SECTION-VII

MATERIALS RESEARCH

Fifth Indian Expedition to Antarctica, Scientific Report, 1988
Department of Ocean Development, Technical Publication No. 5, pp. 421-432

Clothing for Antarctica

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Abstract

The experience of the members of the Fifth Indian Scientific Expedition to Antarctica with the Clothing for Antarctica, developed and supplied by Defence Research and Development Organisation (Defence Materials and Stores Research and Development Establishment, Kanpur), have been described. The optimum requirements of clothing in Antarctica (at locations of the Indian activity) have been discussed. The clothing supplied has been found to meet the thermal protection during the Antarctic winter adequately.

Introduction

Protection against the elements is the primary function of clothing. In a cold environment, the thermal insulation, or the thermal resistance of clothing limits heat loss from the body, enabling it to maintain homeothermic regulation of a constant body temperature (ca 37°C for man). However, bulk, weight and, perhaps, reduced insulation beyond an optimum thickness (Winslow and Herrington, 1949) preclude the use of conventional clothing in extreme cold, as in the polar climates; survival and work outdoors in such climates require the use of functional or protective clothing (Newburgh, 1949, Kitchling and Page, 1945) with special attributes.

Apart from affording protection against extreme cold, high winds and snow, clothing for Antarctica, meant exclusively fo use in expeditions, must also be light and tough for survival and efficient outdoor activity in such hostile environments. It is also desirable that the clothing be permeable to water vapour while retaining its wind resistance. However, usefulness of the clothing depends as much on material as on its design and the right use.

The most essential requisite of the clothing for Antarctica is, of course, its thermal insulation which is crucial for survival in extreme cold. The basic problem in the design of such protective clothing lies in the achievement of adequate thermal insulation with low bulk and weight. Experimental results (Burton et a/., 1955) suggest that the thermal insulation of a dead air space is the ultimate value obtainable with any material including the best animal furs (Scholander et al., 1950) for clothing. This property of a dead air space is also found in suitably filled air spaces such as a layer of any woolly material of low bulk density (ca 64 kg/m^3 for cotton wool) which has the same (or nearly so) thermal insulation per unit thickness as the former (Larose, 1943; Speakman and Chamberlin, 1930). Such a layer, of a material with adequate resilience to retain thickness in use and of the right thickness to produce the necessary insulation computed from biophysical and meteorological data, is used as insulation in the clothing for Antarctica.

On the basis of established design principles, several items of clothing developed by DMSRDE were subjected to performance evaluation in Antarctica during the Fifth Expedition compared with items of available foreign clothing there.

The aim was to determine (on a subjective basis) the optimal clothing requirement in varying weather and terrains in Antarctica, as also the correspondence between laboratory estimate and actual requirement of thermal protection under, service conditions.

Design Principles

The idea behind the thermal protection of clothing is to restrict the rate of dissipation of metabolic heat to the level of its generation rate relevant to the particular state of rest or activity (Table I) for which the clothing is intended.

Table I. Metabolic levels and rates for different activities

Activity	Metabolism	
	$kcal/m^2/hr$	met
Sleeping, postdigestive	36	0.72
Sleeping, digesting	40	0.80
Lying quietly,.postdigestive	40	0.80
Lying quietly, digesting	45	0.90
Sitting	50	1.00
Standing	60	**1:20**
Walking 2.5 kph (very light work)	90	1.80
Level walking 5 kph (Light work)	130	2.60
Level walking 6.5 kph (moderate work)	180	3.60
Walking 5% grade 5.5 kph (moderately heavy work, walking from Maitree to Novo, say)	220	4.4
Walking, 10% grade 5.5 kph (Heavy work, walking up slope)	340	6.8

(After Newburgh, 1949)

The body continuously loses heat, both as latent heat and as sensible heat. The sensible (or non-evaporative) heat is transmitted through the layer(s) of clothing, insulation to the environmental air mainly by convection and radiation. Conductive transfer through air and clothing when its bulk density is low, is negligible (Burton *et al,* 1955).

