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Methods for assessing skin temperature in two breeds of dairy cows and their correlation to indoor and rectal temperature

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ABSTRACT

Routines for assessing body temperature and thermal comfort are not included in official animal welfare controls although European legislation consider it important. This study investigated time consumption and feasibility of using handheld skin temperature sensors in a dairy farm and the correlation of the recordings with indoor and rectal temperature. Skin temperatures in 21 dairy cows of two breeds were recorded monthly during one year at the neck, hip and vulva, using two techniques (infrared radiation (IR) and conduction). Rectal and indoor ambient temperature were recorded on the same occasion. Time spent recording temperature was ~2 s/cow with IR and >1 min/cow with conduction technique. Skin temperatures did not correlate well with rectal temperature but correlated strongly with indoor temperature. Neck temperature recorded by IR best reflected indoor temperature, with no difference between breeds, and could be a tool for quick monitoring of ambient conditions in individual cows.

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Ambient temperature; animal welfare; dairy cow; thermoneutral zone; rectal temperature; skin temperature

Introduction

European Union Council Directive (European Commission, 1998) on the protection of animals kept for farming purposes requires that ill animals must be treated without delay and that indoor temperature must be kept within limits that are not harmful to the animals. Corresponding Swedish regulations and general advice concerning cattle are similar and state 'In stables, animals must have a climate adapted to the type of animal and the type of animal husbandry (thermal comfort)' (Swedish Board of Agriculture, 2019). However, standardised routines for assessing body temperature (fever, hyper- and hypothermia) and thermal comfort are currently not included in official animal welfare controls, and in practice, it is not objectively evaluated. The range of ambient temperature conditions in which animals do not need to perform active strategies to maintain normal body temperature is called the thermoneutral zone, or comfort zone, and is defined by lower and upper critical ambient temperatures (Sjaastad et al., 2016). The lower critical ambient temperature can be identified by animals shivering and the upper temperature by cows sweating and panting (Sjaastad et al., 2016). Changes in skin surface temperature reflect changes in skin blood flow in response to alterations in environmental temperature (Scoley et al., 2019). Within the thermoneutral zone, the animal regulates body temperature by shifting blood flow to/from the skin, which causes alterations in skin temperature. In theory, skin temperature therefore has the potential to be an indicator of whether an animal is at the borders of its thermoneutral zone, i.e. near the initiation of active thermoregulation like shivering or panting/sweating. There are several options available for measuring skin temperature on farm animals (Nogami et al., 2014; Scoley et al., 2019; Furukawa et al., 2024). In this study, we evaluated the feasibility of methods based on conduction and infrared radiation (IR).

Body temperature measurements are also of interest for disease control, since fever is a common symptom of many infectious diseases of the cow (Smith & Risco, 2005). Easy identification of sick animals by farmers and animal welfare inspectors would enable early intervention and treatment. However, both farmers and animal welfare inspectors require quick, reliable and cost-effective methods. Measuring rectal temperature is the gold standard for assessment of body temperature and fever in animals (Sun et al., 2021). Tresoldi et al. (2020) concluded that the threshold of fever differs between researchers,

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from 38.9°C (Hillman et al., 2005) to 40°C (Burfeind et al., 2012; Pohl et al., 2014), and in the present study fever was set to >39.5°C. Measuring rectal temperature is time-consuming and requires physical contact with the animal and is accordingly not feasible neither for farmers nor animal welfare inspectors to perform at herd level. Therefore, there is a need for simpler and less invasive methods for accurate determination of body temperature in dairy cows under farm conditions.

Two breeds are dominating in Swedish dairy production, the Swedish Holstein (SH) and the Swedish Red and White Breed (SRB). Breed differences in body temperature have been observed (e.g. rectal temperature in Carvalho et al., 1995 and reticulorumen in Liang et al., 2013 and Stone et al., 2017), and Holstein cows have been shown to have lower heat tolerance than other dairy breeds (Legates et al., 1991). The SH and SRB breeds differ in terms of colour (black and brown, respectively) and fat accumulation pattern (Hjertén, 2006). Skin colour may affect temperature measurements made using methods based on detection of infrared radiation, since matt black surfaces (including cattle coats) are good emitters of infrared radiation (Hansen, 1990; Hellebrand et al., 2003), while fat accumulation pattern will determine the thickness of the insulating subcutaneous fat layer (Schröder & Staufenbiel, 2006). A recent study on data from Swedish dairy farms indicates, however, that none of the breeds (SH and SRB) have any advantage ameliorating high ambient temperatures in terms of milk production (Ahmed et al., 2022). It is not known if body temperatures differ between SH and SRB and this knowledge is needed if temperature registrations shall be implemented in a Swedish control system. It is well known that SH and SRB differ in terms of milk yield and that milk yield can be positively associated with temperature of the reticulorumen (Liang et al., 2013), and thereby the body temperature.

