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Effect of wind on Svalbard reindeer fur insulation

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Abstract: The heat transfer through Svalbard reindeer (*Rangifer tarandus platyrhynchus*) fur samples was studied with respect to wind velocity, season and animal age. A total of 33 dorsal fur sections were investigated using a wind tunnel. Insulation varied with season (calving, summer, autumn and winter). At zero wind velocity, fur insulation was significantly different between seasons for both calf and adult fur samples. At the same time, there was no significant difference between calf and adult insulation for the summer, autumn and winter seasons. Calf fur insulated as well as adult fur. Winter insulation of Svalbard reindeer was approximately 3 times that of summer. Increasing wind velocity increased heat loss, however, the increase was not dramatic. When wind coefficients (slope) of the heat transfer regression lines were compared, between season and between calf and adult, no significant differences were reported. All fur samples showed similar increases in heat transfer for wind velocities between 0 and 10 $m.s^{-1}$. The conductance of winter fur of Svalbard reindeer was almost half that of caribou fur. Also, conductance was not as greatly influenced by wind as caribou fur.

Key words: fur, heat transfer, insulation, *Rangifer tarandus platyrhynchus*, reindeer, wind.

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Introduction

Forced convection by wind is a major parameter affecting fur heat loss, and a major avenue of heat transfer for homeotherms. At wind velocities close or equal to zero, the dominant mechanism for energy loss can be thermal radiation exchange between a surface and its surrounding (Campbell, 1977). Thermal radiation exchange and conduction must account for some heat transfer even in wind (McArthur & Monteith, 1980). As wind velocity increases, however, convection is the primary mechanism of energy transfer between a solid surface and a liquid or gas, involving conduction, energy storage and mixing motion (Kreith, 1976), and it is determined by the parameters of the boundary layer between the two (Birkebak, 1966).

Wind decreases the insulation value of animal fur as the wind velocity increases. For furs, increasing wind velocity affects more than just the mean surface coefficient of heat transfer in the boundary layer, but also the boundary layer itself by flattening, buffeting, and forced convection through the outer portions of the fur reducing the effective fur depth (Lentz & Hart, 1960). In cattle calves, wind is responsible for most of the heat loss at low ambient air temperatures, making shelter important (Gebremedhin, 1987). Even a modest wind of 0.55 $m.s^{-1}$ increases the heat production of new-born lambs regardless of ambient temperature (Alexander, 1962). Still, caribou possess wind-resistant fur, with close-packed hair and a low fur conductance (Moote, 1955).

The relationship between fur conductance and wind velocity has been studied by several authors. Tregear (1965), and Lentz & Hart (1960), observed non-linear relationships, while Campbell *et al.* (1980) observed that for wind velocities between 0 and 10 $m.s^{-1}$ fur conductance may be treated as a linear function of wind velocity.

Svalbard reindeer (*Rangifer tarandus platyrhynchus*) inhabit the barren windswept Svalbard archipelago (77-81°N) and have been described as a specialised subspecies, with thicker fur than other caribou and reindeer (Krog *et al.*, 1976). Winds measured 10m above level ground at a west coast weather station, average 6 to 9 $m.s^{-1}$ throughout the year. Although fur heat transfer with increasing wind velocity is important for heat loss and ultimately temperature regulation, the thermal properties of Svalbard reindeer fur have not previously been studied. This paper examines the heat transfer through fur samples with respect to age, season and increasing wind velocity.

Material and methods

Fur samples

Whole pelts were collected 26 June, 14 August, 27 October, and on 21 March and 4 April. These represented the calving, summer, autumn and winter seasons respectively. The total was 33 pelts, including 18 adult, 2 sub-adult (less than 2 years old) and 13 calves. All were fleshed, dried and frozen. With one exception all adult fur samples were from females. Results from sub-adult fur were grouped with those from adult fur. Thus adults ranged in age from 1 to 14 years, while the calves ranged from 2-3 weeks to 10 months of age. Fur samples from the mid-back measuring 30 by 30 cm were cut from the whole pelts. Hair length was measured, and density was determined by manually removing and counting individual hairs from an area of 1 cm^2. A brief description of fur characteristics is given in Table 1, for details see Cuyler & Øritsland (accepted).

