M A N   I N   T H E   A N T A R C T I C

A THESIS SUBMITTED FOR THE DEGREE

of

DOCTOR OF MEDICINE

at

THE UNIVERSITY OF GLASGOW

by

John Nelson Norman, M.B., Ch.B.

December, 1960.

CONTENTS

CONTENTS

PLATES

FIGURES

SUMMARY

SUMMARY

MAN IN THE ANTARCTIC

The effects of a cold environment have been sought both in experimental animals and in man. In animals there are well defined indices of physiological change resulting from cold exposure but as study passes to man normally domiciled in a cold climate and then to temperate zone man exposed experimentally to cold evidence of physiological adaptation becomes progressively less well defined. When men living temporarily on a polar base are considered, evidence of cold acclimatization is almost completely lacking and reasons for this lack of evidence were sought by examining the patterns of activity and by measuring the degree of cold to which such men were exposed.

The patterns of activity were derived by means of a time and work study and it was shown that an average of 9% of time was spent outdoors but this was subject to a marked seasonal variation. The mean annual energy expenditure was calculated to be 3,347 Cal/day while the energy expended during manhaul sledging was 5,055 Cal/day.

Criticism is levelled against the use, by the physiologist, of meteorological data expressed in terms of mean and extreme values. There is a requirement for the expression of climatic data in terms of frequency or, ideally, double frequency tables of temperature and wind velocity since environmental stress can only be assessed from a knowledge of the occurrence

and duration of the various combinations of these two parameters.

While the better presentation of meteorological data is an advance towards the evaluation of the climatic stress it does not present the true picture since no account is taken of the shelter used by the men or the clothing worn. To account for these factors two concepts are introduced; the exposure climate - the climate which surrounds the man wherever he may be - and the sub-clothing or micro-climate. The annual mean value of the exposure climate was 14°C while that of the station was -18.6°C. The micro-climate is, however, the ultimate climate to which the greater part of the body is exposed and its mean annual temperature was 32.8°C although it was maintained at a lower temperature while sledging (mean temperature 24.8°C). It is concluded that the degree of cold to which men living on a static base are exposed is considerably less than has been thought in the past and is unlikely to be sufficiently severe to produce measurable evidence of acclimatization.

Loss of body weight following a sledging journey was found to be due to calorie deficiency and possibly also to mild dehydration,but it was felt that training effects following a sudden transition from relatively sedentary activity to very strenuous activity may be an important factor. The fluid requirements of heavy physical work in a cold climate are shown to be high on account of a high rate of sweating and considerable respiratory fluid loss.

An account is given of the medical aspects of life on a polar base.

When activity, clothing and shelter are considered it seems that man has used his intelligence to prevent his body from being unduly exposed to the cold while living and working in polar regions and the adaptation of such men to life in a cold climate must be considered to be largely intellectual rather than physiological.

PREFACE

PREFACE

This study was written from work done by the author while he was employed as medical officer to the Falkland Islands Dependencies Survey base at Halley Bay (75.36 deg. S.; 26.39 deg. W.), on the coast of the Weddel Sea in Antarctica. The personnel consisted of twelve men. Medical duties in an Antarctic base are not demanding and it was possible to undertake a programme of physiological research under the auspices of the Medical Research Council.

The Falkland Islands Dependencies Survey maintains and recruits the staff for two types of base in Antarctica: the static base which is chiefly concerned with geophysics, meteorology, physiology and biology, and usually presents but little opportunity for travel; and the sledging base from which journeys are made for topographical survey and geological research.

Halley Bay is the most southerly British Antarctic base, being some 800 miles from the South Pole. It is situated on an ice-shelf and the living hut is now deeply buried below the snow surface. Entrance is by shafts, some thirty feet deep, down to the doors. Internally the hut is comparatively comfortable and is heated both by electricity and coal fires.

Differential surrounding ice pressures, however, have caused it to tilt some two degrees to the vertical, and ventilation becomes a

Plate 1

The Falkland Islands Dependencies Survey base at Halley Bay.

problem when the hatches are battened down during the frequent blizzards.

The surrounding terrain is completely flat and featureless and only the occasional seal or Emperor penguin relieves the monotony of the surroundings. There is a very large rookery of Emperor penguins at a distance of four miles from the base, but the penguins are only in residence during the breeding season, which is during the four months of darkness.

It is not easy to perform scientific measurements in Antarctica. Complex instruments tend not to function and those which require batteries function for no more than half an hour in winter, after which time the battery has been rendered useless by the cold. This can be overcome sometimes by carrying the battery close to the body, inside the clothing, and by connecting it to the instrument only when it is to be used. Great difficulty, however, is experienced in using instruments which require delicate adjustment with bare hands, since in winter exposed hands become clumsy, slow and useless with great rapidity. Instruments should thus be simple and require the minimum of delicate adjustment.

Life on such a station is not straightforward. The emphasis, however, is on mental rather than physical hardship. Weather conditions are such that little more time is spent outside the hut than is necessary. The scientific programme, though ambitious, tends to be of a routine nature and daily life soon takes on a stereotyped pattern. Added to this there is a sense of irrevocability, since the sea freezes shortly after the departure of the ships and the party is utterly isolated until late the following summer.

Since the various duties require personnel from a wide range of social and intellectual backgrounds, a small group of men from vastly divergent walks of life are brought together in a small hut and have to live together continuously for a year. Hardship does not stem from loneliness, but from the overwhelming burden of constant company.

I N T R O D U C T I O N

Section 1

SECTION I

INTRODUCTION

HISTORICAL BACKGROUND TO PRESENT STUDY

One of the first scientific observations, suggesting that man may undergo certain physiological changes to enable him to exist at low environmental temperatures, was made by Charles Darwin (1906). He described a nude woman, a native of Tierra del Fuego, sitting in a canoe nursing a baby, also nude, while snow was falling and melting on her naked bosom.

Hicks, Matters, Moore and Eldridge (1933, 1934), working on Australian Aborigines in the early 1930's, noted that they exist, unclothed, in a diurnal temperature range of the order of -2°C. to 33°C. Temperature measurements demonstrated that when they sleep huddled round a camp fire the oral temperature falls as far as 33°C., while the skin temperature falls as low as 23°C. In spite of these remarkably low temperatures these workers state that shivering does not occur, nor does metabolism rise.

Considerable efforts have been directed towards investigating the effects of short and long term exposure to cold, and these may conveniently be divided into four main groups:-

(a) Animal experiments;

(b) Experiments on Eskimos living and working in their normal environment and against a background of their normal activity patterns;

(c) Human experiments - both laboratory and field studies on expeditions designed primarily to investigate the problem;

(d) Studies on the personnel of polar stations, where physiology is but one of a large number of subjects being studied.

(a) <u>Animal Experiments</u>

A consideration of the effects of low temperatures on animals shows that they fall into two main groups. First, there are the effects known as adaptation, which refer to changes occuring during a period of several generations; second, there are the effects known as acclimatization, which refer to changes produced in an organism by alterations in its normal environment of relatively short duration.

Adaptation in animals may, moreover, be further subdivided into general and local effects. These general effects include possible alterations in body temperature, metabolic rate and of the degree of insulation.

Irving and Krog (1954, 1955) and Irving (1951) have investigated the skin and body temperatures of about twenty species of Arctic mammals and they found no difference from temperate mammals. Similar examinations in Arctic birds and a comparison of them with tropical birds showed very little difference in the relatively high body temperature which both types possess. (Wetmore, 1921; Irving and Krog, 1954).

A further interesting study in this connection was the measurement of the incubation temperatures of eggs in Arctic nests, which was also conducted by Irving and Krog (1956). They found the temperature to be 35°C., which was the same as that recorded from eggs in the nests of tropical and temperate birds. (Huggins, 1941).

Though the body temperature shows very little species difference it has been shown that the critical temperature (the environmental temperature below which metabolism rises in order to maintain body temperature) varies greatly between species and between environments. It is usually found to be around the level of the coldest temperatures to which the animal is expected to be exposed during the winter. Thus it is found to be +20 to $+30^{\circ}$C. for tropical animals, 0°C. for the polar bear cub and -40°C. for the Arctic fox. (Scholander, Hock, Walters, Johnson and Irving, 1950c). Thus the metabolic economy is reasonably adapted to the particular environment to which the animal is normally exposed.

Ardtic animals experience a considerable range of environmental temperatures and are enabled to survive almost solely by virtue of the insulation which they possess. This is partly formed by fur and partly by sub-cutaneous fat. They are also able to vary this insulation, possibly by variations in blood flow in the fat and certainly by pilo-erection (Burton and Edholm, 1955). Observations of the prolonged and intense exercise of which Arctic animals are capable have demonstrated their ability to dissipate the additional heat of exertion by varying insulation, whereas man has to alter his clothing to suit activity and environment (Irving and Krog, 1955). It has also been observed that the added insulation of these animals enables them to withstand heat stress more easily than animals of temperate zones, and the husky dog finds no difficulty in living in a warm climate - on warm, humid days the animal appears to shrink to about half its normal size, since the fur is allowed to relax and to lie close to the body surface (Meehan, 1957), but the author would indicate the possible distinction between living as opposed to working in a warm climate, where the husky dog is concerned.

Basal metabolic rate has been shown not to be elevated by reason of a cold environment, but to vary only with size and weight, and all Arctic animals lie on the 'mouse-elephant curve'. That does not imply, of course, that the metabolic cost per day is the same for life in Arctic climates as in temperate zones (Irving, 1951; Scholander et al. 1950a; Burton and Edholm, 1955).

When the evidence of more localised adaptation is examined, it is clear that most effects are to be found in the area where the animal comes into contact with the terrain, i.e. in the limbs, and large differences may be found between extremity temperatures and mean body and skin temperatures. Irving and Krog (1955), impressed by the tracks of animals in snow at ambient temperatures of -30 or -40°C. proceeded to measure the temperature gradients in animal limbs. They found that with an air temperature of -30°C. the toe-pad temperature of the skin of the husky dog was 0°C. and on top of the foot, between the toes, it was in the region of 8 to 14°C., while on the skin below the femoral fur it was 35°C. Similar measurements on the Arctic gull showed that temperatures in the leg and feet were close to 0°C., but where the feathers cover the upper part of the limb the temperatures rise rapidly over a short distance to those of the well insulated body.

Another series of experiments by Irving, Schmidt-Nielsen and Abrahamsen (1957) was to measure the melting point of fat taken at various levels in the legs of Arctic mammals. Such a series from the bone marrow of the Alaskan reindeer show a decrease in melting point from about 50°C. in fat from the femur to about 18°C. in the distal part of the phalanges. In the Arctic wolf the change was from 38°C. to 20°C. This seemed good evidence that softening of fats in Arctic animals allows their cold limbs to be more flexible, but a comparison with the tropical deer showed changes of much the same order. Irving concludes that this may be an evolutionary change to allow an animal of the deer family to extend its range to an Arctic climate.

A most fascinating experiment was the measurement of excitation in a section of peroneal nerve excised from the foot of a gull adapted to walking around in cold weather (Chatfield, Lyman and Irving, 1953). The nerve taken from the bare metatarsal portion of the leg continued to conduct at a relatively cold temperature, while the central portion failed to conduct some 10 to 15° higher. When the gulls were kept in a warm environment for a month this adaptation to function in the cold could not be demonstrated, and the peripheral part of the nerve had the same properties as the central portion. Scholander has also observed an apparent loss of adaptation in the gull (Scholander et al., 1950b). He describes a gull, which had been kept inside most of the winter, and which finally escaped from its cage into the snow at Point Barrow, whereupon the web of the foot froze within one minute with consequent gangrene.

Scholander (1955) comments on the counter-current vascular heat exchange technique of heat conservation found in the extremities of many animals. In the tail fin of the whale the veins form a system of venae commitantes which are actually embedded in the arterial wall. Thus if the extremity is maintained at a lower level of temperature, then heat is transferred from the warm arterial blood to the cold venous blood returning from the extremity. Arterial blood supplied to the extremity is thus cooled and heat is conserved. At the same time cool blood is warmed before it reaches the heart (Scholander and Schevill, 1955). Irving and Krog (1955) postulate a similar mechanism in the foot of the herring gull, in which blood can be observed to circulate, though the surface temperature of the foot is nearly $0^{o}C$. Were it not for such a mechanism of heat conservation, the heat loss from the large surface area of the foot would be excessive. Bazett, Love, Newton, Eisenberg, Day and Foster (1948), measuring the temperature gradients between radial and brachial arteries and their venae commitantes in man, have indicated that the amount of heat which may be conserved by such a mechanism may be of a very high order.

The earliest demonstrable change which occurs during acclimatization of animals, exposed to a much colder environment than that in which they normally live, is the increase in metabolic rate which may be recorded when the environmental temperature has fallen below the animals' critical temperatures (Burton and Edholm, 1955). As indicated above the critical temperature has a marked species variation (Scholander et al. 1950c). A large part of this increase in metabolism is due to the increased muscular activity of shivering, preceded by increase in muscular tone and increased action potentials (Burton and Edholm, 1955). Heroux (1956) has demonstrated increased vascularisation of muscle, in cold acclimatized animals, by histological techniques. It has been observed, however, in animals maintained at low temperatures for prolonged periods, that metabolic rate may be maintained at high levels without gross shivering. This has led to the suggestion that there may be a chemical component in the increased rate of metabolism (Blair, Dimitroff and Hingeley, 1951).

Complementary studies of food intake and body weight (Blair et al., 1951) showed a 50% increase in food intake in rabbits exposed to -30°C. for several weeks without any appreciable change in body weight, and unaccompanied by any alteration in rectal temperature, degree of activity or gross shivering. Careful observation of these weight changes in young animals has shown that there is actually an initial loss in weight, followed by a slow recovery to the initial level and therafter growth continues at the pre-stress rate. This is analagous to the stages of the stress syndrome of Selye. Though the observations that shivering becomes minimal or absent do not provide positive evidence that the increased metabolism is motivated by a chemical regulator, they do show that an increase in muscular activity may not be adequate to explain the increased food intake. There is also some evidence that the thyroid and the suprarenal glands, and possibly also the hypophysis, may be concerned in the organism's reaction to the cold (Burton and Edholm, 1955).

Le Blond, Gross, Peackock and Evans (1944) have demonstrated thyroid changes in animals exposed to the cold and, using radio-active iodine, have shown a marked increase of iodine fixation in the thyroid and in its metabolism by the thyroid. They have also shown, however, that the initial increase in metabolism on exposure to cold occurs in thyroidectomised animals, but that these animals do not survive for more than 24 hours of continuing exposure. On the other hand, animals acclimatized to cold can by thyroidectomised and survive. Further, thyroidectomised animals on a small maintenance dose of thyroxine are able to raise the level of metabolism and to maintain it in the cold. Thus sustained metabolism in the cold can be maintained in the absence of the thyroid, although there is undoubted hyperplasia of the thyroid during acclimatization (Burton and Edholm, 1955).

Prolonged cold exposure also causes an increase in weight of the suprarenals and this appears to be partly related to the metabolism of ascorbic acid. The level of ascorbic acid in the tissues falls in the first few hours of cold exposure and thereafter rises and continues to increase for several weeks. Increase in dietary ascorbic acid modifies the cold response, the survival rate at progressively lower temperatures increasing directly with the dose of ascorbic acid (Dugal and Therien, 1949). Animals which synthesize ascorbic acid (e.g. the rat) produce more on exposure to cold, while those which do not synthesize it require more in the diet. The initial weight loss following cold exposure is diminished with ascorbic acid supplements to the diet and the subsequent increase in weight is more rapid than that found in control animals (Burton and Edholm, 1955).

The effects of ascorbic acid administration and the role of the suprarenals in response to cold are difficult to separate. In the initial period of weight loss and stabilisation the content of ascorbic acid in the suprarenals is closely related to the extent of the weight loss and the rapidity of its recovery. The relationship does not hold good after the initial period, after which there is no relationship between increase in weight and suprarenal ascorbic acid levels (Burton and Edholm, 1955).

The marked and sustained hypertrophy of the suprarenal gland on cold exposure has also been shown to be prevented by the addition of ascorbic acid to the diet (Dugal and Therien, 1949). Cholesterol studies by Therien, Le Blanc, Heroux and Dugal (1949) have shown, however, that the addition of ascorbic acid to the diet does not inhibit activity of the suprarenal cortex although it does prevent hypertrophy. Giroud, Martinet and Bellon (1941), have made a most significant finding in their demonstration that ascorbic acid increases the formation and utilisation of cortical hormones.

Thus, in all animals investigated, ascorbic acid increased resistance to the cold and decreased its damaging effects. No effect on calorie intake has been shown, and it would appear that there is an increased requirement for ascorbic acid in the tissues which may be concerned in the utilization of cortical hormones. This evidence serves to indicate that there may be a non-muscular element concerned in the increase in metabolism and further suggestive evidence has been provided by Sellars and You (1950) who have observed a gradual increase in metabolic rate in animals measured in a warm environment while spending the rest of the day in a cold room. Measurements on anaesthetised animals in the cold also show a significant rise (Sellars and You, 1950).

The existence of cold acclimatization has also been demonstrated in animals by comparisons of their susceptibility to cold injury. Non-acclimatized rabbits are unable to withstand temperatures below -30°C. without developing hypothermia or frost-bite, while acclimatized rabbits have been shown to be unharmed by exposure to -45°C. for eight hours (Blair, Dimitroff and Hingeley, 1951).

(b) Physiological Studies on the Eskimo and the Primitive Races

The study of the physiology of the Eskimo, in contradistinction to cold acclimatization studies on man not normally domiciled in polar regions, has tended to follow an hypothesis that he may have adapted to his environment in a similar manner to polar animals.

It has been demonstrated by several workers that the Eskimo has a significantly higher basal metabolic rate than that found in white controls. Rodahl (1952) has reviewed this subject and has shown that a careful technique will eliminate apprehension and hence will reduce this figure considerably, but not to control levels. He also demonstrated that if the enormous quantities of protein eaten by Eskimo subjects were reduced, and they were given "White man's diet" for 3 to 5 days, then the remaining increment was also eliminated. He therefore concludes that there is no racial difference between Eskimos and controls in basal heat production, and that the high basal metabolic rate they exhibit is due to the specific dynamic action of protein.

Brown (1955) has made a detailed study of these people and he reports that their dietary intake has a wide daily fluctuation from over 5,000 Cal. to about 1,300 Cal. He estimated that an average 23% of the diet is derived from protein and 68% from fat, and the most common sources of food were walrus and caribou. Brown's investigation of protein metabolism shows normal plasma albumin/globulin ratio and plasma protein levels. A more recent study (Baugh, Bird, Brown, Lennox and Semple, 1958) has shown, however, that there is a raised level of plasma protein. Urinary nitrogen was also found by Brown to be lower than expected, although most subjects examined were in positive protein balance.
This is interesting since Krogh and Krogh (1913) noted that after a heavy meal of meat only 60% nitrogen was excreted in the urine in the

succeeding 24 hours. Rodahl (1952) is in agreement with this finding, and states that the persistence of a high BMR 14 - 18 hours after the last meal is due to the SDA of protein, effective for an exaggerated length of time.

Fat metabolism was also investigated by Brown (1955) in a single large-scale experiment. He fed large quantities of fat to the Eskimo inhabitants of a village (200 g. walrus blubber per day for eight days) and found no increase in faecal fat and, surprisingly, that the plasma lipids were on the low side of normality. He concluded from these findings and from the absence of demonstrable ketosis that the Eskimo has an amazingly high tolerance for fat.

An interesting finding noted during this survey was the large proportion of Eskimos with hepatomegaly, which Brown regarded as a physiological change rather than a pathological one, because there were no associated symptoms and punch biopsies showed normal liver tissue. Brown relates this to diet since it disappears within a week on a diet of casein, lactose and sucrose. His observations of very high Vitamin A levels in the plasma (probably related to high intake from sea mammals) led him to consider the hepatomegaly as being similar, or identical, to that found in hypervitaminosis A. He maintained from the very low Vitamin C intake of the Eskimo and the observation of low plasma Vitamin C levels that there is possibly a sparing action, viz. as the amount of Vitamin A increases it blocks or impairs the utilization of Vitamin C. This is substantiated by

In reviewing the evidence for adaptation in the Eskimo, it is found that there are many who doubt its existence and who consider that his survival is due more to his clothing and way of life than to any internal change. On the other hand, his increased rate of basal heat production is an advantage in a cold environment, since he can more readily equilibrate to his surroundings. The 'warm hand', too, is functionally useful for work in a cold climate, and the increased peripheral circulation with its ability for rapid vasoconstriction enhances this state. It is a matter for conjecture, however, to what extent the Eskimo is actually exposed to his cold environment. It has not yet been determined to what degree he can modify his insulation by altering his clothing layers, how often he does so, and indeed information concerning his activity patterns is almost completely lacking.

Adaptation to a cold environment is, however, more definitely shown by the primitive races, who have remained largely unclothed. The increased peripheral heat production of the Eskimo is not akin to the response to cold of the Australian Aboriginal, who responds economically to central and peripheral cooling by tolerating it, as shown by his ability to sleep in spite of cold extremities and low oral temperature (Hicks et al., 1934).

The findings of Hicks et al. were confirmed by Scholander, Hammel, Hart, Le Messurier and Steen (1958) with the aid of modern equipment and techniques. They noted that though the skin temperature of the surface of the body facing the fire rose to nearly 45°C. at times, when the temperature of the surface in the shadow was $12^{o}C$ to $15^{o}C.$, there was no complaint of pain or discomfort. The Aborigines were able to sleep through the night, allowing their body temperature to fall considerably without shivering, and to rise in the morning protesting that they had enjoyed an excellent night's rest. The white controls, on the other hand, had shivered and tossed about to increase their heat production and were unable to sleep. This work suggested that Australian Aborigines were able to tolerate a greater degree of body cooling than whites before metabolic compensation was required.

These studies took place in winter, but Morrison (1957) demonstrated that these people are exposed to a cold stress at night even in summer, and that their nocturnal thermal exchanges are not greatly influenced by season. He showed that when the air temperature was $19^{o}C.$, the average mean skin temperature fell from a value of $30.5^{o}C.$ an hour after retiring to $27.2^{o}C.$ at the end of the night, and oral temperature fell from $37^{o}C.$ to $35.1^{o}C.$ He concludes that the only nocturnal difference for the Aboriginal between summer and winter is the size of his fire and the extent to which he must tend it.

Hammel, Elsner, Le Messurier, Andersen and Milan (1959) extended this study to the Aborigines of the Australian coast, where the climate is tropical. They found that the responses of this group fell mid-way between the central Aborigines and the white controls, despite the tropical environment of the coastal group. They confirmed that the Australian Aboriginal has an inborn ability to tolerate a greater degree of body cooling than whites before metabolic compensation occurs and suggested that this can be increased by long exposure to cold.

A similar study of the Bushmen in the Kalahari Desert by Wyndham and Morrison (1958) showed that they were much more able to withstand the cold than white controls. They slept without shivering in environmental temperatures of 10 to 12°C., lying radially round a fire, protected by a wind break and covered by a single skin cloak. Though the Bushmen had a fall in total heat content similar to Europeans, they showed a greater fall in core temperature and a lesser fall in surface temperature. They were also able to sleep in spite of considerable lowering of extremity temperature, while the Europeans shivered and were most uncomfortable in spite of clothing of 2 to 3 clo. units. The micro-climate below the skin cloak was, however, maintained about 26°C. which is not much below the thermo-neutral zone for man, and when the toe temperature fell the feet were drawn under the cloak. Wyndham and Morrison thus conclude that the Bushman is more advanced than the Australian Aboriginal in that he has made use of thermal barriers against the cold, and that his adaptation is largely intellectual rather than physiological. He exhibits, nevertheless, the toleration of body and peripheral cooling without increase in metabolism, seen in the Aborigines also, as his main physiological response to a cold environment.

The thermal and metabolic responses of Lapps have been investigated in a recent expedition to Finmark (Andersen, Løyning, Nelms, Wilson, Fox and Bolstad, 1960). The responses of these people to cold during sleep were studied and like the Aborigines and the Kalahari Bushmen they were able to sleep fairly comfortably in low environmental temperatures (about $0^{o}C$) with very inadequate protection, while the control Europeans tossed about, shivered violently and slept fitfully or not at all. The Lapps and the Athabascan Indians of the Arctic, who were studied simultaneously, showed a greater tolerance for loss of body heat and an ability to sleep with a normal basal metabolic rate in contrast to the unadapted white controls, who markedly increased their resting metabolism to maintain their body temperature. This tolerance of lowered body temperature without increasing metabolism is common to Aborigines, Kalahari Bushmen, Lapp shepherds and Athabascan Indians. Scholander, Anderson, Lorentzen and Steen (1957) have shown, however, that the critical temperature of Lapps is similar to that of white men and that they are able to maintain an almost tropical micro-climate in spite of considerable lowering of environmental temperature.

(c) <u>Experiments on man normally domiciled in temperate zones</u>

A number of changes following upon exposure to cold have been demonstrated in man, both in the cold chambers of laboratories and in specially designed field experiments. Amongst these increased calorie intake has been reported (Burton, Scott, McGlone and Bazett, 1940) and indeed an exponential increase of calorie intake with increasing coldness of the environment has been demonstrated (Johnson and Kark, 1947). Increased calorie output, on the basis of oxygen consumption data has also been found (Horvath, Freedman and Golden, 1947). Other changes include a diuresis lasting for two or three days on exposure to the cold (Burton et al., 1940), and there is some evidence that the adrenal gland is hyperactive in the first few days of cold exposure (Freeman, Pincus and Glover, 1944). There is, at present, no conclusive evidence that there is any alteration in thyroid function or in ascorbic acid metabolism in man in response to a cold environment (Rodahl, 1957).

Carlson, Burns, Holmes and Webb (1953) concluded from field studies that the acclimatized individual loses less metabolic heat (as determined by oxygen consumption) than the unacclimatized person in a cold environment. The hypothesis formulated by these workers states that "Adaptation in human beings involves a change in body economy whereby the individual maintains a relatively lower level of metabolism for a given heat loss and utilises a larger portion of the body weight to supply the heat lost by cooling".

Scholander, Hammel, Lange-Andersen and Løyning (1958) conducted an interesting field study on acclimatization in Norwegians, on the Hardangervidda plateau. A group of fit young men wore summer clothing for six weeks at environmental temperatures of 3°C. to 5°C., sleeping in a partially open shelter and being encouraged to expose themselves to considerable cold. They were able to keep warm by exercise during the day but were unable to sleep at night because of shivering and cold extremities. After the first week, however, they were able to sleep and though they still shivered this no longer wakened them.

On return from the camp cold chamber studies showed that they were still able to sleep in a much colder environment than unacclimatized controls and they maintained a warm surface all night, producing 50 to 55% more heat than they produced under similar circumstances before acclimatization. The controls mobilised less heat and were unable to sleep, complaining chiefly of coldness of the extremities.

The Europeans thus overcame the coldness of the environment by a considerable increase in heat production and in contrast to the toleration of lowered body and peripheral temperatures seen in the Aborigines, Kalahari Bushmen and Lapps, they raised their peripheral temperature and maintained their body temperature by active metabolic compensation. Nelms (1960) draws the distinction between two types of response to the cold - the metabolic response of the Europeans as compared to the insulative or tolerant response of the more primitive racial groups. Scholander et al. (1958) point out that the adaptation of the Aborigines is a more economic response to the cold than that of the acclimatized Norwegians and it is analagous to the cold feet of Arctic birds.

The place of physical fitness in acclimatization to a wider range of environmental temperatures is important in acclimatization both to heat and cold. Rodahl (1957) is of the opinion that the state of physical training of the Eskimo is an important factor in his superior efficiency in a cold climate. He is able to trot behind a sledge all day without undue fatigue and fitness becomes a most important factor in situations where the temperature drops to levels where it is necessary to keep active in order to survive. Adams and Heberling (1958) applied a standardised cold stress to a group of adults before and after a physical training programme which increased their state of physical fitness. As a result of the increased level of fitness they were able to show an increase in average levels of heat production, skin temperature, foot and toe temperature and a slight reduction in rectal temperature. This work is most interesting in that apparently many of the currently accepted indices of cold acclimatization may be produced by changing levels of physical fitness.