The aim of this study was to evaluate the feasibility of using two handheld skin temperature sensors during field conditions and the correlation of the values obtained with indoor temperature and the gold standard of body temperature, i.e. rectal temperature. Another aim was to investigate if rectal and skin temperatures differ between the two breeds. The hypothesis was that these types of recordings have potential as future tools both for farmers and inspectors in official animal welfare controls and that there might be breed differences.

Material and methods

Cows and management system

A total of 21 dairy cows (12 SRB, 9 SH) kept in an isolated and naturally ventilated loose-house system controlled based on indoor temperature through an adjustable open ridge in the ceiling, at the Swedish University of Agricultural Sciences research facility (Lövsta, Uppsala, Sweden), were used in the study. Breed differences have in earlier studies been observed between groups of e.g. eight (Gebremedhin et al., 2011) and 10 (Dikmen et al., 2008) animals of each breed or animal type. Therefore, the sample size was expected to be relevant. All cows were newly calved and were monitored over one year (February 2016 to January 2017), i.e. including the lactation period and in some cows also the following dry period. Information about the cows (breed, date of birth, parity, parturition date, start of dry period) is presented in Supplement A. The research facility, which can accommodate a total of 280 cows, was divided into four sections and lactating cows were moved between these sections depending on their energy requirement, lactation stage and health status. In the period May–August, all cows were kept in an outdoor enclosure at night and were indoors from morning milking until after afternoon milking. The cows were milked twice a day in an automatic milking rotary system (DeLaval AMR™, DeLaval, Sweden). Mean annual milk production was 10,282 kg energy-corrected milk per cow. Insemination was performed approximately two months into the lactation period and the dry period began 5–6 weeks before parturition. At the start of the dry period, cows were moved to a fifth section in the loose-house and kept together with replacement heifers. Two cows had been moved to the calving section by the last date of data collection and were therefore not included on that measurement occasion. Cow 1475 (SRB, see suppl. A) was removed from the study (slaughtered) in May due to disease and was replaced by cow 344 (SRB, see suppl. A) for the remainder of the study period. Three cows (90, 972 and 1475) were diagnosed with endometritis two days before the measurement occasion in March. One cow (972) had a cyst diagnosed at the same time. Cow 5357 was diagnosed with a cyst four days after the measurement occasion in May. Another cow (74) was treated for a sore teat at the measurement occasion in July. No data was removed due to these diagnoses and any findings related to this will be reported in the results section.

The study complied with ARRIVE guidelines and EU Directive 2010/63/EU on animal experiments.

Collection of data

Body temperature

Body temperature measurements were made monthly for 12 months (February 10, March 9, April 19, May

17, June 21, July 18, August 30, September 27, October 13, November 7, December 13, January 18). All measurements were performed by the same person, and all were made inside the barn during the afternoon and evening (12.40–20.10 h) except in October, when they were made during the morning (05.10–10.30 h). In the period May to August, when cows grazed outdoors during the night, the measurements were made in the afternoon, after the cows had been indoors for several hours. The cows were usually loose during the measurements (except for a few occasions when a cow would not stand still and had to be tied up). All cows were accustomed to being tied up occasionally and no adverse behaviour was observed to this.

