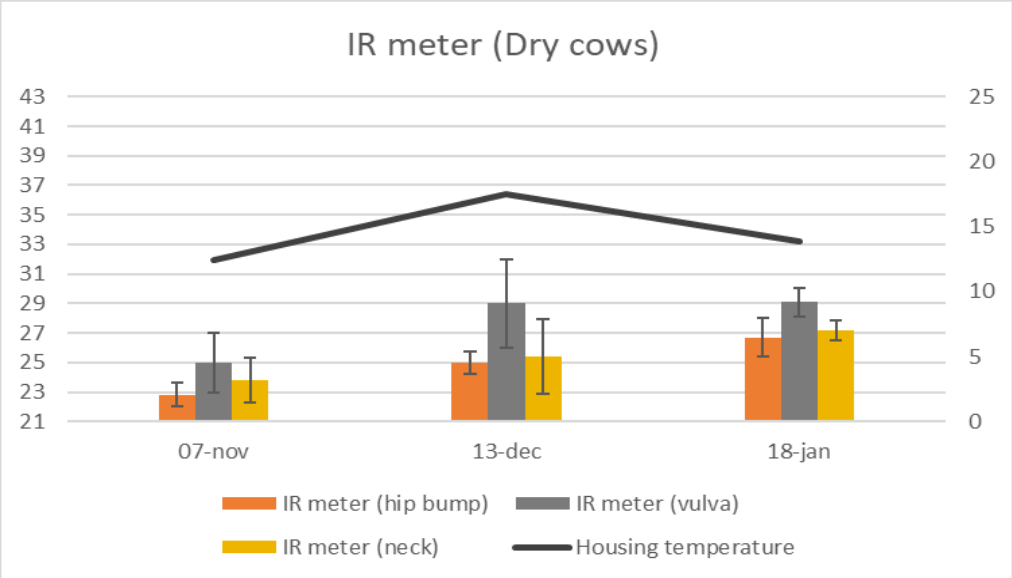

Figure 14: The dry cows' mean temperature (left axis) and the variance obtained with the IR meter ten centimetres below the hip bump, neck and vulva, in comparison to the housing temperature (right axis).

IR cameras

The mean temperature and the variance obtained with the IR cameras (FLIR E8 and FLIR C2) at the eye, udder and vulva is compared to the housing temperature for both the lactating and dry cows. The mean temperatures obtained with both IR cameras are generally higher in the udder and lower in the eye (Figure 15 and Figure 16).

FLIR E8

The lactating cows' mean temperature obtained with the IR camera FLIR E8 was relative constant during the study period. The mean temperatures were also similar to the mean temperature obtained with the rectal thermometer. The highest mean temperature at the eye was 38.3^{o}C 27th September, while the lowest mean temperature was 36.4^{o}C 8th February. The highest mean temperature at the udder was 40.0^{o}C 9th March, while the lowest mean temperature was 38.1^{o}C 8th February. The highest mean temperature at the vulva was 39.3^{o}C 9th March, while the lowest mean temperature was 37.9^{o}C, 17th May. The largest difference in the mean temperature at the eye, udder and vulva was 1.8^{o}C, 1.9^{o}C respective 1.4^{o}C and throughout the study period the cows' overall mean temperature at the eye, udder and vulva was 37.5^{o}C, 38.8^{o}C and 38.5^{o}C (Figure 15).

The variance obtained for the lactating cows was largest at the udder (1.94), 10th February and the largest variance at the eye (1.49) was also obtained 10th February. The highest variance at the vulva (0.99) was obtained 13th October. The smallest variance was obtained in both the eye (0.40) and vulva (0.40), at the measurements taken 30th August respective 7th November. The smallest variance obtained at the udder (0.59) occurred 27th September (Figure 15).

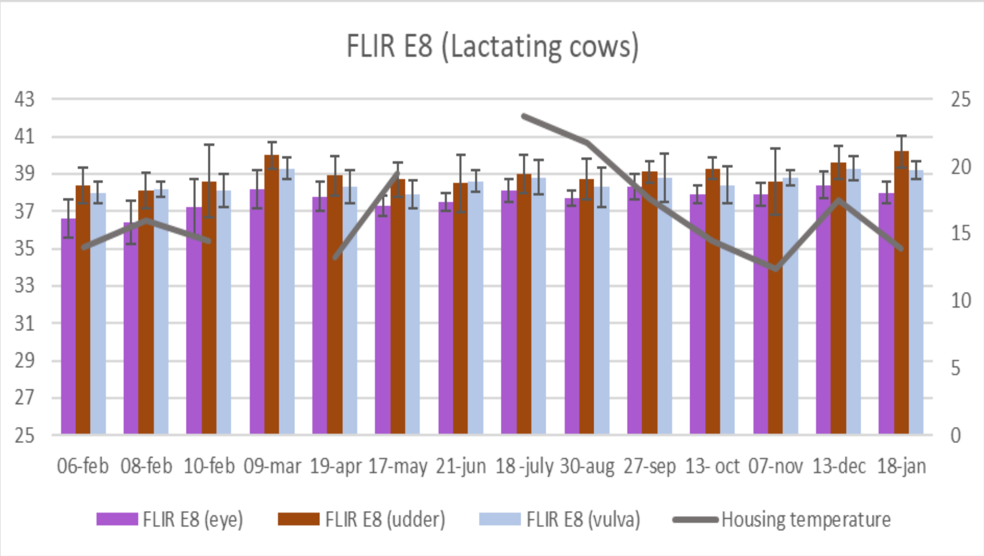

Figure 15: The lactating cows' mean temperature (left axis) and variance, obtained with the IR camera FLIR E8 at the eye, udder and vulva, in comparison to the housing temperature (right axis).

The dry cows' mean temperature obtained with the IR camera FLIR E8 was highest at the measurements taken 18th January. The highest mean temperature at the eye, udder and vulva was 37.2°C, 39.0°C respective 39.2°C. The lowest mean temperature was obtained at the eye, 36.2°C and udder, 37.0°C at the measurements taken 13th December and for the vulva 37.1°C 7th November. The largest difference in the mean temperature obtained at the eye, udder and vulva was 1.0°C, 2.0°C and 2.1°C and throughout the dry period the cows' overall mean temperatures at the eye, udder and vulva was 36.8°C, 37.7°C and 38.3°C (Figure 16).

The dry cows' variance was largest at the udder (2.76) and vulva (2.25) 7th November and at the eye (1.94) 13th December. The smallest variance was instead obtained at the vulva (0.57) and udder (0.74) 18th January and at the eye (0.79), 7th November (Figure 16).

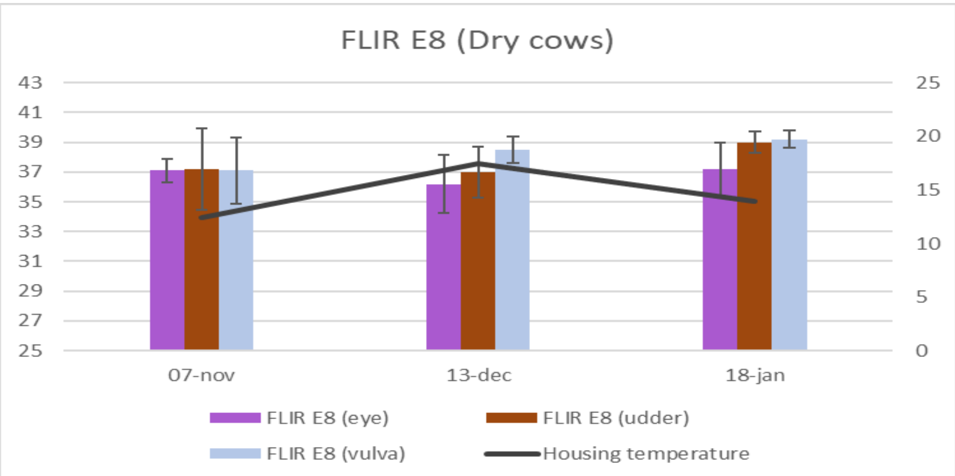

Figure 16: The dry cows' mean temperature (left axis) and the variance obtained with the IR camera FLIR E8 at the eye, udder, in comparison to the housing temperature (right axis).