In the sphere of localised changes these and other workers also indicated a change in peripheral circulation of the extremities, tending to keep them warmer and more efficient. Brown, Hatcher and Page (1953) demonstrated the extent to which these changes and the hunting reaction occur in Eskimos and showed that they were much more marked in Eskimos than even in acclimatized white man. Brown, Bird, Delahaye, Green, Hatcher and Page (1954) suggested that this altered response of peripheral circulation in acclimatized people may be due to a raised level of circulating thyroid hormone in acclimatized people.

Mackworth (1953), by a two-point discrimination test technique, has demonstrated that the hands of men accustomed to living in the cold did not become as numb on exposure as the hands of unacclimatized men.

(d) Observations on Man in Polar Stations

In the past ten years there has been considerable interest taken in the physiology of men living and working in polar bases. The observations have been made against a background of normal polar activity, and the responses of the men to the degree of cold to which they are exposed in the performance of normal routines of work and recreation have been studied.

Changes were first sought in basal metabolic rate and Lockhart (1941) reported a slight fall while Butson (1949) reported a slight rise. Both of these studies were, however, carried out under difficult conditions and with poor apparatus. More accurate measurements made by Wilson (1956, 1960a, 1960b) and Lewis (1958) showed no change in basal metabolic rate as a result of life in a polar station.

Considerable increase in calorie intake has been noted during sledging but this has not been shown to be in excess of expenditure (Lockhart, 1941; Lewis and Masterton, 1958 a, b, c; Wilson, 1960a). Lewis (1958) found little change in physical fitness, haematology or oral temperatures in North Greenland, though Roberts (1949) reports a slight lowering in oral temperatures in Grahamland. Frazier (1945) and Wilson (1953), however, found no significant change in the red cell count, but they both noted a fall in the white cell count as the year progressed. Simpson (1959) has followed the eosinophil levels and noted that they responded markedly to comparatively little emotional stress, but hardly at all to considerable cold and physical stress. Lockhart (1941) and Frazier (1945) refer vaguely to the effects of increased levels of circulating adrenaline but Wilson (1953) was unable to find an increased level under conditions of even greater cold stress. Blood sugar levels have been reported to be slightly increased by Wilson (1953) and Butson (1949).

One change which has been reported frequently (Lewis, 1958; Lewis, Masterton and Rosenbaum, 1956; Graham, 1959; Wyatt, 1960) is an increase in body weight and in subcutaneous fat thickness occurring during the cold, dark months of the year. Lewis has, however, suggested that this may be due more to the inactivity of the winter months than to an effect of the increasing coldness of the environment.

Loss of body weight has been demonstrated following sledging journeys and Massey (1956) has suggested that this may be due both to calorie deficiency and to dehydration, since the loss is largely regained within a short time of returning to base, and this view has also been taken by Wyatt (1960) and Wilson (1960a).

Massey (1960) also repeated the work of Mackworth (1953), in the setting of a polar station, and he has found that the hands of the men living on such a station become progressively less numb on exposure to cold as time passes. Butson (1949) had also noted this but he was unable to make confirmatory measurements.

Frazier (1945) and Massey (1960) have noted that men who have spent two years in polar regions show a diminished tendency to frost-bite. While it is possible that this is due to acclimatization, it may also be due to an increase in experience of polar life. This may also be said for the claim of acclimatization of Goldsmith (1960) and Butson (1949) based on clothing records, which show that more clothes are worn at the beginning of the year than at the end. It is a common experience of polar explorers that they wear too many clothes at first, having wrongly assessed the severity of the Antarctic summer. The amount of clothes which experienced explorers wear when relieving a station is not usually conspicuously different from those worn by the party they are relieving.

It would appear that the further we move from the case of the naked animal exposed to prolonged cold in the experimental chamber to the clothed, sheltered man leading a fairly normal life at a polar station, the less obvious does it become that adaptive changes to a cold environment occur. The most likely explanation is that the men are adequately insulated and so are not exposed to sufficient cold to produce similar changes to those observed in animals.

It is pertinent at this point to consider what may constitute physiological changes, which would allow man to function more efficiently in the cold, in contradistinction to pathological changes occurring in response to excessive cold. It may be that to increase the cold stress of experinemtal subjects would be a study of pathological hypothermia rather than environmental physiology, and many of the physiological effects described may, in fact, be reversible pathological changes.

Eriksen, Krog, Andersen and Scholander (1956) have shown that man's critical temperature lies in the region of 26°C. and they have concluded, since the critical temperature of tropical mammals is 22 - 27°C., that man responds as a tropical mammal. MacPherson (1958) points out that in order to determine the neutral conditions for man he must be considered in a situation devoid of clothes, shelter and fire, and that in such circumstances man is best suited to the equable environment of a tropical forest. He concludes that a temperate climate does not represent the neutral condition for man, in which environmental stress is minimal and from which adaptation is possible to both hotter and colder conditions to an equal degree. On the contrary, he states, man in a temperate climate is approaching the extreme range of adaptation to cooler conditions. It follows that it is useless to attempt to demonstrate profound physiological changes in temperate man on exposure to severe cold because, since the greater part of the possible change in this direction has already been made in a temperate climate, any further changes in this direction must necessarily be small.

The maintenance of the health of these isolated communities demands considerable fore-thought in the provision of an adequate diet, together with the essentials of clothing, heating and housing. Little or nothing has been recorded of the patterns of activity of the personnel at risk, nor yet of the extent of individual or seasonal variation. The food supplied must be of sufficient quantity to replace the energy expended with due allowance made for waste. Criticism may be levelled at certain aspects of meteorological recording if the true climatic stress to which these individuals are subject is to be evaluated and countered.

It is with these questions in mind that this study is presented.

The following sections deal with each aspect in turn in order to provide basic data from which an understanding of the physiological changes implicit in a polar existence may stem.

THE EXPERIMENT

Section 2

SECTION 2

THE EXPERIMENT

1. AIMS

1. To investigate the patterns of activity of Antarctic scientists living and working on a static base; to demonstrate possible seasonal variations in these patterns, and to relate activity both to energy expenditure and to activity patterns already investigated in other classes of occupation.

2. To demonstrate the advantages of expressing the climate of the station in terms of frequency data rather than in the conventional meteorological manner.

3. (a) To compare the climate of Antarctica with the climate actually surrounding the man during the complete twenty-four hour period.

(b) To set out the proportion of time during which the man was exposed to the climate of Antarctica.

4. (a) To define and measure the sub-clothing or micro-climate, and to compare it both with the general climate of Antarctica and the climate surrounding the man.

(b) To investigate the manner in which the micro-climate varies in response to exposure to various environmental conditions.

5. To discuss the relationship of loss of body weight during sledging to calorie or fluid imbalance.

6. To define the cold exposure to which the man is subjected, and to indicate the importance of the concepts described in this thesis in assessing the changes of physiological function due to exposure to a cold environment.

7. To note the minor medical and surgical conditions which may arise in a polar station.

EXPERIMENTAL METHODS

Apparatus

A Kelvin and Hughes Hand Anemometer was used to measure wind velocity and a Cassella Whirling Psychrometer was employed to measure wet and dry bulb temperatures. Both of these instruments were of the standard pattern used by the Air Ministry Meteorological Office. The Centigrade temperature scale was employed throughout and wind velocity was measured in knots (one knot is defined as a velocity of one nautical mile - 1.15 statute miles - per hour).

The sub-clothing or micro-climate of the subject's trunk was measured by means of a temperature-sensitive vest designed by Wolff (1958). This is an electrically continuous garment, knitted of flexible, insulated wire which acts as a resistance thermometer. Careful knitting ensured that the number of stitches per unit area, and hence the length of wire per unit area, was constant, so that good integration was obtained. Since the wire garment acts as an extra layer of clothing, with a temperature gradient across it, the reading obtained will always be lower than skin temperature, but it will give an accurate measure of integrated sub-clothing temperature.

The wire used was 0.039 ins. (1 mm.) in diameter and it contained 60 strands of 0.0016 ins. silver-plated copper wire. It is insulated with polyvinylchloride containing a non-migratory plasticizer and it does not give rise to any skin reaction even after prolonged wearing. The fabric is also very flexible so that it does not limit movement or produce discomfort.

Readings of resistance were obtained by means of a simple, portable Wheatstone bridge energised by a 4½ volt bell battery. The variable resistance in the bridge was balanced against that of the vest by zeroing the galvanometer. The bridge was readable to the nearest ohm, but as the ratio of resistances in the fixed arm of the bridge was 10:1, variations of 0.1 ohm could be detected in the vest.

Since the resistance temperature co-efficient of copper is 0.4%/deg.C. and the resistance of the vest when worn was approximately 50 ohms, a change in temperature of 1°C. in the vest was equivalent to a change of

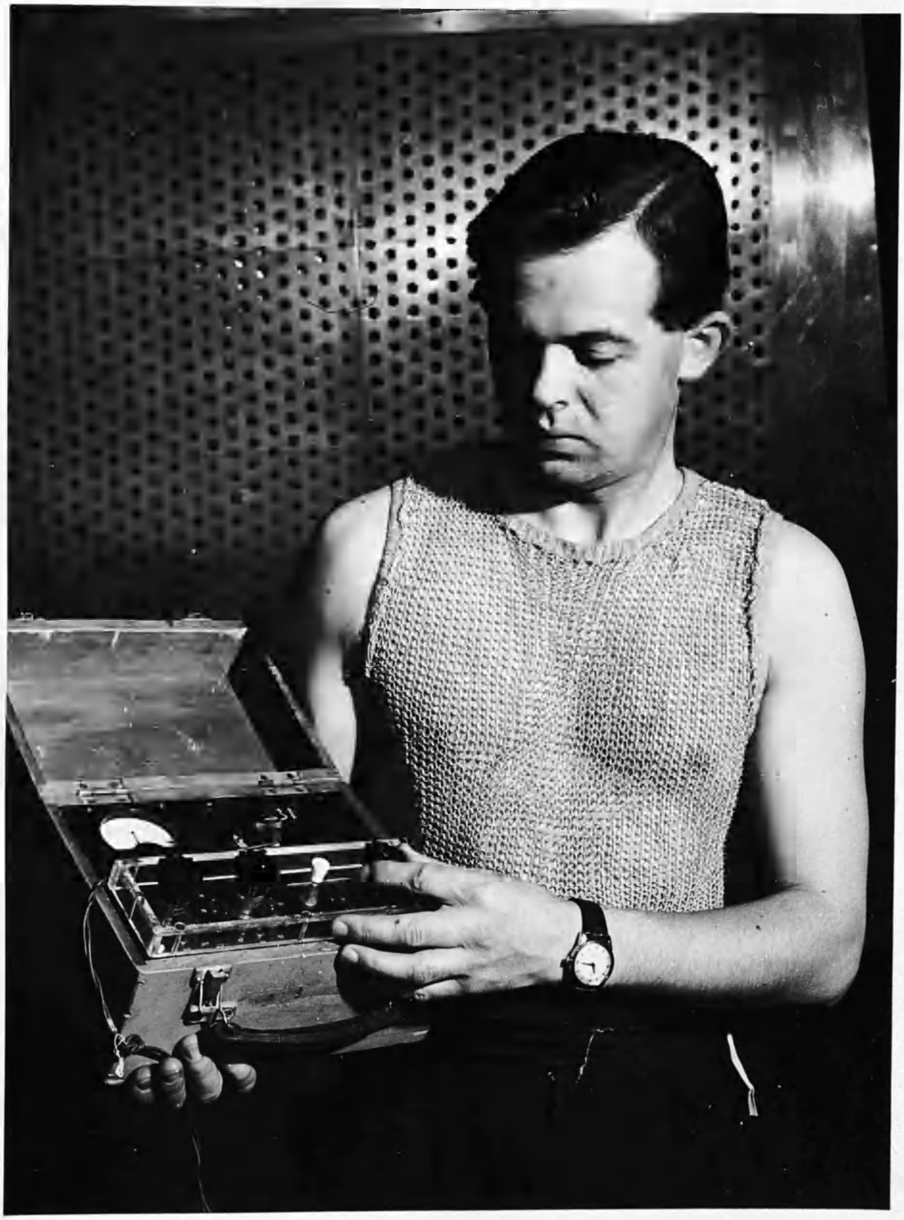


Plate 2

This illustration shows the temperature sensitive vest as it is worn below the clothing. The Wheatstone bridge with which changes of resistance in the vest were measured is also shown.

resistance of 0.2 ohms. The bridge was capable of detecting a variation of 0.1 ohm in the vest, and so a resolution of 0.5°C. was obtained.

The vest was calibrated at intervals in a water-bath. Resistance was plotted against water-bath temperature over the range of 20 - 40°C., and a straight line drawn through the points. The slope was then determined (i.e. ohms change/deg. C.) and from this the temperature co-efficient of the wire, which is: $\dfrac{\text{ohms change/deg. C.}}{\text{resistance at } 20^\circ\text{C.}}$

From this the resistance at an unknown temperature, T, was given by:

$$\left[\frac{\dfrac{R_T}{R_{20}} - 1}{\alpha}\right] + 20 = T$$

where: α is the temperature co-efficient of the wire;

R_T is the resistance at $T^\circ C$;

R_{20} is the resistance at 20°C.

A conversion chart was constructed which made it possible to convert a large number of resistance readings to temperature values rapidly.

The patterns of activity were measured during a time and work study when the time spent in each activity of the subject was noted on specially prepared cards. One card was provided for each 20 minute period of the 24 hours and a space was reserved on each card for the meteorological measurements referable to the period. Each square on the card represented one minute, so that activity changes were measured to the nearest minute. The clothing worn and the subject's comfort vote were recorded in two further spaces set aside for this purpose on each card.

Body weight was measured by means of an Avery beam balance which was accurate to 50g. While sledging, food was weighed on a spring balance which was accurate to the nearest ½ oz.

Choice of Subjects

Four subjects were chosen whose range of activity represented a cross-section of the disciplines commonly studied at these stations. These four men were observed throughout the year and the observations and measurements made on them are described in the following sections.

Methods

The four subjects were studied in rotation once per month - one subject each week for a period of 24 hours. During each 24 hour period the subject's activity, his clothing and subjective sensation of comfort were noted by the author using a method based on Garry's diary technique (Garry, Passmore, Durnin and Warnock, 1955). Measurements of wet and dry bulb temperature and wind velocity of the environment to which the subject was exposed were made every twenty minutes. The temperature of the micro-climate was measured at the same time by means of the temperature-sensitive vest and the period during which the subject was exposed to a dry bulb temperature below $0^{o}C$, was noted. These

G.M.T.— 21.40 HOURS

MINS.					25					30
ACTIVITY	X SITTING			WRITING		- -	-	- -X	xPREPARING	
CLOTHING	AS	BEFORE	-						+ ANORAK + Socks x2	
COMFORT	- -	COMFORTABLE								
NOTES										
MINS.					35					40
ACTIVITY	TO GO OUT		-	-	-	- -X	WALKING	x	X OUT.	
CLOTHING	+ MUKLUKS		+W.P. TROUSERS.	+ BALACLAVA						
COMFORT	—	—	—	—	—	—	—	—	—	—
NOTES										

WET BULB	-11.7°C	WIND VEL.	10 Knots.	WOLFF TIME	15.20
DRY BULB	-11.7°C	VEST TEMP.	499 Ω		
Rel. Humidity = 91%		i.e. V.T. = 33.3°C			

Plate 3

This illustration shows one of the proformata used to record the results of each twenty minute period of the experiment. Notes of activity, clothing and comfort were referred to the nearest minute - each box represents one minute - and the space at the bottom was used for the meteorological measurements of the period under consideration. The proformata were bound into books of which each book contained 72 proformata - one for each twenty minute period of the twenty-four hours.

measurements were all recorded on the cards referred to above and each card thus gives a complete account of the significant variables in the man's existence during the twenty minute period. Since it was important to study these subjects during normal activity, every effort was made to ensure that the experiment did not interfere with their routines of work or recreation, and that the instruments applied to them did not limit their activity or cause them discomfort. The only instrument applied directly to the subjects was the wire vest which did not cause any inconvenience or discomfort. The micro-climate measurements were made by means of a lead which protruded through the clothing from the wire vest and which could be applied to the Wheatstone bridge by the author without requiring the subject to interrupt his work.

These measurements were made in the same unobtrusive manner during a sledging journey, when the bridge was attached to the rear of the sledge. A long lead from one of the sledge traces to the bridge enabled measurements of the micro-climate to be made while the subject was man-hauling without stopping the sledge. On these occasions the person who was steering the sledge made the recordings. If the subject happened to be steering then he made micro-climate recordings upon himself on the adjacent bridge.

Results

The results are described in the following sections.

A C T I V I T Y   P A T T E R N S

Section 3

SECTION 3

ACTIVITY PATTERNS

The subjects were four scientists. Three of these men were meteorologists and as such they were required to be on night duty every sixth night, in addition to their normal duties. They were allowed to make up their sleep during the following day and they usually prepared for night duty by having three or four hours sleep during the evening prior to their duty. In addition to normal meteorological duties one was in charge of the radar set, a second was responsible for radio sonde flights each morning, while the third was responsible for inflating the weather balloons each morning. The fourth man was the auroral observer and he was on constant night duty from the end of March until October. He was also engaged in analysing geo-magnetic recordings, an occupation which involved many long summer hours spent poring over charts.

In addition to their scientific duties all of these men were required to take their turn at the daily domestic routine, which included brushing, scrubbing and polishing floors, serving at table and washing the dishes. The routine also included constant attention to the four coal fires. This duty came round about every eighth day and no relief from normal scientific duties was allowed. Finally, all these men shared the common responsibility of general base work as it arose, including digging out and re-siting buried stores and transporting food boxes, coal and fuel drums from distant dumps to the hut by tractor sledge. The boxes, bags and drums had only to be handled at either end of the journey.

The observer recorded the activity of each subject, minute by minute, and the first approach to the analysis of the recording was to group the activities into broad categories. This classification, while demonstrating readily the general activity pattern of the scientists on the station, also permitted of a comparison with the results of time and work studies conducted in more civilized parts of the world.

The following are the grades of work chosen:-

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 was taken as lying. Sitting includes sitting talking, writing, reading, eating, listening to the radio, playing cards and doing instrument maintenance. Standing includes reading instruments and operating instruments. Light work (inside) means, in general, domestic duties (referred to above), washing and dressing; light work (outside) refers to most activities greater than walking, including the extra energy expended in moving on soft snow surfaces when heavy clothing is worn, and to other tasks such as launching radio sondes and weather balloons and climbing instrument towers. Heavy work (outside) is reserved for such tasks as continuous digging of snow and the manual labour involved in moving heavy boxes, coal bags and oil drums. At this stage, the distinction between outside and inside activity is retained in order to give some idea of the ratio of outside activity to inside.

A series of four histograms were then drawn up in which activity was plotted against time, and these are presented in Fig. 1, one for each man from each season. The other results may be seen in tabular form in Appendix 1.

These histograms are similar in pattern, though each represents a different man at a different season. Thus, the main theme of activity is fairly stereotyped. The second outstanding point is the remarkably sedentary nature of the life, as the subjects spent 73%, 66%, 80% and 75% respectively of their time between the occupations of sitting and lying. The next interesting observation is the percentage of time spent in outdoor activities, 17%, 9%, 8% and 17% respectively, indicating that a very short time is spent during the average day in contact with the polar environment. There is, moreover, a reflection of a seasonal trend in outdoor activities since the first and last figures represent autumn and summer and the middle two represent winter and spring.

In order to show whether the activities of this particular group were

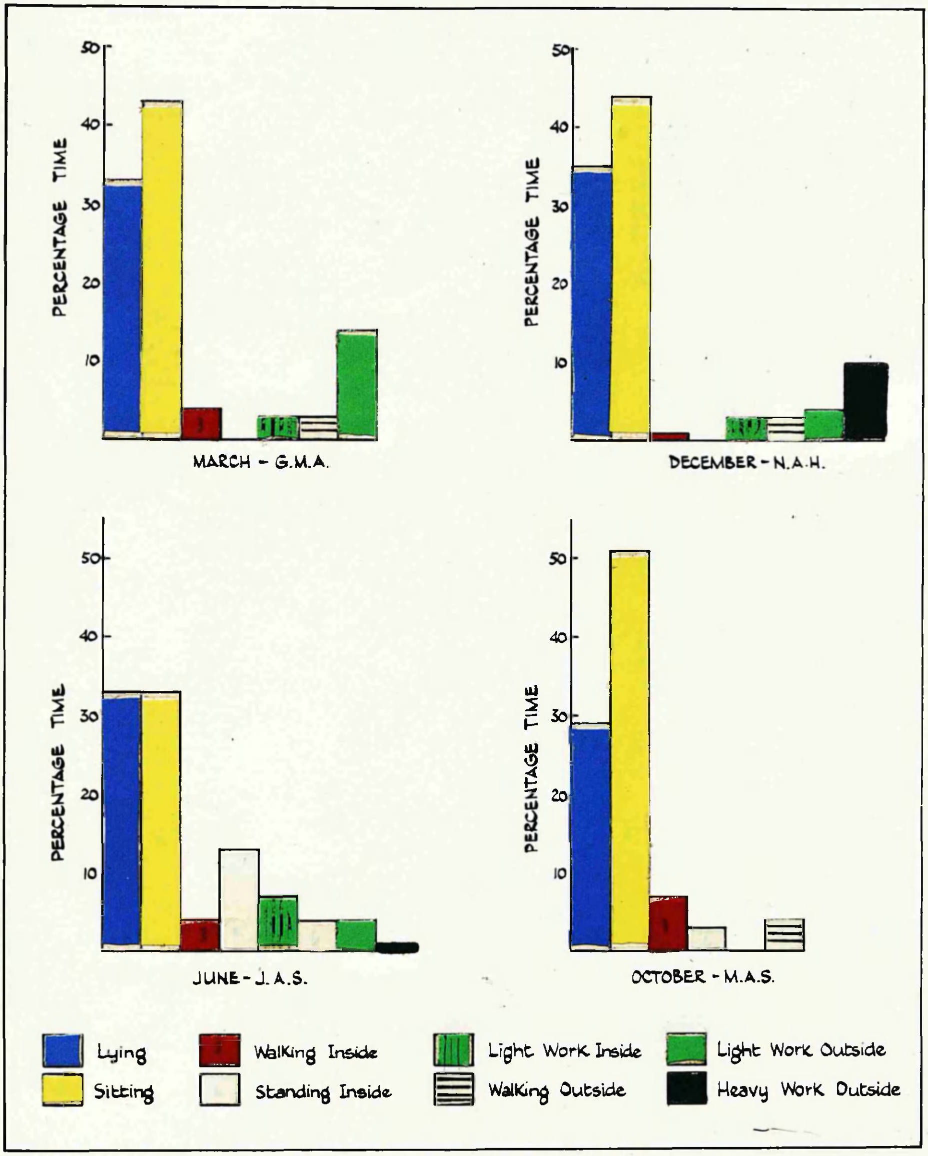


Fig. 1

Activity patterns. The percentage of time spent daily by four subjects in the various activities; one day selected from each season.

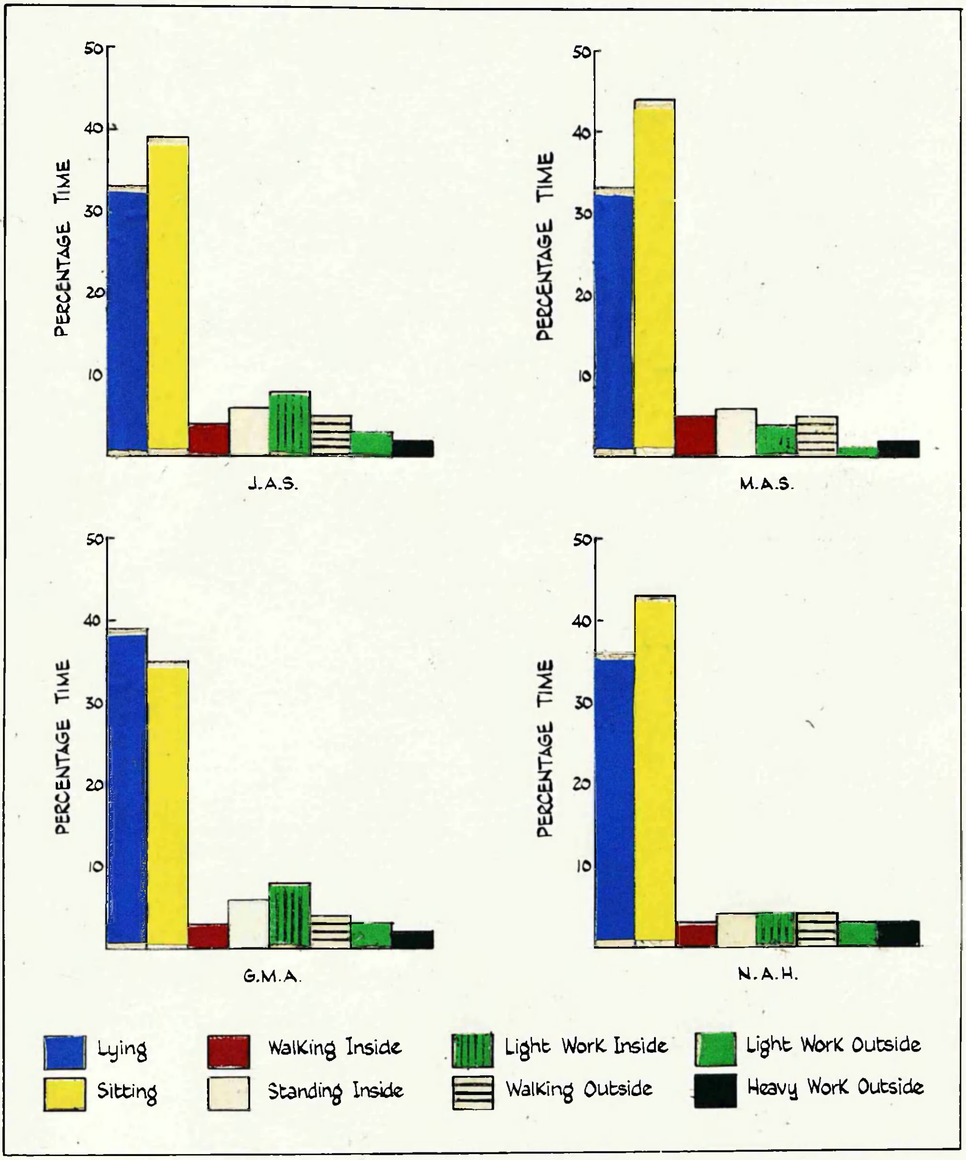


Fig. 2

Activity patterns. The annual mean pattern of activity of each of the four subjects.

indeed closely related to each other, the mean annual patterns for each man were constructed and may be seen in Fig. 2.

The subjects are seen to have average annual activity patterns which are very similar, with values for the sedentary activities (sitting and lying) of 74%, 72%, 77% and 79% respectively, while values for outside activities are 9%, 10%, 8% and 10% respectively. In the more detailed groups, heavy work values are 2%, 2%, 1% and 3%. The mean annual pattern of the four subjects was calculated and is set out in Table 1, together with the values for each activity, and this pattern has been used in the comparisons with the work of other authors.

Activity		% Time	
1	Lying	35	75%
2	Sitting	40	
3	Working (inside)	4	25%
4	Standing (inside)	6	
5	Light work (inside)	6	
6	Walking (outside)	4	
7	Light work (outside)	3	
8	Heavy work (outside)	2	

Table 1
The average percentage of time spent during one year in the various activities by the 4 subjects.

