COLD EXPOSURE AND PATTERNS OF ACTIVITY AT A POLAR STATION

By J. N. NORMAN

THE effects of a cold environment have been sought both in experimental animals and in man. Well-defined physiological changes have been described in animals following prolonged exposure to a cold environment (Burton and Edholm, 1955), but evidence of cold acclimatization has been almost completely lacking in man living at a polar station (Butson, 1949; Lewis, 1958; Lockhart, 1941; Wilson, 1956, 1960).

It seems possible that the failure to demonstrate cold acclimatization in such men is due partly to the protective effect of clothing, heating and housing. Rodahl (1957) has pointed out, at a discussion on Arctic clothing, that "in the technical aspects of Arctic operations we really do not know the basic problems involved. First of all, we do not know the environmental exposure to which the man will be exposed or expected to be exposed." Rodahl thus drew attention to the surprising inadequacy of basic knowledge in studying the effects and demands of the polar environment, which is largely due to the form in which meteorological information is presented. There is a requirement to measure and record meteorological data in forms applicable to man. In order to assess the environmental stress, it is of little value to know, for example, maximum or minimum temperature on a particular day; it is more important to know the temperature distribution. An attempt has been made, therefore, to describe meteorological conditions at Halley Bay in terms useful to the physiologist.

In this study, measurements have been made of the climatic stress to which men were exposed while living for one year at Halley Bay (lat. 75°36′S., long. 26°39′W.), on the Caird Coast of the Weddell Sea, some 800 miles (1,290 km.) from the South Pole. A brief account of this work has already been published (Norman, 1962). The activity patterns of the subjects were also investigated. Such information is needed for the assessment of energy expenditure and hence the required level of food intake. In addition, it is useful to know if the activity pattern is related to the environmental conditions, including light and darkness as well as climate. Studies in this country on a variety of groups have shown that even in arduous occupations a high proportion of time is spent lying and sitting (Edholm and others, 1955). Comparisons of the results obtained in the Antarctic with those reported for various groups in a temperate climate could also indicate the possible effects of climate.

At the time of this study, Halley Bay was a static base, with little or no sledging. A manhauling sledge journey lasting one week was therefore included to compare activity and exposure conditions with life at the station.

Subjects

Four subjects were studied in rotation once a month. Three were meteorologists and the fourth was the auroral observer. Their average weight was 79·5 kg. and surface area 1·98 m.². Two of these subjects were in the group of four who carried out the manhauling experiment, the others being a geophysicist and the doctor. The four men whose activity patterns and exposure conditions were studied, in addition to their scientific duties, took their turn in the daily domestic routine, brushing, scrubbing and polishing floors, serving at table and washing up. Each man looked after the four coal fires in turn and also shared in the general base work: digging out and re-siting buried stores, and transporting food boxes, coal and fuel drums from distant dumps by tractor sledge. The three meteorologists were on night duty every sixth night; one was in charge of the radar set, a second was responsible for the daily radiosonde flights, and the third inflated the weather balloons each morning. The auroral observer was on night duty from the end of March until October.

Recording of daily activities

Each subject was observed for a 24 hr. period each month, and each week one subject was studied. During the period of observation the observer recorded the subject's activity each minute of the day on cards similar to those designed by Garry and others (1955) when they studied coal miners. The cards were modified by Edholm and others (1955) for studies of the activity patterns of soldiers.

Activity was classified in eight grades:

1. Lying.
2. Sitting.
3. Standing.
4. Walking (inside).
5. Light work (inside).
6. Walking (outside).
7. Light work (outside).
8. Heavy work (outside).

Time spent in bed, including sleep, was taken as lying. Sitting included sitting talking, writing, reading, eating, listening to the radio, playing cards and doing instrument maintenance. Standing included operating and reading instruments. Light work inside included dressing, washing and domestic duties; outside light work included launching radio-sondes and weather balloons, and climbing instrument towers. Activities such as digging snow, moving heavy boxes, coal bags and oil drums were categorized as heavy work.

Energy expenditure was computed from the published results of direct measurement of the energy cost of various tasks (Passmore and Durnin, 1955; Masterton, Lewis and Widdowson, 1957; Rennie, 1957; Adam and others, 1958). Clothing and subjective sensations of comfort were also recorded.

Meteorological measurements

During the period of observation of each subject, measurements of wet- and dry-bulb temperature and the air movement were made every 20 min. in the immediate vicinity of the

Fig. 1. The temperature-sensitive vest as it was worn below the clothing, together with the Wheatstone bridge used to measure changes of resistance in the vest.

subject, both indoors and outdoors. A Kelvin and Hughes hand anemometer was used to measure air movement, and a Casella whirling hygrometer for the measurement of wet- and dry-bulb temperatures.

Micro-climate

The sub-clothing or micro-climate was measured using a temperature-sensitive vest designed by Wolff (1958). This consists of an electrically continuous garment, knitted of flexible insulated wire which acts as a resistance thermometer and gives an accurate measure of integrated sub-clothing temperature over the trunk (Adam, 1959). A lead from the wire vest protruded through the subject's clothing and readings of resistance were made with a simple, portable Wheatstone bridge. A change of 0·1 Ω could be measured, and this was equivalent to a temperature difference of 0·5° C (Fig. 1).