FLIR C2

The lactating cows' mean temperature obtained with the IR camera FLIR C2 followed the fluctuation in the housing temperature the most after the IR meter and the skin temperature meter. No measurements were however taken 17th May and 21th June, which made the analyse of this measuring method more difficult. The highest mean temperature at the eye was 35.8°C 18th July, while the lowest mean temperature was 32.3°C 13th December. The highest mean temperature at the udder was 37.3°C 19th April, while the lowest mean temperature was 35.3°C 13th December. The highest mean temperature obtained at the vulva was 37.1°C 18th July, while the lowest mean temperature was 35.4°C, 7th November. The largest difference in the mean temperature at the eye, udder and vulva was 3.5°C, 2.0°C respective 1.8°C. Throughout the whole study period the cows' overall mean temperature at the eye, udder and vulva was 33.9°C, 36.5°C and 36.2°C (Figure 17).

The variance obtained for the lactating cows was largest at the eye (6.84) at the measurements taken 30th August and at the udder (1.70) and vulva (1.68) at the measurements taken 13th October respective 8th February. The smallest variance was obtained at the vulva (0.5), 30th August, at the udder (0.6), 19th April and at the eye (1.05), 18th July. The variance obtained at the eye was during the study period overall larger compared to the variance at the udder and vulva (Figure 17).

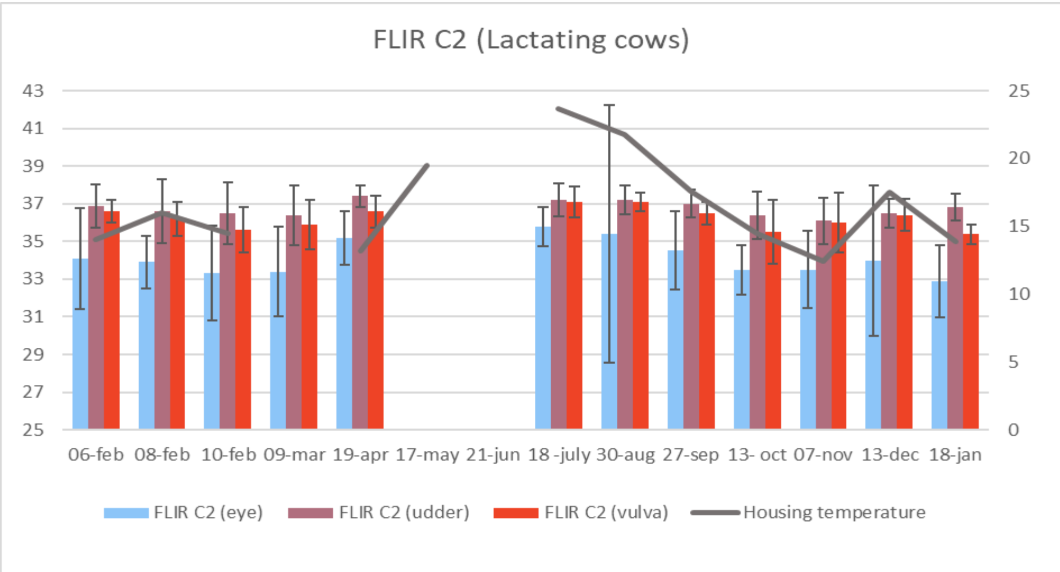

Figure 17: The lactating cows' mean temperature (left axis) and variance obtained with the IR camera FLIR E8 at the eye, udder and vulva, in comparison to the housing temperature (right axis). No measurements was taken 17th May and 21th June.

The dry cows' mean temperature obtained with the IR camera FLIR C2 increased during the dry period and was highest at the last measurements taken 18th January. The highest mean temperatures were all obtained at the measurements taken 18th January and the highest mean temperature at the eye, udder and vulva was 33.0°C, 35.6°C respective 36.0°C. The lowest mean temperatures were all obtained at the measurements taken 7th November and the highest mean temperature at the eye, udder and vulva was 29.8°C, 33.4°C respective 33.3°C. The largest difference in the mean temperature obtained at the eye, udder and vulva was

3.2ºC, 2.2ºC and 2.7ºC and throughout the dry period the cows' overall mean temperatures at the eye, udder and vulva was 30.9ºC, 34.3ºC and 34.8ºC (Figure 18).

The dry cows' variance was largest in the eye (6.82), udder (3.42) and vulva (2.58) at the measurements taken 13th December. The variance was instead smallest in the eye (0.5), udder (1.48) and vulva (0.82) at the measurements taken 18th January (Figure 18).

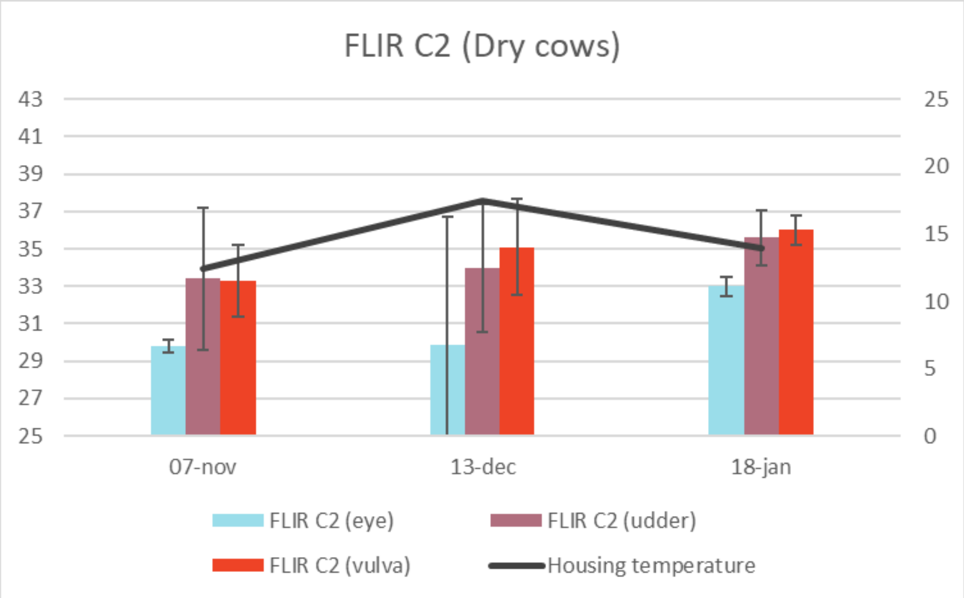

Figure 18: The dry cows' mean temperature (left axis) and the variance obtained with the IR camera FLIR E8 at the eye, udder and vulva and the variance, in comparison to the housing temperature (right axis).

Comparison of temperatures obtained at the same measurement location

The lactating cows' mean temperatures and variance taken at the same measuring location, but with different measurement methods is compared to the housing temperature. These comparisons is made at the hip bump, neck, eye, udder and vulva (Figure 19 to Figure 23).

Hip bump

The mean temperature and variance obtained at the hip bump, with the skin temperature meter and IR meter, is compared to the housing temperature (Figure 19). The mean temperature obtained with the skin temperature meter is higher the whole study period and there are also a lower increase in the mean temperature during the summer. The IR meter has also a larger variance in the beginnig of the study period and at the measurements taken 13th October. The overall mean temperature during the study period is with the skin temperature meter 34.9ºC and with the IR meter 29.3ºC, which gives a differens in the mean temperatures between the two measuring methods of 5.6ºC (Figure 19).