However, assuming a thermal steady state in the clothing as a rough approximation (Burton, 1934), the thermal flux transmitted across the clothing is customarily expressed by the Fourier equation for conductive transfer in one dimension. A familiar form of this equation gives the thermal resistance or thermal insulation, Ic, of the clothing material of thickness dx and thermal conductivity k as:

$$Ic = dx/k = (Ts - Tc)/F \qquad ...(1)$$

where F is the flux, and Ts and Tc are the skin and clothing surface temperatures, respectively. The conductivity factor k, as experimentally determined (B.S. 4745: ASTM C518) for clothing materials, mainly involves convective and radiative transfer in steady state and represents the apparent thermal conductivity (Tye, 1969).

The same flux F is dissipated by the clothing (for a steady state) following Newton's law of cooling with close approximation (Burton, 1944). Since the dissipated flux F is thus proportional to the temperature drop from clothing surface to air, like the clothing the air also has a thermal insulation la given by:

$$la = (Tc - Ta)/F \qquad ...(2)$$

where Ta is the air temperature. Practical units of clothing insulation, the tog and the clo, are defined in a like manner (Burton, 1934; Pierce and Reese, 1946).

Thus, as in series heat flow through layered materials, the sensible heat must be dissipated by the body through a total thermal insulation I given by:

$$\begin{aligned} I &= Ic + la \\ &= (Ts - Tc)/F + (Tc - Ta)/F = (Ts - Ta)/F \qquad ...(3) \end{aligned}$$

The values of Ts, Ta, F, la are obtained from available data (vide infra) so that the thickness dx of clothing with known k factor, required for the appropriate value of Ic (= dx/k) to satisfy (3) for body heat balance may be calculated.

Now the skin temperature Ts is taken to be 33°C for a comfortably resting man (Burton *et al,* 1955), so that at any air temperature Ta:

$$I = (Ts - Ta)/F = (33 - Ta)/F$$

But the sensible heat flux in the basal non sweating state is about 3/4th of the total heat loss from the body for any particular activity (Dubois, 1927), so that:

$$\begin{aligned} F = 3n/4 \text{ met} &= 3n/4.50 \text{ kcal/m}^2\text{/hr} = 37.5n \text{ kcal/m}^2\text{/hr} \\ &= 3n/4.58.3 \text{ W/m}^2 = 43\ .725n \text{ W/m}^2 \qquad ....(4) \end{aligned}$$

Where n is the metabolic rate, whence

1= (33 - Ta)/F
 = 10(33 - Ta)/43.725n togs
 = 0.2287 (33 - Ta)/n togs ...(5)

The insulation of air (i.e. the reciprocal of flux per unit temperature drop) varies very little with temperature but considerably with windspeed. A standard set of values of la has been adopted (Frazier, 1945) which gives the value of la at different wind speeds (Tabe II). Thus at any ambient temperature Ta and windspeed given by met data, for any particular metabolic rate (maintaining the non-sweating state) relevant to the state of rest or activity, I, and hence Ic in togs, can be calculated from (5). However, using the value of la for any particular wind speed the value of Ic required can be quickly read off a temperature-insulation plot (Fig. 1) of eqn. (5).