Table 1. Physical properties of Svalbard reindeer mid-back fur examined.

Season	Fur sample	*n*	Mean hair density {$hairs.cm^{-2}$} Total	Guard[1]	Hair[2]	Mean hair length {cm} Guard[1]	Hair[2]
Calving							
	Calf	3	3215	128	3087	4.1	2.3
			(71)*	(52)	(83)	(0.12), s^2 = 0.01**	(0.04), s^2 = 0.16
Summer							
	Calf	3	2064	35	2029	4.2	3.2
			(403)	(59)	(452)	(0.29), s^2 = 0.08	(0.25), s^2 = 0.06
	Adult	6	1089	38	1051	4.7	2.9
			(129)	(11)	(125)	(0.80), s^2 = 0.64	(0.51), s^2 = 0.26
Autumn							
	Calf	4	1481	51	1429	10	6.6
			(221)	(32)	(235)	(0.41), s^2 =0.17	(0.25), s^2 =0.06
	Adult	5	1080	9	1079	8.3	6.4
			(169)	(14)	(169)	(0.75), s^2 =0.56	(0.42), s^2 =0.17
Winter							
	Calf	3	2038	87	1951	9.5	6.5
			(250)	(43)	(230)	(0.50), s^2 =0.25	(1.00), s^2 =1.00
	Adult	9	1281	25	1255	8.9	6.7
			(211)	(11)	(210)	(1.18), s^2 =1.39	(0.51), s^2 =0.26

[1] Guard: those few exceedingly long hairs protruding above the fur surface.
[2] Hair: those hairs creating the visible fur surface, and bulk of a fur.
* Standard deviation in parenthesis. ** Symbol of variance: s^2.

Wind tunnel
The wind tunnel facility is described in Øritsland *et al.* (1980). Fur samples were mounted over a heat flow disc (C.W. Thornthwaite Associates) (Øritsland & Smith, 1975; Øritsland & Lavigne, 1976), and positioned at an angle with respect to wind direction to simulate the cylindrical nature of an animal's body (Lentz & Hart, 1960). The heat flow disc, embedded in a layer of grease, was positioned over a steel chamber through which water of 38±0.2 °C was continuously circulated. Heat flow through the disc was observed on a digital millivoltmeter (Keithley, 195A). A grease layer sealed the sample to the steel chamber and assured uniform thermal contact. Thermoelements in three locations were used: one in the grease layer, another on the skin surface, and a third above the fur. The latter two determined the temperature difference in the theoretical considerations described below. Temperature measurements were expressed on a digital thermocouple thermometer, accuracy ±0.2 °C (Fluke 2100A).

Heat flow through the fur samples was measured at wind velocities of 0, 2, 4, 6, 8, and 10 $m.s^{-1}$. Each fur sample was measured a minimum of 3x at each wind velocity. Heat flow was recorded when stable for 30 minutes. Usually 30 minutes passed before stability was reached, so each measurement took an hour or more. Two industrial sized variable-speed fans generated wind by one pulling and one pushing the air. A lattice of tubes, 40 cm deep, between the fan pushing the air and the fur sample, reduced turbulence and produced a steady rate of wind velocity. Wind direction was in line with the grain of the fur. Wind velocities were measured with a hot wire anemometer (Wallac Oy, Turker, Finland) positioned 10 cm above the fur surface, and an anemometer positioned flush with and behind the fur sample's surface.

Between season and age differences in heat transfer were studied, and not within fur sample or within season differences in heat transfer. Therefore to calculate the seasonal and age mean values for heat transfer at each wind velocity, we used the means from each fur sample at that wind velocity, with respect to season and age.

Theoretical considerations
The relation of the rate of heat transfer (Q) from a fur sample to the air is determined by the parameters of the boundary layer between the two. The most significant is the surface coefficient of heat transfer, or mean convective heat transfer coefficient (Kreith, 1976). The rate of heat transfer is a function of the wind velocity (Tregear, 1965; Campbell *et al.*, 1980), and is given by the following equation:

$$Q = \bar{h}_c (T_S - T_a) = \bar{h}_c \Delta T \qquad [W.m^{-2}] \qquad (1)$$

where the equation's final units are watts per square meter $[W.m^{-2}]$; = the mean surface coefficient for heat transfer, in watts per square meter per degree Celsius $[W.m^{-2}.°C^{-1}]$; and Ts and Ta = skin and fur surface temperature respectively [°C]. These may also be represented as the temperature difference ΔT [°C]. This study used ambient air temperature rather than fur surface temperature. Primarily because radiation and conduction between the fur surface and air were assumed negligible as wind velocity increased. Also, fur surface location for measurement was impractical because it was changeable, as increasing wind velocities penetrated, buffeted and disturbed the fur surface.