Before proceeding to more general comparisons, however, it is interesting to consider the question of seasonal variation in activity. If a considerable decrease of activity can be demonstrated in the cold, dark months of winter it will, at least, add weight to the suggestion of Lewis (1958) that the increase in skinfold thickness and body weight, so commonly observed in winter in polar stations, are due more to the inactivity of the dark months than to acclimatization changes resulting from the increasing coldness of the environment. In other words, that skinfold thickness and body weight variations, in these circumstances, are parameters of activity and calorie intake rather than of acclimatization.

In the seasonal grouping the dark months are taken as May to September and the light months as October to April. Though the sun sets in the middle of April it was included with the light months since there is considerable preparation for winter during this month, and though 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 on the station remained at a minimum level.

The values in Table 2 show very little seasonal variations in the ratio of inside activities, but indicate a marked falling off in outside activities during the dark months, when they are reduced by a factor of almost two-thirds.

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

<u>Table 2</u>

The 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, while winter is defined as the dark months, May to September.

The first comparison is with data obtained during a manhaul sledge journey. Such an occurrence is not part of the normal activity of static scientists and the data obtained here were not used in arriving at the general activity patterns of base life. It was hoped, however, to be able to show the distinction between static activity patterns and those possible while sledging. Manhaul sledging is very hard work and is not commonly resorted to nowadays when dogs and mechanical transport are available. The values set out in Table 3 compare favourably with those shown by Masterton, Lewis and Widdowson (1957) in comparing base activity with sledging activity on the British North Greenland Expedition.

Activity	Base % Time	Base % Time	Sledging % Time	Sledging % Time
		Sedentary		Sedentary
1 Lying	35	75%	53	61%
2 Sitting	40		8	
3 Walking	6	Active	9	Active
4 Standing	8	25%	9	39%
5 Light work	9		7	
6 Heavy work	2		14	

Table 3

This shows the comparison between the average percentage of time spent in the various activities at base and during sledging.

The sledging figures are derived from the mean activity figures of two men observed continuously for four days. Lying is considered as time spent in the sleeping bag and it will be noted that the relationship between time spent sitting and lying at base is significantly altered on the sledge journey. If these two quantities are taken together, however, then the resultant measure of sedentary activity during sledging can be compared with the sedentary activity of base life. The values show a general increase in activity during sledging, sedentary activity falling from 75% to 61% and outdoor activity rising from 25% to 39%. This, however, does not constitute as great a change as might be expected and the comparisons of the various components of activity reveal close similarities. The striking, and the only real difference, is in the performance of heavy work, which rises from 2% at base to 14% while sledging. The extra time spent performing heavy work is drawn, in large measure, from the sedentary activity time and the other values show small changes only. It is therefore suggested that an estimate of activity might be given by the ratio of sedentary activity to heavy work, which is 75:2 or 37:1 for base activity and 61:14 or 4:1 for sledging activity.

In reviewing the literature for time and work studies reported in terms which would permit of comparison with the above data, the selection chosen was:-

1. The study of Garry, Passmore, Warnock and Durnin (1955) on miners and clerks in Fife;
2. The study of Edholm, Fletcher, Widdowson and McCance (1955), and Widdowson, Edholm and McCance (1954) on Sandhurst cadets in training;

3. The study of schoolchildren by Bedale (1923).

The results which these authors reported were grouped under the same heading as in the present study and were expressed in the same units; they may be seen together in Table 4.

Activity		Base % Time		Sledging % Time		Miners % Time		Clerks % Time		Cadets % Time		School-children % Time	
1	Lying	35	75	53	61	32	66	32	67	35	75	50	69
2	Sitting	40		8		34		35		40		19	
3	Standing	6	23	9	25	7	22	18	32	1	19	6	20
4	Walking	8		9		11		8		7		5	
5	Light work	9		7		4		6		11		9	
6	Heavy work	2		14		11		1		5		11	

Table 4

This table shows the average percentage of time spent in the various activities of a variety of occupational groups.

The results set out in Table 4 have been used in calculating the following ratios between sedentary and strenuous activity.

1. Halley Bay Scientists 37/1
2. Halley Bay Sledging. 4/1
3. Miners . . . . 6/1 (contd.)

4.	Clerks	67/1
5.	Cadets	15/1
6.	Schoolchildren	6/1

A complete survey of the activity patterns typical of all occupations would be necessary to demonstrate more precise relationships, but it is clear from the ratios set out above that patterns of activity on a static base are considerably different from those of industrial workers, such as miners on the one hand, and from sedentary workers such as clerks on the other. Sledging by the manhauling method is shown to be the most strenuous of all the occupations considered.

A more ready comparison of activity between occupational groups can be arrived at by the comparison of the energy cost of the various employments, and an attempt has been made to achieve this end by estimating the daily calorie expenditure of these subjects, using Garry's diary technique (Garry et al., 1955). The calorie values of the various activities were derived from the work of Passmore and Durnin (1955) and Adam (personal communication) and Rennie (1957), The values for heavy and light work were derived from the values allocated by Masterton, Lewis and Widdowson, (1957) in their assessment of work on the British North Greenland Expedition.

From these values the approximate energy expenditures for Halley Bay were assessed in terms of annual mean activity, winter activity, summer activity and sledging activity. The results were calculated in the manner set out in Table 5. The precise method of allocation of calorie values to the various activities may be seen in Appendix I. The mean values for the four men were used for those values which were referred to body weight or to surface area. These were 79.5 Kg. and 1.98 sq.m. respectively.

Activity	Allocated Value	Annual Mean		Winter		Summer		Sledging	
		Min.	Cal.	Min.	Cal.	Min.	Cal.	Min.	Cal.
Lying	0.67 Cal/M^2/min	504	665.3	518	683.8	490	646.8	763	1007.2
Sitting	1.9 Cal/min	576	1094.4	576	1094.4	562	1067.8	115	218.5
Standing	2.1 Cal/min	86	180.6	130	273.0	57	119.7	129	270.9
Walking Inside	4.8 Cal/min	58	278.4	59	283.2	58	278.4	-	-
Light work Inside	2.08 Cal/M^2/min	86	354.3	86	354.3	86	354.3	-	-
Walking Outside	4.53 Cal/min	58	262.7	43	194.8	86	389.6	130	588.9
Light work Outside	4.4 Cal/min	43	189.2	14	61.6	43	189.2	101	444.4
Heavy work Outside	12.5 Cal/min	29	362.5	14	175.0	58	725.0	202	2525.0
	Total	1440	3387	1440	3120	1440	3771	1440	5055

Table 5

The assessment of energy expenditure of Halley Bay scientists in terms of annual mean energy expenditure, winter, summer and sledging activities.

	Employment	Source	Value
1.	Olympic Athletes	Schenk (1936)	7,300 Cal/day
2.	American University Football Players	Edwards, Thorndike & Dill (1935)	5,600 Cal/day
3.	North Greenland Sledging	Masterton, Lewis & Widdowson (1957)	5,198 Cal/day
4.	Halley Bay Sledging		5,055 Dal/day
5.	Soldiers (arduous combat trial)	Adam et al. (1956)	4,943 Cal/day
6.	Blacksmith	Orr & Leitch (1938)	4,729 Cal/day
7.	Soldiers (Preliminary training)	Adam et al. (1958)	3,900 Cal/day
8.	Halley Bay (Summer)		3,771 Cal/day
9.	Miners	Garry et al. (1955)	3,656 Cal/day
10.	North Greenland (base)	Masterton, Lewis & Widdowson, (1957)	3,581 Cal/day
11.	Joiners	Orr & Leitch (1938)	3,545 Cal/day
12.	Sandhurst cadtts	Edholm et al. (1955)	3,416 Cal/day
13.	Halley Bay (Annual)		3,387 Cal/day
14.	Carpenter or painter	Orr & Leitch (1938)	3,239 Cal/day
15.	Halley Bay (Winter)		3,120 Cal/day
16.	Locksmith	Orr & Leitch (1938)	2,948 Cal/day
17.	Clerks	Garry et al. (1955)	2,804 Cal/day
18.	Unemployed	Orr & Leitch (1938)	2,290 Cal/day
19.	Schoolchildren	Bedale (1923)	2,035 Cal/day

Table 6

Winter, summer, annual and sledging energy expenditure of Halley Bay scientists are compared with various values from the literature for other occupations. The values are arranged in descending order of magnitude.

The mean daily calorie expenditures of the scientists - per annum, for winter, summer and for the sledge journey - are shown in Table 6, together with the results of similar studies by other authors. The various values have been set out in decreasing order of magnitude.

This classification, then, places Halley Bay's annual mean activity between Sandhurst cadets in training and carpenters. It also indicates the seasonal variation, with the summer value near the top of the list and the winter value close to the bottom, thus reflecting the activity patterns described above.

It is clear from the results that the major activities of the subjects tended to occur within a relatively narrow part of the 24 hours. A large proportion of their time was spent in the lying or the sitting position, so much so that the author cannot but agree with Edholm et al. (1955) when they stated "It looks as though man should be regarded now, if not in the past, as predominantly a sedentary rather than an upright animal".

METEOROLOGY AND MAN

Section 4

SECTION 4

METEOROLOGY AND MAN

Dr. Kaare Rodahl (1957) during a group discussion on Arctic clothing for soldiers, at the 5th Macy Conference on Cold Injury, said:

"Isn't it true to say that in the technical aspect 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 soldier 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. Errors have been made in supplying equipment to polar stations, when the choice has resulted from considering conventional meteorological data, such as maximum and minimum values of temperature and wind velocity. Considerable money has, indeed, been needlessly spent in the past in supplying equipment and living accommodation capable of withstanding, say, -60°C. and 70 knots of wind velocity, in areas where these values have been known to occur. What is not shown is that they may have occurred separately for an almost insignificant length of time and probably never together. In like manner, there is no indication of the common ranges of temperature and/or wind velocity which can be expected for the majority of the time. As indicated by Burton and Edholm (1955) frequency data rather than mean data are required if the true climatic picture is to be appreciated. These would indicate, for example, the range of temperature for each period of time and its duration. From the physiological viewpoint it is much more meaningful to be able to say that a man was exposed to, say, $-10^{o}C$ for 30% time and to $-20^{o}C$ for 70% time than that he was exposed to $-17^{o}C$ as an average.

Given a knowledge of the activity patterns of a place, then, by the use of frequency data, one can begin to arrive at a concept of the exposure. Similar frequency data are, of course, required for wind velocity, which is certainly the chief cause of discomfort and the main governor of outside work potential in polar regions. It is also a most significant factor in body cooling.

Though both of these analyses are important in themselves, probably the most significant of all are double frequency analyses of wind velocity and temperature. The frequency with which combinations of low temperature and high wind velocity occur together is important in the assessment of man's actual exposure to cold and to the provision of suitable clothing, equipment and living accommodation for a given station. No less significant, of course, is the observation of the frequency with which high temperatures accompany low wind velocity, high temperatures accompany high wind velocity and low temperatures accompany low wind velocity. For a given place, an integrated view of all these parameters makes it possible to build up a picture of the likely exposure of a man to that particular environment.

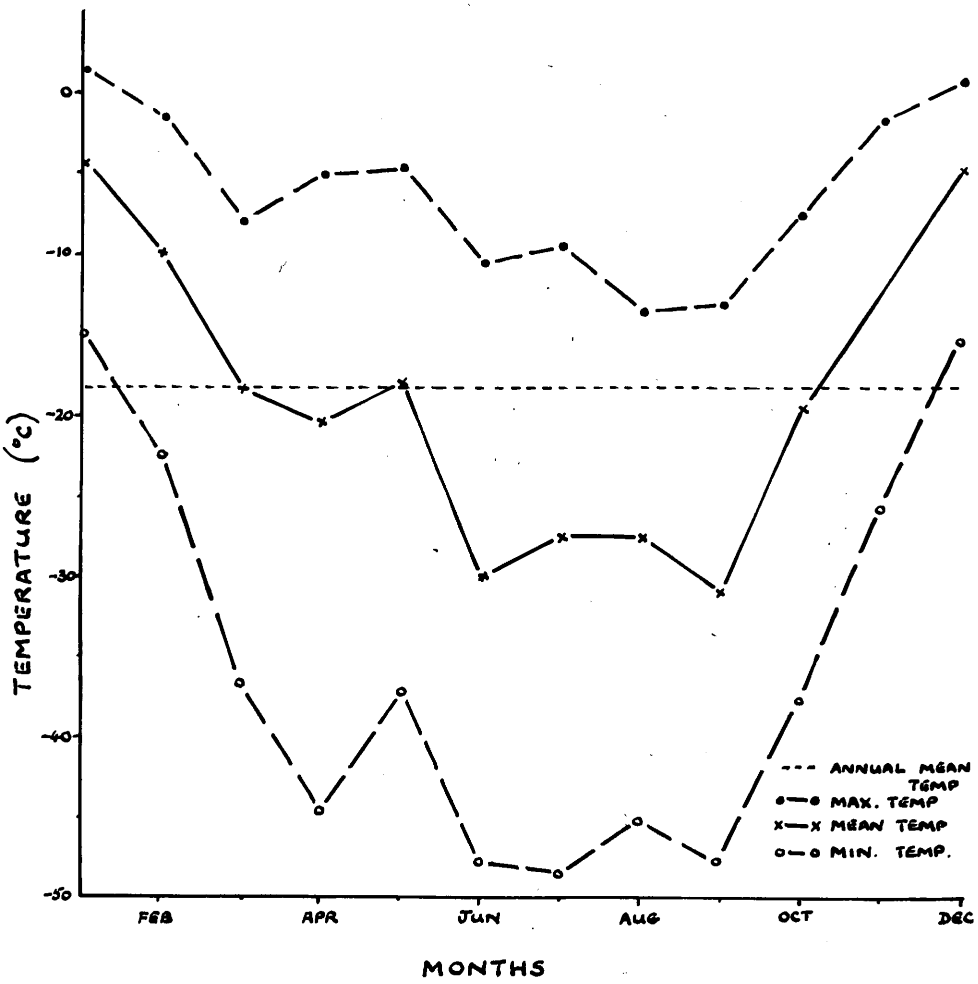


Fig. 3

This figure shows monthly mean values of dry bulb temperature for the year together with the annual mean value and the monthly maximum and minimum values.

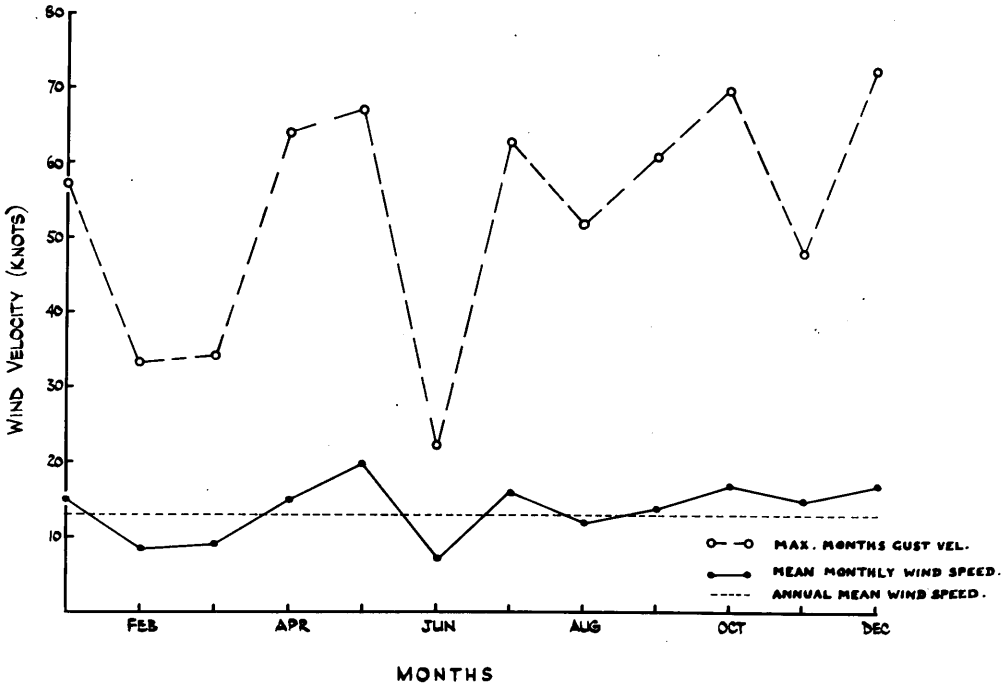


Fig. 4

This figure shows the monthly mean values of wind velocity for the year together with the highest gust recorded each month and the annual mean value.

The Climate of Halley Bay

In order to obtain a broad view of climatic conditions, it is useful, firstly, to examine the conventional presentation of meteorological data. The monthly and annual means, maxima, minima and ranges of temperature and wind velocity have been compiled for Halley Bay for the year of the present study and may be seen in Figs. 3 and 4.

Examination of these diagrams indicates that Halley Bay is a cold and windy place. The temperature recordings ranged from $+1.5^{\circ}$C. to -48.1°C, and wind velocities up to 73 knots were noted. These figures give no indication of the conditions prevailing in and around the station, and it is necessary to obtain the relative frequency and duration of each variable and the values of each which occur together before an adequate appraisal can be gained.

The first step in assessing the every-day exposure to which man is liable is to examine the same data arranged in the form of frequency charts. The frequency distribution of temperature for the month of March together with the annual frequency distribution for 1959 may be seen in Fig. 5. The values for the remaining months have been compiled in tabular form and appear in Appendix 2.

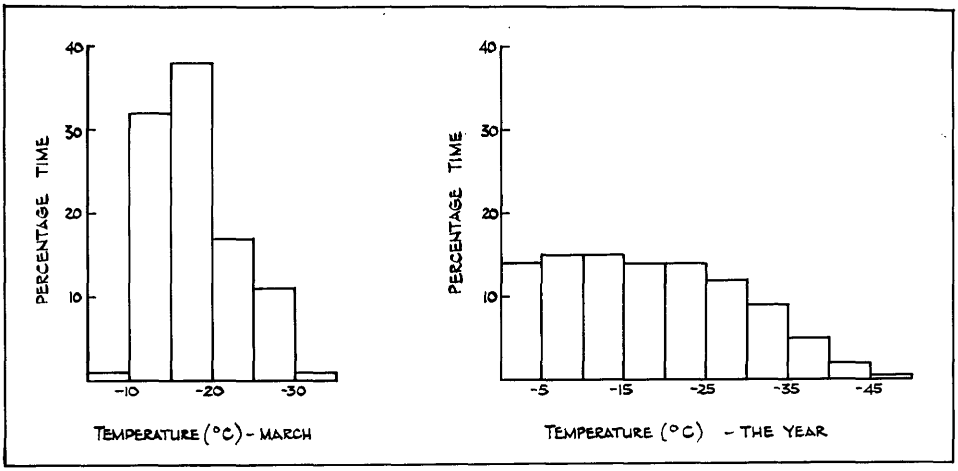


Fig. 5

This figure shows the frequency distribution of the various ranges of temperature which occurred during the month of March and during the entire year. The duration of each range is expressed in terms of percentage of time.

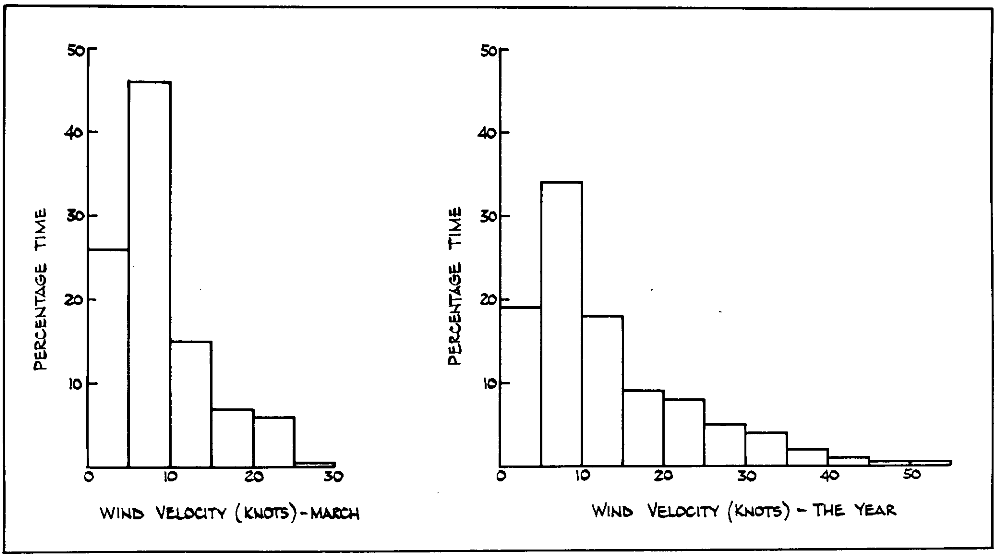


Fig. 6

This figure shows the frequency distribution of the various ranges of wind velocity which occurred during the month of March and during the entire year. The duration of each range is expressed in terms of percentage of time.

Similar data have been compiled for wind velocity and may be sean in Fig. 6, while the remaining values are presented in Appendix 2.

From Fig. 5 it can be stated that for the month of March the significant range of temperature is from -10°C. to -30°C., of which the range -15 to -20°C occurs most commonly. It is also shown that for 66% of the time a temperature range of -10 to -20°C. occurred while for only 26% of the time was it between -20 and -30°C.

Just as higher temperatures predominate in frequency, so do the lower wind velocities, and the commonest range was between 5 and 10 knots. Reference to the appendix, and to the annual figure, show that this is indeed the commonest range during the whole year - though one's subjective idea was of very much stronger winds. Throughout the year though the commonest range was 5 - 10 knots, the next two common ranges were those on either side of that range, 0 - 5 knots and 10 - 15 knots, so that the range 0 - 15 knots occupies 72% of the time. At Halley Bay a wind velocity of 15 knots had the special significance that any outside work usually ceased at this wind force, independent of temperature, due principally to discomfort and limitation of vision from drifting snow. It can therefore be stated that the time during which it was theoretically possible to be exposed to the true environment was the percentage of time during which the wind velocity was below 15 knots, which was 72% of time. Assuming half of this time to occur during the night a value of 36% remains when it was possible to work outside.

Though it is now possible to state the durations and frequencies of the various ranges of temperature and wind velocity, it is still not possible to show their relationship to each other. It had been observed during the year that as the wind velocity rose so did the temperature, but the extent and the frequency with which it took place can only be arrived at by constructing double frequency tables of wind velocity and temperature. A double frequency table of wind velocity and temperature for the month of August may be seen in Table 7, together with one for the whole year.

A set of charts in this form gives all the necessary practical information about temperature and wind velocity. Table 7 shows that temperatures of -45°C to -50°C were observed less than 1% of the time and then never in conjunction with a wind velocity of more than 5 knots. On the other hand winds of 50 - 55 knots were also observed less than 1% of the time and then never in conjunction with a temperature lower than -10°C. In wind velocities of over 15 knots the temperature was lower than -30°C. for less than 1% of time. The shape of the diagram also indicates how truly the temperature does rise, as the wind velocity increases and vice versa. This picture modifies the impression of the severity of conditions and a study of the charts will indicate the extremes of condition actually experienced during the year in relation to the important factor of time.

Physiologists and climatologists have been searching, for some time, for a method of expressing the combined effects of wind velocity and temperature on man in terms of a single factor. The problem has not yet been solved completely.

TEMPERATURE (°C)

WIND VELOCITY (KNOTS)	0 -5		-15		-25		-35		-45	
				1	2	4	7	2	4	20
10				2	7	9	13	2	2	35
			1	4	10	6	4			25
20				1	3	2				6
				1	2	3	1			7
30			2	1		2				5
				3						3
40										
50										
TOTAL			3	13	24	26	25	4	6	100%

AUGUST

TEMPERATURE (°C)

	0 -5		-15		-25		-35		-45		
	1·9	2·6	3·2	2·4	2·0	2·2	2·4	1·8	0·8	0·07	19·4
10	2·5	2·5	3·6	4·5	5·1	5·9	4·9	3·2	1·4		33·6
	2·9	2·0	2·4	2·9	3·6	2·4	1·6	0·5	0·1		18·4
20	2·0	1·6	1·5	1·4	1·5	0·9	0·3	0·2			9·4
	2·1	1·5	1·0	0·7	1·4	0·7	0·1				7·5
30	1·4	1·2	1·1	0·6	0·5	0·1					4·9
	1·2	1·4	0·9	0·5	0·3						4·3
40	0·3	0·5	0·3	0·3	0·1						1·5
	0·07	0·3	0·2	0·4	0·07						1·0
50				0·07	0·07						0·1
	0·07	0·07									0·1
	14·4	13·7	14·2	13·8	14·6	12·2	9·3	5·7	2·3	0·07	100%

THE YEAR.

Table 7

This table shows double frequency tables 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 August and during the year.

4. One of the attempts is the Wind-chill scale of Siple (Siple, 1945; Siple & Passel, 1945). In this scale the effects of various combinations of wind velocity and temperature are expressed in terms of their dry atmospheric cooling as kilocalories of heat lost per unit of surface area per hour. The objection to the application of this scale to man is that it is based on the cooling power of various environmental conditions on uninsulated cans of water, which obviously have no metabolism. It is therefore not possible to translate them to man with any accuracy, since in the case of man the rate of cooling, in response to change of environment, varies in relation to metabolic rate, clothing worn, variations in physiological insulation and possibly also to state of acclimatization. The net result is that the cooling values at the top of the scale tend to be too high, since at the coldest temperatures man has a physiological protection by which he can conserve his heat. Examples of this were noted at Halley Bay in relation to the occurrence of minor degrees of frost-bite in certain exposure conditions. The Wind-chill literature states that exposed flesh freezes at Wind-chill factors greater than 1,400 Cal/sq.m/hour, and at 2,000 Cal/sq.m./hour exposed flesh will freeze in less than 1 minute. The following cases were observed:

1. Freezing of face following 20 min. exposure to Wind-chill factor of 1,830 Cal/sq.m./hour

2. Freezing of face following 30 min. exposure to Wind-chill factor of 1,900 Cal/sq.m./hour

3. Freezing of face following 40 min. exposure to Wind-chill factor of 1,888 Cal/sq.m./hour

4. Freezing of face following 70 min. exposure to Wind-chill factor of 2,000 Cal/sq.m./hour.

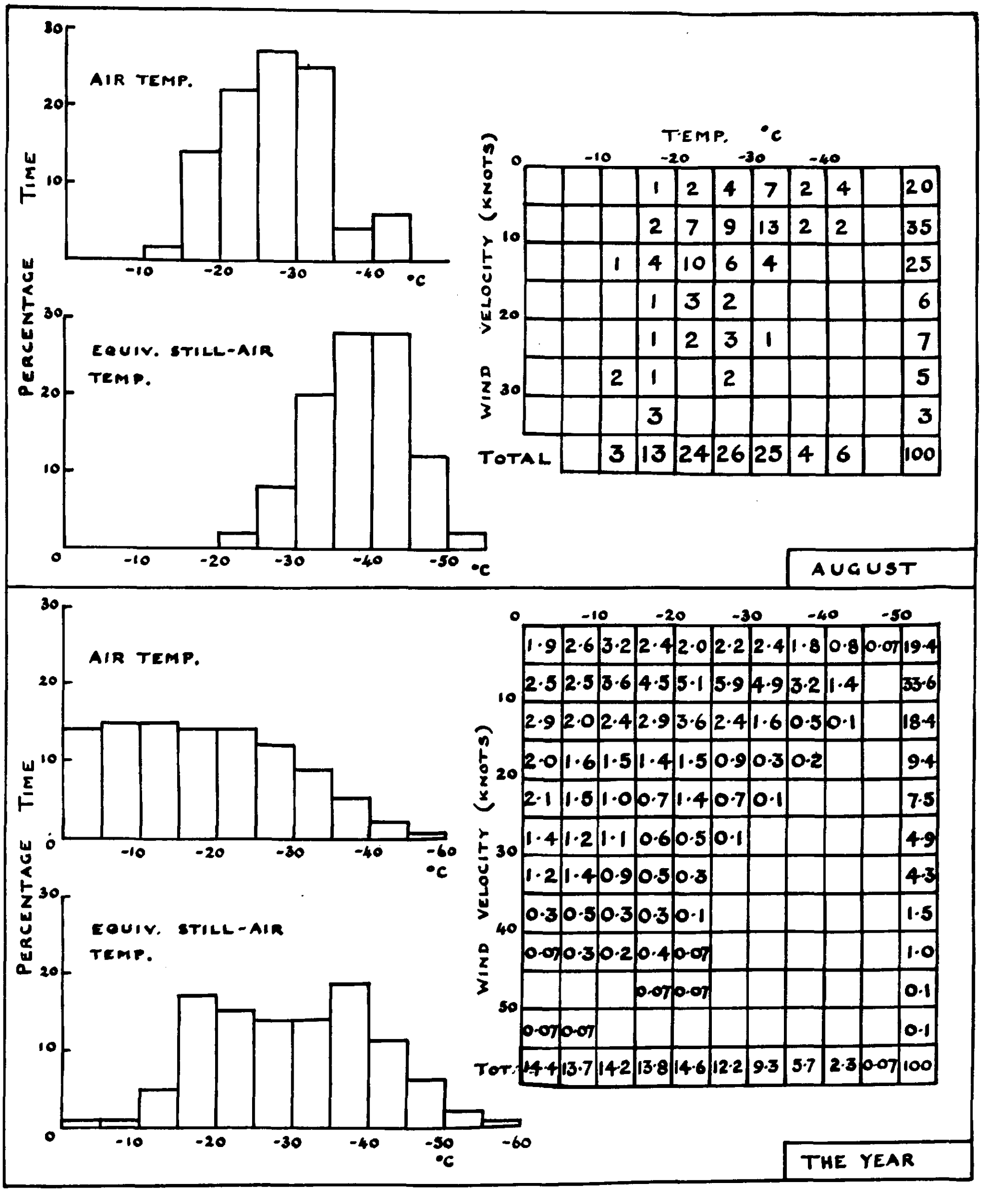
It was often found possible, in practice, to be outside for 7 - 12 minutes without damage to the face in conditions which the Wind-chill scale suggested would cause freezing of exposed skin within half a minute (i.e. a Wind-chill factor of greater than 2,300 Cal/sq.m./hour). On the other hand this is a most convenient method of indicating the combined effects of wind velocity and temperature and the Wind-chill scale is still widely used to give an indication of the order of magnitude of the cooling power of these two parameters.