Rectal temperature was measured using a digital rectal thermistor thermometer (MT20RA, Microlife AG, Widnau, Switzerland, precision 0.1°C), which was inserted 7–8 cm into the rectum and touched the intestinal wall. Skin temperature was recorded at three positions on the body, one in the cranial and two in the caudal direction (Figure 1), using a medical thermistor thermometer (MTT) (DM 852, Ellab, Hillerød, Denmark, range −1 to +50°C, precision 0.1°C) and an infrared thermometer (IRT) (TN1, ETI Ltd., AzoNetwork, UK Ltd, Manchester, UK, range −33 to 220°C, precision 0.1°C). The positions were: (1) neck (centred on a line between the withers and larynx, approximately 15 cm from the top of the neck), (2) hip (10 cm below tuber coxae) and (3) vulva (Figure 1). Areas least affected by the lying position and most exposed to ambient temperature was chosen as described in Scoley et al. (2019).

During measurement, MTT was placed under the hairs, to ensure contact with the skin, while IRT was placed on top of the hair (close but no contact). One recording was made at all positions with MTT, while two measurements were made at all position with IRT and the higher value was used in further analysis. According to Yan et al. (2021), maximum IR skin temperature is less sensitive to environmental parameters, but more correlated with core body temperature. In cow 961, a MTT measurement at the neck position was only available for one occasion (June 21), since the cow showed avoidance behaviour when the neck was approached. For practical reasons, MTT measurements were made on only one cow in May.

All data were collected by the first author and noted by an assistant who also registered time of day of registrations, the latter done by a stopwatch.

Indoor temperature and relative humidity

At the time of the cow measurements, indoor temperature and relative humidity (RH) were measured using a weather station (Nexus prologue, model: IW004/36-5136, Clas Ohlson, Insjön, Sweden) in the middle of the different loose-house sections, once each measurement day. Temperature and humidity index (THI) were calculated according to Tucker et al. (2008).

Statistical analysis

The data were analysed with a MIXED model (SAS, Version 9.4, SAS Institute Inc., Cary, NC, USA) with temperature as the dependent variable (y) and date and breed as fixed factors and individual as random factor. Correlations were analysed using Pearson correlation analysis (SAS, Version 9.4, SAS Institute Inc., Cary,

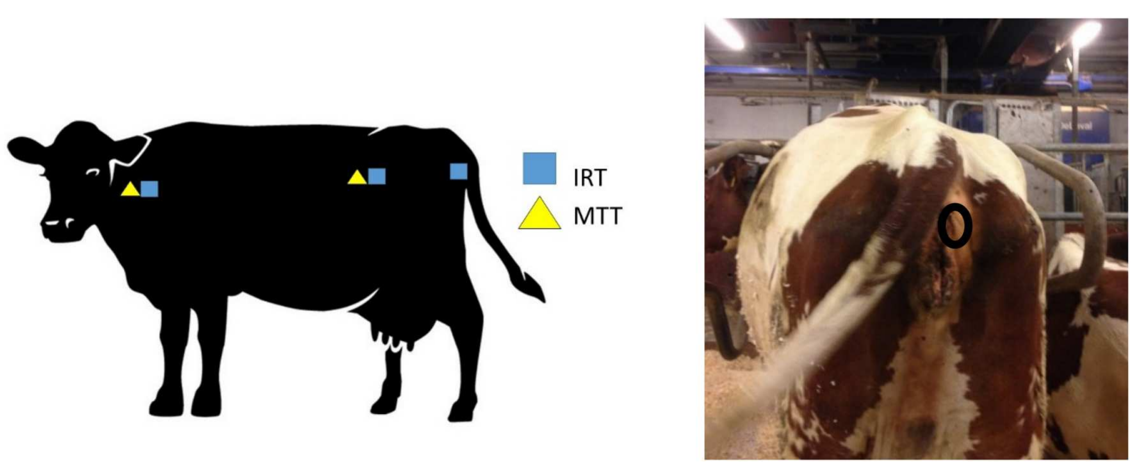

Figure 1. Positions on the cow's body at which skin temperature was measured using a medical thermistor thermometer (MTT) and an infrared thermometer (IRT): neck (centred on a line between the withers and larynx, approximately 15 cm from the top of the neck), hip (10 cm below tuber coxae) and vulva (IRT only, circle in image on the right).

NC, USA), with $P < 0.05$ considered significant. Values shown are least square (LS) Means ± standard error (SE) unless otherwise stated.