The $\bar{h}_c$ is dependent on many parameters within a boundary layer system (Kreith, 1976):
(1) the velocity of the fluid;
(2) the physical properties of the fluid (thermal conductivity, viscosity, density, and temperature);
(3) the geometry and finish of the surface; and
(4) the temperature gradient (typically a small source of error and usually ignored).

The $\bar{h}_c$ may also vary from point to point over a surface and therefore one considers a local or average $\bar{h}_c$ (Kreith, 1976).

According to Campbell *et al.* (1980) and Lentz & Hart (1960), the relationship of the mean surface coefficient for heat transfer, $\bar{h}_c$, to wind velocity may be written as:

$$\bar{h}_c = h + bV^c \qquad [W.m^{-2}.°C^{-1}] \qquad (2)$$

If the relationship is linear, the exponent c (an experimentally determined factor) on the wind velocity is 1 and the equation then becomes:

$$\bar{h}_c = h + bV \qquad [W.m^{-2}.°C^{-1}] \qquad (3)$$

where h = the calm air thermal conductance $[W.m^{-2}.°C^{-1}]$ determined by extrapolating the line through zero wind velocity; b = an experimentally determined wind coefficient; and V = wind velocity $[m.s^{-1}]$.

A fur sample's calm air conductance (h) equals the mean surface coefficient for heat transfer ($\bar{h}_c$) at wind velocity zero. Fur insulation $[W^{-1}.m^2.°C]$ is the inverse of the fur's thermal conductance $[W.m^{-2}.°C^{-1}]$.

Non-parametric t-test statistics utilising the

Table 2. Heat transfer through Svalbard reindeer mid-back fur samples at zero wind velocity, with respect to age and season.

Season	Fur sample	# Individual fur samples (n)	Calm air conductance (h) [$W.m^{-2}.°C^{-1}$]	s (standard deviation)
Calving				
	Calf	3	3.44	0.34
Summer				
	Calf	3	2.09	0.14
	Adult	6	2.09	0.51
Autumn				
	Calf	4	0.87	0.05
	Adult	5	0.78	0.12
Winter				
	Calf	3	0.65	0.06
	Adult	9	0.66	0.06

Table 3. Heat transfer through Svalbard reindeer mid-back fur samples as measured in a wind tunnel. The linear relationship between surface coefficient of heat transfer and wind velocity, = $h + b$V [$W.m^{-2}.°C^{-1}$], with respect to age and season.

Season / Fur Sample[1]	Heat transfer regression: Calm air conductance y-intercept (h)	s_x[2]	95% confidence intervals lower	95% confidence intervals upper	Wind coefficient slope (b)	s_x	95% confidence intervals lower	95% confidence intervals upper	Regression statistics r^2	df *	P
Calving											
Calf	**3.03**	0.12	2.78	3.28	**0.10**	0.02	0.05	0.14	0.61	17	0.000
Summer											
Calf	**2.12**	0.06	2.00	2.25	**0.06**	0.01	0.04	0.08	0.72	17	0.000
Adult	**2.16**	0.19	1.79	2.54	**0.04**	0.03	-0.02	0.10	0.05	35	0.189
Autumn											
Calf	**0.86**	0.04	0.78	0.93	**0.03**	0.01	0.02	0.05	0.58	23	0.000
Adult	**0.76**	0.03	0.69	0.83	**0.04**	0.01	0.03	0.05	0.60	29	0.000
Winter											
Calf	**0.64**	0.04	0.55	0.72	**0.02**	0.01	<0.01	0.03	0.29	17	0.022
Adult	**0.63**	0.02	0.58	0.68	**0.03**	<0.01	0.02	0.04	0.49	53	0.000

[1] the number of fur samples for each season is given in Tables 1 and 2.
[2] denotes standard error of the mean.
* includes the means at each wind velocity and the number of fur samples used.