Food and water intake

During the manhauling sledge journey the food consumed by each man was measured, recording the weight of the various items of the ration before and after each meal.

Results

Activity patterns

The average time spent in the eight categories of activity is shown in Fig. 2, where the mean results of all four subjects throughout the year are presented in the form of a histogram. There were only small differences between the subjects. The most striking feature of these results is the high proportion of time spent sitting and lying, which is, on the average, 75·5 per cent of the elapsed time. The individual figures are 77, 72, 79 and 74 per cent.

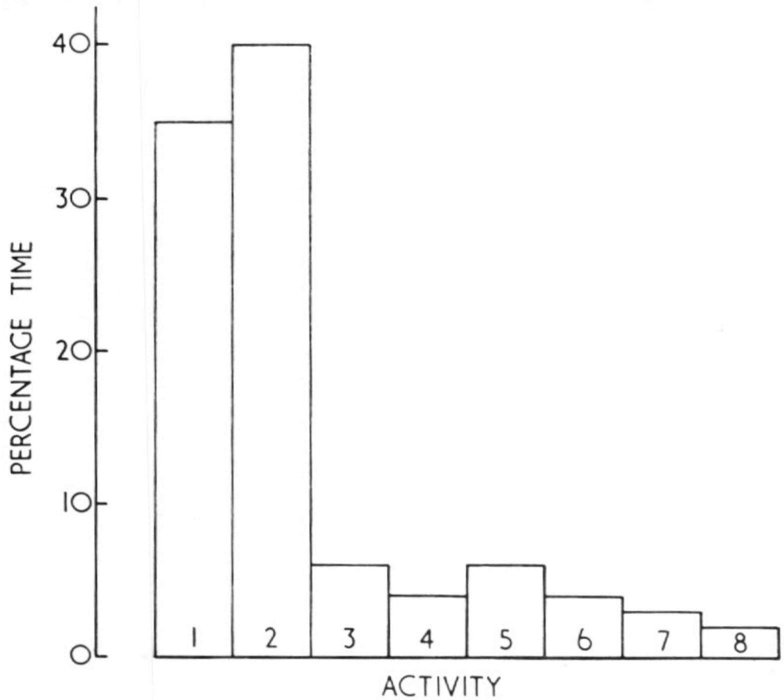

Fig. 2. The percentage of time spent by the four subjects in the various activities during the year. 1, lying; 2, sitting; 3, standing; 4, walking (inside); 5, light work (inside); 6, walking (outside); 7, light work (outside); 8, heavy work (outside).

The second feature is the distribution of time spent indoors and outdoors, the latter averaging 9 per cent of time throughout the year for the four subjects. Again, there was little variation between the subjects, the averages being 9, 10, 8 and 10 per cent.

The individual variations are shown by the results given in Table I for the four subjects in the months of March, June, October and December. Although the averaged figures for

TABLE I. ACTIVITY PATTERNS. THE PERCENTAGE OF TIME SPENT BY EACH SUBJECT IN THE VARIOUS ACTIVITIES. THE MONTHLY VALUE SHOWN REFERS IN EACH CASE TO A PERIOD OF OBSERVATION OF 24 hr. ON EACH SUBJECT

Subject	*Time* (per cent)							
	Sleeping	*Sitting*	*Walking (Inside)*	*Standing (Inside)*	*Light Work (Inside)*	*Walking (Outside)*	*Light Work (Outside)*	*Heavy Work (Outside)*
				MARCH				
1	28	22	6	6	6	6	5	22
2	33	42	4	8	7	4	1	—
3	49	36	3	1	3	3	4	1
4	33	43	4	—	3	3	14	—
Mean	36	36	4	4	5	4	6	6
				JUNE				
1	43	22	1	21	10	1	1	—
2	33	33	4	13	7	4	4	1
3	35	40	6	6	4	3	4	3
4	35	35	3	11	8	4	—	4
Mean	36·5	32·5	3·5	13	7	3	2	2
				OCTOBER				
1	29	51	4	3	4	7	1	—
2	33	49	3	1	8	3	3	—
3	40	35	5	7	7	4	4	1
4	40	35	4	3	4	7	—	7
Mean	35·5	42·5	4	3·5	6	5	2	2
				DECEMBER				
1	33	51	7	4	1	4	—	—
2	33	42	3	—	4	15	3	—
3	35	44	1	—	3	3	4	10
4	33	36	1	3	14	13	—	—
Mean	33·5	44	3	2	5·5	9	2	2·5

the whole year are very similar for the four subjects, there are some individual differences in each of these months.

The seasonal effects are shown by examining the averaged figures for the light months, October to April, and the dark months, May to September (Table II). The sun sets in the middle of April but this month has been included with the light months as there is work out of doors in preparation for winter, and, although the sun rises at the end of August, September was included with the dark months, since it is the coldest month of the year and outdoor activity is at a minimum. In the winter months only 5 per cent of time was spent out of doors compared with 13 per cent in the light months. The average time out of doors in each month is shown in Fig. 3.