Results

Climate conditions

Indoor temperature ranged between 13.2 and 23.7°C (Figure 2) and RH was 67, 57, 47, 40, 53, 43, 51, 69, 68, 79, 51 and 72%, respectively from February to January. THI was 58, 57, 56, 64, 65, 69, 66, 63, 58, 55, 62 and 57 (February to January).

Findings in practical data collection

The time spent obtaining temperature measurements with MTT and IRT at each body position was approximately 70 and 2 s, respectively. However, if a cow did not stand still and had to be tied up, measurement with MTT could take several minutes. One cow also showed avoidance behaviour when the neck was approached, which resulted in missing values.

Rectal temperature and skin temperature

Individual minimum and maximum body temperature values varied by several degrees Celsius on all measurement occasions (Table 1). There was a significant effect of month on rectal temperature ($P = 0.02$), with the lowest mean values (38.3 ± 0.1°C) recorded in October and the highest (38.8 ± 0.1°C) in August (Figure 2). There was also a significant effect of month on skin temperature ($P < 0.0001$) (Figure 2).

There was no effect of breed on rectal temperature ($P = 0.932$) and generally no effect of breed on skin temperature. The only exception was temperature recorded at the hip, which was higher for cows of the SH breed than for SRB cows when measured with IRT (29.7 ± 0.2 vs. 29.1 ± 0.2°C, respectively, $P = 0.02$), and lower when measured with MTT (34.7 ± 0.2 vs. 35.1 ± 0.1°C, respectively, $P = 0.02$). We found no elevated rectal temperature on cows with diagnoses compared to their own mean value the other months.

Table 1. Minimum and maximum individual rectal temperatures (digital thermistor thermometer) and skin temperatures over one year of 21 dairy cows kept in an isolated loose-housing system.

	N =	Minimum °C	Maximum °C
Rectal	197	37.4	39.2
IRThip	205	21.2	35.7
IRTvul	201	22.6	35.6
IRTneck	190	22.8	33.9
MTThip	188	29.5	37.3
MTTneck	164	28.9	37.7

Note: Skin measurements were made 10 cm below tuber coxae (hip), at the lateral side of the vulva (vul) and at the neck, using an infrared thermometer (IRT) and a medical thermistor thermometer (MTT, conduction) at the hip and the neck.

Correlations

All skin temperature measurements showed very weak correlations ($r = 0.15$–0.18, $P < 0.04$) with rectal temperature (Table 2). Rectal temperature was not correlated

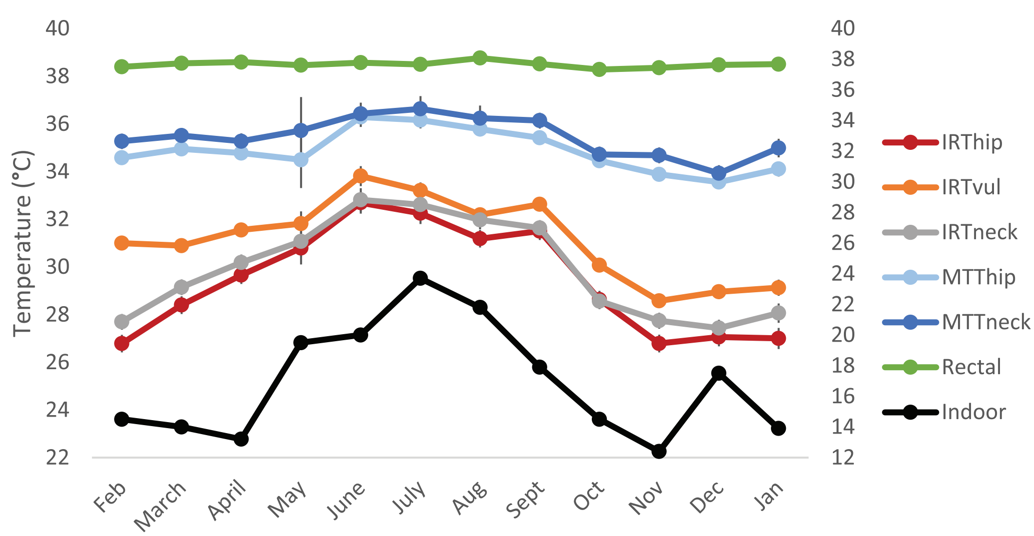

Figure 2. Monthly (February-January) rectal temperature (green) and skin temperatures (left axis) of 21 dairy cows recorded with an infrared thermometer 10 cm below tuber coxae (red, IRThip), at vulva (orange, IRTvul) and at the neck (grey, IRTneck) and with a medical thermistor thermometer 10 cm below tuber coxae (light blue, MTThip) and at the neck (dark blue, MTTneck). All cows calved between 22 December and 5 February. Black line shows indoor temperature (right axis).