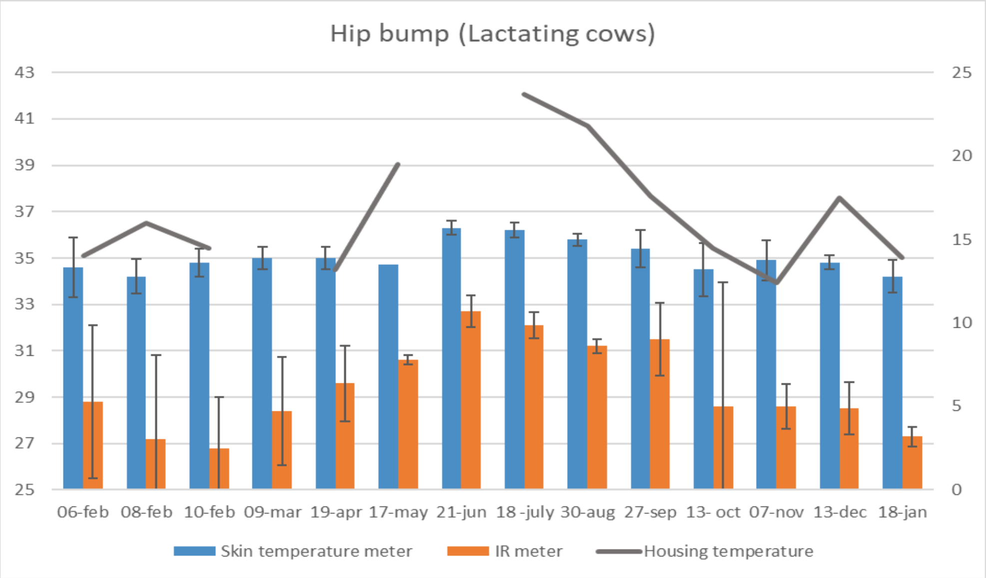

Figure 19: The mean temperature (left axis) and variance at the hip bump obtained with the skin temperature meter and IR meter in comparison to the housing temperature (right axis).

Neck

The mean temperature and variance obtained at the neck, with the skin temperature meter and IR meter is compared to the housing temperature (Figure 20). The mean temperature obtained with the skin temperature meter is higher during the whole study period compared to the mean temperature taken with the IR meter. The variance is larger in the beginning of the study period with the IR meter (Figure 20). The variance at the neck is smaller during the study period compared to the mean temperatures measured at the hip bump (Figur 19). The overall mean temperature measured with the skin temperature meter was 35.5°C and with the IR meter 30.6°C, which gave a difference between the two measuring methods of 5.1°C (Figure 20).

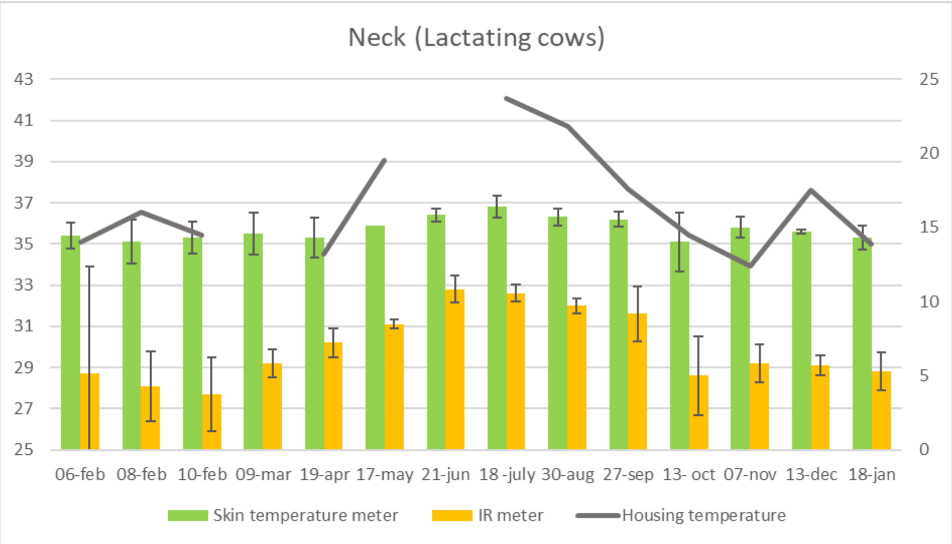

Figure 20: The mean temperature (left axis) and variance obtained at the neck with the skin temperature meter and IR meter, in comparison to the housing temperature (right axis).

Eye

The mean temperature and variance obtained at the eye, with the IR cameras FLIR E8 and FLIR C2 is compared to the housing temperature (Figure 21). The mean temperature obtained with the IR camera FLIR E8 was higher during the whole study period compared to the IR camera FLIR C2. The IR camera FLIR C2 obtained a really high variance at the measurements taken 30th August (6.84) and 13th December (3.99). The variance obtained with the IR camera FLIR E8 was lower, but the highest variance was obtained 10th February (1.49). The lowest variance for the IR camera E8 and FLIR C2 was obtained at the measurements taken 30th August (0.40) respective 18th July (1.05). The overall mean temperature measured with the IR camera FLIR E8 was 37.5°C and with the IR camera FLIR C2 was 30.9°C, which gave a difference between the two measuring methods of 6.6°C (Figure 22).

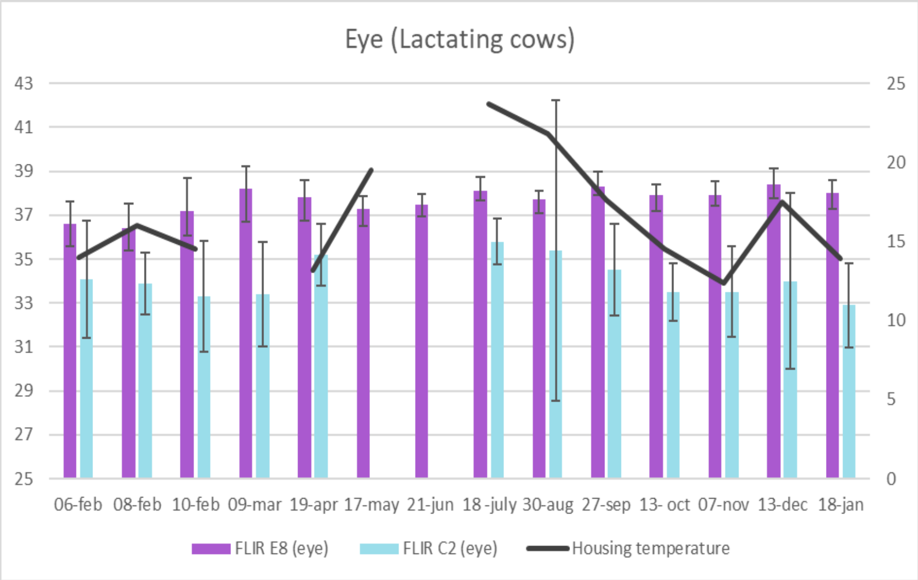

Figure 21: The mean temperature (left axis) and variance obtained with the IR camera FLIR E8 and FLIR C2 at the eye, in comparison to the housing temperature (right axis).

Udder

The mean temperature and variance obtained at the udder, with the IR cameras FLIR E8 and FLIR C2 is compared to the housing temperature (Figure 22). The mean temperature obtained with the IR camera FLIR E8 was higher during the whole study period compared to the mean temperature obtained with the IR camera FLIR C2. The variance is largest at the measurements taken 10th February and 7th November, with both IR cameras. The abslute largest variance were obtained 10th February with the IR camera FLIR E8 (1.94) and with the IR camera FLIR C2 (1.62). The smallest variance were instead obtained 27th September for the IR camera FLIR E8 (0.59) and 19th April for the IR camera FLIR C2 (0.60). The overall mean temperature measured with the IR camera FLIR E8 was 38.8°C and with the IR camera FLIR C2 was 36.5°C, which gave a difference between the two measuring methods of 2.3°C (Figure 22).