Another method, more recently produced by Burton (1953), and which is more acceptable theoretically, is the calculation of the equivalent still-air temperature. Here a value is calculated, in terms of degrees of temperature, to represent the thermal decrement of wind at various velocities, and this is applied as a correction to the environmental temperature. The thermal wind decrements for various wind speeds are given by Burton (1953) from his equation of the thermal steady state of man, and he shows that the decrement is equivalent to the product - in appropriate units - of the total heat loss (Cal.), and the insulation-wind-decrement (clo units). Since the thermal wind decrement, as applied to man, varies with his activity, separate standards have been constructed for different degrees of activity. This overcomes one of the greatest disadvantages of the Wind-chill scale, in that various levels of heat production resulting from different degrees of activity have been accounted for. The other disadvantage, that it does not take into account the clothing worn, can be overcome by first estimating the thermal demand of the environment and taking the insulation of the clothing worn into account after the equivalent still-air temperature has been calculated.

This is a very convenient method of combining wind velocity and temperature data so that the effects of these two parameters can be expressed as a single factor. Fig. 7 shows the application of the thermal wind decrement to the temperature distribution of August and of the whole year.

To provide a comprehensive climatic picture it would be necessary, of course, to add an increment to the equivalent still-air temperature to account for solar radiation. This is not included here because it is not yet possible to measure the radiation heat load on man with any great accuracy. The effects of solar radiation may well be considerable in Polar regions, particularly in spring and autumn when the sun circles a few degrees above the horizon. Under these conditions about one third of the body surface is exposed to radiation, in contrast to tropical regions, where the sun shines directly down from above, affecting a relatively small area of the body surface (Underwood, 1960 - personal communication).

Liljequist (1956) has made an extensive study of solar radiation at Maudheim, some 200 miles north of Halley Bay. He states that the extinction of the solar beam in the atmosphere is mainly due to the scattering of the radiation against the air molecules and the suspended particles in the air and also the absorption of the radiation by water vapour. Since the



August (Temp. °C, columns in 5° steps from 0 to −50; rows: wind velocity in 5-knot steps from 0 to 35)

										Total
			1	2	4	7	2	4		20
			2	7	9	13	2	2		35
		1	4	10	6	4				25
			1	3	2					6
			1	2	3	1				7
		2	1		2					5
			3							3
TOTAL		3	13	24	26	25	4	6		100

The Year (Temp. °C, columns in 5° steps from 0 to −55; rows: wind velocity in 5-knot steps from 0 to 55)

1·9	2·6	3·2	2·4	2·0	2·2	2·4	1·8	0·8	0·07	19·4
2·5	2·5	3·6	4·5	5·1	5·9	4·9	3·2	1·4		33·6
2·9	2·0	2·4	2·9	3·6	2·4	1·6	0·5	0·1		18·4
2·0	1·6	1·5	1·4	1·5	0·9	0·3	0·2			9·4
2·1	1·5	1·0	0·7	1·4	0·7	0·1				7·5
1·4	1·2	1·1	0·6	0·5	0·1					4·9
1·2	1·4	0·9	0·5	0·3						4·3
0·3	0·5	0·3	0·3	0·1						1·5
0·07	0·3	0·2	0·4	0·07						1·0
			0·07	0·07						0·1
0·07	0·07									0·1
14·4	13·7	14·2	13·8	14·6	12·2	9·3	5·7	2·3	0·07	100

Fig. 7
Meteorological data for August, and for the year, expressed as double frequency tables of temperature and wind velocity and showing the application of the thermal wind decrement in both cases. In each group the frequency distribution of ambient temperature is shown and is followed by the distribution of equivalent still-air temperature derived from the double frequency table.

Antarctic air is free of particulate matter and its content of water vapour is small, the direct solar radiation is strong and it reaches values which in more temperate regions are generally found only on mountains at altitudes of 2,000 - 3,000 metres.

The albedo or reflecting power of the snow is another important factor and Liljequist concludes that approximately 90% of the total radiation is reflected in this manner. He also showed that owing to the selective albedo and the multiple reflections between cloud base and snow surface in overcast weather, that the radiation under these conditions is much richer in visible light than with a clear sky. This possibly explains why all the cases of snow blindness occurring at Halley Bay since its establishment were in association with overcast weather, when people tended to remove their goggles believing, wrongly, that the light is less intense under these conditions. This dangerous tendency to remove goggles has also been noted by Adam (1958 - personal communication) in inexperienced Polar travellers having visual difficulties in overcast conditions.

A man in polar regions facing the sun for an hour or so, when it is only a few degrees above the horizon, has been noted to have a temperature gradient between the front and the back of his clothing which may be of a high order (Pugh and Chrenko - in preparation). Recent temperature measurements of the black rubberised roofing of an Antarctic hut - made on a clear day when the air temperature was well below zero - revealed that the temperature was in the region of 80°F. (Cumming, 1960 - personal communication).

Solar radiation is thus an important factor in the measurement of the thermal exchanges of man in polar regions and it must be accounted for as soon as suitable instruments for its measurement on man are devised.

M I C R O - M E T E O R O L O G Y   A N D   M A N

Section 5

SECTION 5

MICRO-METEOROLOGY AND MAN

In the previous section reference has been made to the climate which was recorded by conventional meteorological means in Halley Bay and its surroundings. It is obvious that the man living at Halley Bay will not be exposed to this climate constantly, since he spends a large portion of his time within the heated hut. The meteorologist's account of the climate does not therefore indicate the true climate to which the man is exposed. In order to determine this, it is necessary to measure the precise environment which surrounds the man throughout the whole 24-hour period, wherever he may be. Although the measurement and the use of such a climate provide a better estimate of the climatic stress to which the man is exposed than the conventional meteorological climate, the complete picture, nevertheless, is not presented, since no allowance is made for the effect of varying insulation worn.

A third concept must be introduced at this point and this is the sub-clothing or micro-climate, which denotes the ultimate climate which surrounds the naked body. It is only with the variations in this climate that the body is fundamentally concerned. The hypothesis may be formulated that an estimate of the climatic stress on man may only derive from considerations of simultaneous recordings of the actual climate to which he is exposed and his micro-climate. This constitutes the study of micro-meteorology on man.

In order to facilitate the description and discussion of these various climatic states, the following terms have been employed:

1. The met climate: This refers to the climate of Halley Bay, as measured by the meteorologists.

2. The exposure climate: This refers to the environment to be found in close proximity to the subject wherever he might be in any part of the 24-hour period. It includes two main components; one derived from measurements made inside the hut, and the other from measurements made outside. When the man is outside, the met and the exposure climates will, of course, be the same.

3. The micro-climate: This refers to the sub-clothing climate, also measured wherever the subject might be in any part of the 24-hour period.

The relationship between the met, exposure and micro-climates may be seen in Fig. 8, where the mean monthly values of each variable for one year are set out.

It is immediately clear from these values that the exposure climate is considerably different from the met climate and reflects the adequacy of the protection afforded to the men on whom the measurements were made. These values are, however, mean monthly values and so the criticism may fairly be levelled that no indication has been given of the trends or relationships due to fluctuations in these values. Such a criticism may be answered by quoting the extreme values recorded by the author, which were in July 1959. On this occasion the subject left the hut in

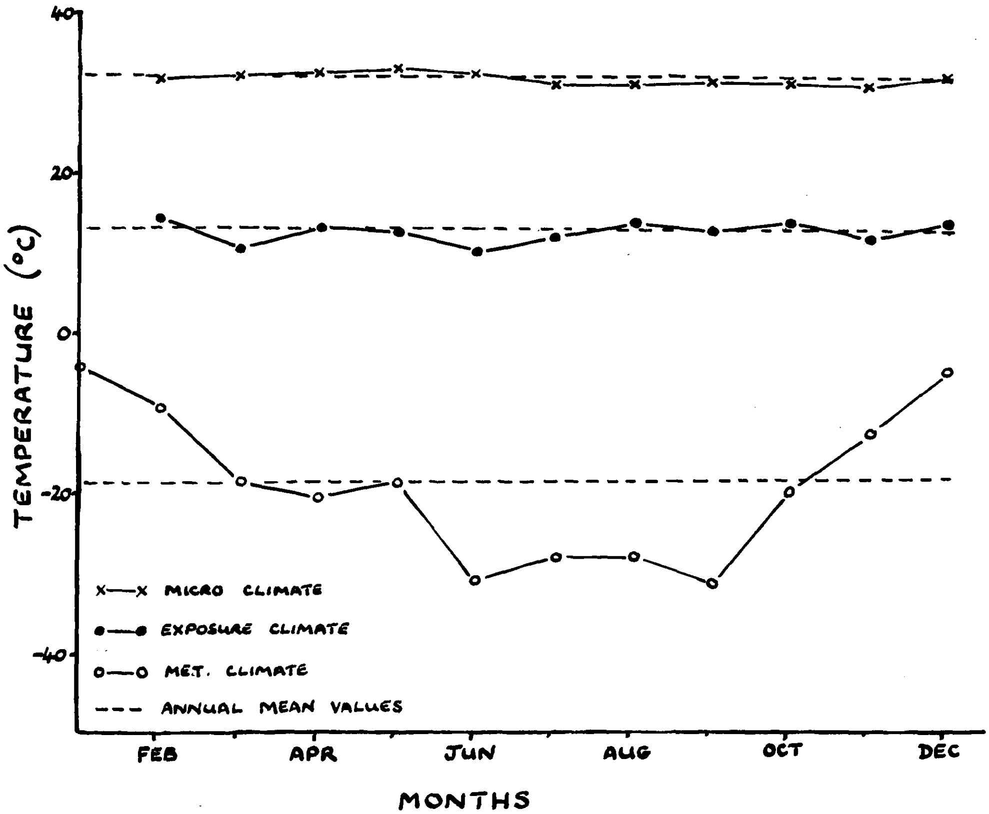


Fig. 8

Monthly mean values of the temperature of the met climate, the exposure climate and of the micro-climate to which the four subjects were exposed during the year. The annual mean value of each climate is also shown.

darkness, and experienced a sudden change in exposure climate of 61.6°C. to a met climate of -43°C. He carried out light work for a period of seventy minutes in this met and exposure climate and during this time the fall in temperature of the micro-climate was only 8.2°C. All the measurements were made at 10, 30, 50 and 70 minutes after leaving the hut. The choice of this example is a happy one because the recording took place in darkness thereby precluding the additional criticism that radiant energy from the sun might have modified the man's micro-climate without affecting the met climate recordings.

The use of the frequency distribution has already been discussed in relation to the better description of met climates and it is felt that the same holds true with regard to exposure climate variations. The percentage of time spent in each five degree range of exposure temperature was determined for four subjects for one year. There may be seen, in Fig. 9, three examples of exposure climate described in this manner - the values for one man for one day in March, the mean values for four subjects for the month of March and the mean values for the four subjects for the whole year. The mean values for the four subjects, month by month, may be seen in Appendix 3.

An examination of the histogram setting out the values for the whole year shows that the four scientists spent 49% of their time in an exposure climate ranging from 15 to 20°C., and 82% of their time between 0 and 25°C. It is suggested that the latter figure is unlikely to be very different for a majority of the population of the United Kingdom. Indeed, it seems

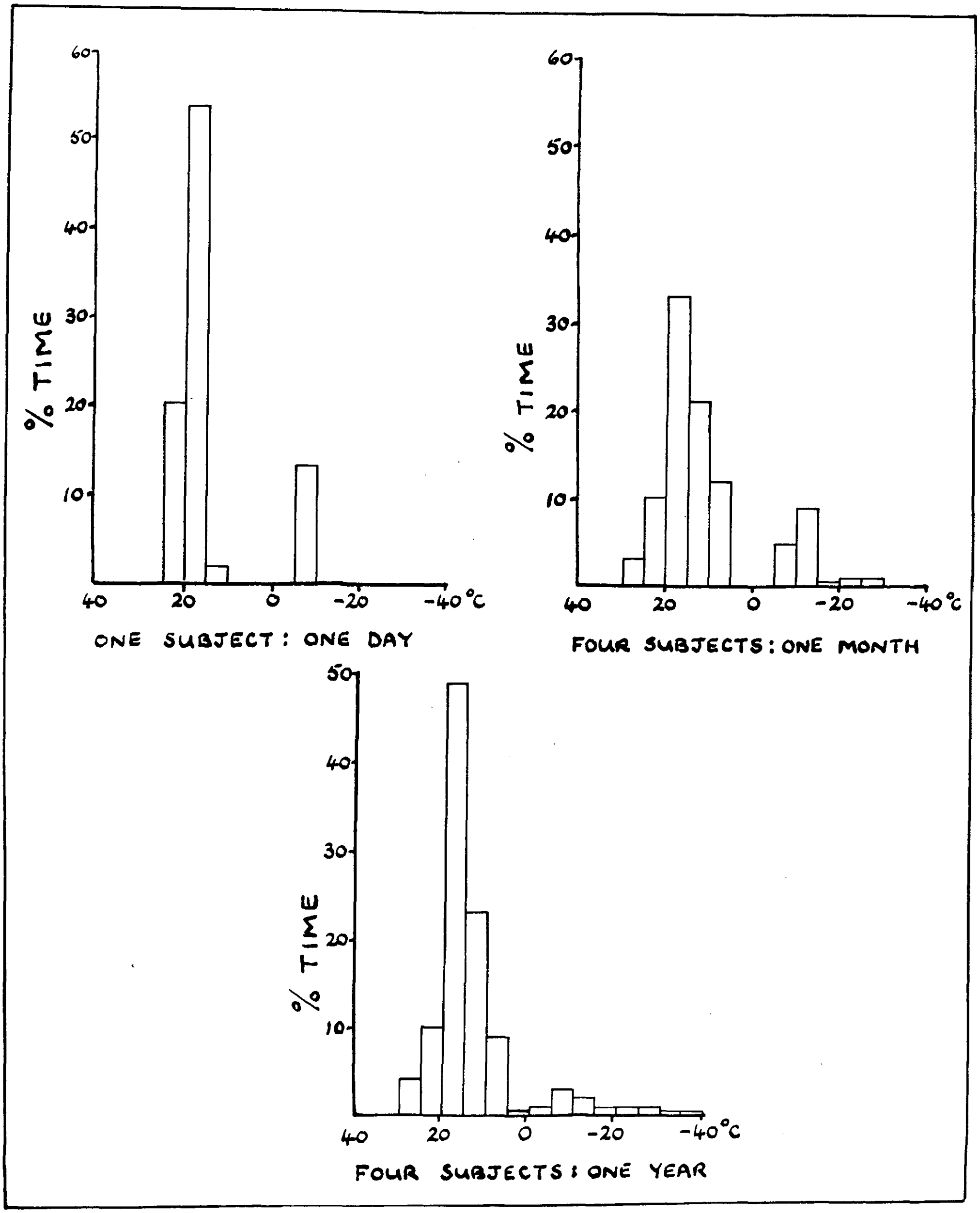


Fig. 9

Exposure Climates. This figure shows the exposure climate of one subject for one day, of 4 subjects for one month and of 4 subjects for the year, expressed as the percentage of time to which the subjects were exposed to the various ranges of temperature.

probable that certain occupation groups such as fishermen and agricultural workers, particularly in the North, might have, if they were to be investigated, exposure climates of a lower order.

The four scientists spent 9% of their time in an exposure climate below $0^{o}C.$, of which 6% was in the range 0 - $15^{o}C.$, and only 1% was below $-25^{o}C.$ This value, 9%, represents a total of 33 days spent in sub-zero temperatures of which 22 days were spent in the range 0 to $-15^{o}C.$, and less than four days in an exposure climate of less than $-25^{o}C.$ Expressed in this way the picture of cold exposure, which is presented, is very different from the usual picture obtained, such as that described by Frazier (1945) which implied that men often worked out of doors at $-76^{o}F.$ ($-60^{o}C$) and that the common range of exposure temperature was in the region of $-40^{o}F$ ($-40^{o}C.$) and below. Frazier was writing about Little America III, where the met climate is certainly not more severe than that of Halley Bay.

The individual variation of time spent in the sub-zero exposure climate by the four subjects was 8.9%, 9.5%, 8.2% and 8.6%. The mean percentage of time spent in sub-zero exposure climate by the four subjects each month is set out in Fig. 10. It will be seen that during the winter months these values are at their lowest, having a mean value of 4.3%. The summer months differ considerably and have a mean value of 13.1%. Here, then, is factual evidence of the marked disinclination to leave the hut during the darkest months, and that sub-zero temperatures did not deter them from so doing once the sun had re-established itself.

This explains why the mean values of the exposure climate vary so

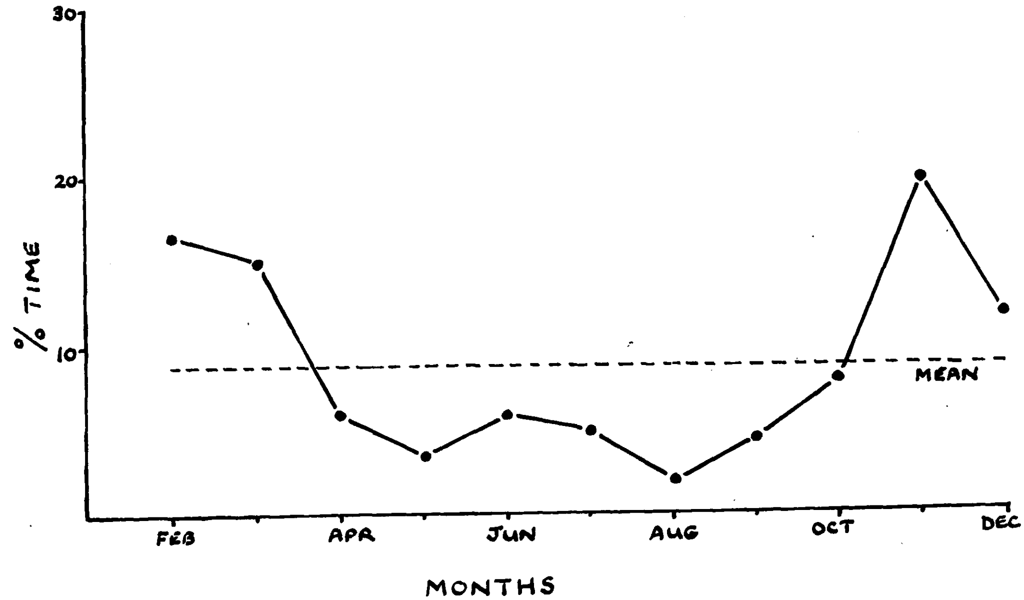


Fig. 10

This shows the mean monthly percentage of time spent out of doors by the four subjects, i.e. the time during which they were exposed to the sub-zero temperatures of the met climate each month.

little from month to month. Though the outside component of the exposure climate is very cold in winter, the time of exposure is relatively short. Thus the total severity of the cold stress does not alter much when it is considered both in terms of intensity and of time.

The final comparison which it is interesting to make is a superimposition of the met climate and the exposure climate. Siple's profile method by which he illustrated the climates of America (Siple, 1949) has been used. This is a visual method of illustrating a large mass of meteorological data in a concise manner, and it may appear confusing at first sight since it is rather unconventional. Consider first the shaded shapes which represent both components of the exposure climate. The wider the shape of the pattern opposite a range of temperature, the longer has the temperature persisted within that range. The met climate is represented by the unshaded shape in each diagram and it is superimposed upon the exposure climate. The met climate will, of course, encircle the outside components of the exposure climate. This diagram gives a good picture of the relationship between the exposure and the met climates, and shows the extent to which they interdigitate from month to month.

It appears, from these diagrams, that the exposure to the met climate in winter practically always falls in the low part of the temperature range of the met climate. This is true for the months of May to September, the months previously defined as winter (Section I). The reason for this is that when the temperature is low, the wind velocity is also low, as has been shown. This again illustrates the important factor of wind velocity in

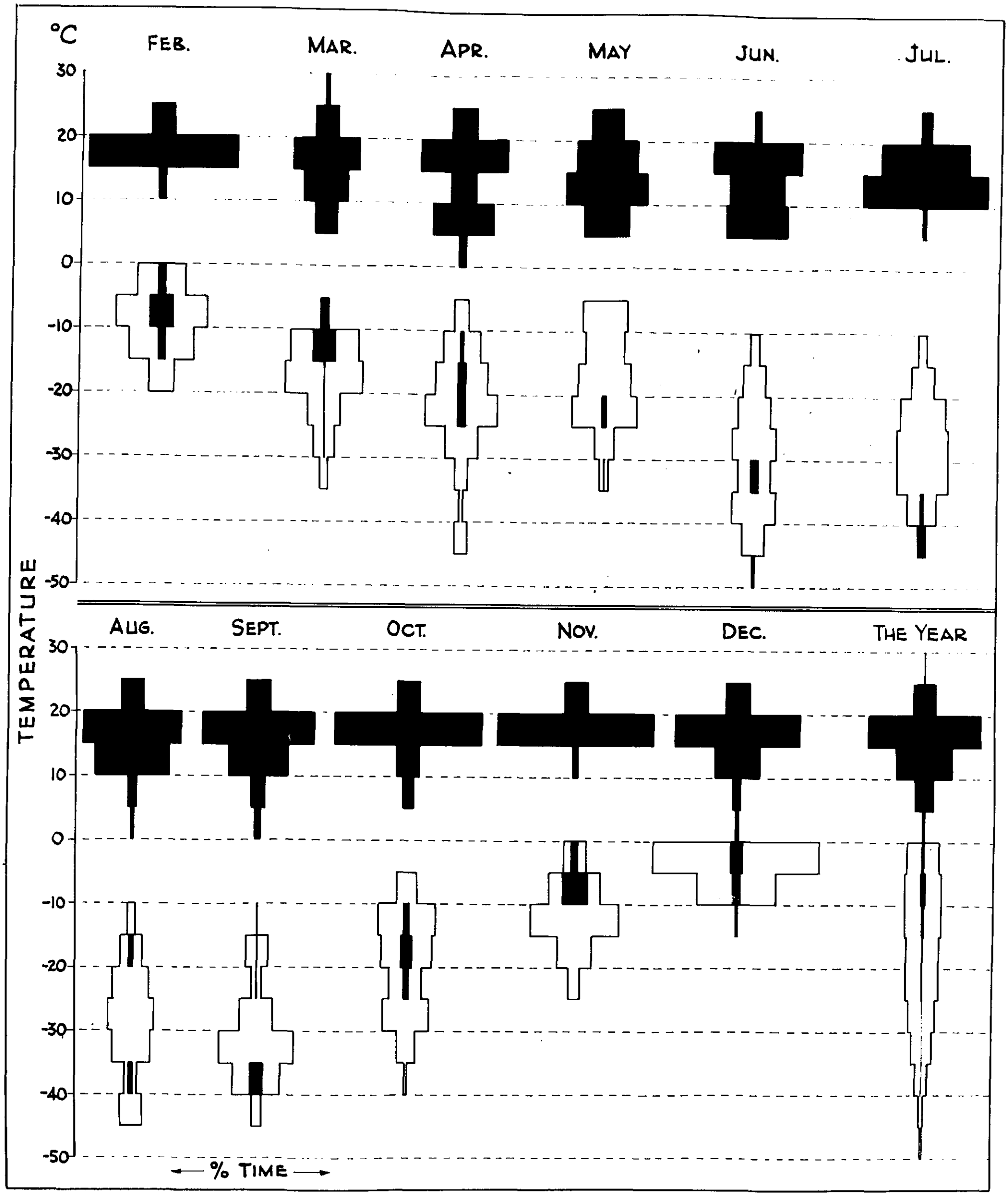


Fig. 11

This shows superimposition of the monthly temperature profiles of the met climate and the exposure climate of the 4 subjects. The shaded areas represent the exposure climate, the upper part occurring inside the hut and the lower part outside. The unshaded area represents the met climate. The thicker the shape opposite a range of temperature, the longer has the temperature persisted at that point. This shows the relationship between the met climate and the exposure climate and demonstrates how the length of time to which the subjects are exposed to the met climate diminishes with the increasing coldness of the met climate.

governing voluntary exposure. Also in the summer months the main part of the exposure occurs in the upper part of the outside temperature range. The reason for this is that there tends to be a diurnal temperature variation in summer, the low temperatures occurring during the sleeping hours, when the declination of the sun is low. These temperature profiles may be seen in Fig. 11.

The Micro-Climate

Frequency diagrams have been prepared for the micro-climate in a similar manner to the exposure climate, and the monthly values for each man are set out in Appendix 4. Fig. 12 represents the annual frequency distribution of the micro-climate for each of the four subjects, while Fig. 13 shows an example of a 24 hour period for two men. In each case the frequency distribution of the micro-climate for the 24 hour period is given together with the exposure climate to which it is related.

It is interesting to note that the values fluctuate around a modal value of 32°C to 33°C in all cases. Since the micro-climate results from the inter-action of skin temperature and exposure temperature and is dependent upon the clothing, these results reflect the adequacy of the protection provided.

The dependence of the micro-climate on the exposure climate is clearly shown, nevertheless, in Fig. 13 where, in the upper half of the diagram (N.A.H., Sept.) the close grouping of both components of the exposure climate is reflected by a similar grouping of the values of the micro-climate. In the lower half of the diagram (M.A.S., April) the scatter of the values of the exposure climate is again reflected by the frequency distribution of the temperature recordings of the micro-climate.