Table 2. Correlations coefficients (r), *P* values and number of observations (N) for rectal temperature and skin temperatures registered 10 cm below tuber coxae (hip), at the caudal side of the vulva (vul) and at the neck using an infrared thermometer (IRT) or a medical thermistor thermometer (MTT).

		IRThip	IRTvul	IRTneck	MTThip	MTTneck
Rectal temperature	*r*	0.1545	0.1708	0.1489	0.1503	0.1788
	P	0.0301	0.0164	0.0425	0.0401	0.0233
	N	197	197	186	187	161

with indoor temperature, but all skin temperature values showed a strong correlation with indoor temperature (Table 3). The strongest correlation was obtained for measurements made with the IRT method at the neck.

Discussion

Rectal temperature values remained stable throughout most of the study period and no cow was observed with fever (>39.5°C, Suthar et al., 2012; Radostits et al., 2000) which limited our possibilities to link skin temperatures to fever or heat stress. However, a slight significant elevation was observed in August (+0.3°C compared with July), despite the fact that ambient temperature and THI peaked in July (23.7°C). Accordingly, the highest mean rectal temperature was not observed when ambient temperature and THI were highest (in July, 23.7°C and 69, respectively). The reason for the elevated temperature in August is unclear. No health problems were observed in the herd at that time, and it might be due to differences in physical activity. The few treatments in the herd during the study did not affect the measured temperatures. The study shows that cows (at peak and mid-lactation) were able to maintain their heat balance even when indoor temperature exceeded >19.5°C (on four occasions) and when it peaked at 23.7°C. However, active heat dissipation (sweating and elevated breathing frequency) might have occurred, but this was not observed during measurements. According to Li et al. (2020), heat stress is triggered at ambient temperature of around 25°C, rectal temperature of 38.6°C and respiration rate of 48 bpm. A study of Israeli Holstein cows found that rectal temperature increased with air temperatures of between 26°C and 36°C and concluded that the upper critical temperature is 25–26°C, irrespective of previous acclimatisation or milk production (Berman et al., 1985). Based on this, the air temperature in the present study did not reach the critical temperature to increase rectal temperature. However, milk production might be negatively affected at the ambient temperatures observed in this study. In a recent study by Ahmed et al. (2022) a sharp decrease in production was observed in Swedish dairy cows when the average maximum daily temperature of the past 7 days exceeded 22–23°C.

All skin temperature measurements showed a very weak correlation with rectal temperature, indicating that measurements at the positions evaluated (neck, hip, vulva) cannot be used to assess changes in actual body temperature (rectal temperature) at individual level in healthy cows (no fever) at the ambient temperature range prevailing in the study period (12.4–23.7°C). This finding is not surprising, since the mechanisms used by dairy cows to maintain constant body core temperature are both sensitive and fine-tuned, with thermoreceptors in skin and organs responding to temperature changes of less than 0.1°C and sending signals to the hypothalamus to adjust peripheral vasculature (Sjaastad et al., 2016). Blood is thereby directed to/away from the core and core temperature is maintained. The potential of the handheld temperature sensors to detect modified body temperature (e.g. elevated rectal temperatures in heat environment outside the thermoneutral zone) remains to be determined, since climate conditions were not extreme in the present study.

On the other hand, all skin temperature measurements showed a strong positive correlation with indoor temperature, reflecting effects of radiation from the surrounding and the effects of vasodilation or vasoconstriction. IRT measurements at the neck showed the strongest correlation ($r = 0.73$, $P < 0.0001$) with indoor temperature. In the period May–September, when indoor temperature was within the range 17.6–23.7°C, IRT values at the neck exceeded 31.5°C. During the rest of the year, when indoor temperatures were lower, the

Table 3. Correlations coefficients (r), *P* values and number of observations (*N*) for indoor temperature and rectal and skin temperatures registered 10 cm below tuber coxae (hip), at the caudal side of the vulva (vul) and at the neck using an infrared thermometer (IRT) or a medical thermistor thermometer (MTT).