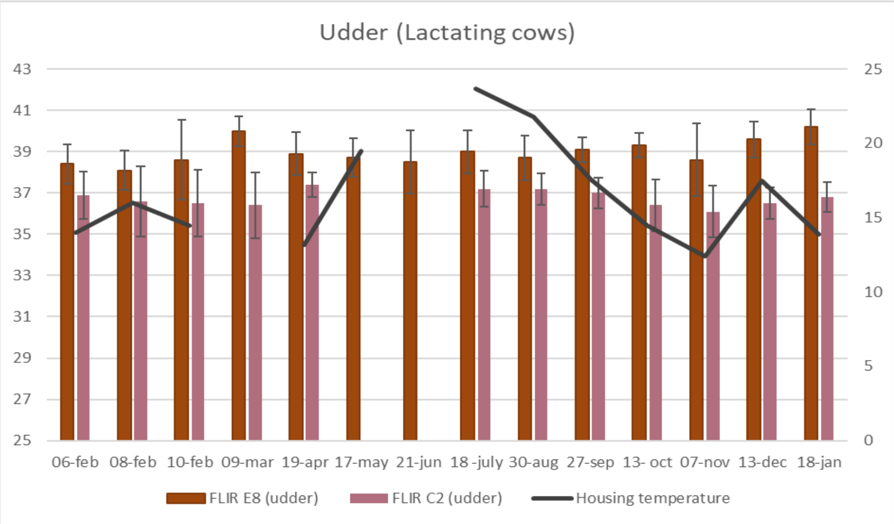

Figure 22: The mean temperature (left axis) and variance obtained with the IR camera FLIR E8 and FLIR C2 at the udder, in comparison to the housing Temperature (right axis).

Vulva

The mean temperature and variance obtained at the vulva, with the IR meter, and the IR cameras FLIR E8 and FLIR C2 is compared to the housing temperature (Figure 23). The mean temperature obtained with the IR camera FLIR E8 is higher during the whole stury period. The mean temperature obtained with the IR meter is instead the lowest during the whole study period. The variance was largest at the measurements taken 6th February with the IR meter (3.02) and with the IR cameras FLIR E8 (0.99) and FLIR C2 (1.68) 13th October. The smallest variance were instead obtained 17th May and 13th December with the IR meter (0.14) and for the IR cameras FLIR E8 (0.40) and FLIR C2 (0.50) 7th November respective 30th August. The overall mean temperature measured with the IR meter and IR camera FLIR E8 and FLIR C2 was 27.7ºC, 38.5ºC and 36.2ºC. The difference in mean temperature between the IR meter and both IR cameras were therefore 11ºC and 8.5ºC and the difference between the two IR cameras were 2.3ºC (Figure 23).

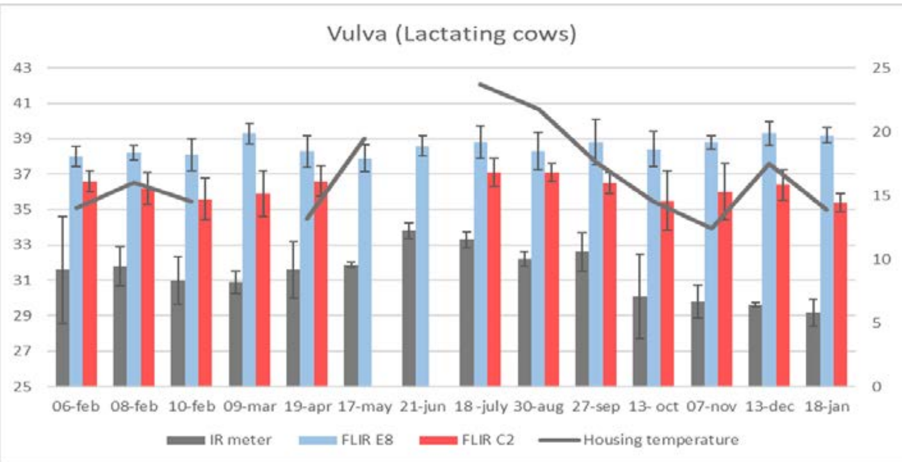

Figure 23: The mean temperature (left axis) and variance obtained with the IR meter and the IR camera FLIR E8 and FLIR C2 at the udder, in comparison to the housing temperature (right axis).

The participating cows' lactation curve

The participating cows' average milk yield per kilogram and month can be seen in Figure 24. The data used is from one lactation period, so the milk from cows that had entered a new lactation period in January was excluded (Appendix 5). The milk yield increases until peak lactation, which occurs in March 2016 and after that the milk yield starts to decline (Figure 24).

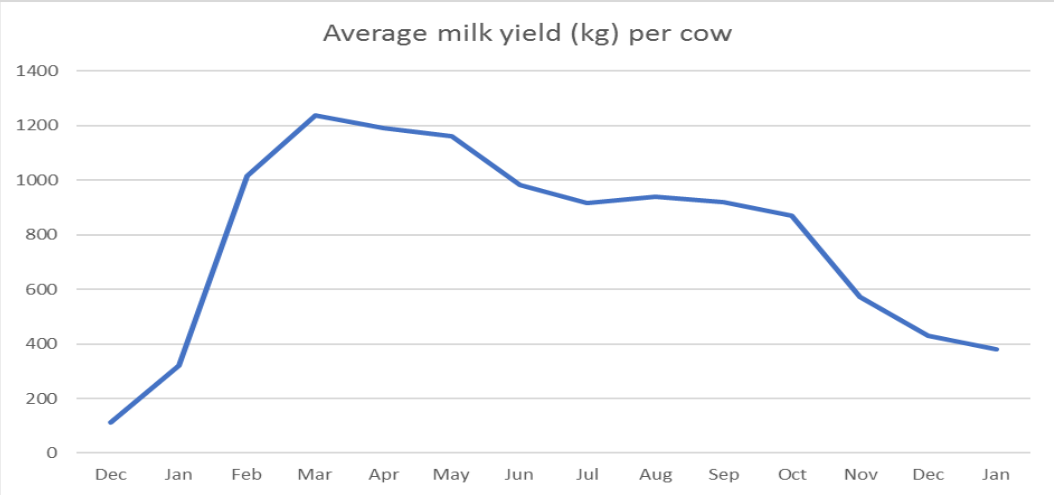

Figure 24: The average milk yield (kg) for the participating cows in kilogram per month.

The average milk yield per cow and month were also set in relation to the mean temperature obtained with the IR cameras FLIR E8 and FLIR C2 at the udder (Figure 25). The IR camera FLIR E8 has an increased mean temperature during March, when the peak lactation occurs and the housing temperature starts to increase. The IR camera FLIR C2 does not show the same pattern during the peak lactation and remains low until March when it starts to increase slowly. The mean temperature obtained with both IR cameras start to increase in November, even if the average milk yield is declining (Figure 25).

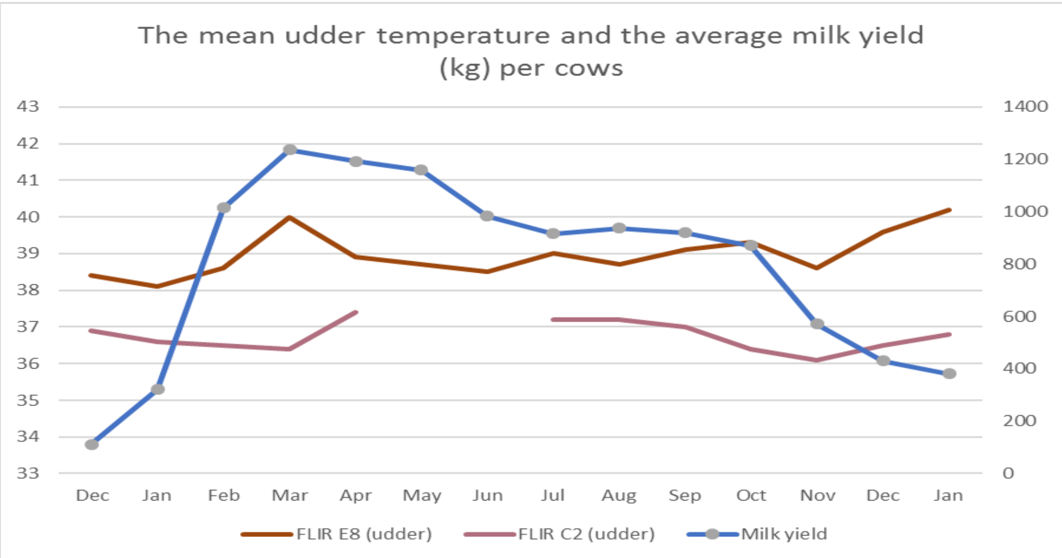

Figure 25: The mean udder temperature (left axis) in relation to the average milk yield (kg) per cow and month (right axis), from December 2015 to January 2017.