In order to demonstrate the manner in which the temperature of the micro-climate varies with the temperature of the exposure climate more precisely, diagrams were prepared in which the course of both these parameters was followed through the 24-hour period. Two are presented in Fig. 14, and

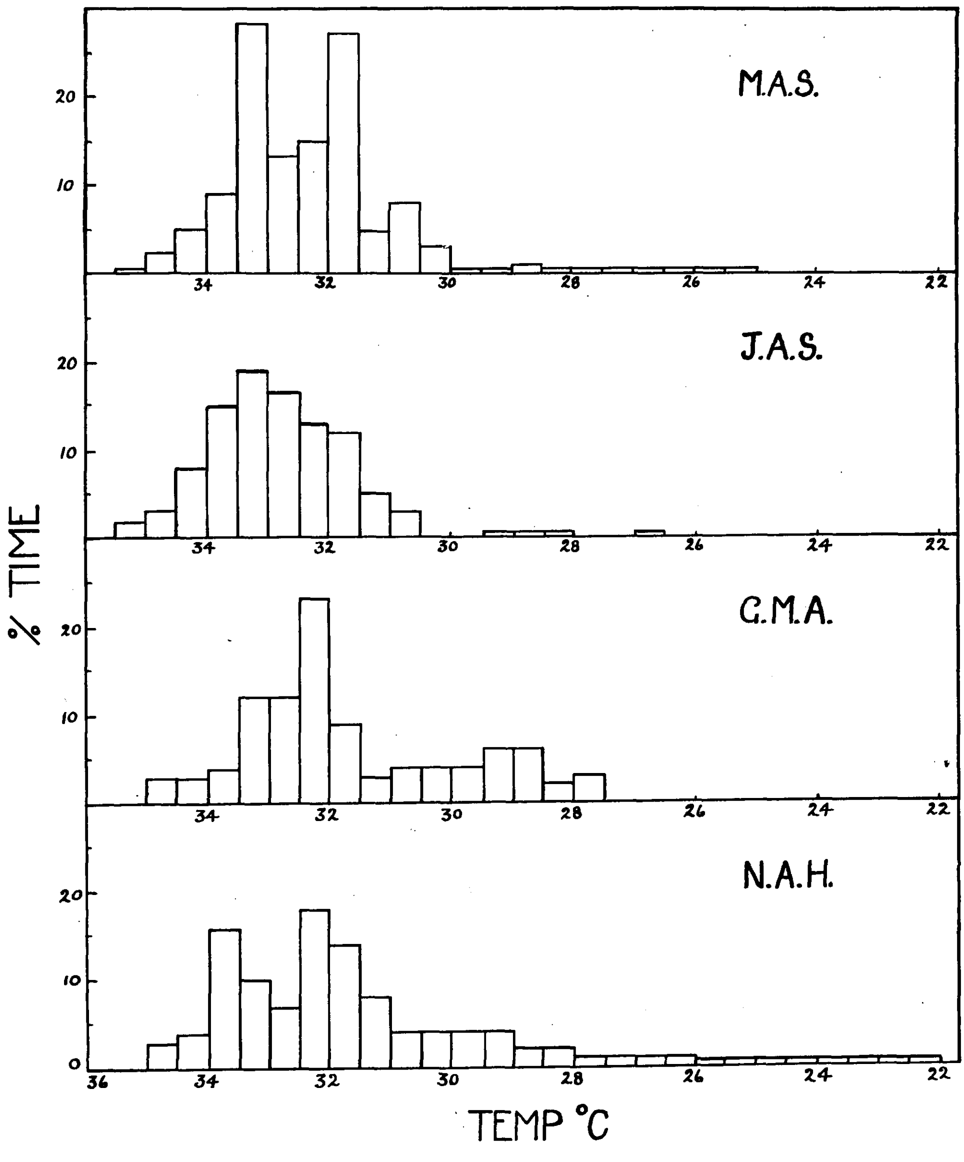


Fig. 12

Micro-climates. This figure shows the annual frequency distribution of the micro-climate for each of the four subjects expressed as the percentage of time during which each subject was exposed to the various temperatures of the micro-climate.

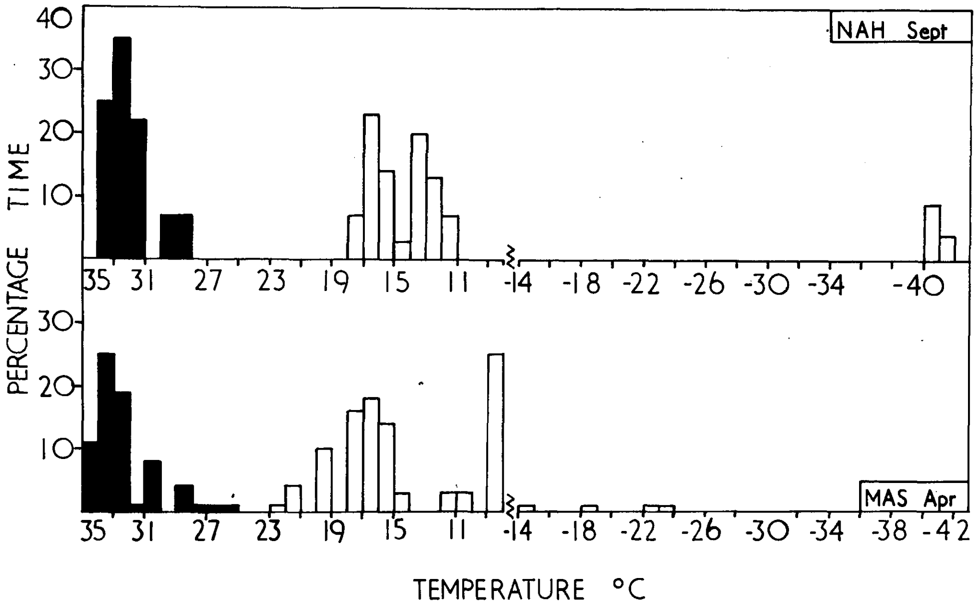


Fig. 13

This shows the frequency distribution of the micro-climate for each of two subjects during a twenty-four hour period. The exposure climate to which each is related is also shown. The shaded area represents the micro-climate.

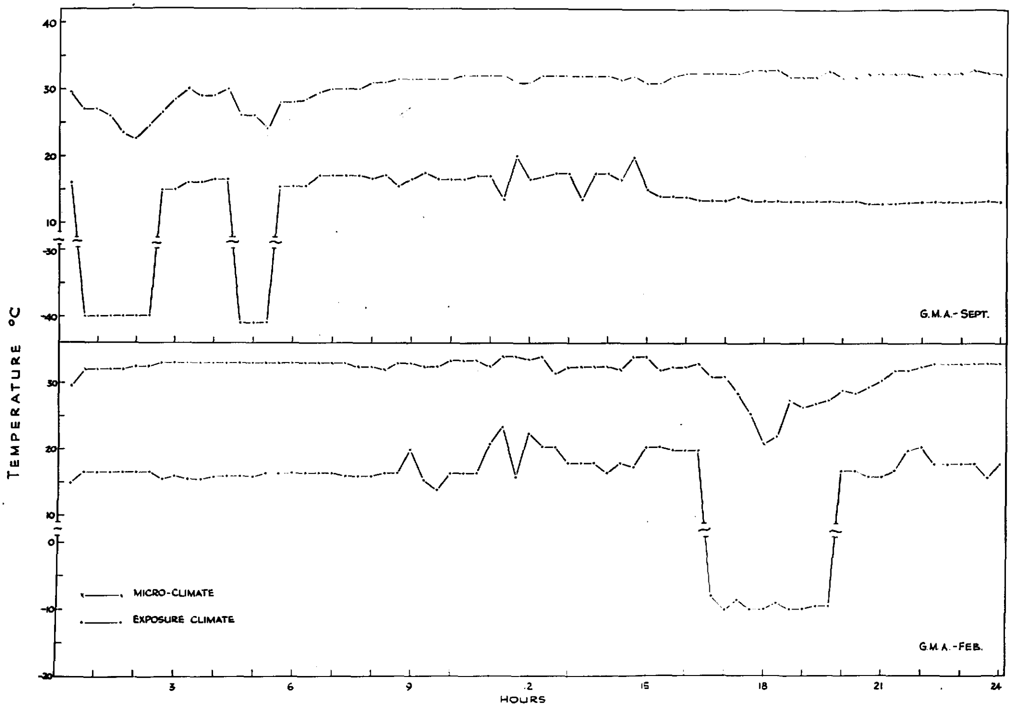


Fig. 14

This figure shows the temperature values of the micro-climate followed bver two twenty-four hour periods in the same subject - one in summer and one in winter. The value of the exposure climate recorded simultaneously with the micro-climate readings is also given showing the manner in which the micro-climate varies with the exposure climate.

are both from the same subject, but they represent different times of the year, one in summer and one in winter.

The variations of temperature of the micro-climate measured inside the hut are of the order that might be expected inside a comfortable room at home. Thus for over 90% of the time the micro-climate behaved much as it would be expected to behave in a temperate climate. This is not surprising since the exposure for over 90% of the time is to a temperate climate.

The remaining 9% of time is, however, significant and the remainder of this section is directed to its consideration. From the above figures it can be seen than on exposure to the met climate the temperature of the micro-climate alters from its previous state. This, again, is not surprising, since the change of ambient temperature may be anything from 40 to 60°C.

When man exposes himself to the met climate the temperature of the micro-climate falls. This fall apparently occurs rapidly, for on many occasions, when readings were taken within 3 to 6 minutes of exposure, a fall in the temperature of the micro-climate was demonstrated. There does not appear to be a prolonged lag period between exposure to the met climate and this fall in the temperature of the micro-climate.

From Newton's physical laws of cooling, the micro-climate must be expected to cool on exposure to the met climate and the rate of cooling to be proportional to the temperature gradient, the surface area of the micro-climate and its insulation. This cooling of the micro-climate will consequently cause an increase of heat flow from the body and at some point the body can be expected to take action to maintain its temperature.

In order to arrive at some estimate of the order of magnitude of the rate of cooling of the micro-climate, examples of short exposures were extracted from the records of each man. Certain criteria were adopted for each exposure in order to standardise each:

a) The same clothing was worn on each occasion;

b) The activity was the same, viz. walking;

c) The man was inside the hut for at least two hours prior to exposure.

On this basis, various rates of cooling were calculated for each man. In order to account for the differing temperatures and wind velocities of each exposure, the cooling rates were then assessed in terms of degrees cooling of the micro-climate per minute per degree equivalent still-air temperature below zero of the met climate. These cooling rates are set out in Table 8.

The duration of each exposure from which these figures were calculated is given in Table 8, since the rate of cooling would be expected to decrease as the temperature gradient lessened. In order to demonstrate this, the various rates of cooling were plotted against the appropriate exposure time, and the results are shown in Fig. 15. A line was drawn through the highest value for each time, and another through the lowest. The mean value of cooling rate is shown in Fig. 16 where the mean values of arrays are given.

These figures indicate a very short lag period soon followed by rapid cooling rising to a maximum by about 10 minutes and steadying in about ½ hour.

Subject	TIME Mins. after Exposure	Degrees Cooling per Degree Equiv Still-Air Temp below $0^{o}C$
M.A.S.	4	0.0070
	6	0.0190
	9	0.0090
	9	0.0190
	12	0.0130
	13	0.0069
	20	0.0055
	28	0.0057
	33	0.0028
	40	0.0027
	53	0.0026
	60	0.0018
J.A.S.	1	Nil
	3	0.0055
	8	0.0160
	20	0.0037
	25	0.0062
	30	0.0037
	30	0.0048
	30	0.0050
	40	0.0014
	60	0.0022
G.M.A.	4	0.0060
	4	0.0150
	7	0.0180
	8	0.0080
	8	0.0060
	10	0.0060
	20	0.0061
	40	0.0042
	60	0.0041
N.A.H.	3	0.0050
	10	0.0085
	10	0.0170
	23	0.0029
	30	0.0016
	43	0.0016
	50	0.0060

Table 8

This gives the various rates of cooling in response to various periods of exposure in four subjects. The rate of cooling is expressed as degrees cooling/min/degree equivalent still-air temperature below $0^{o}C$ of the met climate.

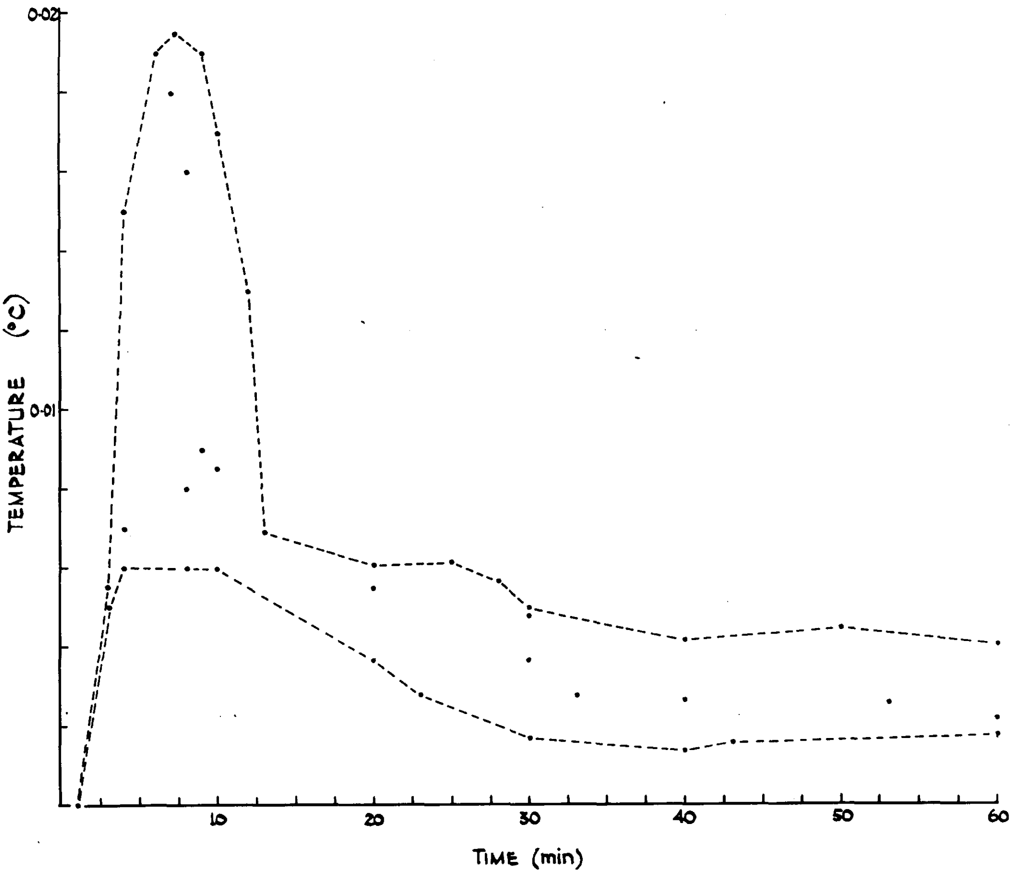


Fig. 15

This figure shows the rates of cooling of 4 subjects in terms of degrees cooling/man/degree equivalent still-air temperature below $0^{\circ}C$ of the met climate. Each value is plotted against the period of exposure preceding the measurement. A curve is drawn through the highest values at each time, and another through the lowest values. This shows a short lag period followed by rapid cooling which has steadied in about half an hour.

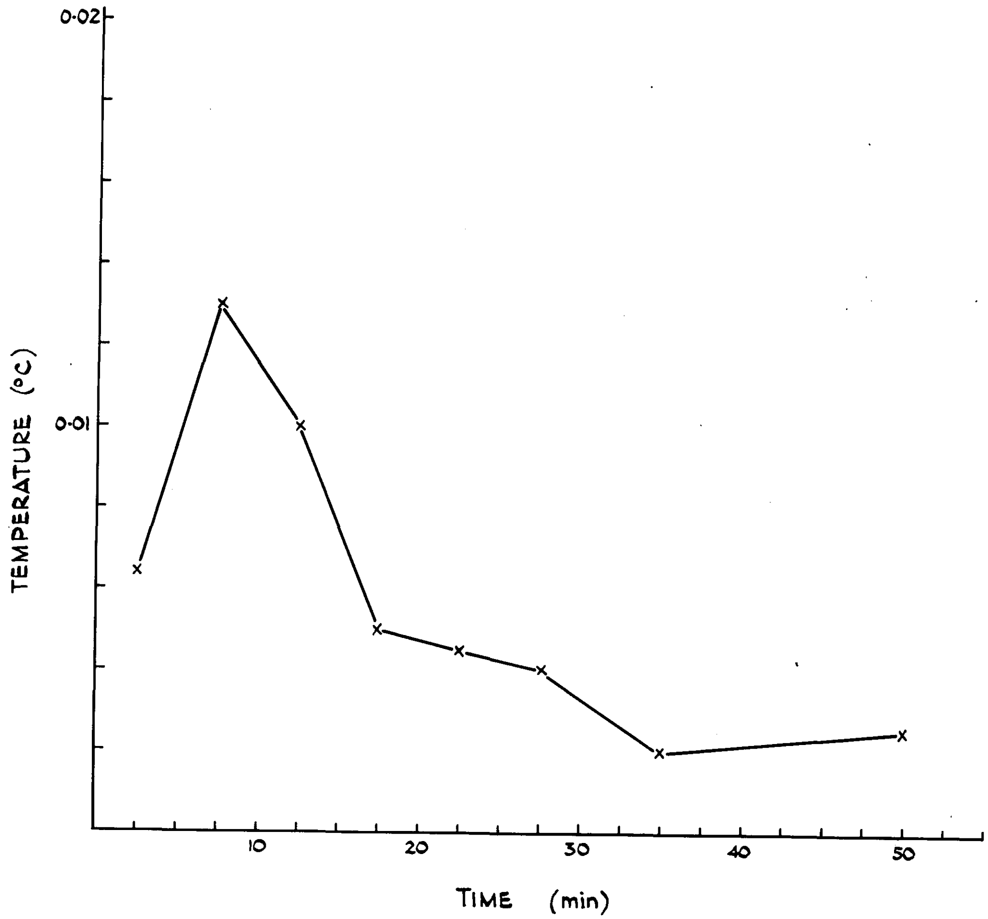


Fig. 16

This figure shows the mean values of the cooling rate of the four subjects. These values were calculated from the figures shown in fig. 15.

Turning now to the consideration of the longer exposure, it was noted that patterns of micro-climate temperatures recurred persistently, and these did not seem to be correlated, in their general form, to the activity of the subject or to the severity of the exposure, though each individual exposure must be modified by both of these considerations. A series of these patterns is reproduced in Fig. 17.

The temperature drops at a decreasing rate on exposure, in every case, as expected, then about half an hour after the start of the exposure there is a rise in temperature. One would expect the increased rate of heat flow from the body, consequent upon the cooling of the micro-climate, to cause some reaction from the body tending to maintain its heat. Though no readings of deep body temperature are available it may be possible to say that at this point active heat production takes place and is reflected - by vasodilatation - in this rise in temperature of the micro-climate. Burton and MacDougal (1941) produced a similar picture of fall in surface temperature followed by a rise in three to four hours in men exposed to the cold in heavy flying clothes. Simultaneous estimations of metabolic rate indicated that the increase in heat production reflected by a rising surface temperature was accompanied immediately by a rise in metabolic rate.

An increase in heat production is the most reliable indication that the body as a whole has found it necessary to make some adjustment in response to a cold environment. It may thus be possible, in an endeavour to define the extent of the cold stress at a given polar station, to

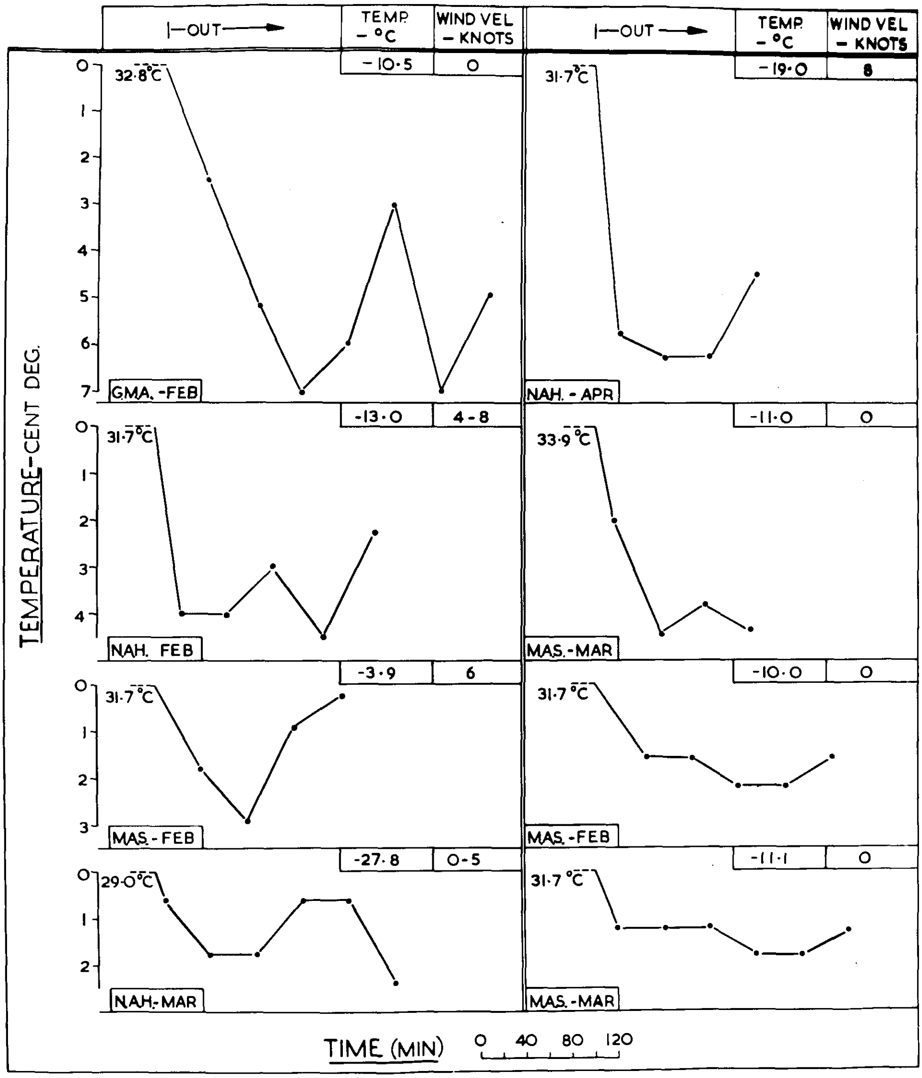


Fig. 17

This figure shows typical variations in the temperature of the micro-climate in individual subjects following exposure to the met climate for various lengths of time.

postulate that short exposures, in full polar clothing, are not sufficient to cause an alteration in general body routine, and that any consideration of general functional alterations, in response to the environment, should be made against a background of exposure time in which only individual exposures of more than one hour are included. Baker and Daniels (1956) also noted the occurrence of spontaneous re-warming in their work on correlations between rates of cooling of the body surface and skin-fold thickness. They found that it occurred about three times more frequently on the trunk than on the extremities.

The pattern of temperature changes in the micro-climate obtained during a man-haul sledging journey fluctuate widely. The patterns for two days are reproduced in Fig. 18 and the time actually spent hauling the sledge is indicated as an interrupted line while readings taken during all other activities are represented by a continuous line.

It is interesting to note that though the temperature of the micro-climate sometimes rises during man-hauling, that this is not always the case. In some instances, the temperature of the micro-climate actually falls. The interpretation of this does not appear straightforward. Eichne, Park, Nelson, Horvath and Palmes (1950) noted that though rectal temperature rises and plateaus when nude man does work in a warm or a cold environment, skin temperature drops in the cool environment and rises in the warm environment. They concluded that though the thermo-regulation of the deep tissues adjusts itself to the environment, so that the deep body temperature for a given task is the same and independent of

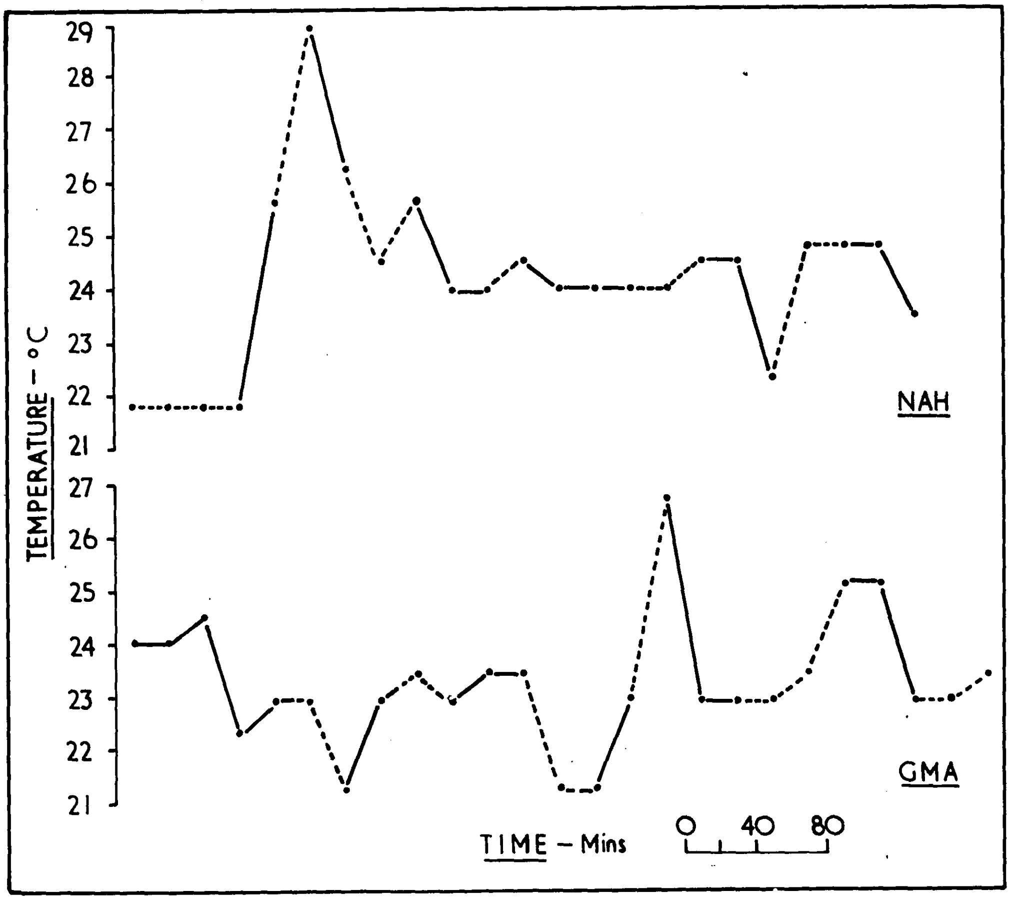


Fig. 18

This figure shows the fluctuations in the temperature of the micro-climate of two subjects each during a day spent in manhaul sledging. The uninterrupted lines represent time actually spent hauling the sledge.

environment, after acclimatization, skin temperature is not similarly adjusted, may vary widely, and tends to approach environmental temperature. Thus though the state of the micro-climate must vary with activity, the relationship does not appear to be direct or simple.

It was also noted that the micro-climate was maintained at a lower level of temperature during this journey than was typical of the values obtained at base. Fig. 19 illustrates, by frequency diagrams, the micro-climate of two men while sledging and, for comparison, the micro-climate obtained for each during the previous month at base is given. Fig. 19 shows a shift of the temperature values of the micro-climate, obtained while sledging, to a lower region of the temperature scale.