		Rectal	IRThip	IRTvul	IRTneck	MTThip	MTTneck
Indoor temperature	*r*	0.0797	0.6804	0.6168	0.7262	0.5572	0.5045
	P	0.2657	<.0001	<.0001	<.0001	<.0001	<.0001
	N	197	205	201	190	188	164

IRT values at the neck were always below 30.2°C. The use of IRT at the neck gives a quick measurement with limited interaction with the cow and could therefore be investigated further as a tool for monitoring thermoregulation. IR cameras can also be permanently installed for temperature monitoring e.g. when approaching a water station (Schaefer et al., 2012) or a milking parlour.

There were variations in measured temperature values at all body sites. Mean rectal temperature ranged between 38.3 and 38.8°C, i.e. showed variation of <0.5°C, which can be taken as the normal within-individual variation in healthy cows. Previous studies (e.g. Liang et al., 2013) show that cows have a diurnal rectal temperature pattern with the lowest temperatures in the morning. At one occasion (October), temperatures were registered in the morning instead of the afternoon/evening in the present study but there was no significant difference compared to the other registrations.

Skin temperature measurements made using MTT showed variation of 2.7°C, with the highest temperatures obtained during the warmest period of the year (June–September) and not at the start of peak lactation (March to May), when metabolic rate can be expected to be highest. Skin temperature measurements made using IR showed the highest overall variation, with the largest variation (5.4°C) in temperature measured at the hip during June–September.

There was no difference in rectal temperature between the two dairy breeds but a difference between breeds was observed for temperature at the hip, where cows of the SH breed had higher temperature than SRB cows when measured using IR, but lower temperature when measured using MTT. The reason for this is unclear and might be of no biological relevance. However, it is possible that differences in colouring and subcutaneous fat layers played a role, as the IR and MTT values are in accordance with SRB being lighter (brown, not black) and having more insulation, i.e. subcutaneous fat (Hjertén, 2006). Arp et al. (1983) observed higher skin IR temperatures and respiratory rates in mostly black Holstein compared with mostly white Holstein at an ambient temperature of 33°C and concluded that black cattle are more subject to heat stress than red and white cattle. A correlation between total animal heat production and IR temperature at the flank has been observed previously in Holstein cows (Montanholi et al., 2008). Since SH generally have slightly higher milk (and heat) production than SRB, they can be expected to have higher IR temperatures at the flank, and perhaps also below the hip.

For temperature measurements to be included in official animal welfare controls, as well as in large-scale management systems, they must be possible to perform in a quick and safe way. Of the two handheld methods tested in the present study, the MTT sensor took much longer to obtain each measurement (more than one minute) and also required physical contact with the cow, a stationary cow and adjustment of the equipment by the operator, which was a challenge on some occasions. This technique is therefore not optimal as a routine tool for animal welfare control. The IRT device was quick (∼2 s per measurement) and required no physical contact with the cow, and therefore has greater potential in this context. This type of equipment is also reasonably cheap (∼200 Euro, Google search on 15 October 2023) and can be used without great financial risk in dirty indoor conditions.

Conclusions

In our study, there were few significant changes in rectal temperature over an indoor ambient temperature range of 12.7–23.7°C and no cow was observed with fever which limited our possibilities to link skin temperatures to fever and heat stress (defined as significantly elevated rectal temperatures). There was no difference between breeds in rectal temperature. Skin temperature values did not correlate well with rectal temperature under the prevailing conditions, but skin temperatures correlated well with indoor temperature, with IR temperature measurements at the neck best reflecting ambient temperature (and with no difference between breeds). The IR sensor was also quick to record and with limited interaction with the cow and could therefore be interesting for future studies investigating animals outside the thermoneutral zone.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Ethics approval

All procedures involving cows were approved by Uppsala Animal Ethics Committee, approval number C 114/15 for Lövsta Research Centre.

Data and model availability statement

The datasets used in this study are available from the corresponding author upon reasonable request.

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