Temperature and relative humidity in the stable

The lactating cows' housing temperature and RH can be seen in Table 2 and Figure 26. The housing temperature was not recorded 9th March and 21th June and the RH was not recorded 9th March. There was a negative correlation between the housing temperature and RH (Figure 26). When the housing temperature increased, the RH decreased and when the housing temperature instead decreased the RH increased. It is visible that the lactating cows not were affected by heat stress, during the measurements, when the THI (Figure 2) were studied. This, because the THI never exceeded 72 units since the housing temperature always was below 25.0^{o}C.

At the measurements 7th November, five cows had started their dry period and they were held in a different part of the stable, where the housing temperature and RH was 3.5^{o}C and 65 percent. At the measurements 13th December, seven cows were on their dry period and two cows were held in the calving area. The dry cows' housing temperature and RH was 8.3^{o}C and 55 percent, while the cows held in the calving area had a housing temperature and RH of 13^{o}C and 65 percent. The difference in housing temperature between the lactating and dry cows were approximately 9.0^{o}C, while the difference between the lactating cows and the cows that were held in the calving area were approximately 4.0^{o}C. At the measurements 18th January, six cows were on their dry period and the housing temperature and RH were 6.3^{o}C and 47 percent. The difference between the lactating and dry cows' housing temperature at this measurement were approximately 8.0^{o}C.

Table 2: *Shows the temperature and RH in the lactating cows' stable during the whole study period. The housing temperature was not recorded 9th March and 21th June and the RH was not recorded 9th March*

	Temperature (^{o}C)	**Relative humidity (%)**		**Temperature (^{o}C)**	**Relative humidity (%)**
06-Feb	14.0	70	18-Jul	23.7	43
08-Feb	16.0	63	30-Aug	21.8	51
10-Feb	14.5	67	27-Sep	17.9	69
09-Mar	-	-	13-Oct	14.5	68
19-Apr	13.2	47	07-Nov	12.4	79
17-May	19.5	40	13-Dec	17.5	51
21-Jun	-	53	18-Jan	13.9	72

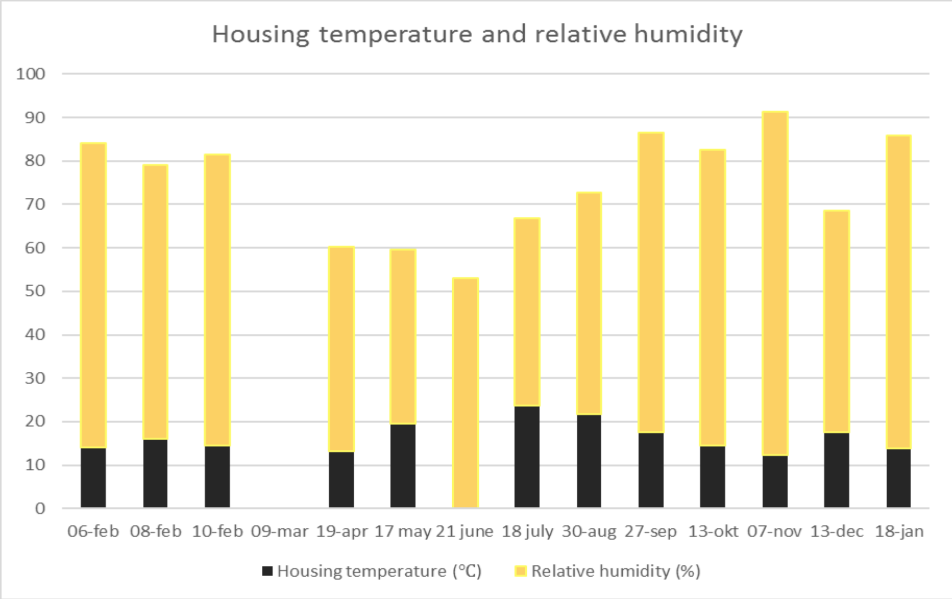

Figure 26: Shows the housing temperature (°C) and relative humidity (%) for the lactating cows, during the whole study period. The housing temperature was not recorded 9th March and 21th June and the RH was not recorded 9th March.

Discussion

This study reviled that the lactating cows had a higher heat production, compared to the dry cows. The reason for this can be the production of milk, which increased the cows need for heat loss. It can also be that the cows were on their lactation period during the summer, when the weather was warmer which also contributed to the higher heat production. The cows started their dry period at the measurement taken 7th November, which meant a lower stable temperature.

The mean rectal temperature was relative constant during the whole study period, which showed that the cows were in thermal comfort during the whole study period. The other measuring methods, measured the heat loss from the skin to the surroundings. The result showed that these measuring methods had different ability to measure the cows' heat loss and therefore also if the cows were in thermal comfort. The IR meter was the measuring method had had largest ability to capture the cows' regulation within the thermoneutral zone. It was also the measuring method that followed the housing temperature the most.

The choice of measuring locations

Both IR cameras was used to measure the temperature at the eye, udder and vulva. The IR meter measured also the temperature at the vulva, but also at the neck and hip bump, like the skin temperature meter. The decision to measure the temperature at different locations were made because the intention was to measure heat loss on a larger area on the cows' body. This was done without the consideration that it would make the comparison of the measuring methods harder.

The reason that the skin temperature meter only measured the temperature at the neck and hip bump was because this measuring method was so time consuming. It was therefore not possible to also measure the temperature at the vulva and udder because the cows would not have stood still for that long. The IR meter could also have measured the temperature at the udder, but this was realised in the end of the study period. The reason that only the IR cameras measured the temperature at the eye was because it was not possible to measure the temperature at this location with the other measuring methods.

The measuring locations, eye, udder and vulva were chosen for the IR cameras because the cows have less hair in these areas, which shows a higher heat loss compared to other parts of the body. Sjaastad *et al.* (2010), states that the temperature of the skin is depending on the peripheral blood flow. The blood flowing through all these measuring locations differs, which made it hard to analyse and compare the measuring methods in terms of their ability to measure thermal comfort. If this study were made again, the same measuring locations would have been chosen for all measuring methods that measure the skin temperature.

Calculation of the mean values and variance

Lactating cows have a higher production of heat, due to the milk production, compared to dry cows. Araki *et al.* (1984) also supports this and states that lactating cows create much more metabolic heat due to the milk production. That the dry cows have a lower heat production in combination to the fact that they was held in a different part of the stable, in this study, contributed to a lower stable temperature. The result from this study showed that the housing temperature differed approximately 9.0°C between the lactating and dry cows. The decision to calculate the mean values and variance separate for the lactating and dry cows were therefore made. If the mean values and the variance would have been calculated on the lactating and dry cows together, it would have meant that more values from the dry cows would have been removed. This, because the decision to only include values that were within three SD from a normal distribution were made.

The values that were removed, were not within three SD from a normal distribution. These values were therefore either to low or too high in comparison to the other values taken with the same measuring method. It is important to have in mind that the removed values could have been the true values of the cows' temperature, but because the decision to only include values within three SD from a normal distribution were made, these values had to be removed.

The rectal temperature of one cow was too high and was therefore removed. The reason for this can be that the cow had fever when the measurement was conducted. The measured rectal temperature was 39.7°C and Burfeind *et al.* (2010) and Sheldon *et al*. (2004) concluded that cows had fever if the rectal temperature was ≥ 39.4°C respectively ≥ 39.7°C. The rectal temperature could also be too high because the thermometer was inserted too deep into the rectum, which Burfeind *et al.* (2010) also concluded.

Values could have become too low with the skin temperature meter because the cows moved when the measurement was conducted, which meant that the temperature could not be read properly. The skin temperature meter may also not have had enough contact with the skin during the measurement or the investigator could have waited too little time before reading the result.