The pattern of the temperature changes in the micro-climate during the re-warming period, when the man re-entered the hut, also followed a general plan. Rather than re-warming occurring directly to a level typical of inside conditions there was a tendency for rapid re-warming initially, so that the temperature of the micro-climate typical of inside conditions was exceeded. The temperature subsequently fell to a level typical of inside conditions. Examples of this are shown in Fig. 20. This tendency to a higher immediate micro-climate was particularly marked when the outside exposure had been associated with a high wind velocity. Under these circumstances the temperature of the micro-climate may over-shoot by as much as 3 or 4^{o}C before a steady level is reached. Examples of such exposures are shown in Fig. 21

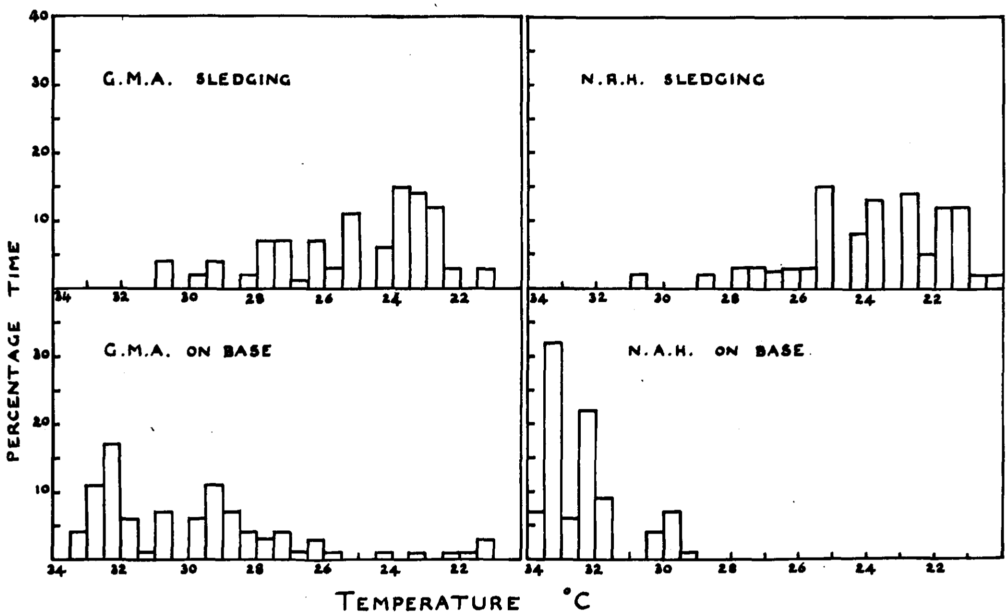


Fig. 19

This figure shows a comparison of the daily frequency distribution of the micro-climate of two subjects while sledging, with that exhibited by each subject during a day in the previous month at base.

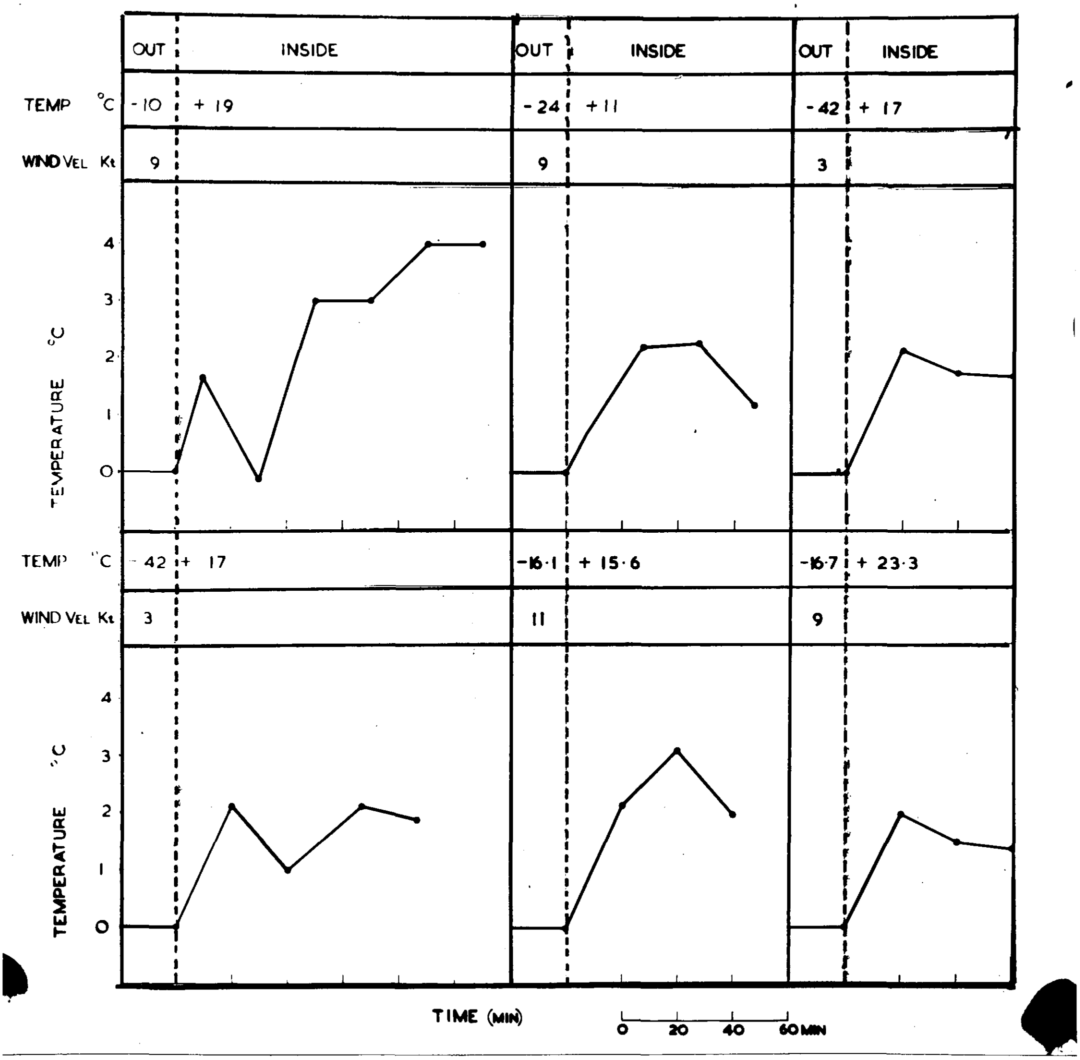


Fig. 20

This figure shows several examples of typical variations in the temperature of the micro-climate after the subjects had been exposed to the met climate for various lengths of time.

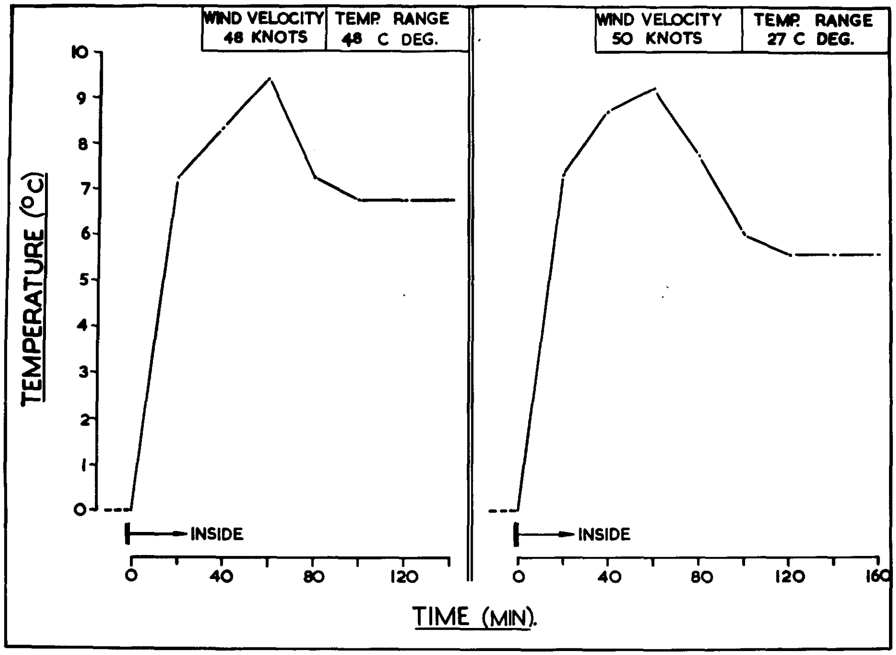


Fig. 21

This figure shows two examples of the typical variation in the temperature of the micro-climate found after the subject had been exposed to the met climate when the wind velocity was high. Note the considerable over-shoot in the temperature of the micro-climate before the level typical of conditions inside the hut was reached.

This over-shoot was observed after most exposures of greater than half an hour, and though it was commonly observed in association with spontaneous re-warming during the exposure, the association was not constant. In the case of over-shooting associated with exposures, in which there was a high wind velocity, it often occurred following relatively short exposures of as little as 15 - 20 minutes.

It would thus appear that following exposure to the met climate, the micro-climate fluctuates more widely than is usual for a period of one or two hours following that exposure. Vere (1958), investigating the temperature variations in the skin and immediately subcutaneous structures by a very precise method, always left his subjects for an hour after cleaning the skin with alcohol before making any readings. From the above, this would appear to be a sound precaution.

In order to arrive at an approximation of the rate of re-warming, a series of values were estimated for one man. In this case only the periods prior to the peak were considered. The results were again related to the equivalent still-air temperature of the met climate in question and they were expressed as degrees of re-warming of the micro-climate/minute/degree equivalent still-air temperature below zero of the met climate. The results were then plotted against time in the same manner as the cooling rates. The curve is shown in Fig. 22. This figure suggests that, for this man, re-warming reaches a peak about ten minutes after the end of the exposure, which is the time of occurrence of the peak of the cooling rate following exposure.

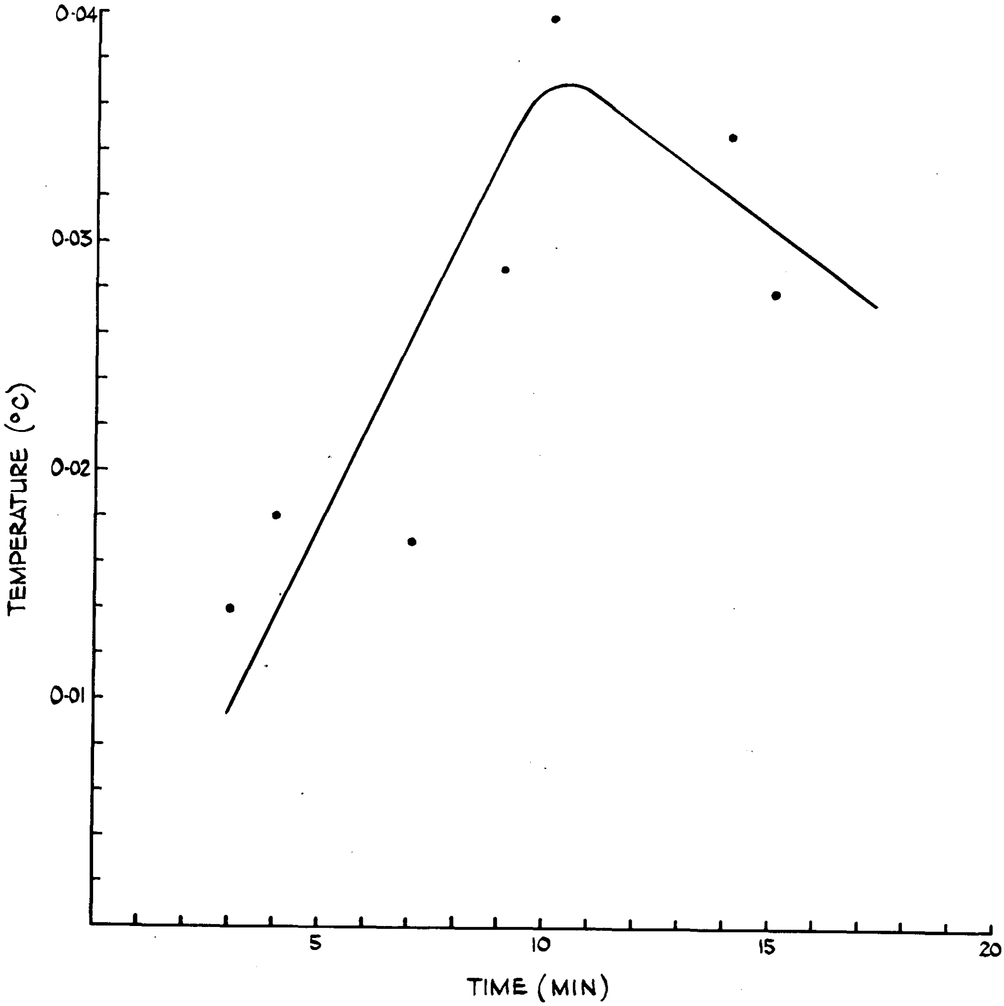


Fig. 22

Rewarming rates. This figure shows the rate of rewarming of one subject expressed as degrees rewarming/min/degree equivalent still-air temperature of the met climate below zero. Each point is related to the time elapsing between the end of the exposure and the measurement of the temperature of the micro-climate.

Comfort

In spite of wide fluctuations in the temperature of the micro-climate during the year, and the sustained low levels obtained during the sledging journey, complaints of bodily discomfort were rare. In fact the subjects frequently protested that they were comfortable at times when the temperatures of the micro-climates had reached their lowest ebb. The complaints which were made were all in association with a rapid fall in the temperature of the micro-climate, and the temperature at which many of these complaints were made was relatively high. Indeed, though the temperature at the next reading may have fallen to an even lower level, providing that the rate of cooling to that level was relatively slow, then the subject stated that he felt quite comfortable. Complaints of discomfort were only made when the temperature of the micro-climate altered by about 4^{o}C. in twenty minutes. Thus the sensory end organs of the trunk appear to be more attuned to the detection of rapid change of environmental temperature than to the registration of its absolute value.

Discussion

These results demonstrate that the micro-climate of the trunk varies in response to the exposure climate. The variations of the micro-climate measured inside the hut are small and are distributed around modal values of 32 - 33^{o}C. during all experimental periods. Different results would not be expected from studies in this country. It has been established previously that 82% of the year was spent in an environment of 10 to 25°C and that 49% of the time was spent between 15 and 20°C. Though this represents a rather colder range of inside temperatures than would commonly be experienced in this country, the clothing worn inside the hut was heavier than that usually worn in temperate zones. It would thus appear that the cold stress applied to the man inside the hut is not significantly greater than that which would be expected in a temperate climate.

When the man is exposed to the met climate it has been shown that the temperature of the micro-climate falls significantly, even though he is in full polar clothing. On a prolonged exposure, such as is experienced on a sledging journey, the temperature of the micro-climate is maintained at a lower level than is usual at base, i.e. it is maintained at about 23 to 25°C. The mean sledging temperatures of the micro-climate are not greatly lower than the thermo-neutral zone for man, indicated by Erikson et al. (1956) to be about 27°C.

It is thus postulated that since these sledging figures were recorded the summer following a season in Antarctica, man still reacts as a tropical animal in his response to the cold as suggested by Erikson et al. (1956) and MacPherson (1958). There is no evidence that man allows the state of his micro-climate to vary significantly (from its state at the beginning of the year) by virtue of a year's life under these circumstances. This substantiates the work of Adam (1958) who found no difference between the temperatures of the micro-climate of the new arrivals to Antarctica and those who had been living and working there for a year.

In an endeavour to define the extent to which man is exposed to a significant cold stress, in such a life, it can be concluded that since the micro-climate falls rapidly on exposure to the met climate, and is maintained thereafter at a lower level than is typical for its response to the temperate climate of the hut, the length of time in which the man is exposed to a significant cold stress is indicated accurately by the length of time during which he is exposed to the met climate. Reference to the exposure section indicates that this amounted to some 9% of time for the year.

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, it is useless to seek profound physiological changes in response to extreme cold. Since man is only exposed to the met climate on this static base for 9% of the year gross physiological changes could not be expected. Applying these results to other static polar bases, it is not surprising that convincing physiological changes have been few in number.

The micro-climate when inside the hut could be regarded as a tropical climate (Annual mean temp. 32.2°C.) and since the micro-climate never fell below 19°C. in any subject, then the coldest climate to which the trunk was ever exposed was certainly no colder than a temperate climate.

Evidence of acclimatization would thus only be expected in the extremities. Mackworth (1953) has indicated the increased tolerance to cold of the hands occurring in progressively long cold exposure, and the only convincing evidence of the Eskimo's adaptation to a cold climate is his functionally superior 'warm hand'. The face is, however, the part which is subjected to maximum exposure, and this seems the logical site to reveal evidence of possible acclimatization. Little has been reported concerning the reaction of the face to cold but Brown (1955) has commented on the rarity of cold injury of the face in Eskimos. During the year of the present study all the members of the party suffered minor frost-bite of the face during winter, except the man who was serving his second year. This man stated, however, that he did suffer from cold injury of the face during his first year. Frazier (1945) also comments on the reduced incidence of cold injury of the face in second year personnel, compared to those serving their first year. This was also noted by Roberts (1949) at Hope Bay, in Grahamland.

It is now clear that the measurement of meteorological effects on man is neither simple nor does it consist entirely of the measurement of the climatic variables of the district in which he lives. Man uses his intelligence to protect himself from unnedessary exposure to the extremes of temperature by providing himself with clothing and shelter. In order to understand the climatic stress to which man is exposed, it is thus essential to think in terms both of his exposure climate and of his micro-climate.

L O S S   O F   B O D Y   W E I G H T
W H I L E   S L E D G I N G

Section 6

SECTION 6

LOSS OB BODY WEIGHT WHILE SLEDGING

Loss of body weight, determined on returning from sledging journeys, has been reported on many occasions although little research has been undertaken to elucidate its cause. Massey (1956) suggested that it may be partly due to calorie deficiency and partly to dehydration. The basis for his observation was that he found that large quantities of fluid are usually drunk following such journeys and the weight loss is restored very rapidly on return to base. Wyatt (1960) differentiated weight loss due to calorie deficiency on a basis of alterations of skinfold thickness, and that due to loss of water. Wilson (1960) also is of the opinion that both calorie deficiency and dehydration are involved. If some degree of dehydration does occur then this may be a physiological dehydration in which the metabolism of water is altered in response to exposure to the cold. This would imply an increase in efficiency of the body for function in the cold. It is also possible, however, that it may be a pathological dehydration due to inadequate intake. If this were true a decrease in the efficiency of the body would be implied.

In order to investigate this question four subjects were studied on a manhaul sledging journey lasting six days. An abundant supply of food was provided in an attempt to prevent calorie deficiency from low intake, and appetites were always satisfied. Similarly, the men were encouraged to drink as much as they desired and this was found to be practicable as a relatively long halt was made every mile to perform a number of geophysical measurements. One of the men, who was not deeply involved in these activities, ensured that the Thermos flasks were kept full of coffee or cocoa. Fluid was thus in abundant supply and there was ample opportunity for drinking it.

Any consideration of change in bodily function related to environmental stress should be accompanied by a picture of the environment in question, expressed in terms of physiological significance. The variations in the micro-climate in response to the exposure climate are also required, together with an account of the patterns of activity of the subjects during the period under consideration. It was only possible to perform meteorological measurements during the day but, by comparison of these with observations performed simultaneously at the base, it has been possible to extrapolate values for the night. It has been assumed that, apart from the time during which the primus stove was lit for cooking, the temperature in the tent was but little higher than the temperature outside, and that air-speed within the tent was negligible.

Methods

a) Measurement of body weight: The weight of each man was measured daily, before breakfast, for a week prior to departure. On return it was measured within an hour, and every morning and evening for the succeeding week. The bladder was emptied before each weighing and the clothing was standardised.

b) The exposure climate: Thd dry bulb temperature and wind velocity of the exposure climate were recorded every hour during the working day.

c) The micro-climate: Measurements of the micro-climate were made every twenty minutes during the working day. The resistance bridge, used to measure the variations in the temperature sensitive vest, was attached to the rear of the sledge. A long lead from the end of one of the sledge traces enabled the man who was steering to take readings while the sledge was in motion. No interruption in the pattern of activity was therefore caused by these measurements. Two men were studied in this way continuously during the waking hours of the journey, each wearing the vest on alternate days.

d) The patterns of activity were observed continuously during the journey in the manner indicated in Section I.

e) Food Intake: A detailed record was kept of the weight of dry ingredients in the diet of each man for each day. The weighings were performed by means of a spring balance which was accurate to $\pm$ 15 Gm.

f) Fluid balance: The fluid intake of each man was measured each day. The capacity of the Thermos flasks was measured and the empty flasks were always filled to a set mark. Water used in cooking was estimated by measuring the various amounts of water added to the stews and porridges and by dividing this quantity of fluid between the men in proportion to their intake of these dishes. No account was taken of the evaporative loss of water in cooking.

g) Urine output: Urine output was measured directly by means of a plastic measuring jar graduated in fluid ounces. Twenty-four hour urinary volumes were recorded for each day of the journey and also for the first week following return to base. Figures for beverages drunk are quoted for two of the men on return to base.

Results

The following were the physical measurements of the subjects:

1. N.A.H. Ht. 175.3 cm; Wt. 85 kg.; Surface area 2.00 sq.m.
2. G.M.A. Ht. 180.3 cm; Wt. 88 kg.; Surface area 2,08 sq.m.
3. W.W. Ht. 173.3 cm; Wt. 83 kg.; Surface area 1.97 sq.m.
4. J.N.N. Ht. 171.0 cm; Wt. 67 kg.; Surface area 1.79 sq.m.

The mean values are: Ht. 175 cm; Wt. 80.5 kg.; and surface area 1.96 sq.m.

Fig. 23 shows the fluctuations in body weight before and after the journey and it can be seen that each subject lost weight as a result of the journey. In all cases there is a tendency to increase weight gradually, but only in one case is the pre-sledging weight regained within the week.

The meteorological data are expressed in terms of frequency and double frequency diagrams. Fig. 24 indicates the frequency of occurrence of the various. meteorological conditions which occurred during the journey.

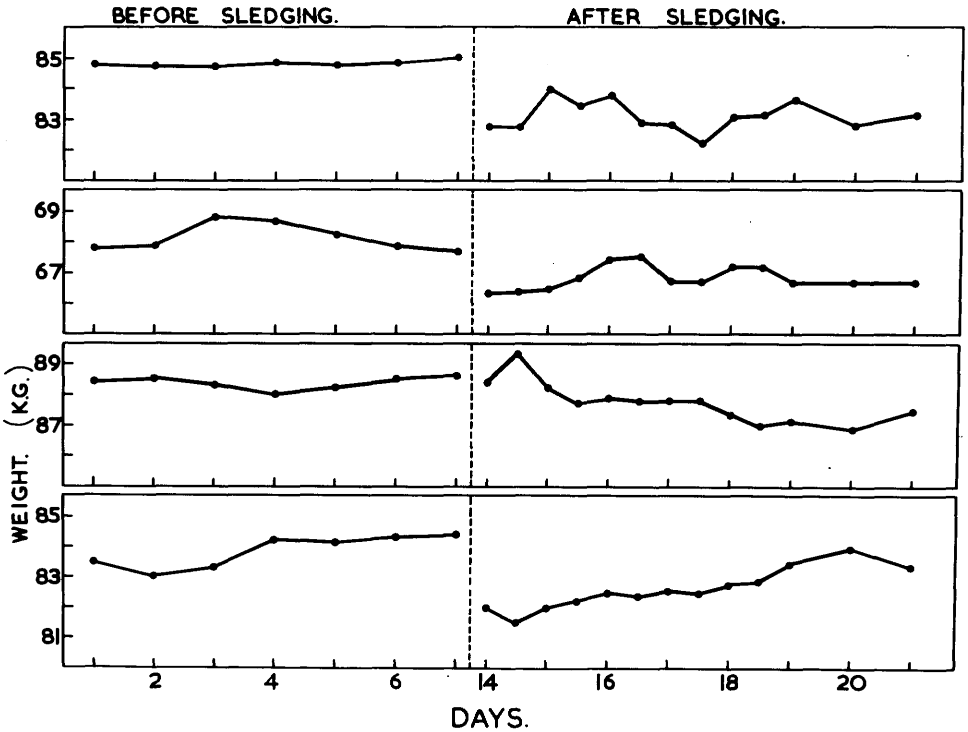


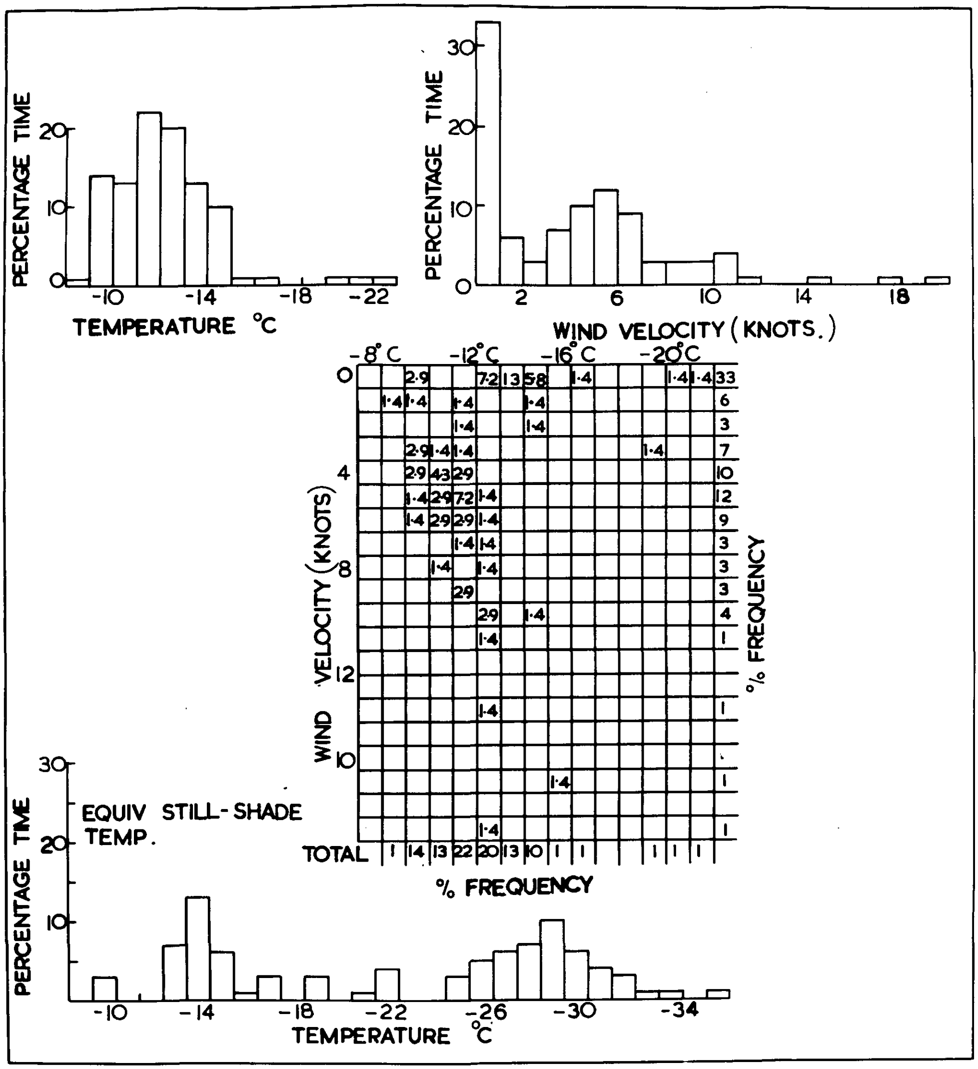
Fig. 23

This figure shows the morning weight of each of the four subjects for one week before the sledging journey and both the morning and the evening weight of each for the week following return.