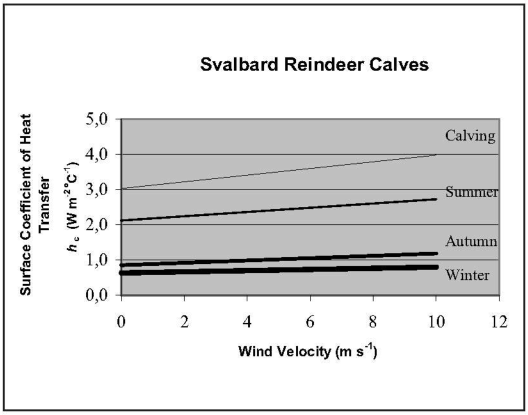

Fig. 1. Linear regressions of the surface coefficient of heat transfer on increasing wind velocity for Svalbard reindeer calves.

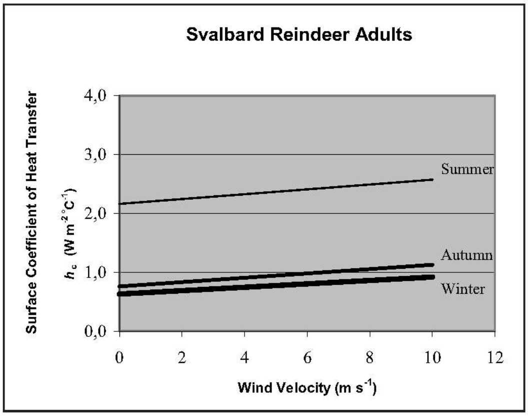

Fig. 2. Linear regressions of the surface coefficient of heat transfer on increasing wind velocity for Svalbard reindeer adults.

SPSS program package were used throughout. Slopes were tested as per Fowler & Cohen (1990, p. 157). Microsoft excel program package was used for linear regressions of heat transfer as a function of wind velocity (determined by the method of least squares) and for the regression line analysis.

Results

At zero wind velocity, the calm air conductance (*h*) was measured for all fur samples (Table 2). The difference in *h* was significant for the adult fur samples between summer and autumn, (t=5.626, df=9, P=0.000) and between autumn and winter (t=-2.608, df=12, P=0.023). Similarly, there was a significant difference in *h* for calf fur samples between the calving season and summer (t=-6.516, df=8, P=0.000), summer and autumn (t=16.784, df=5, P=0.000), and autumn and winter (t=-5.577, df=6, P=0.001). When calm air conductance was compared between adults and calves within seasons, no significant difference was observed regardless of the season (summer, t=-0.003, df=7, P=0.998), (autumn, t=-1.424, df=7, P=0.197), (winter, t=0.138, df=11, P=0.893).

Increasing wind velocity does effect heat transfer through the fur samples tested, since typically the regression lines presented in Figs. 1 and 2 have slopes significantly different from zero (Table 3). Specifically summer adult fur had a poor r^2 value. This is probably because half of the summer pelts were still moulting. This appeared to affect the data from individual fur samples.

Testing for differences between regression line slopes from different seasons revealed no significant differences. For adult fur there was no significant difference in the wind coefficient, slope *b*, between summer and winter (t=0.016, df=86, P>0.1), or between autumn and winter (t=0.067, df=80, P>0.1). Calf fur samples showed no significant difference in the wind coefficients (slope *b*) between seasons. The results were as follows, between calving season (June) and summer (t=0.127, df=32, P>0.1), between calving season (June) and winter (t=0.270, df=32, P>0.1), between summer and winter (t=0.240, df=32, P>0.1), or between autumn and winter (t=0.074, df=38, P>0.1).

Similarly, when calves were tested against adults within a season, there was no significant difference in the slope of the regression line for heat transfer. Between calf and adult fur there was no significant difference in the wind coefficient, slope *b*, in summer (t=0.028, df=50, P>0.1), autumn (t=0.067, df=48, P>0.1) or winter (t=0.074, df=66, P>0.1).