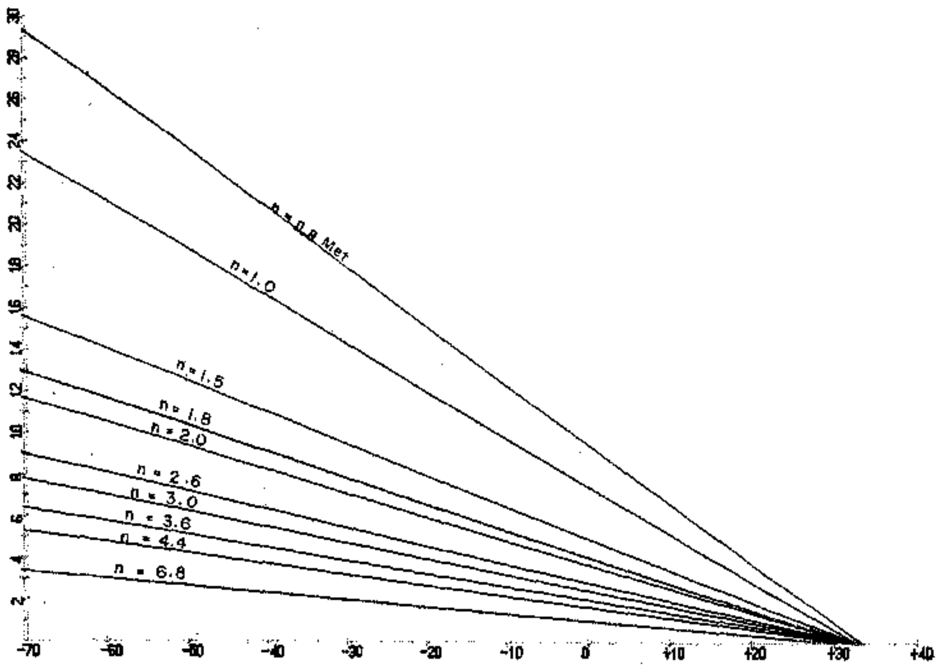

Fig. 1.Insulation requirement for different metabolic rates, n = 0,8, 1.0, 1.5, 1.8, 2.0. 2.6, 3.0, 3.6, 44, 6.8, met

It is evident that the insulation required depends, apart from the meteorological factors, on the metabolic rate as well (Table III). However, for a more exact estimate and analysis of insulation requirement other factors like wind-chill, the.mal wind decrement, solar radiation, etc., have to be considered to determine the net thermal demand of the environment.

Table II. Standard values of insulation and air movement

Velocity of air movement, knots	Insulation, la togs
44.36	0.16
19.75	0.23
10.39	0.31
4.20	0.47
2.08	0.62
1.19	0.78
0.54	0.93
0.49	1.09
0.35	1.24
0.29	1.32

Table III. Insulation required for different activities

Activity	Metabolic rate, met	Ambient Temp. °C	Insulation togs
Sleeping in tent	0.8	-29	17
Sleeping in tent with lamp on	0.8	-12	12
Brisk walk against Wind	6,0	-34	2.3
Doing office work	1.0	+21	1.6
Level walk 6 kph	3.0	4-4	1.6
Brisk walk against wind	6.0	-20	1.6

Considering the facts that below -35°C not much useful work can be done (Lunardini, 1981) and that the average lower limit of summer temperature at Dakshin Gangotri can be safely taken as -10°C (Maitree is always warmer), the rough limits of insulation required in Antarctica can be deduced from Fig. 1 and

Table IV. However, the above estimate of insulation requirement considers only the series heat loss from the body (Fig. 2) while under adverse weather conditions (specially, if aided by faulty clothing design and use) the heat loss along parallel paths may be as much as half the resting heat loss from the body.

Table IV. Limits of Insulation Requirement in Antarctica

Metabolic Rate, met	Insulation Requirement, tog	
	Summer	Winter
0.8	12	19
6.8	1.5	2.3

Materials and Method

Layered clothing (for easy adjustment to different metabolic rates and thermal demands) has been in use for quite some time (Hall and Williams, 1964). So long as the bulk density is low the nature of the filling material appears to have no influence on the insulation of the assembly. Laundered polyester batting due to their low bulk density and ability to retain shape and thickness under service conditions, have been standard filling material for long. About 1.4 kg of this material used as insulant is reported (Kennedy and Vanderbie, 1964) to provide thermal protection upto —65°C. To save cost, acrylic single pile is used for clothing layers intimate to the body (with obvious indoor use in view) partly sacrificing lightness. An extra layer of thin reflecting (metallized) fabric included with the insulation cuts down radiative transfer.

Ten items of clothing for Antarctica (Table V), developed by or under

Table V. Antarctic clothing subjected to Performance Evaluation in Vth Expedition