The prevailing temperature range was $-12^{\circ}C$ to $-15^{\circ}C$ which occupied 94% of the time and of this $-12^{\circ}C$ was the most frequent temperature recorded, occurring for 22% of the time. No wind velocity was recorded for a third of the time and the wind velocity exceeded 11 knots during 3% of the time. The two parameters of wind velocity and temperature are related diagramatically by indicating the ranges of equivalent still-air temperature which would result from the application of the thermal wind decrement to the temperature recordings in the manner indicated by Burton (1953).

Fig. 25 indicates the micro-climate of the two men studied during the period of the journey. A comparison is given for each from measurements made the previous month during the waking hours at base. This demonstrates that the micro-climate was maintained at a lower level during the journey than at base. The mean annual temperature of the micro-climate measured at base was $32.8^{\circ}C.$, while the mean temperature of the readings made during the sledging journey was $24.4^{\circ}C.$

Food intake was measured for each man each day. From this the calorie intake was calculated using the values quoted by Lewis and Masterton (1958a, b, c) in their various papers on sledging rations for polar travel. Other values were obtained from the work of McCance and Widdowson (1946). Table 9 shows the calorie intake of each man for each day. The average intake figure was estimated from the four complete days of the journey - the first and last days of the journey were excluded since they were incomplete. The average figure of 4427 Cal/day is not much less than



<u>Fig. 24</u>

This figure shows the meteorological data for the sledging journey. Frequency distributions of temperature and wind velocity are given together with a double frequency table of both these parameters. The equivalent still-air temperature distribution, resulting from the application of the thermal wind decrement to the double frequency table, is also given.

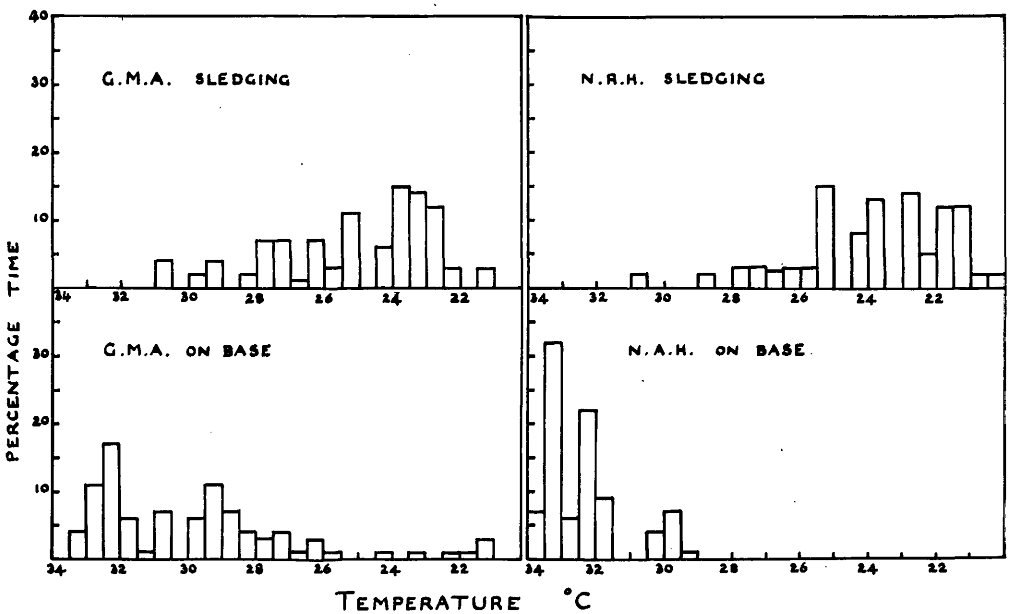


Fig. 25

This figure shows a comparison of the daily frequency distribution of the micro-climate of two subjects while sledging with that of each during a day in the previous month at base.

the figure of 4,770 Cal/day quoted by Masterton, Lewis & Widdowson from their studies in North Greenland (Masterton et al., 1957). Johnson and Kark (1947) quote 4,900 Cal/day for soldiers training in the Arctic on unrestricted food intake.

Subject	Day 2 Cal/day	Day 3 Cal/day	Day 4 Dal/day	Day 5 Cal/day	Mean Cal/day
N.A.H.	4,649	4,410	3,465	4,504	4,257
G.M.A.	4,346	4,286	4,230	4,719	4,395
W.W.	4,818	5,037	3,703	5,260	4,705
J.N.N.	4,401	4,687	3,583	4,729	4,350
				Mean	4,427

Table 9
This gives the calorie intake of each of 4 men for each complete day of the journey.

The pattern of activity was determined in the manner indicated in Section 1, and from this the energy expenditure was estimated by the same means. The term heavy work is reserved solely for time spent man-hauling. Fig. 26 shows the activity pattern while sledging, and the mean annual activity pattern at base is given for comparison.

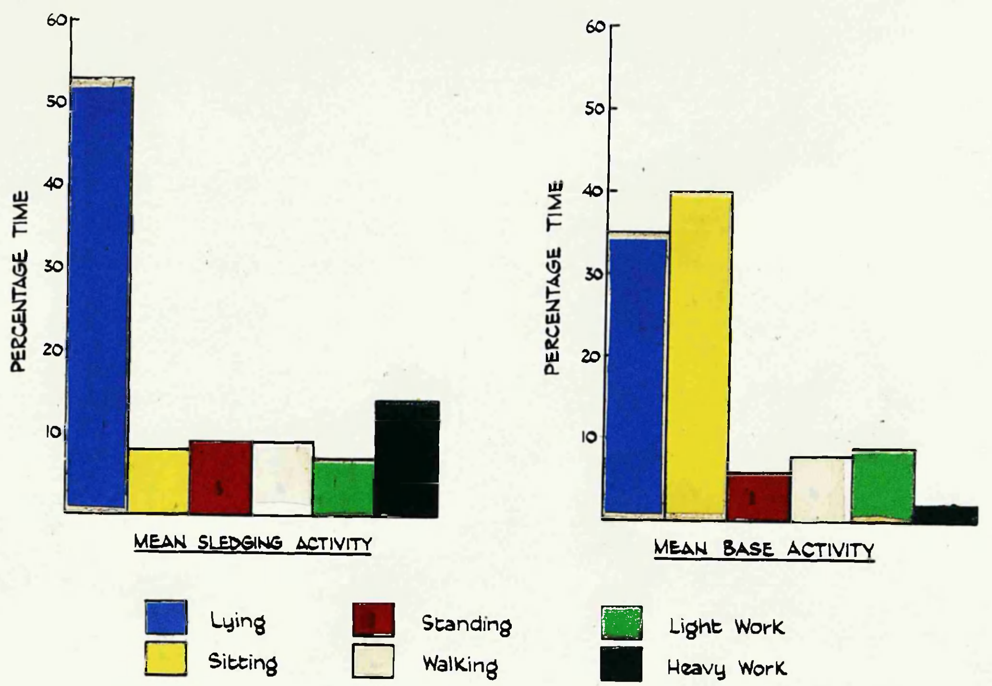


Fig. 26

This shows the mean percentage of time spent daily in the various activities by four men while sledging compared with the mean percentage of time spent daily in the various activities by four men at base.

Table 10 shows the mean energy expenditure of the four men for the four complete days of the journey. The mean energy expenditure over the four days was 5,055 Cal/day. Masterton, Lewis and Widdowson (1957) estimated an expenditure of 5,198 Cal/day for dog sledging in North Greenland.

Activity	Value	Day 2		Day 3		Day 4		Day 5	
		Min.	Cal.	Min.	Cal.	Min.	Cal.	Min.	Cal.
Lying	0.67 Cal/M^2/min	740	969	780	1,022	760	996	780	1,022
Sitting	1.9 Cal/min	80	152	170	323	80	152	90	171
Standing	2.1 Cal/min	160	336	35	74	170	357	135	283
Walking	4.53 Cal/min	100	450	155	697	160	720	130	581
Light work	4.4 Cal/min	140	616	115	506	90	396	90	396
Heavy work	12.5 Cal/min	220	2,750	185	2,315	180	2,250	215	2,687
	Total	1,440	5,273	1,440	4,935	1,440	4,871	1,440	5,140

Table 10

The assessment of the average energy expenditure of four subjects for each complete day of the sledging journey.

Table 11 compares the calorie intake of the four complete days of the journey with the estimated expenditure for each of these days.

Day	Cal. Intake Cal/day	Expenditure Cal/day
Day 2	4,554	5,273
Day 3	4,605	4,935
Day 4	3,745	4,871
Day 5	4,805	5,140

Table 11
Comparison of average calorie intake and estimated calorie expenditure during each complete day of the sledging journey.

Fig. 27 shows the fluid intake and the urine output of each man for each twenty-four hour period of the journey and also for the week following return to base. Fluid intake rose to high levels during the journey though the urine output remained low throughout. On return to base the fluid intake diminished but the urine output rose rapidly to a higher level.

Discussion

All four subjects lost weight as a result of the sledging journey and the mean weight loss amounted to 1.25 kg. during the six days of the journey.

Though the subjects had a seemingly adequate diet it is suggested from the results in Table 9 that they were not in calorie balance, thus accounting for at least part of the weight loss. The same results

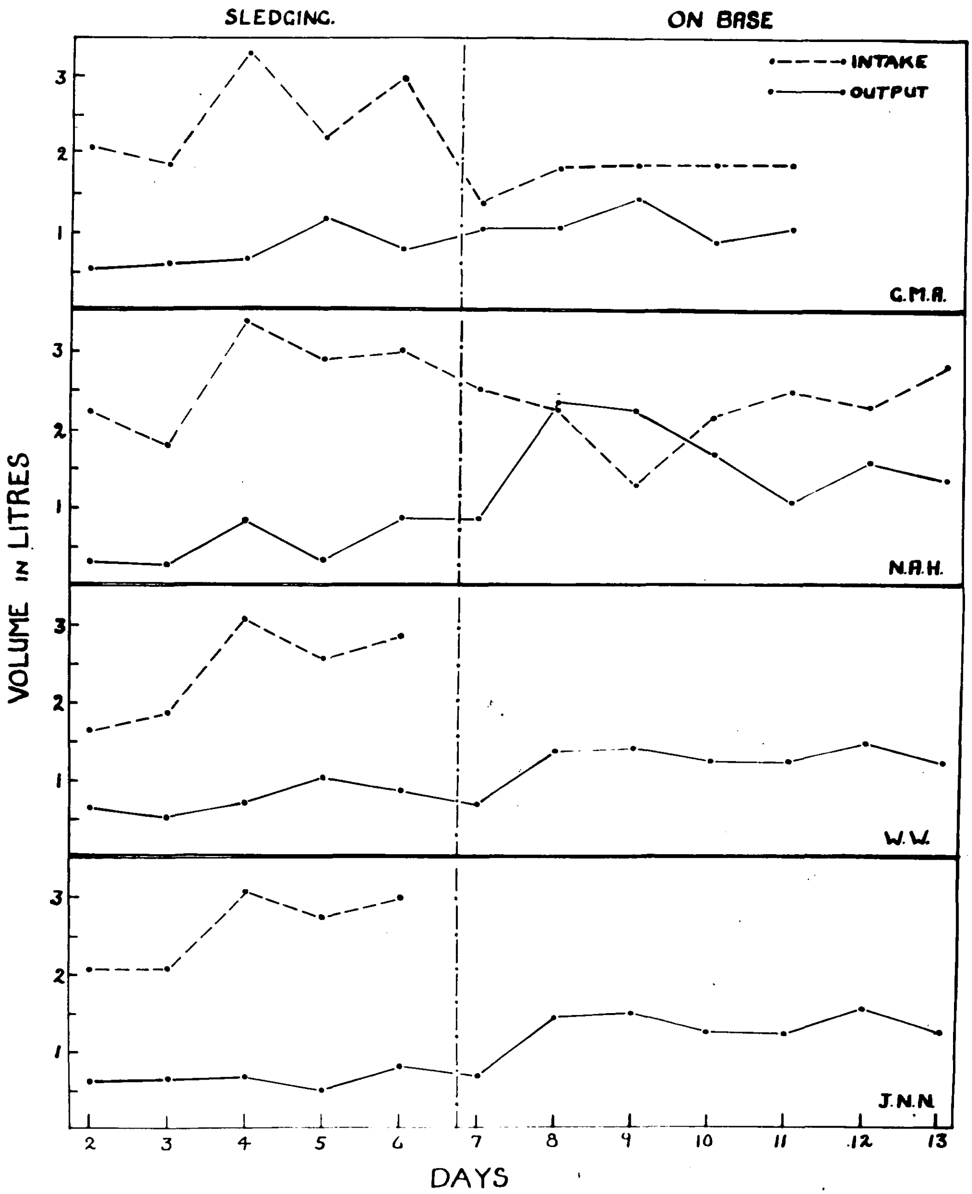


Fig. 27

This figure shows the four subject's daily fluid intake and urine output during the sledging journey and for several days following return to base.

indicate a mean calorie deficit of 3,721 Cal. during the six day period and assuming the weight loss to consist of loss of fat this would account for a mean weight loss of 0.4 kg. for each man, which leaves 0.85 kg. to be accounted for.

It has been shown that the activity of manhaul sledging is very much more strenuous than the normal activity of scientists working on a static base. It may be that part or all of the unaccounted moiety of body weight was lost as a constitutional or training effect in man transferred for a week from months of relatively sedentary activity to very strenuous activity.

It is possible that this is a most significant factor and that the effects of this journey on weight loss appear exaggerated by reason of its brevity. Certainly weight is usually lost at the beginning of a long journey, after which there may be no further loss. Sir Vivian Fuchs (personal communication) reports a loss of a few pounds following a journey of 1,000 miles and no change at all after a journey of a further 1,000 miles the succeeding year.

The third factor which must be considered is the possibility of mild dehydration. Discounting loss of weight due to training effects the mean fluid deficit amounts to no more than 800-900 ml. for the six-day period.

Inspection of the fluid diagrams (Fig. 27) reveals that in all cases the level of urine output is lower while sledging than on return. If the level of urine secretion at base is regarded as normal for these individuals, then the level obtained while sledging is low. On many occasions, indeed, the sledging urine output is not greatly in excess of obligatory urine secretion. Fluid intake is very much greater during the journey than it is at base, and, in view of the low urine outputs obtained, it appears that despite this increased intake, it was not sufficiently high to sustain a normal level of urine output for each individual. Fluid requirements while sledging must therefore be of a high order.

It is possible to estimate many of the variables in the water balance. Metabolic water production can be calculated from a knowledge of the fat, protein and carbohydrate content of the diet, while fluid loss from humidification of respired air can be estimated from a knowledge of the weight of air breathed, derived from metabolic rate. If the usual figure for faecal water loss of 100 ml. per day is taken, and the fluid intake and urine output are known, then the only unknown quantity is water loss from sweating.

No good method has been advanced for estimating the sweat loss in polar travel, though some estimates have been made of the loss occurring during sleep from weighings of sleeping bags. (Priestley, 1921; Rennie, 1957). These methods, however, are open to great inaccuracies because of the fluid exchanges between sleeping bag and the surface on which it rests, and the enhanced facility for evaporation due to the negligible value of the absolute humidity of Antarctic air.

If metabolic water production and respiratory water loss can be estimated in this case, then it is possible to arrive at a figure indicating the order of magnitude of the sweat loss.

Using the values of 41 gm water/100 gm protein; 108 gm water/ 100 gm.fat and 55 gm water/100 gm carbohydrate (Lovatt Evans, 1952) a figure of 500 ml per day is arrived at as the metabolic water required for these sledging rations.

Respiratory water loss was dalculated, using Webster's formulae (Webster, 1952) and the mean daily evaporative loss in the expired air of the four subjects was:-

Day 2 - 1,266 gm water

Day 3 - 1,185 gm water

Day 4 - 1,170 gm water

Day 5 - 1,236 gm water

Correcting the fluid intake and the urine output figures for these additional quantities and subtracting the corrected intake from the corrected output the remainder represents the sweat value for each day and these figures are shown in Table 12.

Name	Day 2 ml	Day 3 ml	Day 4 ml	Day 5 ml
N.A.H.	1,165	600	1,845	1,840
W.W.	640	740	1,720	1,515
J.N.N.	225	660	1,700	800
G.M.A.	960	600	1,705	280

Table 12

Calculated values for fluid loss from sweating for each of four subjects, during the complete days of the sledging journey.

These figures indicate that the sweat rate is probably of a high order. Wilson (1960) notes that the rate of sweating during polar sledging may be in the region of 1.5 litres per day. On general principles it seems reasonable to postulate that a reduced tendency to sweating, under a moderate heat load, would be a favourable adaptation to function in a cold climate, thereby reducing the adverse effects of sweating on the insulation of the clothing. Nevertheless Cherry-Garrard states in 'The Worst Journey in the World' the following: "The trouble is sweat and breath. I never knew before how much of the body's waste comes out through the pores of the skin". (Cherry-Garrard, 1948a).

Sweating must therefore be regarded as an important source of fluid loss in the cold, particularly when heavy muscular work is being performed and even though the temperature of the micro-climate is low. Burton and Edholm (1955) point out that muscular exercise brings about sweating in men in very cold environments though the skin temperature at which it occurs may be much lower under these conditions.

Though the majority of the values for daily sweat loss shown in Table 12 might reasonably be expected during the performance of heavy muscular work in a cold climate, certain of them are low (six values of 600 - 800 ml and two values of 200 - 300 ml). It is unlikely that the true sweat loss would be so low in the work conditions prevailing, and it is possible that the individuals concerned were mildly dehydrated on these occasions.

On day 3 the fluid intake was in the region of two litres per man and on this day all the subjects gave values of sweat loss between 600 and 800 ml while on Day 4 the fluid intake was over 3 litres in all cases and all the subjects show a sweat loss well in excess of 1½ litres.

An interesting point raised by Goldsmith (personal communication) is that in such circumstances as polar sledging, though calorie and water intake may be apparently unrestricted, they are nevertheless restricted in a social sense. In other words when one man drinks they all drink. Study of the fluid intake diagrams for the four men show them to be very similar in pattern, so that a degree of social restriction may well have been in operation.

People living in hot climates realise that there are considerable fluid losses from sweating, and they drink large quantities of fluid, even though they do not feel thirsty. People living in the cold are not yet sufficiently aware of the high fluid requirements of moderate and severe exercise, and may not drink enough. It is therefore of some practical importance to give an estimate of fluid requirements for various grades of activity while living and working in cold climates. This study tends to suggest that fluid intake for manhaul sledging should be of the order of 3 litres per day, and certainly not much less.

It can be concluded that, although the subjects maintained a fairly high level of fluid intake, it was no more than adequate and that they may have been mildly dehydrated. This emphasises the relatively high fluid requirements of heavy muscular work in polar regions where more than one litre of fluid per day may be required to humidify expired air alone, and where the loss of fluid from sweating may amount to 1½ litres or more.

There is no evidence, in this study, that dehydration occurred as a physiological change due to a cold environment and as a means of increasing the efficiency of the body in the cold, nor is there any evidence that pathological dehydration occurred. There is, however, the suggestion that had the fluid intake been much lower a demonstrable degree of dehydration might have ensued. It is therefore considered necessary to emphasise the high fluid requirements of muscular exertion in a cold climate, particularly since man may be rendered inefficient by this lack during journeys in polar regions.

Scientists on long sledging journeys are often aware of an unusual degree of carelessness and apathy in their field work. It may be that the effects of mild dehydration are more pronounced in a mental rather than a physical respect. Kark (1957) has pointed out that trained soldiers, who had spent all their lives in Northern Canada, became completely apathetic and useless militarily at the end of 36 hours, when water was not supplied and they had to eat snow.

It may finally be stated, in this case, that the loss of body weight was partly due to calorie imbalance and whereas a small portion of the remaining weight loss may have been due to fluid depletion it is more probable that it was the result of heavy exercise after the long period of relatively sedentary activity.

M E D I C A L   A S P E C T S   O F   P O L A R   L I F E

Section 7

SECTION 7

NOTES ON MEDICAL ASPECTS OF POLAR LIFE

Polar physiology is largely concerned with the responses of Man to a cold climate. The cold is not, however, the only abnormal factor in polar life; indeed there are many other agents to which he may be subjected for a greater portion of time, though in a less dramatic manner. A diet consisting entirely of tinned or dehydrated food or an atmosphere with a habitually low water content are examples of these factors, though polar clothing, the unusual living and sleeping arrangements and the sense of irrevocability of the situation are all abnormal influences compared to life in a civilised community. In laboratory experiments these factors can be measured, regulated and standardised, but this is not generally true of studies in polar communities, where an attempt to standardise these factors would destroy an endeavour to assess the effect of polar existence on man. For this reason it is not usually possible to translate the findings of laboratory experiments directly to a polar station. In like manner care must be taken before attributing the cause of functional changes, observed in these people, to the coldness of the climate.

The cold is the most obvious and dramatic factor implicit in a polar existence and it is very tempting to attribute all physiological changes observed to it. For example, Butson (1949) and Wilson (1953) noted a rise in levels of fasting blood sugar in polar communities which they attributed to the cold exposure. If this were true it could be explained on the basis of the elevated levels of circulating adrenaline mentioned by Frazier (1945) and Lockhart (1941), but Wilson (1953) was unable to confirm that there was an increase in circulating adrenaline. It is quite possible that the raised levels of fasting blood sugar are due to a dietary rather than a climatic effect, though this and other similar thoughts have usually been obscured by the ease of attributing everything to the cold. Many of the complaints of haempotysis reported in the days of Shackleton and Scott and alleged to be due to the formation of ice crystals in the lungs from the inspiration of very cold air, may possibly have been due either to scurvy or to pulmonary tuberculosis.

This study has been concerned with an attempt to define the extent to which a static polar community is, in fact, exposed to cold but it would not be complete if a few words were not written about the other unusual, though perhaps less dramatic, aspects of such a life, and the pathological conditions with which the men living in these places might be expected to come into contact.

The Diet

At Halley Bay the food was tinned or dehydrated, and, though the varieties supplied were of good quality they were small in number and the diet became monotonous. Vitamins, in tablet form, always appeared on the table with the cruet and there has been no recent suggestion of vitamin deficiency from British bases. Though the food is apparently adequate for the maintenance of life and health, the extreme monotony of the diet had an adverse effect on an existence already fraught with monotony. The provision of fresh meat and vegetables could alleviate this and these delicacies might easily be stored in the copious deep-freeze available just outside the door. Small scale trials have shown that meat and vegetables keep very well under these circumstances. Adam (personal communication) has described how his party, in 1958, partook with relish of fresh food items which they found in Little America III after 20 years of cold storage.

Clothing

The clothing supplied to modern British polar bases is excellent. It is light, easy to wear and adequate in the coldest conditions. The main insulative principle employed is the trapping of still air within the interstices of loose fitting garments and the use of a windproof outer covering. Typical clothing for winter is a string vest and short pants, light wool shirt, seaman's jersey and battle dress trousers. Over these, windproof trousers and anorak are worn, with a ski cap or balaclava helmet for the head. Though these garments are bulky, their total weight is probably not more than that of clothing typically worn in a temperate country in winter. The feet are adequately protected by two pairs of army socks and a pair of mukluks, which are canvas boots with a thick rubber sole and a thick felt insole. Heavy duty leather gloves are worn with one or two pairs of felt inner gloves. In summer less clothing is worn, but windproof clothing is always necessary if the wind velocity is appreciable, i.e. more than ten knots.

Water Supply

In many bases water is brought into the hut in the form of large blocks of compressed snow and ice. Their procurement is hard work and care must be taken to select the blocks from a site which has not been fouled by the dogs. One of the advantages of being permanently buried at Halley Bay was that it was possible to construct shafts through the roof to the water tanks below. It was easy to shovel snow down these shafts and, since supplies of snow were constantly being replaced by blizzards there was never far to go for clean snow. One of the water tanks, which was in the bathroom, was heated by a coal fire so that there was always a supply of hot water. Two men per day were able to wash their clothes and have a bath, and this was repeated every five or six days.

Disposal of waste

Sewage and fluid kitchen waste were disposed of effectively by the ingenious system of embedding a bottomless fuel drum in the snow and by pouring down it several gallons of boiling water. It was possible thereafter to dispose of as much waste as arose, adding an occasional bucket of bath water to maintain the patency of the channel. The excreta of twelve men, fifteen to twenty gallons per day of fluid kitchen waste and the ashes of five coal fires were disposed of easily by this means for over two years, though where this vast quantity of material went remained a mystery!

The living hut

The living hut at Halley Bay was comfortable and warm, but the bunk-room system gave rise to many complaints. In a situation where it is impossible to be alone for any time in the hut, and where there are little or no facilities for outside recreation, the mental strain - particularly for the scientific staff - would have been greatly alleviated had it been possible for them to retire occasionally to some private corner such as is afforded by a system of cubicles. By this means the social intercourse of the party would have been greatly enhanced and the mental strain considerably lessened.

The water content of the atmosphere

The moisture content of the Antarctic atmosphere is very low, vapour pressure running at an annual mean of 1.61 mb. and varying from less than 1 mb. in winter to just under 4 mb. at the height of summer. A low moisture content was also found in the hut's atmosphere, however, so that the man was constantly exposed to an atmosphere in which the water content was considerably lower than that to which his mucous membranes were accustomed.

Doubt has been cast on the view that exercise at very low ambient temperatures, since it causes increased ventilation, will cause ice crystal formation in the lungs, with consequent pulmonary haemorrhage. It has been shown, by temperature measurements of tracheal air, that the upper respiratory mucosa warms inspired air rapidly and efficiently (Armstrong and Burton, 1941). Nevertheless haemoptysis occurs following violent exertion in very low environmental temperatures (Wyatt, 1960 - personal communication).

Frazier (1945) is of the opinion that the blood originates not from the lungs but from the back of the throat, which may become congested and damaged by direct impingement of cold air while mouth-breathing during strenuous periods of exertion in very low environmental temperatures. This seems a reasonable view but it is a question which is worthy of further research.

There were two cases at Halley Bay of a transient febrile condition following strenuous exertion in low temperatures. In both of these cases the oral temperature rose usually for one day to the region of 102-104°F., the patients complaining of headache and malaise only. Thorough physical examination revealed no localising signs and the temperature dropped to normal the following day and remained normal. The condition suggested absorption of foreign material, e.g. blood clot. In both cases the upset occurred on the second day following the exposure. While it is unlikely that these cases were caused by rapid inspiration of large quantities of cold air per se, it could be that the effects of such inhalation on a pulmonary mucosa already affected in some way by long exposure to low humidity, was sufficient to produce damage to the pulmonary mucosa. That low humidity has some effect is demonstrated by the complaints of sore throat, cough and expectoration, which are to be found in the medical reports of every polar expedition.

In order to give some estimate of the extent of this change in humidity, frequency data have been produced for the conditions inside the hut. These are derived from the wet and dry bulb temperature recordings which formed part of the measurement of the exposure climate. The frequency distribution for one month and the annual frequency distribution may be seen in Fig. 28. The other monthly values appear in Appendix 3.

Dental conditions

Dental problems have always held a position of pre-eminence in the minds of polar explorers and numerous tales of painful dental catastrophes exist. Cherry-Garrard (1948b) writes in 'The Worst Journey in the World': "There was no unnecessary conversation; I don't know why our tongues never got frozen, but all my teeth, the nerves of which had been killed, split to pieces". Again Frazier (1945) wrote: "As the cold increased with the coming of winter, the alloy fillings contracted and pulled away from the cavities they were protecting".