The reason that values became too low and too high with the IR meter can be that the temperature was measured at slightly the wrong location or that the IR meter did not get the contact needed on the skin. Another reason that values became too high in comparison to the other values taken with the IR meter can be that the cows had been or were exposed for sunlight which increased their heat production.

Values taken with both IR cameras were removed because they were too low and the reason can be because the photos were taken in a bad angel or that they had a bad quality. One value taken with the IR camera FLIR E8 became too high, which can be because the cows had been or were exposed to sunlight. This, because Fuquay (1981) concludes that almost all heat gained during daytime, comes direct or indirect from solar radiation.

Rectal thermometer

The lactating and dry cows had a relative constant mean rectal temperature, 38.5°C, during the whole study period. In the literature, the mean rectal temperatures range from 38.3°C to 38.9°C (Bewley *et al*., 2008a; Naylor *et al*., 2012; Sheldon *et al*., 2004; Smith & Risco, 2005) and the participating cows in this study had a mean rectal temperature within that range.

When the mean temperature obtained separate for the lactating and dry cows was studied, it was visible that the lactating and dry cows' mean rectal temperature varied 0.40°C respective 0.50°C during the study period. This is a small variation, which shows that the cows are able to keep their body temperature constant even if the milk production, feed intake and housing temperature increases. The reason that the dry cows had 0.1°C higher variation can be that the cows were in different stages of their dry period and had different amount of time left before the next calving.

Bewley *et al*. (2008a) mentions that the rectal temperature is directly affected by the ambient temperature and that it will increase in warmer weather. This is not confirmed in this study because the rectal temperature remained constant, with small fluctuations even if the housing temperature increased during the summer. The reason that the cows were able to keep their body temperature constant during the summer can be because the climate in Sweden is colder compared to other parts of the world. It can also be because the cows were grazing during night and was therefore less exposed for direct sunlight. Church *et al*. (2014) concludes that direct sunlight increases the eye temperature and Bohmanova *et al*. (2007) mentions that solar radiation contributes to heat stress. The cows in this study were not heat stressed because if they were, their rectal temperature would have increased, like Srikandakumar & Johnson (2004), Cincović *et al*. (2011) and Lemerle & Goddard (1986) concluded in their studies. The THI (Avendaño-Reyes, 2012) showed also that the cows not were affected by heat stress when the temperature in combination to the RH was studied. The reason that the cows not did become heat stressed can be because they were less exposed for direct sunlight during the day, which may have made it easier for them to keep their body temperature stable.

Skin temperature meter

The skin temperature meter was the most time-consuming measuring method and if the cows moved, the measurement had to be taken again. This measuring method showed however that the cows had an increased skin temperature during the summer and Zygmunt *et al.* (2013) concludes that the skin temperature increases in a warmer stable. That the skin temperature increased during the summer can therefore be explained by the higher housing temperature, in combination to the milk production. This shows that the cows have a higher heat loss when the weather is warmer in order to keep their thermal comfort.

The skin temperature meter can be set in relation to the rectal thermometer, which remained the same even if the housing temperature increased. The reason that these measuring methods produce different results can be explained by the fact that the skin temperature meter measure the radiation from the skin (Instrumart, 2017), while the rectal thermometer instead use electronic heat sensors to measure the body temperature (Mayo clinic, 2015).

The lactating and dry cows had a higher mean temperature and variance at the neck compared to the hip bump during most of the study period. The reason for this can be that more blood is flowing through the neck, compared to the hip bump. Sjaastad *et al.* (2010), states that animals lower their body temperature by transporting heat in the blood to the skin, which then ends up in the surroundings. This confirms that the cows have a higher heat loss in the neck, due to a larger blood flow in that area. The dry cows had overall 2.6°C lower mean temperature at both measurement locations. The reason for this can be that dry cows naturally have a lower skin temperature due to the lack of milk production. This means that they have a lower need to transport heat to the skin to keep their thermal comfort. It is however important to remember that the housing temperature were lower in the part of the stable where the dry cows were held, which also impacts the need for heat loss.

The dry cows had overall a larger variance compared to the lactating cows. This can be because the dry cows were fewer and in different stages of their dry period. When the cows are in different stages of their dry period the involution of their mammary tissue will differ as well as the time left before the next calving. This means that the cows have different need for heat loss to keep the thermal regulation.

IR meter

The IR meter was the measuring method that followed the housing temperature the most. Sjaastad *et al.* (2010) states that the skin temperature can vary very much because it is the body's most efficient tool for keeping a nearly constant body temperature. The IR meter reflects the indirect blood flow to the skin, which directly affects if the cows needs to get rid of or save heat in the body to keep their body temperature stable. The IR meter therefore capture the cows' regulation within the thermoneutral zone.

The lactating cows had a higher mean skin temperature and a larger difference in the mean temperature, compared to the dry cows. This shows that the lactating cows have a larger need for heat loss to keep their thermal comfort due to the milk production. The highest mean temperature was obtained at the vulva, for both the lactating and dry cows. This means that more blood is flowing through that area, in an attempt to keep the body temperature and the thermal comfort.

The lactating cows had a higher variance in the beginning of the study period and the reason for this can be that the cows recently had entered their lactation period or that the investigator measured the temperature at slightly the wrong location. It can also be because the measurements were taken more closely in the beginning of the study period. The lactating cows had also a higher variance 13th October and the reason for this can be that some cows soon would enter their dry period which gave them a lower mean temperature. The dry cows had a high variance 13th December and this can be because the cows were in different stages of their dry period. The fact that the cows had a large difference in the mean temperature compared between the moths when the housing temperature increased and that the variance were low, shows that the IR meter is very sufficient when it comes to measure the cows' thermal comfort.

IR camera FLIR E8

In the beginning of the lactation period the measurements taken with the IR camera FLIR E8 follow each other more and then they become more varied. This can be due to a higher housing temperature, the increased milk production or the fact that the cows were held outside during night in the summer. Berry *et al*. (2003) concluded that cows that had access to an outdoor enclosure had a significant increase in the temperature obtained in the udder while the rectal temperature remained the same.

The mean temperature at the udder and vulva reached the highest value at the measurements taken 9th March. This is also the time when the cows reach their peak lactation which may have contributed to the high mean temperature. The mean temperature was overall lowest at the eye and a reason can be that less heat is produced in that area. Hoffmann *et al*. (2013) supports this because the result from that study showed that the body temperature always was higher compared to the temperature in the head. The dry cows' mean temperature was highest 18th January and a reason for this can be that the cows soon would enter a new lactation period.

The lactating and dry cows had largest variance in the udder and a reason for this can be that the measurements were taken either before or after milking. Araki *et al*. (1984) supports this because that study showed that the udder temperature gets higher due to the milk production and that the temperature is lowered when the cows are milked. In this study, this can only be a speculation because it was never documented if the cows had been milked before or after the measurements were conducted. Most of the measurements taken around the morning milking were however taken after the cows had been milked and around the evening milking before the cows had been milked.

IR camera FLIR C2

It was hard to analyse the IR camera FLIR C2 because no temperatures were collected at the measurements 17th May and 21th June. Something that was visible was however that the IR camera FLIR C2 had a larger difference in the mean temperature for both the lactating and dry cows compared to the IR camera FLIR E8. The reason for this can be that the IR camera FLIR C2 is more capable to measure heat loss, even if the temperature range and detector resolution is smaller compared to the IR camera FLIR E8. The reason can also be that the photos were taken before milking in a larger quantity compared to the IR camera FLIR E8, which made the cows' body temperature higher.

The variance obtained for the lactating cows was overall largest at the eye while the dry cows overall had a larger variance at the udder. The reason that the lactating cows obtained a higher variance at the eye can be because the IR camera FLIR C2 have a lower detector resolution and temperature range compared to the IR camera FLIR E8 (ELFA DISTRELEC, 2016a, 2016b). The dry cows had overall a larger variance at the udder and this can be because they are in different stages of their dry period, which means that they produce different amount of heat and that their formation of mammary tissue differs. It is also important to remember that the time when the photos were taken with the IR cameras may have an impact on the variance. All the photos were either taken around the morning or the evening milking, which meant that some cows had been milked and some had not, when the photos were taken. The IR cameras are also not designed to analyse the temperature from live animals and Metzner *et al*. (2014) mentions that the tools available on the market for analysing photos are designed for buildings and industrial constructions. The IR camera FLIR C2 is after the IR meter and skin temperature meter the measuring method that followed the fluctuation in the housing temperature the most.