SI. No.	Nomenclature	Weight kg	Thickness mm	Bulk density kg/m^3	Insulation togs (at 2.44) togs/cm)
1.	Wind cheater	0.49	0.125		
2.	Jacket	0.88	15.4	19.48	3.76
3.	Waist-coat	0.44	6.3	83.33	1.54
4.	Vest (integrated)	0.75	6.3	83.33	1.54
5.	Trouser		9.3	16.13	2.27
6.	Outer Trouser	0.14	0.125	—	—
7.	Work Overall	2.8	7.2	72.92	1.76
8.	Duffles Polyester				
9.	Boots combat Rubber	2.6	—	—	—
10.	Boots MUKLUK (Canadian)	2.1	—	—	—

investigation (item 10) by DMSRDE, were subjected to performance evaluation in Antarctica (summer and winter). Items 2 and 5 had polyester insulation while items 3, 4 and 7 had acrylic sjngle pile insulation. No extra backing or facing is needed for items 3 and 4 for obvious reasons. Items 1 through 6 constitute the complete outfit named Antarctica suit. The sectional views (Fig. 3) show the structural details of the composite fabrics and the materials used for the clothing are shown in perspective in Fig. 4.

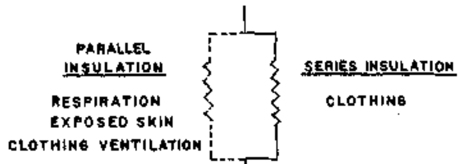

Fig. 2 Insulation of body heat.

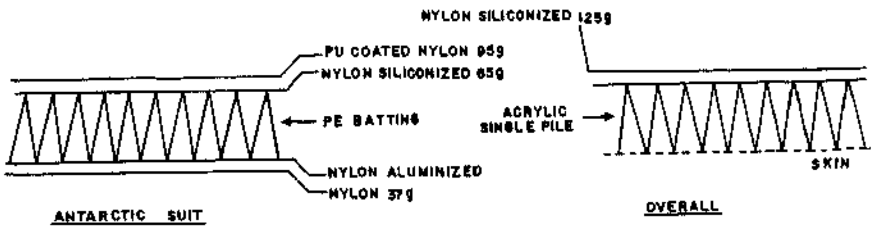

Fig. 3 Sectional view of clothing.

It can be seen (Table VI) that different combination of the developed clothing offer a wide range of insulation values to cope with varying thermal demands

Table VI. Range of Insulation for Different Combinations of Clothing for Antarctica (DMSRDE)

(Rough estimate only, actual values likely to be about 10% lower)

Combination of clothing	Insulation, togs
Work overall	1.76
Overall with Waist-coat	3.30
Full Antarctica Suit without Waist-coat	5.30
Overall with Jacket	5.52
Full Antarctica Suit	6.84
Overall with Jacket and Waist-coat	7.06

and metabolic rates. Also, their design characteristics compare well with polar clothing used elsewhere (Table VII). It is to be noted, however, that the insulation values given are all still air values and the closeness with which these values are approached under service conditions will depend on the efficiency with which wind penetration can be prevented by the wind cheater used. It is known (Breckenridge and Woodcock, 1950) that wind penetration can cut down the insulation of clothing by more than 40%.

Table VII. Relative Weight and Insulation Ratings of some Polar Clothings

Clothing	Weight, kg	Insulation, togs
Eskimo Costume	5.5 - 8.2	12.4 - 15.5
European Uniform	9.1 - 13.6	4.7 - 6.2
Russian Overall (Novo)	11	6.2 - 7.8
QMCD Clothing ensemble (US)*	16	6.7
Arctic Uniform (US)	5.5	5.4
Antarctica Suit (DMSRDE)	2.7	5.3 - 6.8
Work overall (DMSRDE)	2.8	1.6 - 1.9

Some data after Lunardini, 1981
*Ralph P. Goldman: The Arctic Soldier, Possible Research solutions for his Protection. Alaska Sc. Conf. 1964, p. 402.

The clothing was used by the participants of the expedition in all the terrains of Indian activity (viz. DG, Maitree, and Wohlthat) in different job situations, under diverse weather and terrain conditions. Opinion of these users on different aspects of the different items of clothing were recorded in questionnaire proformae. A comparative assessment of the clothing vis-a-vis items of available imported clothing were made by interviewing members of the Second Wintering Team at Dakshin Gangotri, who had used such clothing, for more than a year.

Results and Discussion

The thermal protection of the Antarctica Suit was found to be more than adequate for the Antarctic winter and much more than is necessary for the summer. All the items supplied were not used by the members in the summer as they were not needed.