Discussion

As expected, fur insulation and fur length increased from summer to winter. For adults, when calm air conductance was compared between seasons a significant difference was always apparent. Heat transfer through calf fur yielded the same result. Similar to Hart's (1956) findings for the fur of large mammals, fur conductance decreased from summer to winter while insulation increased.

The calf and adult fur insulation was equal during the summer, autumn and winter seasons. When calm air conductance for adults and calves was compared within these seasons, no significant differences were observed. Calf fur samples from the calving season (taken from June calves less than one month old), however, showed the highest rates of heat transfer relative to furs from all other seasons.

The Svalbard climate is rigorous for adults and calves alike. Specifically winter is challenging for thermoregulation. Therefore, it was not unexpected that the winter fur of Svalbard reindeer calves provided the same insulation as the winter fur of adults, with calm air conductance of 0.7 W.m-2.°C-1. Unexpected was the seeming lack of correlation between hair density and insulation. Although calves and adults within a given season evidenced similar fur insulation, the calf fur samples always had higher hair density, often possessing longer hair as well. Calf fur samples from June had the highest rate of heat transfer, the highest hair density, highest number of guard hairs, and the shortest hair length. The relative importance and interplay of the physical factors of fur on heat transfer is incompletely understood.

Wind can decrease the insulation value of fur considerably causing substantial changes in the rate of heat transfer (Tregear, 1965; Davis & Birkebak, 1975). Campbell *et al.* (1980) observed that fur conductance could best be treated as a linear function of wind velocity. The results of the present study agree. Increasing wind velocity increased heat loss in all seasons and all ages, however, the influence on heat loss was smaller than expected, as shown by the shallow slopes of the regression lines.

Although fur insulation, as shown by the change in calm air conductance, changed between season, the effect of increasing wind velocity on heat loss (as shown by the wind coefficient, slope *b*) was the same regardless of season or age. There was no significant difference in the wind coefficient between seasons or between adults and calves. The wind coefficient expresses the effect of wind on heat transfer through the fur, and is an indicator of the importance of windchill (Øritsland, 1974). With similar wind coefficients for summer and winter, windchill has no more effect in winter than in summer, or between calves and adults.

Comparison of Svalbard reindeer fur conductance to other studies

The insulation value of summer Svalbard reindeer fur was similar to results from other caribou/reindeer. Hammel (1955) observed a calm air conductance of 1.03 W.m^{-2}.°C^{-1} for adult caribou fur 3.1 cm thick (*Rangifer arcticus*, presently known as *R. t. groenlandicus* or barren-ground caribou), while Moote (1955) observed a summer value of 2.7 W.m^{-2}.°C^{-1} for adult fur of 2 cm (unspecified subspecies of caribou). The present study's mean summer calm air conductance, 2.1 W.m^{-2}.°C^{-1} for 3 cm fur, suggests that the summer fur of Svalbard reindeer is not more insulative than other caribou/reindeer.

Unlike the summer results, Svalbard reindeer winter fur, both calf and adult, had lower calm air conductances than Moote's caribou. The present study's winter fur had conductance values, which were almost half Moote's winter value for adult caribou. Moote (1955) reported winter calm air conductance of about 1.2 W.m^{-2}.°C^{-1} for fur of 5 cm, while this study observed 0.7 W.m^{-2}.°C^{-1} for fur of 6.6 cm. Svalbard reindeer fur provided better insulation than caribou fur in winter. This is supported by Nilssen *et al.* (1984) who reported a lower critical temperature for Svalbard reindeer of approximately -50 °C, versus -30 °C for Norwegian reindeer. Jacobsen (1980) observed a positive correlation between fur depth and thermal resistance. The added fur length in the Svalbard reindeer may be the contributing factor.

The results suggest that Svalbard reindeer fur is not as greatly influenced by wind as other reindeer/caribou studied. Moote (1955) reported that caribou winter insulation dropped 42% from its calm air value at winds of about 10 m.s^{-1}, and to 50% for other animal fur. Svalbard reindeer fur, however, showed only a 29% drop in winter insulation at wind velocity 10 m.s^{-1}. Comparisons with Peary caribou (*R. t. pearyi*) would have been appropriate, however, there is no literature on heat transfer from the fur of the Peary caribou.

The Svalbard reindeer are better protected against steep temperature gradients and the effects of wind than others of their species.

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