TABLE II. AVERAGE PERCENTAGE OF TIME SPENT BOTH DURING SUMMER AND WINTER IN THE VARIOUS ACTIVITIES BY FOUR SUBJECTS. SUMMER IS DEFINED AS THE LIGHT MONTHS (OCTOBER TO APRIL) AND WINTER AS THE DARK MONTHS (MAY TO SEPTEMBER)

Activity	*Time* (per cent)			
	Light Months (Oct.–April)	*Light Months* (Oct.–April)	*Dark Months* (May–Sept.)	*Dark Months* (May–Sept.)
		Inside hut		*Inside hut*
1. Lying	34		36	
2. Sitting	39		40	
3. Walking (inside)	4	87	4	95
4. Standing (inside)	4		9	
5. Light work (inside)	6		6	
		Outside hut		*Outside hut*
6. Walking (outside)	6		3	
7. Light work (outside)	3	13	1	5
8. Heavy work (outside)	4		1	

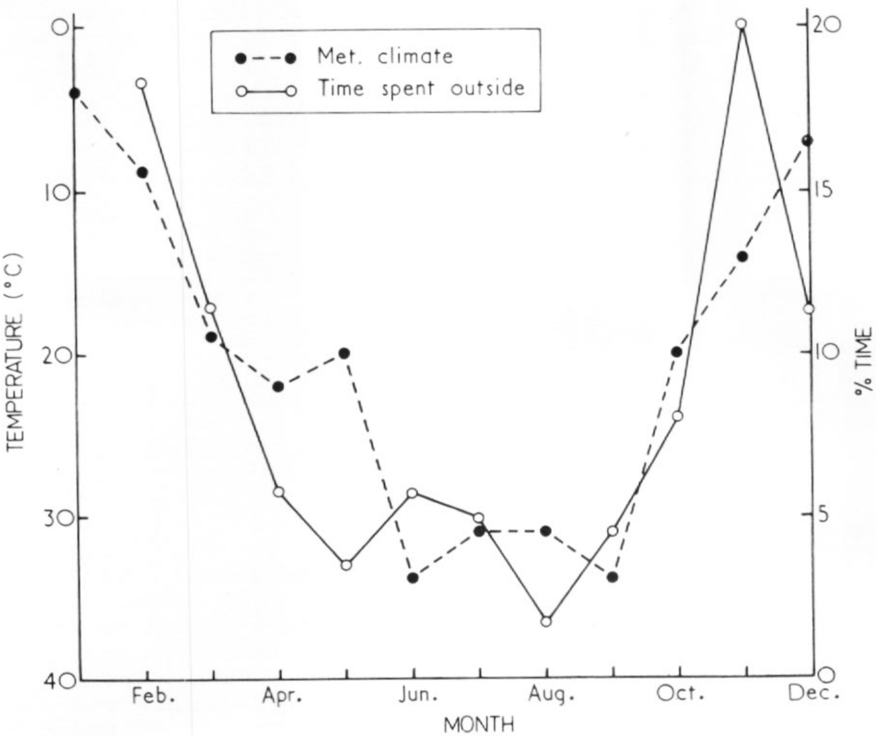

Fig. 3. The monthly mean values of the meteorological climate plotted with the monthly mean percentages of time spent out of doors by the four subjects.

During the manhaul sledging experiment the activity patterns were, naturally, rather different. Time spent in the tent was considered as indoors, and this occupied 61 per cent of the total time. Outdoor time at 39 per cent was very much higher than at the station. Details are given below:

	per cent	
Lying (in sleeping bag)	53	Indoors 61 per cent
Sitting (in tent)	5	
Standing	9	Outdoors 39 per cent
Walking	9	
Light work	7	
Heavy work	14	

Time spent in manhauling was classified as heavy work. A halt was made every mile to carry out a number of geophysical measurements, and involved light work as well as standing.

Energy expenditure and food intake

The computed energy expenditure for the four men at the base station averaged 3,390 kcal./day for the whole year. During the light months (October to April) the figure was 3,770 kcal./day and it was 3,120 kcal./day during the dark months (May to September). During sledging the energy expenditure was computed to be 5,050 kcal./day. Food intake was measured during the second to fifth days of the sledge journey and averaged 4,430 kcal./day. The results for the four days are given in Table III. There was a calorie deficit each day and the four subjects lost, on the average, 1·25 kg. body weight. Part of this weight loss was probably due to mild dehydration.

TABLE III. FOOD INTAKE (kcal./day) FOR EACH OF FOUR MEN DURING THE SECOND TO FIFTH DAYS OF THE SLEDGE JOURNEY

Subject	*Day 2*	*Day 3*	*Day 4*	*Day 5*	*Mean*
1	4,649	4,410	3,465	4,504	4,257
2	4,346	4,286	4,230	4,719	4,395
3	4,818	5,037	3,703	5,260	4,705
4	4,401	4,687	3,583	4,729	4,350
				Mean	4,427

Meteorological measurements and micro-climate

The meteorological conditions of temperature and wind are given in Table IV in the form of a double-frequency table. It is clear that high wind speeds were associated with relatively warm days, and that wind speed was low when the temperature was low. A combination of high wind speed and low temperature does not appear in the table.