It was found that in the summer the wind cheater alone, used on top of the overall, was sufficient for necessary comfort and protection in most job situations, including in mild blizzards (-4°C, 35 knots, say). In moderately strong (summer) blizzards (-6°C, 40 knots) also, this combination was found to provide adequate protection as established personally by a prolonged encounter with such a blizzard for a period of about eight hours. Also, at lower temperatures

(—12°C) under relatively calm wind conditions (less than 2 knots, say), this combination was found adequate. Members of the Wintering Team were of the view that the overall, with the Jacket and wind cheater on top, is sufficient for the winter also. It needs to be pointed out, however, that the above weather conditions can be faced with the clothing mentioned only with a metabolic rate much in excess of the resting metabolism. The use of normal undergarments with the clothing mentioned is also understood.

The Antarctica Suit, as already mentioned, was found to be more than adequate for the winter and the waist-coat is mostly not required. It was found to have a distinct weight advantage over imported clothing of similar warmth (as per users experience)

Fig. 4 Some items of clothing subjected to performance evaluation during the expedition.

There is a little to choose between the Boots Combat and the Canadian MUKLUK except that, in the winter the former tends to stiffen and slip on hard ice a little more than the latter. The polyester duffles, being light, are convenient for indoor use, but outdoors they cannot provide adequate warmth and tend to slip and gather at the toes while walking. The blanket duffles (Croft and Roberts, 1940) were found, to be -essential for outdoor activities due to their ability to retain the thickness under body weight providing necessary warmth.

It is well known (Reese, 1941) that, in general, the insulating value of a clothing assembly depends on its thickness and the looseness of its fit, irrespective of the material used, the insulation per unit thickness, as experimentally determined, approaching that of dead air (2.9 togs/cm corresponding to a k value of about 0.03 W/MK; the true thermal conductivity of air is, of course, very much lower due to obvious reasons). However, due to body curvatures and parallel heat loss, the insulation value achieved in practice for clothing under service conditions is found (Siple and Cochran, 1944) to be about 2.44 togs/cm. Practical limitations restrict the thickness (Burton *et ah,* 1955) of clothing to about 38mm, setting an upper limit of about 9.3 togs/cm to clothing insulation. It is, therefore, evident from the results of the performance evaluation that clothing insulation does not have to be stretched to its full practical limit at the locations of present Indian activity in Antarctica.

There is evidence (Frazier, 1945; Butson, 1949) to the effect that the insulation requirements of the body diminish with time to a slightly lower stable value due to cold acclimatization, even over a one year period. Members (of US teams) have been found to need no extra clothing for the winter in Antarctica after having spent the summer there. Computation of insulation requirement for the winter with the help of equation (5) could, therefore, lead to overclothing of an acclimatized man.

In spite of having the necessary thermal insulation, the performance of clothing may be found to be deficient under service conditions if it is tight fitting. The internal wind created by bodily movements in clothing with the right fit aids ventilation and lowers, upto as much as half (Belding, 1949) its insulation value leading to quicker dissipation of extra metabolic heat. This design feature (i.e. loose fit and play for air inside) is the basis of Eskimo clothing (mostly using caribou). It also helps in avoiding overheating and perspiration, and the subsequent hazard associated with it over a period of relative inactivity, with the insulation destroyed by the moisture.

Even if a suitable fabric is found with low air porosity and. high water vapour permeability (there is no correlation between the two, Tucker *et al,* 1944, Fourt and Harris, 1947) the problems of overheating and perspiration have to be managed and controlled for most part by the right use (viz. ventilation, discarding, and changing, if need be) of the clothing for Antarctica.

Acknowledgement

The authors wish to thank Dr. B.V. Ramani, Director, DMSRDE Kanpur, for his active technical interest and guidance in the design and evaluation of the clothing for Antarctica. The cooperation extended by Shri M.K. Kaul, Leader of the Fifth Indian Scientific Expedition to Antarctica, and Dr. V.K. Dhargalkar, Leader of the Third Wintering Team in the performance evaluation of the clothing is gratefully acknowledged. Thanks are also due to Shri G.P. Sharma, N. Kanan, and B.B. Das, for active involvement in the evaluation work, and help in preparing a part of th_{92} material for publication.

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