Comparison of measuring methods, measured at the same location

A comparison between the measuring methods that measure the mean temperature at the same measuring location is made. This, because it makes it easier to understand how efficient the measuring methods is when it comes to measure the cows' thermal comfort.

The comparison of the measurements taken at the hip bump was made for the skin temperature meter and the IR meter. The mean temperature obtained with the skin temperature meter is higher compared to the IR meter. The reason for this can be that the skin temperature meter measures the temperature against the skin under the fur, while the IR meter measures the temperature on top of the fur. The reason can also be that the IR meter is more effective to measure the cows' heat production, compared to the skin temperature meter. The variance obtained is smaller for the skin temperature meter compared to the IR meter. The reason for this can be that the skin temperature meter is a precision thermometer that measure radiation (Instrumart, 2017), while the IR meter is a non-contact infrared thermometer that measure infrared radiation (Azo sensors, 2015; Ross Brown Sales Pty Ldt). The comparison of the measurements taken on the neck was also made for the skin temperature meter and the IR meter. The result is the same as for the hip bump, namely that the skin temperature meter obtained a higher mean temperature, with a smaller variance. The same conclusions can therefore be drawn as for the mean temperature measured at the hip bump.

The comparison of the measurements taken at the vulva was made for the IR meter and for the IR cameras FLIR E8 respective FLIR C2. The IR cameras have a higher mean temperature compared to the IR meter, where the IR camera FLIR E8 has the highest mean temperature. These measuring methods is non-cotact measuring methods that measure infrared radiation (ELFA DISTRELEC, 2016a, 2016b; Ross Brown Sales Pty Ldt). The reason that the IR cameras obtained higher mean temperatures can be that the program (FLIR Tools) that analyses the photos automatically gives the highest temperature. The IR meter measure instead the temperature on a specific location, at slightly different places on all the cows. This means that the investigator does not know if the measured temperature is the highest one in that area.

The comparison of the measurements taken at the eye was made for the IR cameras FLIR E8 and FLIR C2. The IR camera FLIR C2 obtained a very high variance at the measurements taken 30th August and 13th December. The reason that the variance was so high 30th August can be that some cows had been exposed for sunlight. Fuquay (1981) concludes that almost all heat gained during daytime, comes direct or indirect from solar radiation. The hair colour could also have contributed to the high variance. The cows participating in this study were mostly brown or black and this could have contributed to a higher eye temperature. Church *et al*. (2014) concluded also this and saw that the hair colour and the exposure for sunlight increased the eye temperature and that this could contribute to false positive results. The same comparison was made with the IR cameras FLIR E8 and FLIR C2 but at the udder. As for the measured temperature at the eye the temperature at the udder was also higher when it was measured with the IR camera FLIR E8. The variance obtained with the two IR cameras was quite the same at each measurement, which shows that the cows had a small difference in their mean udder temperature.

Thermal comfort

The result from this study shows that the participating cows were in their termoneutral zone and therfore in thermal comfort during the whole study peirod. The result showed also that the rectal thermometer was the measuring method that was least suitable to measure if the cows were in thermal comfort. This because the mean rectal temperature had a small fluctation during the study period and did not increase during the summer like the mean temperature did with the other measuring methods. The rectal thermometer use electronic heat sensors to measure the body temperature (Mayo clinic, 2015) and are therefore more suitable to measure if the cows are ill. The other measuring methods measure the IR radiation, which means that they measure the animals' heat loss through the skin. The IR meter was the measuring method that registered the largest difference in the heat loss through the skin. This means that the IR meter is most suitable to measure the heat radiation from the cows' skin. The skin temperature meter can to some extent measure the cows' thermal comfort because the mean temperature increases in relation to the housing temperature. The IR cameras measured the mean temperatures at different measuring locations compared to the IR meter and the skin temperature meter. This made it hard to compare these measuring methods. It was however visible that the IR camera FLIR C2 followed the fluctuation in the housing temperature more compared to the IR camera FLIR E8, which means that it is more suitable to measure the cows' thermal comfort. The IR camera FLIR E8 is after the rectal thermometer the measuring method that is the least suitable to measure the cows' thermal comfort.

The participating cows' milk yield

The cows who participated in this study produced a lactation curve (Figure 24) that were relative similar to the graphic example of how a lactation curve should look like (Figure 3). The peak lactation occurred approximately five to six weeks into the lactation period like the graphic example in Figure 3. During peak lactation, there was also a small increase in the mean udder temperature and this can be explained by Araki *et al*. (1984), who states that heat is stored in the milk. An increased housing temperature resulted not in an increased mean udder temperature during the summer. This means that the cows were able to compensate for the higher housing temperature by a higher heat loss through the skin.

The average milk yield was also set in relation to the mean temperature obtained at the udder (Figure 25). It was visible that the mean temperature also increased when the cows reached their peak lactation and the reason is the increased milk production that generate more heat.

Conclusions

The IR meter is the measuring method that was most suitable to measure the cows' thermal comfort, because the mean temperature followed the housing temperature the most which showed that the cows evaporated more heat in a warmer environment. The variance was low even if the housing temperature increased. The skin temperature meter and the IR camera FLIR C2 were after the IR meter the measuring methods that were most suitable to measure the thermal comfort. These measuring methods was less suitable compared to the IR meter because they followed the housing temperature less. The measuring methods that was the least suitable to measure the cows' thermal comfort were the rectal thermometer and the IR camera FLIR E8. It is however important to remember that the result for the IR cameras could have been different if different measuring locations would have been chosen. More research is needed to construct the most effective method to measure cows' thermal comfort in practise. It is also important to look at the farmers' perspective and generate a method that they practically can use to improve the cows' thermal comfort.

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Appendix 1

Temperature values removed, because they were not within 3 SD from a normal distribution

Date	ID number	Temperature measuring method	Temperature (ºC)	Reason for removal
16-02-06	47	IR meter (Vulva)	27.6	To low
16-02-06	361	IR meter (Neck)	38.3	To high
16-02-06	375	Skin temperature meter (Hip bump)	31.1	To low
16-02-06	375	Skin temperature meter (Neck)	32.3	To low
16-02-06	375	Rectal thermometer	39.7	To high
16-02-06	370	FLIR E8 (Vulva)	35.3	To low
16-02-08	972	FLIR C2 (Udder)	32.7	To low
16-02-10	213	Skin temperature meter (Hip bump)	30.9	To low
16-03-09	47	FLIR E8 (Eye)	40.9	To high
16-04-19	74	Skin temperature meter (Hip bump)	31.7	To low
16-09-27	74	FLIR C2 (Vulva)	32.0	To low
16-09-27	352	FLIR C2 (Udder)	33.1	To low
16-10-13	83	Skin temperature meter (Neck)	28.9	To low
16-10-13	83	FLIR C2 (Udder)	31.2	To low
16-11-07	90	IR meter (Hip bump)	21.2	To low
16-11-07	358	FLIR E8 (Eye)	34.3	To low