Since the greater part of the subjects' time was spent indoors, the environmental conditions in which they lived was very different from the meteorological measurements. The results of all measurements made are summarized in Fig. 4. There was little variation in the mean monthly values of the micro-climate or sub-clothing temperature, or of the exposure climate, although the monthly mean outdoor temperature ranged from −4° C to −32° C. The

TABLE IV. DOUBLE-FREQUENCY TABLE OF TEMPERATURE AND WIND VELOCITY EXPRESSED IN TERMS OF THE PERCENTAGE OF TIME DURING WHICH THE VARIOUS COMBINATIONS OF TEMPERATURE AND WIND VELOCITY OCCURRED DURING THE YEAR

Wind Speed (kt.)	Temperature (°C) −45		−35		−25		−15		−5	0	Total
0	0·07	0·8	1·8	2·4	2·2	2·0	2·4	3·2	2·6	1·9	19·4
10		1·4	3·2	4·9	5·9	5·1	4·5	3·6	2·5	2·5	33·6
		0·1	0·5	1·6	2·4	3·6	2·9	2·4	2·0	2·9	18·4
20			0·2	0·3	0·9	1·5	1·4	1·5	1·6	2·0	9·4
				0·1	0·7	1·4	0·7	1·0	1·5	2·1	7·5
30					0·1	0·5	0·6	1·1	1·2	1·4	4·9
						0·3	0·5	0·9	1·4	1·2	4·3
40						0·1	0·3	0·3	0·5	0·3	1·5
						0·07	0·4	0·2	0·3	0·07	1·0
50						0·07	0·07				0·1
									0·07	0·07	0·1
Total	0·07	2·3	5·7	9·3	12·2	14·6	13·8	14·2	13·7	14·4	100·0

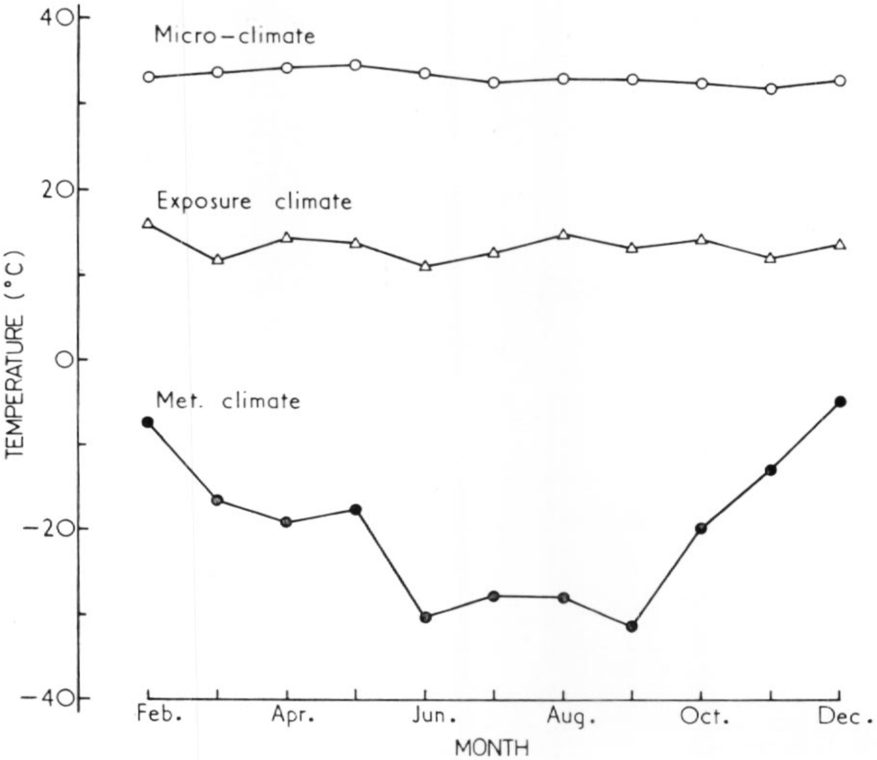

Fig. 4. Monthly mean values of the temperature of the meteorological climate, the exposure climate and the micro-climate to which the four subjects were exposed during the year.

distribution of the exposure climate for the four subjects for the whole year is shown in Fig. 5.

The relationship between the exposure temperature and the meteorological temperature

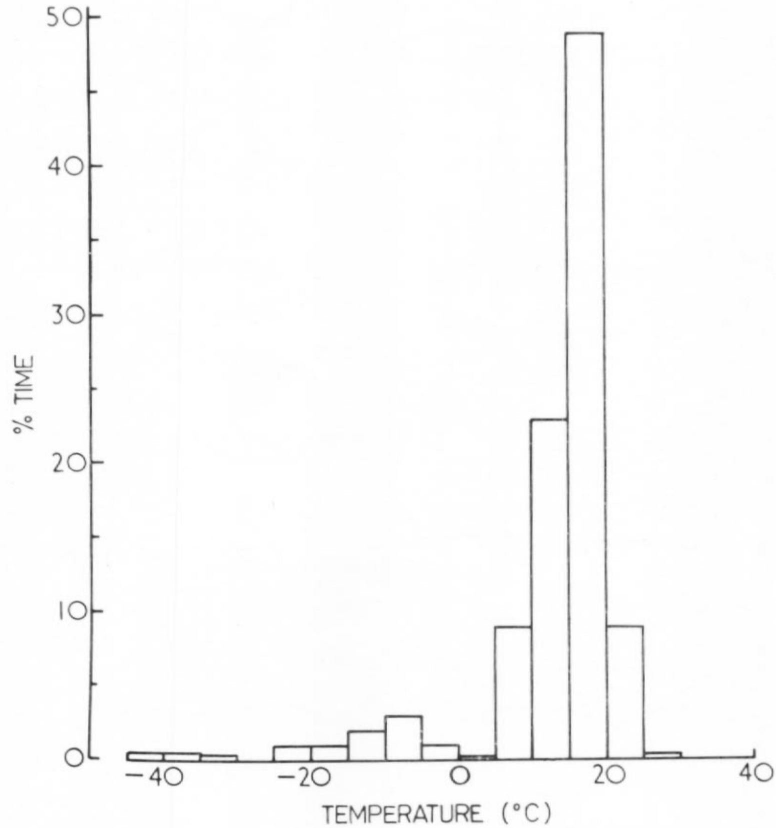

Fig. 5. Annual mean distribution of exposure climate of the four subjects.

is shown in Fig. 6, where the two conditions have been plotted according to Siple's (1949) profile method. It will be seen that in the warmer months (October to April) the outdoor exposures were during the higher temperatures, whereas, paradoxically, in the winter months most of the outdoor exposure was during the coldest part of the day. In October to April the lowest temperatures were during the hours of sleep, and in May to September time spent out of doors was, in general, when air movement was low, which is when air temperature is also low. Work out of doors was restricted to periods when wind velocity was less than 15 kt. (7·4 m./sec.) as, due to drifting snow, visibility was poor at winds of 15 kt. (7·4 m./sec.) or more. Even more important, body cooling at these high wind speeds was very rapid and frostbite more of a hazard.

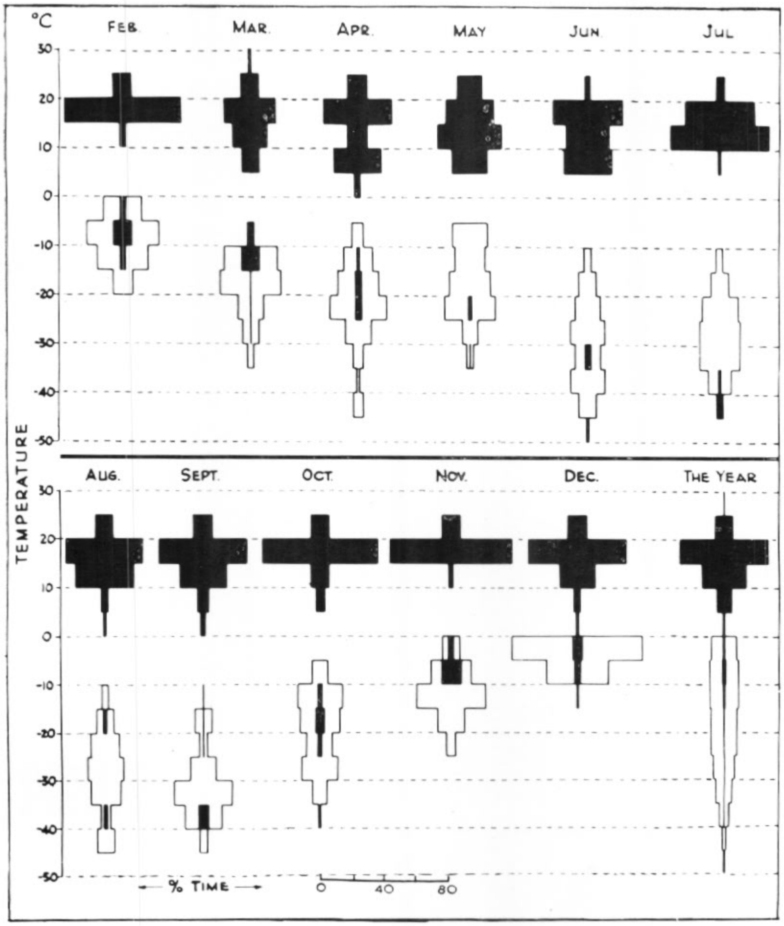

Fig. 6. Temperature profiles. Superimposition of the monthly temperature profiles of the meteorological climates and the exposure climate of the four subjects. The shaded area represents the exposure climate, the upper part occurring inside the hut and the lower part outside. The unshaded area represents the meteorological climate. The thicker the shape opposite a range of temperature the longer has the temperature persisted at that point.

Details of the measurements of micro-climate are shown in Fig. 7, which gives the average results for the four subjects for the year. The nodal value of 32–33° C was the same in all four subjects. During the period inside the hut, which accounted for 91 per cent of the total time, the micro-climate scarcely ever fell below 30° C. Out of doors, the lowest micro-climate temperature recorded was 19° C, for a short time on one subject. On moving from the hut to the outside the exposure temperature could drop 40 to 60° C; the micro-climate usually fell 4 to 6° C within 10 to 15 min., and then, depending on the wind speed and activity, would either fall much more gradually or stabilize.