Appendix 2

The number of cows included at every measuring

Measuring method	**6-Feb**	**8-Feb**	**10-Feb**	**9-Mar**	**19-Apr**	**17-May**	**21-Jun**	**18-Jul**	**30-Aug**	**27-Sep**	**13-Oct**	**7-Nov**	**13-Dec**	**18-Jan**
Rectal thermometer	17	20	20	20	20	6	7	14	18	20	20	20	20	14
Skin temperature meter (Hip bump)	18	20	19	20	19	1	8	12	15	20	20	20	20	14
Skin temperature meter (Neck)	16	19	19	19	18	1	9	7	7	18	17	18	19	13
IR meter (Hip bump)	20	20	20	20	20	6	13	14	20	20	20	19	20	14
IR meter (Vulva)	19	20	20	20	20	6	9	14	20	20	20	20	20	14
IR meter (Neck)	17	20	20	20	19	5	9	13	14	20	20	19	20	13
FLIR E8 (Eye)	16	20	20	19	20	20	19	19	20	20	20	19	20	14
FLIR E8 (Udder)	16	20	20	20	20	20	20	19	20	20	20	20	20	14
FLIR E8 (Vulva)	15	20	20	20	20	20	20	19	20	20	19	20	20	13
FLIR C2 (Eye)	18	19	18	20	17	-	-	18	20	19	20	18	19	14
FLIR C2 (Udder)	19	18	17	19	19	-	-	19	20	19	19	20	19	14
FLIR C2 (Vulva)	14	19	17	18	19	-	-	17	20	18	20	20	20	14

Appendix 3

The mean temperatures calculated on the lactating and dry cows, at every measuring location

Measuring method	**6-Feb**	**8-Feb**	**10-Feb**	**9-Mar**	**19-Apr**	**17-May**	**21-Jun**	**18-Jul**	**30-Aug**	**27-Sep**	**13-Oct**	**7-Nov**	**Dry**	**13-Dec**	**Dry**	**18-Jan**	**Dry**
Rectal thermometer	38.4	38.4	38.4	38.5	38.5	38.5	38.5	38.5	38.7	38.5	38.3	38.4	38.2	38.5	38.5	38.4	38.7
Skin temperature meter (Hip bump)	34.6	34.2	34.8	35.0	35.0	34.7	36.3	36.2	35.8	35.4	34.5	33.9	30.8	33.8	32.2	34.2	34.0
Skin temperature meter (Neck)	35.4	35.1	35.3	35.5	35.3	35.9	36.4	36.8	36.3	36.2	35.1	34.8	31.9	33.6	32.1	35.3	34.6
IR meter (Hip bump)	28.8	27.2	26.8	28.4	29.6	30.6	32.7	34.6	31.1	31.5	28.6	28.6	22.8	28.5	25.0	27.3	26.7
IR meter (Vulva)	31.5	31.8	31.0	30.9	31.6	31.9	33.8	35.8	32.2	32.6	30.1	29.8	25.0	29.6	29.0	29.2	29.1
IR meter (Neck)	28.7	28.1	27.7	29.2	30.2	31.1	32.8	35.4	32.0	31.6	28.6	29.2	23.8	29.1	25.4	28.8	27.2
FLIR E8 (Eye)	36.6	36.4	37.2	38.2	37.8	37.3	37.5	38.1	37.6	38.3	38.0	37.9	37.1	38.4	36.2	38.0	37.2
FLIR E8 (Udder)	38.4	38.1	38.6	40.0	38.9	38.7	38.5	39.0	38.7	39.1	39.3	38.6	37.2	39.6	37.0	40.2	39.0
FLIR E8 (Vulva)	38.0	38.2	38.1	39.3	38.3	37.9	38.5	38.8	38.3	38.8	38.4	38.8	37.1	39.3	38.5	39.2	39.2
FLIR C2 (Eye)	34.1	33.9	33.3	33.4	35.2	-	-	35.8	35.4	34.5	33.5	33.5	29.8	34.0	29.9	32.9	33.0
FLIR C2 (Udder)	36.8	36.6	36.5	36.4	37.3	-	-	37.2	37.2	37.0	36.3	36.1	33.4	36.5	34.0	36.8	35.6
FLIR C2 (Vulva)	36.6	36.2	35.6	35.9	36.6	-	-	37.1	37.1	36.4	35.5	36.0	33.3	36.4	35.1	35.4	36.0

Appendix 4

The variance calculated on the lactating and dry cows' temperatures, at every measuring location

Measuring method	6-Feb	8-Feb	10-Feb	9-Mar	19-Apr	17-May	21-Jun	18-Jul	30-Aug	27-Sep	13-Oct	7-Nov	Dry	13-Dec	Dry	18-Jan	Dry
Rectal thermometer	0.27	0.24	0.19	0.08	0.12	0.07	0.05	0.04	0.14	0.16	0.10	0.06	0.25	0.08	0.10	0.19	0.07
Skin temperature meter (Hip bump)	1.28	0.74	0.62	0.49	0.49	-	0.29	0.31	0.26	0.80	1.15	0.86	1.05	0.30	2.64	0.71	1.61
Skin temperature meter (Neck)	0.61	1.07	0.79	1.00	0.98	-	0.30	0.53	0.40	0.38	1.42	0.50	5.24	0.10	3.68	0.57	0.06
IR meter (Hip bump)	3.29	3.61	2.18	2.32	1.63	0.21	0.69	0.44	0.29	1.58	5.34	0.97	0.81	1.13	0.77	0.43	1.28
IR meter (Vulva)	3.02	1.11	1.35	0.63	1.59	0.14	0.46	0.41	0.41	1.07	2.39	0.94	2.00	0.14	2.99	0.76	0.96
IR meter (Neck)	5.19	1.69	1.81	0.66	0.70	0.21	0.66	0.31	0.36	1.32	1.90	0.93	1.50	0.48	2.53	0.91	0.69
FLIR E8 (Eye)	1.03	1.14	1.49	1.03	0.79	0.56	0.45	0.62	0.40	0.69	0.48	0.64	0.79	0.71	1.94	0.58	1.75
FLIR E8 (Udder)	0.95	0.97	1.94	0.71	1.04	0.94	1.54	1.04	1.10	0.59	0.60	1.76	2.76	0.88	1.69	0.84	0.74
FLIR E8 (Vulva)	0.56	0.41	0.90	0.57	0.90	0.77	0.57	0.92	1.06	1.30	0.99	0.40	2.25	0.68	0.92	0.45	0.57
FLIR C2 (Eye)	2.67	1.40	2.52	2.39	1.42	-	-	1.05	0.84	2.08	1.31	2.06	0.34	3.99	6.82	1.92	0.50
FLIR C2 (Udder)	1.15	1.70	1.62	1.58	0.60	-	-	0.87	0.76	0.73	1.25	1.24	3.80	0.76	3.42	0.71	1.48
FLIR C2 (Vulva)	0.61	0.89	1.20	1.31	0.85	-	-	0.80	0.50	0.60	1.68	1.59	1.90	0.86	2.58	0.52	0.82

Appendix 5

The milk yield obtained for each cow in kilogram per month, from December 2015 to January 2017

ID number	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
47			1117	1611	1585	1495	1241	1240	1159	1042	1055	862	805	1079
74		198	1427	1583	1482	1389	1271	577	1204	1197	851			
83			1146	1325	1340	1212	1067	1008	924	847	393			
90		544	1108	1299	1277	1212	1019	929	941	914	952	880	890	854
213		644	1258	1455	1416	1340	1031	989	941	899	844	597	154	
336		531	966	1170	1198	1115	978	920	994	1002	1033	891	424	
347		164	797	965	995	980	881	868	910	923	983	891	923	919
352		482	1128	1203	1138	1114	830	845	936	864	992	770	881	717
358		609	986	1142	1107	1106	937	912	929	989	984	917	943	882
360		0.97	875	1214	1168	1210	1055	1027	1058	1052	1150	1011	711	20
361		153	671	929	962	912	791	824	823	823	781			
363		589	1040	1180	1102	1083	989	958	956	977	1050	947	848	690
367		345	868	994	957	917	795	793	770	745	379			
370		420	1007	1117	1144	1095	936	926	924	944	1023	1055	1001	918
375		259	802	1010	995	1011	875	863	874	831	812	157		
961		662	1390	1552	1394	1249	1059	1002	1046	992	989	824	671	538
972		323	1331	1695	1577	1444	1205	1002	1161	1177	1000	645	67	
1475/344	111	753	750	807	622	1029	947	925	966	923	985	415		
1581		107	1082	1345	1278	1193	973	908	589	697	649	167		
5357		163	908	1140	1104	1091	780	829	390	543	491	397	169	