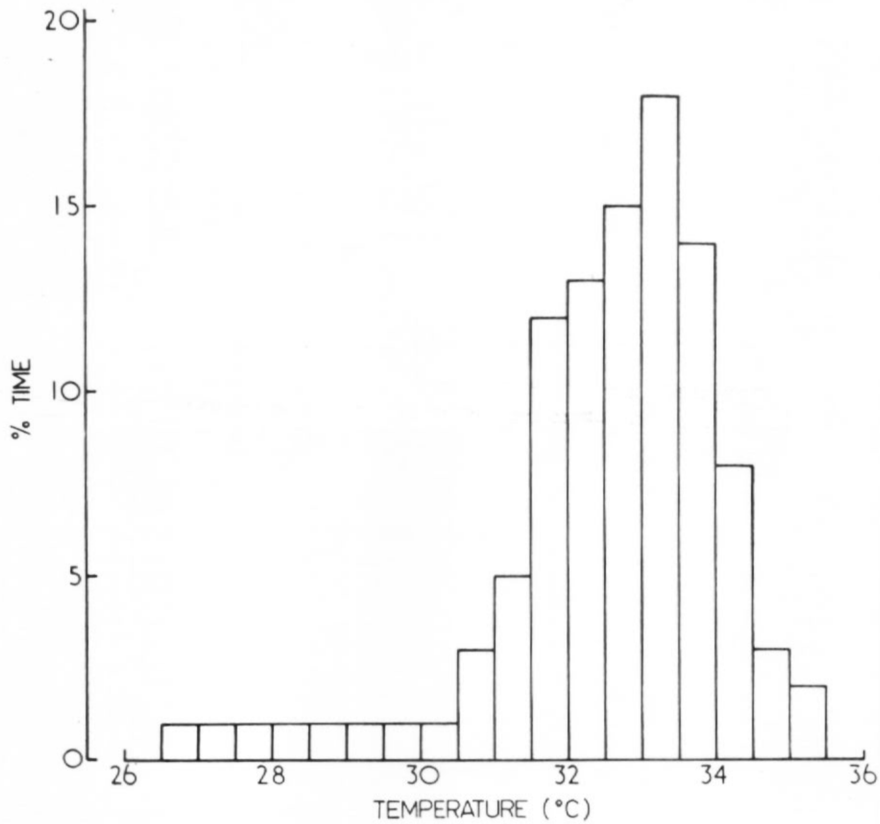

Fig. 7. Annual mean distribution of the micro-climate of the four subjects.

During the sledge journey, the outside temperature ranged from −8° C to −23° C, but for 94 per cent of the time it was between −12° C and −15° C. The air was calm for 33 per cent of the time and only exceeded 11 kt. (5·5 m./sec.) for 3 per cent of the time. Nevertheless, since a much longer time was spent out of doors the micro-climate was considerably lower than at the station. The fluctuations in sub-clothing temperature during sledging are shown in Fig. 8.

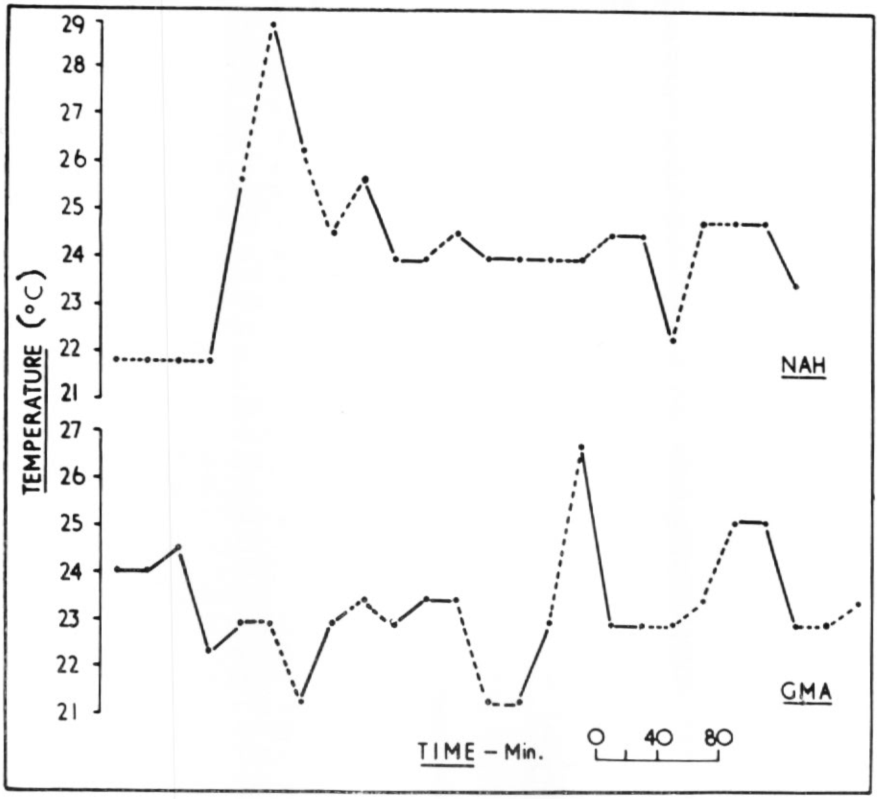

Fig. 8. Fluctuations in the temperature of the micro-climate of two subjects during periods of one day spent in manhaul sledging. The interrupted lines represent time actually spent hauling the sledge.

Discussion

The pattern of activities of the four subjects at the station showed that 75 per cent of the time was spent sitting or lying. Similar figures have been obtained by investigators in the United Kingdom. Edholm and others (1955) found that military cadets also spent 75 per cent of their time lying and sitting, while Bedale (1923) reported a figure of 69 per cent for school children, and Garry and others (1955) stated that coal miners spent 66 per cent and clerks at the colliery 67 per cent of their time in these activities. At first, these are surprising figures but there is no doubt that in many sedentary occupations there are even higher figures for time spent sitting and lying. Edholm and others (1955) observed that "man should be regarded as predominantly a sedentary rather than an upright animal". It is no less true at a polar station. This does not impy that the level of physical work or energy expenditure was particularly low. It averaged 3,400 kcal./day throughout the year, which is the same as the daily energy expenditure of cadets during training; coal-mining, which is an arduous occupation, involves an energy expenditure of 3,650 kcal./day.

The figure for manhaul sledging of 5,050 kcal./day is similar to the findings of Masterton, Lewis and Widdowson (1957) that sledging in north Greenland involved an expenditure of 5,200 kcal./day. Sledging must be considered to be one of the hardest tasks from the point of view of energy expenditure. The daily food intake of 4,430 kcal./day during sledging was similar to that observed in north Greenland of 4,770 kcal./day (Masterton, Lewis and Widdowson, 1957).

The maintenance of the health of isolated polar communities demands considerable forethought in the provision of an adequate diet, together with the essentials of clothing, heating and housing. Knowledge of the activity of the personnel of a particular station is an important element in such forethought. The results obtained at Halley Bay indicate that the degree of cold exposure to which a man living and working at a polar station will be subjected will be related only to a limited degree to the local climate, since a high proportion of time will be spent indoors. In assessing the degree of cold exposure likely for a man living in a cold climate, it is necessary to take into account the conditions of his living quarters and the percentage of time during which his recreation and occupation require him to be exposed to the local climate of the station.

Errors can easily be made in assessing the climatic stress likely for the personnel by the use of conventional meteorological data, such as maximum and minimum values of temperature and wind velocity. 70 kt. (35 m./sec.) of wind and temperatures of −60° C have been mentioned in papers on polar physiology from areas where these values have been known to occur (Frazier, 1945). There has been no further analysis to indicate whether they occurred for a significant length of time and whether separately or together.

The double-frequency table of temperatures and wind speeds shows that high winds and low temperatures very rarely occur together. The double-frequency distribution gives a better impression of the severity of the meteorological climate and, at the same time, gives an idea of the worst conditions likely to be encountered and how often they are likely to occur.

The frequency distribution of both exposure and micro-temperatures will give a better indication of true climatic stress on the individual than the mean or ranges. At Halley Bay, the subjects spent 90 per cent of their time in an exposure climate over 0° C.

It seems possible that certain occupational groups in the United Kingdom, such as fishermen and agricultural workers, particularly in Scotland, might have an even colder exposure climate. As shown in Fig. 4, the percentage of time spent out of doors varies directly with the outdoor temperature, and this explains why the mean values of the exposure climate vary so little from month to month. The total severity of the cold stress does not alter much from month to month when it is considered in terms of intensity and of time.

The frequency distribution of the sub-clothing temperature reflects the adequacy of the clothing and housing provided. This temperature is lower than skin temperature, and the average figure of 32·8° C indicates a skin temperature of the order of 33·5 to 34° C (Adam, 1959). This is only a little lower than would be found in subjects living in a temperate climate.

Macpherson (1958) has suggested that since man living in a temperate climate must have adapted considerably to life in a cooler climate than that for which he is best suited, viz. a tropical climate (Erikson and others, 1956), it is useless to seek profound physiological changes in response to extreme cold.

It seems possible that the difficulty which has been experienced in finding unequivocal evidence of acclimatization to cold in Antarctic personnel is due to the relatively short exposure to cold. Until more observations have been made, it will not be certain that the findings reported in this paper apply to other polar stations. However, similar observations have been made at the British Antarctic Survey station on the Argentine Islands (lat. 65°15′S., long. 64°16′W.) with similar results (personal communication from A. Cumming).

The degree of cold exposure required to stimulate physiological adaptation in man is not known. Mackworth (1953) found that 2 hr. exposure daily in a cold room was sufficient to produce local acclimatization in the finger, but 1 hr. was inadequate. Davis (1961) demonstrated a marked diminution in shivering as a result of keeping his nude subjects in a cold chamber for 8 hr./day. The exposure was severe and sufficient initially to cause violent shivering. The men at Halley Bay, however, were seldom cold enough to shiver and only rarely complained of discomfort. Nevertheless, Davis also demonstrated a significant diminution in shivering in men who spent some 7 weeks in Alaska. They were out of doors between 4 and 7 hr. daily, clad in standard Arctic clothing, so their exposure time was greater than that experienced by the subjects at Halley Bay.

It appears probable that in the normal routine of a polar station, where there is little or no sledging, the exposure is not sufficiently severe or prolonged to produce any significant physiological change. Rather, the adaptation may be considered to be behavioural since it is so greatly influenced by the use of adequate housing, heating and clothing.

MS. received 6 January 1965

REFERENCES

ADAM, J. M. 1959. Subjective Sensations and Sub-clothing Temperatures in Antarctica. *J. Physiol., Lond.*, **145**, No. 2, 26–27*P*.

———, BEST, T. W., EDHOLM, O. G., FLETCHER, J. G., LEWIS, H. E. *and* H. S. WOLFF. 1958. The Dietary Intake and Energy Expenditure of Recruits in the British Army. *Army Personnel Research Committee, Med. Res. Coun., Lond., Report*, No. APRC 58/3.

BEDALE, E. M. 1923. Energy Expenditure and Food Requirements of Children at School. *Proc. R. Soc.*, **B**, **94**, No. 662, 368–404.

BURTON, A. C. *and* O. G. EDHOLM. 1955. *Man in a Cold Environment*. London, Edward Arnold Ltd.

BUTSON, A. R. C. 1949. Acclimatization to Cold in the Antarctic. *Nature, Lond.*, **163**, No. 4134, 132–33.

DAVIS, T. R. A. 1961. Chamber Cold Acclimatization in Man. *J. appl. Physiol.*, **16**, No. 6, 1011–15.

EDHOLM, O. G., FLETCHER, J. G., WIDDOWSON, E. M. *and* R. A. MCCANCE. 1955. The Energy Expenditure and Food Intake of Individual Men. *Br. J. Nutr.*, **9**, No. 3, 286–300.

ERIKSON, H., KROG, J., ANDERSEN, K. L. *and* P. F. SCHOLANDER. 1956. Critical Temperature in Naked Man. *Acta physiol. scand.*, **37**, Fasc. 1, 35–39.

FRAZIER, R. G. 1945. Acclimatization and the Effects of Cold on the Human Body as Observed at Little America III, on the United States Antarctic Service Expedition 1939–1941. *Proc. Am. phil. Soc.*, **89**, No. 1, 249–55.

GARRY, R. C., PASSMORE, R., WARNOCK, G. M. *and* J. V. G. A. DURNIN. 1955. Expenditure of Energy and the Consumption of Food by Miners and Clerks, Fife, Scotland (1952). *Spec. Rep. Ser., Med. Res. Coun., Lond.*, No. 289.

LEWIS, H. E. 1958. Physiology. (*In* HAMILTON, R. A., ed. *Venture to the Arctic*. Harmondsworth, Penguin Books Ltd., 145–66.)

LOCKHART, E. E. 1941. Acclimatization in the Antarctic. *Science*, **94**, No. 2450, 550.

MACKWORTH, N. H. 1953. Finger Numbness in Very Cold Winds. *J. appl. Physiol.*, **5**, No. 9, 535–43.

MACPHERSON, R. M. 1958. Acclimatization Status of Temperate-zone Man. *Nature, Lond.*, **182**, No. 4644, 1240–41.

MASTERTON, J. P., LEWIS, H. E. *and* E. M. WIDDOWSON. 1957. Food Intakes, Energy Expenditures and Faecal Excretions of Men on a Polar Expedition. *Br. J. Nutr.*, **11**, No. 3, 346–58.

NORMAN, J. N. 1962. Micro-climate of Man in Antarctica. *J. Physiol., Lond.*, **160**, No. 2, 27–28*P*.

PASSMORE, R. *and* J. V. G. A. DURNIN. 1955. Human Energy Expenditure. *Physiol. Rev.*, **35**, No. 4, 801–40.

RENNIE, D. W. 1957. Energy Metabolism in the Cold. (*In* FERRER, L. M., *ed. Cold Injury*. Transactions of the Fifth Conference, Josiah Macy Jr. Foundation. New York, Josiah Macy Jr. Foundation, 253–90.)

RODAHL, K. 1957. Human Acclimatization to Cold. (*In* FERRER, L. M., *ed. Cold Injury*. Transactions of the Fifth Conference, Josiah Macy Jr. Foundation. New York, Josiah Macy Jr. Foundation, 177–252.)

SIPLE, P. 1949. American Climates. *Bull. Am. Inst. Archit.*, September, 16–35.

WILSON, O. 1956. Basal Metabolic Rate in the Antarctic. *Metabolism*, **5**, No. 5, 543–54.

———. 1960. Changes in Body Weight of Men in the Antarctic. *Br. J. Nutr.*, **14**, No. 3, 391–401.

WOLFF, H. S. 1958. A Knitted Wire Fabric for Measuring Mean Skin Temperature or for Body Heating. *J. Physiol., Lond.*, **142**, No. 2, 1–2*P*.