While fracturing of the teeth and contraction of metal fillings may have occurred in the heroic age of exploration they have not been reported in more recent times. No metal fillings were lost by this means at

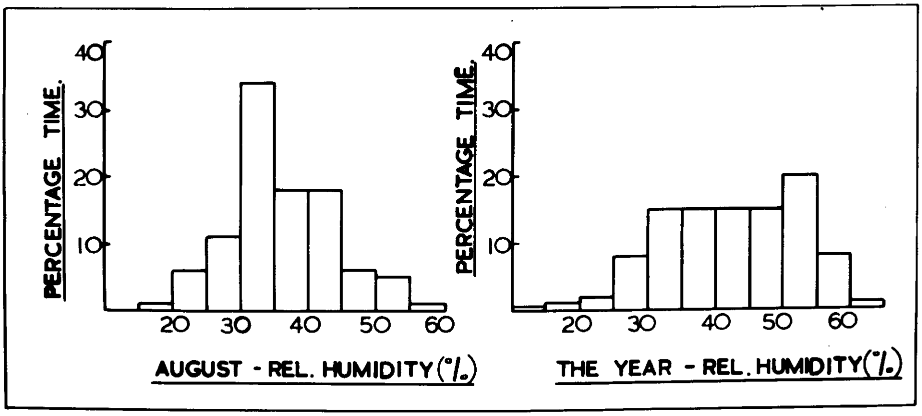


Fig. 28

This figure shows the frequency distribution of relative humidity within the hut for the month of August and for the whole year.

Halley Bay during 1959 and there is no evidence that it occurred at any British Base during that year. Knodeler and Stanmeyer (1958) did not observe it on the United States Navy Operation, Deep Freeze II - indeed it seems unlikely that the temperature of the oral mucosa ever falls to lower levels than it would attain while eating ice-cream or drinking an iced beverage. Pigeon (1960) in a survey of the Antarctic bases of the Falkland Islands Dependencies Survey found a surprisingly low incidence of caries and no fracturing of teeth from the cold, even though in many cases the standard of oral hygiene had been poor. The only unusual occurrence at Halley Bay was the absence of bleeding following two extractions and Knoedler and Stanmeyer (1958) report an incidence of 22.73% of cases of alveolar osteitis (dry socket) in a series of 44 extractions in Deep Freeze II, compared with an incidence of 0.9% in a series performed in the U.S.A. Practically all the dental attention required at Halley Bay was in the case of the only man who did not have adequate dental treatment before departure, and he required seven fillings and one extraction in all.

It is clear that the most important factor in the prevention of dental trouble in polar regions is thorough and adequate attention prior to departure and the maintenance of a reasonable standard of hygiene while on the station. If these precautions are taken it seems unlikely that serious dental trouble will result from one or two years in the Antarctic.

Wound healing and sepsis

A popular myth states that sepsis does not occur in the Antarctic.

It may not occur while living or journeying in the open but it certainly does occur in base huts, where man is accompanied by his own bacterial flora. Septic lesions, nevertheless, do not tend to occur with any great frequency and sepsis is seldom a complicating factor in the healing of a wound. Wound healing, thought to be slow in the past, did not appear so to the author, provided the wound was protected from the cold, in which case the rate of repair was rapid. If, on the other hand, frost-bite of the devitalised wound edges occurred, then the would took a considerable time to heal.

Insomnia

Insomnia affected about half the party to a more than moderate degree during the long winter. Barbiturates were found to be effective at first, but their ability to produce sleep waned rapidly despite increasing the dose, on occasion by as much as three times. Sleep, however, was restored to all those inflicted in this way when the sun returned and their out-door activity increased.

Insomnia is very frequently reported in winter (Dalgleish, 1956; Smart, 1957; Brooker, 1958) but Lewis and Masterton (1957) and Graham (1959) have shown that if all the hours of sleep, including naps taken during the day, are measured, then the average amount of sleep which each person takes is eight hours per day. This tendency to insomnia in winter may well be related to the low level of winter activity, compared to summer, and the frequency with which people have naps.

Cold Injury

Cases of severe frost-bite in the Antardtic are rare and those which occur are usually due to carelessness. Minor degrees of frost-bite were, however, relatively common and they usually involved the face in the region of the zygomata, the muco-cutaneous junction of the nose, and the tips of the fingers. These lesions healed very rapidly and required no special treatment. There were no cases of frost-bite which involved loss of tissue.

DISCUSSION

DISCUSSION

An attempt has been made in the preceding sections to demonstrate the basic conditions of the life of scientists living and working at a static base in the depths of Antarctica. The patterns of their activity, their exposure climate and its correlation with the met climate have been shown, together with their sub-clothing or micro-climate, and the manner in which it varies in response to cold. In the sixth section a practical problem of Antarctic travel, namely loss of body weight while sledging, has been discussed in relation to the findings, while the final section describes the medical conditions which occurred during the year and indicates their significance.

The activity patterns are remarkably similar to the results of time and work studies performed in more civilised parts of the world. The popular conception of the activity of a polar expedition is one of very hard physical work, almost amounting to maximum effort. This is true of polar travel, but the degree of physical exertion at a static base need not be great; indeed a comparable level of activity may be found in many occupations in a temperate climate. The energy expenditure at Halley Bay was not unduly high, being comparable to that of painters and carpenters in this country, and the considerable similarity in the annual patterns of activity of the subjects reflects the stereotyped nature of the life and work of such a station.

The great decrease in outside activity shown in winter strengthens the suggestion (Lewis, 1958) that the winter increase in body weight and skinfold thickness (often reported from polar bases) is due to a significant decline in energy expenditure during winter, while calorie intake is presumed to remain relatively constant. The relatively small percentage of time during which the personnel are exposed to the met climate in winter provides further evidence that the skinfold thickness and body weight changes are not due to the increasing coldness of the environment.

The predominance of sedentary activity in man has been amply demonstrated in the polar setting, where even during sledging 61% of the time was spent between the activities of lying and sitting. Manhaul sledging has been shown to be the most strenuous of all the occupations considered, yet even in this situation the percentage of the day actually spent in heavy work appears rather small. The relative amounts of time spent in sedentary activity and in heavy manual work appear to be the chief factors characterising the level of activity of an occupational group and hence govern the amount of energy expended. For this reason the ratio of the time spent in sedentary activity and that spent in heavy manual work provides a convenient index for the comparison of the degrees of activity typical of various occupations. A series of such activity ratios, based on time and motion studies, would provide an easily understandable and convenient method of classifying activity.

It has been necessary in the past only to state that a group of subjects spent some time in Antarctica to establish that they had been exposed to severe cold for that time. It is suggested that a different series of environmental measurements are required to establish the degree of cold to which men are really exposed, and an attempt has been made to define them. The mean exposure climate of the Halley Bay scientists has been shown to be of a temperate nature, though the met climate was one of extreme cold. This was due to the comfortable conditions existing inside the hut and to the relatively short time during which the men were exposed to the extremes of the met climate. The fact that the mean exposure temperature did not vary much from month to month indicates that as the met climate became colder the time during which the men exposed themselves to it became progressively less. Thus in considering the degree of cold exposure likely for a man living in a cold climate, it is necessary to know the conditions of his living quarters and the amount of time during which his occupation and recreation requires him to be exposed to the local climate of the station.

Even when the man ventures from the hut it cannot be said that he is exposed to the full severity of the met climate, since account must be taken of his highly efficient, specialised clothing. The micro-climate is the ultimate climate to which the man's body is finally exposed and it has been shown not to have fallen to particularly low levels at Halley Bay. While in the hut the micro-climate was maintained at a sub-tropical level and though it fell shortly after exposure to the met climate, it was apparently about an hour after exposure that the body required to make some compensation for the loss of its heat. In the normal routine of this static base the percentage of time during which the exposure was sufficiently severe or prolonged to affect the micro-climate significantly was so small as to be unlikely to produce any marked alteration in physiological function. The adaptation of the personnel of a static base to life in a cold climate must be considered to be more intellectual than physiological, since it is so greatly influenced by the use of adequate housing, heating and clothing.

The conditions during the manhaul sledging journey were very different, however, in that the exposure and the met climates practically coincided, and the micro-climate was maintained at a lower level than at base, and showed greater variations. The loss of body weight, which often occurs while sledging, has been shown to be partly due to calorie deficiency and partly to an effect of training, and it is unlikely that dehydration played a significant part in these weight changes. It is nevertheless emphasised that prolonged exercise in a polar environment must be accompanied by a greatly increased fluid intake.

The medical and surgical conditions occurring in this group of men were all of a minor nature. Dental trouble may be expected if adequate attention has not been obtained before departure from home. This may be partly due to the soft, tinned and dehydrated foods supplied but it is probably not more severe than would occur following two or three years absence from dental attention in any other part of the world. No dental conditions were encountered which could be directly ascribed to the cold. Provided adequate precautions were taken, wound healing was not a problem and all the cases of frost-bite which occurred were slight and healed rapidly.

Life on a static Antarctic station presents a wide variety of problems and the present study has dealt with only a limited number of them. The effect of a monotonous diet, consisting entirely of tinned or dehydrated food, or of drinking melted snow for a year have not been touched upon, and the psychological effects of this unnatural existence have also been excluded - yet this constitutes a most important question, modifying each man's behaviour and reactions to a different extent. It is important not to regard life on an Antarctic station as complete isolation, for there is no question of isolation while living in close contact with the other members of the base. The isolation is relative, and consists of life in a simple, as opposed to a complex, community. If the life of the community is to be harmonious then its members must adhere to a precise code of behaviour in much the same manner as in a complex society - though the requirements of social intercourse are not necessarily similar in both instances.

More important from the point of view of understanding the physiology of the men, however, is a knowledge of the individual variations in performance which occur in extreme cold. There are wide variations in the degree of cold which call forth complaints and also in the length of time during which each man is able to work in severe cold. It was noticed at Halley Bay that this was not always related to the extent to which the man was exposed to the met climate. One man in particular was able to work outdoors for many hours at a time in very low temperatures repairing the tractor, although most of his time was normally spent in the generator shed, which was much warmer than the hut. Other people, who spent much more time outside than he did, were unable to work for such long periods in similar conditions or with so little protection on their hands.

Macpherson (1958) has pointed out that since man is a tropical animal it is useless to seek profound changes in response to severe cold in temperate man, since the bulk of the possible change in that direction will have taken place in response to his life in a temperate climate. This may partly explain the paucity of reports of physiological change in response to a cold climate from the results of physiological research carried out in polar bases but it must also stem from the temperate nature of the exposure climate and the small amount of time during which the micro-climate is lowered.

Since the precise measurement of the degree of cold exposure of men living in polar stations is now possible, the scope of physiological investigations can be enlarged. This is particularly true in static bases where the personnel are isolated for one or two years in a situation which lends itself to extended, carefully controlled experiments. Such an experimental situation would be almost impossible to obtain elsewhere. (Goldsmith and Lewis, 1960).

A C K N O W L E D G E M E N T S

ACKNOWLEDGEMENTS

I wish to acknowledge the considerable help, guidance and encouragement which I have received from the staff of the Division of Human Physiology of the Medical Research Council in preparing this thesis; in particular Dr. O.G. Edholm, Dr. H.E. Lewis and Major J.M. Adam, R.A.M.C.

My thanks are also due to my colleagues at Halley Bay who acted as subjects with great patience and co-operation, and to Sir Vivian E. Fuchs both for permission to write this thesis and for encouragement to do so.

To Mr. H.S. Wolff I am indebted for the provision of equipment, to Dr. A. Cumming for many laborious hours spent checking figures and reading proofs, to Mr. J. Carter-Fea for photography and to Mrs. A. Peck for typing.

R E F E R E N C E S

<u>REFERENCES</u>

Adam, J.M., Best, T.W., Edholm, O.G., Fletcher, J.G., Lewis, H.E. & Wolff, H.S. (1958). The dietary intake and energy expenditure of recruits in the British Army. <u>A.P.R.C.</u> 58/3

Adam, J.M., Best, T.W., Edholm, O.G. & Wolff, H.S. (1956). Combat ration trial, Northern Ireland. <u>A.P.R.C.</u> 57/1

Adam, J.M. (1958). Subjective sensations and sub-clothing temperatures in Antarctica. <u>J. Physiol.</u> **145**, 26-27P.

Andersen, K.L., Løyning, Y., Nelms, J.D., Wilson, O., Fox, R.H. & Bolstad, A. (1960). Metabolic and thermal response to a moderate cold exposure in nomadic Lapps. <u>J. appl. Physiol.</u> **15**, 649-653

Armstrong, H., & Burton, A.C. (1941). Unpublished observations. Cited by Burton, A.C. & Edholm, O.G., in <u>Man in a cold environment</u> 1955. 1st ed. p.238. London: Edward Arnold Ltd.

Baker, P.T. & Daniels, F. (1956). Relationship between skinfold thickness and body cooling for two hours at 15°C. <u>J. appl. Physiol.</u> **8**, 409-416.

Bedale, E.M. (1923). Energy expenditure and food requirements of children at school. <u>Proc. Roy. Soc.</u> B, **94**, 368-404.

Baugh, C.W., Bird, G.S., Brown, G.M., Lennox, C.S. & Semple, R.E. (1958). Blood volumes of Eskimos and white men before and during acute cold stress. J. Physiol. 140, 347-358.

Bazett, H.C., Love, L., Newton, M., Eisenberg, L., Day, R. & Foster, R. 11. (1948). Temperature changes in blood flowing in arteries and veins in man. J. appl. Physiol. 1, 3-19.

Blair, J.R., Dimitroff, J.M. & Hingeley, J.E. (1951). Acquired resistance to cold in rabbit and rat. Fed. Proc. 10, 15.

Brown, G.M. (1955). Metabolic studies of the Eskimo. In Cold Injury, ed. Ferrer, L.M., trans. 3rd Conference Josiah Macy Jr. Foundation, pp. 52-96. New York: Josiah Macy Jr. Foundation Publications.

Brown, G.M., Bird, G.S., Delahaye, D.J., Green, J.E., Hatcher, J.D. & Page, J. (1954). Cold acclimatization. Canad. med. Ass. J. 70, 258-261.

Brown, G.M., Hatcher, J.D. & Page, J. (1953). Temperature and blood flow in the forearm of the Eskimo. J. appl. Physiol. 5, 410-420.

Brooker, A. (1958). Medical Report, 1958-59. Halley Bay.

Burton, A.C. (1953). Assessment of the thermal demand of the environment. Fourth Commonwealth Defence Conference on clothing and general stores. H.M.S.O.

Burton, A.C. & Edholm, O.G. (1955). Man in a cold environment, 1st ed. London: Edward Arnold Ltd.

Burton, A.C. & MacDougall (1941). An analysis of the problem of protection of the aviator against cold and the testing of the insulating power of flying clothes. A.C.A.M.R. Report No. C.2053.

Burton, A.C., Scott, J.C., McGlone & Bazett, H.C. (1940). Slow adaptation in the heat exchanges of man to changed climatic conditions. Amer. J. Physiol. 129, 84-101.

Butson, A.R.C. (1949). Acclimatization to cold in the Antarctic. Nature, Lond. 163, 132-133.

Carlson, L.D., Burns, H.L., Holmes, T.H. & Webb, P.P. (1953). Adaptive changes during exposure to cold. J. appl. Physiol. 5, 672-676.

Cherry-Garrard, A. (1948a). The Worst Journey in the World. p.259. London: Penguin Books.

Cherry-Garrard, A. (1948b). The Worst Journey in the World. p.306. London: Penguin Books.

Chatfield, P.O., Lyman, C.P. & Irving, L. (1953). Physiological adaptation to cold of peripheral nerve in leg of the herring gull (Larus argentatus). Amer. J. Physiol. 172, 639-644.

Dalgleish, D. (1956). Medical Report, 1956-57. Halley Bay.

Darwin, C.R. (1906). The Voyage of the Beagle. pp. 202-203. London: J.M. Dent & Sons Ltd.

Dugal, L.P. & Therien, M. (1949). The influence of ascorbic acid on the adrenal weight during exposure to cold. Endocrinology. 44, 420-426.

Edholm, O.G., Fletcher, J.G., Widdowson, Elsie & McCance, R.A. (1955). The energy expenditure and food intake of individual men. Brit. J. Nutr. 9, 286-300.

Edwards, H.T., Thorndike, L.A. & Dill, D.B. (1935). Energy requirements in strenuous muscular exercise. New Engl. J. Med. 213, 532-535.

Eichna, L.W., Park, C.R., Nelson, N., Horvath, S.M. & Palmes, E.D. (1950). Thermal regulation in a hot, dry (desert type) environment. Amer. J. Physiol. 163, 585-597.

Erikson, H., Krog, J., Andersen, K.L. & Scholander, P.F. (1956). Critical temperature in naked man. Acta physiol. scand. 37, 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 Service Antarctic Expedition 1939-1941. Proc. Amer. phil. Soc. 525, 249-255.

Freeman, W.G. Pincus, G. & Glover, E.D. (1944). The excretion of neutral urinary steroids in stress. (ABSTRACT) Endocrinology, 35, 215.

Garry, R.C., Passmore, R., Warnock, Grace M., & Durnin, J.V.G.A. (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. (London: H.M. Stationary Office).

Giroud, A. & Martinet, M. & Bellon, M.T. (1941). The relationship between ascorbic acid and cortico-adrenal function in man. C.R. Soc. Biol., Paris. **135**, 514-520.

Goldsmith, R. (1960). The use of clothing records to demonstrate acclimatization to cold in man. J. appl. Physiol. (in the press).

Goldsmith, R. & Lewis, H.E. (1960). Polar Expeditions as Human Laboratories. J. Occ. Med. **2(3)**, 118-122.

Graham, J. (1959). Falkland Islands Dependencies Report. Loubet Coast.

Hammel, H.T., Elsner, R.W., LeMessurier, D.H., Andersen, H.T. & Milan, F.A. (1959). Thermal and metabolic responses of the Australian Aborigine exposed to moderate cold in summer. J. appl. Physiol. **14**, 605-615.

Heroux, O. (1956). Capillary counts in different organs of warm and cold acclimatized white rats. Fed. Proc. **15**, 92.

Hicks, C.S. & Matters, R.F. (1933). Standard metabolism of Australian Aborigines. Aust. J. exp. Biol. med. Sci. **11**, 177-183

Hicks, C.S., Moore, H.O. & Eldridge, E. (1934). Respiratory exchanges of Australian Aborigines. Aust. J. exp. Biol. med. Sci. 12, 79-89.

Horvath, S.M., Freedman, A. & Golden, H. (1947). Acclimatization to extreme cold. Amer. J. Physiol. 150, 99-108.

Huggins, R.A. (1941). Egg temperatures of wild birds under natural conditions. Ecology. 22(2), 148-157.

Irving, L. (1951). Physiological adaptation to cold in Arctic and Tropic animals. Fed. Proc. 10, 543.

Irving, L. & Krog, J. (1954). Body temperatures of Arctic and sub-Arctic birds and mammals. J. appl. Physiol. 6, 667-680.

Irving, L. & Krog, J. (1955). Temperature of skin in the Arctic as a regulator of heat. J. appl. Physiol. 7, 355-364.

Irving, L. & Krog, J. (1956). Temperature during the development of birds in Arctic nests. Physiol. Zool. 29. 195-205.

Irving, L., Schmidt-Nielsen, K. & Abrahamsen, N.S.B. (1957). On the melting points of animal fats in cold climates. Physiol. Zool. 30, 93-105.

Johnson, R.E. & Kark, R.M. (1947). Environment and food intake in man. Science. 105, 378-379.

Kark, R.M. (1957). In Cold Injury, ed. Ferrer, L.M., trans 5th Conference Josiah Macy Jr. Foundation, pp. 263-269, New York: Josiah Macy Jr. Foundation Publications.

Knoedler, D. & Stanmeyer, W. (1958). Dental observations made while wintering in Antarctica, 1956-1957. J. dent. Res. **37**, 614-622.

Krogh, A. & Krogh, Marie (1913). A study of the diet and metabolism of Eskimos. pp. 28-38. Copenhagen: Bianco Luno.

Leblond, G.P., Gross, J., Peacock, W. & Evans, R.D. (1944). Metabolism of radio-iodine in the thyroids of rats exposed to high or low temperatures. Amer. J. Physiol. **140**, 671-676.

Lewis, H.E. & Masterton, J.P. (1957). Sleep and wakefulness in the Arctic. Lancet. **1**, 1262-1266

Lewis, H.E. (1958). Physiology. In Venture to the Arctic, pp. 145-166. ed. Hamilton, R.A. Harmondsworth: Penguin Books Ltd.

Lewis, H.E. & Masterton, J.P. (1958a). Rations for polar travel. Proc. Nutr. Soc. **17**, 170-173.

Lewis, H.E. & Masterton, J.P. (1958b). Nutritional problems of a polar expedition. The New Scientist, **3**, 14-16.

Lewis, H.E. & Masterton, J.P. (1958c). A modern sledging ration. The Geographical Journal. 124, 85-88.

Lewis, H.E., Masterton, J.P. & Rosenbaum, S. (1956). Changes in body weight and subcutaneous fat thickness in man on a polar expedition. Abstr. xx int. physiol. Congr. 565-566.

Liljequist (1956). Energy exchange of an Antarctic snow-field. Norwegian-British-Swedish Antarctic Expedition, 1949-52. Scientific results, Vol.2, Part 1A. Oslo: Norsk Polarinstitutt.

Lockhart, E.E. (1941). Acclimatization in the Antarctic. Science, 94, 550.

Lovatt Evans, C. (1952). Principles of human physiology. 11th ed. p.820. London: Churchill.

McCance, R.A. & Widdowson, Elsie M. (1946). The chemical composition of foods. Spec. Rep. Ser. med. Res. Coun., Lond. No. 235. (London: H.M.S.O)

Macpherson, R.K. (1958). Acclimatization status of temperate-zone man. Nature, Lond. 182, 1240-1241.

Mackworth, N.H. (1953). Finger numbness in very cold winds. J. appl. Physiol. 5, 533-543.

Massey, P.M.O. (1956). Acclimatization to cold in Antarctica. M.D. thesis: Cambridge.

Massey, P.M.O. (1959). Finger numbness and temperature in Antarctica. J. appl. Physiol. 14, 616-620.

Masterton, J.P., Lewis, H.E. & Widdowson, Elsie M. (1957). Food intakes, energy expenditures and faecal excretions of men on a polar expedition. Brit. J. Nutr. 11, 346-358.

Meehan, J.P. (1955). Cold Injury, ed. Ferrer, L.M. trans 5th Conference, Josiah Macy Jr. Foundation, p. 31. New York: Josiah Macy Jr. Foundation Publications.

Morrison, P.R. (1957). Body temperature in Aboriginals. Fed. Proc. 16, 90.

Nelms, J.D. (1960). Acclimatization to cold in Lapps and Arctic Indians. Institute of Aviation Medicine, Farnborough. F.P.R.C. No. 1087.

Orr, J.B. & Leitch, I. (1938). The determination of the caloric requirements of man. Nutr. Rev. 7, 509-529.

Passmore, R. & Durnin, J.V.G.A. (1955). Human energy expenditure. Physiol. Rev. 35, 801-840.

Pigeon, J. (1960). The report of the Dental Research Officer for the summer season, 1959-60. Falkland Islands Dependencies Survey Report.

Priestley, R.E. (1921). The psychology of Exploration. <u>Psyche</u>, pp. 18-28.

Rennie, D.W. (1957). Energy metabolism in the cold. In <u>Cold Injury</u>, ed. Ferrer, L.M. Trans. 5th Conference, Josiah Macy Jr. Foundation, pp. 253-290. New York: Josiah Macy Jr. Publications.

Roberts, J.M. (1949). The Falkland Islands Dependencies Survey. <u>Brit. med. J.</u> <u>ii</u>, 863-864.

Rodahl, K. (1957). In <u>Cold Injury</u>, ed. Ferrer, L.M. Trans. 5th Conference, Josiah Macy Jr. Foundation. pp. 177-252. New York: Josiah Macy Jr. Foundation Publications.

Rodahl, K. (1952). Basal metabolism of the Eskimo. <u>J. Nutr.</u> <u>48</u>, 359-368.

Schenk, P. (1936). Sport - und Truppenarztl. Die Verpflegung von 4700 Wettkempfern aus 42 Nationen im Olympischen Dorf wahrend der XI Olympischen Spiele 1936 zu Berlin. <u>Munch. med. Wschr.</u> <u>83</u>, 1535 - 1539.

Scholander, P.F. (1955). Evolution of climatic adaptation in homeotherms. <u>Evolution</u>. <u>9</u>, 15-20.

Scholander, P.F., Andersen, K.L., Krog, J., Lorentzen, P.V. & Steen, J. (1957). Critical temperature in Lapps. <u>J. appl. Physiol.</u> <u>10</u>, 231-234.

Scholander, P.F., Hammel, H.T., Hart, J.S., LeMessurier, D.H. & Steen, J. (1958). Cold adaptation in Australian Aborigines. J. appl. Physiol. 13, 211-218.

Scholander, P.F., Hammel, H.T., Andersen, K.L. & Løyning, Y. (1958). Metabolic acclimatization in man. J. appl. Physiol. 12, 1-8.

Scholander, P.F., Hock, R., Walters, V. & Irving, L. (1950a). Adaptation to cold in Arctic and tropical mammals and birds in relation to body temperature, insulation and basal metabolic rate. Biol. Bull. 99, 259-271.

Scholander, P.F., Walters, V., Hock, R. & Irving, L. (1950b). Body insulation of some Arctic and tropical mammals and birds. Biol. Bull. 99, 225-236.

Scholander, P.F., Hock, R., Walters, V., Johnson, F. & Irving, L. (1950c). Heat regulation in some Arctic and tropical mammals and birds. Biol. Bull. 99, 237-258.

Scholander, P.F.& Schevill, W.E. (1955). Counter-current vascular heat exchange in the fins of whales. J. appl. Physiol. 8, 279-282.

Sellars, A.E., You, S.S. (1950). Role of the thyroid in metabolic responses to a cold environment. Amer. J. Physiol. 163, 81-91.

Simpson, H. (1959). Stress: Studies in Antarctica. The New Scientist. 6(156), 927-929.

Siple, P. (1945). General principles governing selection of clothing for cold climates. Proc. Amer. phil. Soc. 89, 200-234.

Siple, P. (1949). American climates. Bull. Amer. Inst. Arch. Sept. 16-35.

Siple, P. & Passel, C.F. (1945). Measurement of dry atmospheric cooling in sub-freezing temperature. Prod. Amer. phil. Soc. 89, 200-234.

Smart, R. (1957). Medical Report, 1957-58. Halley Bay.

Therien, M., LeBlanc, J., Heroux, O. & Dugal, L.P. (1949). Effets de l'acide ascorbique sur plusieurs variables biologique normalement affectees par le froid. Canad. J. Res. Sect. E., 27, 349-363.

Vere, D.W. (1958). Heat transfer measurement in living skin. J. Physiol. 140, 359-380.

Webster, A.P. (1952). Caloric requirements of man in cold climates: theoretical consideration. J. appl. Physiol. 5, 134-142.

Wetmore, A. (1921). A study of the body temperature of birds. Smithsonian misc. Coll. 72, No. 12.

Widdowson, Elsie M., Edholm, O.G. & McCance, R.A. (1954). The food intake and energy expenditure of cadets in training. Brit. J. Nutr. 8, 147-155.

Wilson, O. (1956). Basal metabolic rate in the Antarctic. Metabolism. 5, No. 5, 543-554.

Wilson, O. (1953). Physiological changes in blood in the Antarctic. Brit. med. J. **2**, 1425-1428.

Wilson, O. (1960a). Changes in body weight of men in the Antarctic. Brit. J. Nutr. **14**, 391-401.

Wilson, O. (1960b). Basal metabolic rate of "tropical man" in a polar climate. Proc. 2nd International Bioclimatological Congress (in the press)

Wolff, H.S. (1958). A knitted wire fabric for measuring mean skin temperature or for body heating. J. Physiol. **142**, 1-2P.

Wyatt, H. (1960). Falkland Islands Dependencies Report, Stonington Island and Loubet Coast (in preparation).

Wyndham, C.H. & Morrison, J.F. (1958). Adjustment to cold of Bushmen in the Kalahari Desert. J. appl. Physiol. **13**, 219-225.

APPENDICES

APPENDIX I

a. 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 hours on one subject and one table is devoted to each subject.

Subject	Month	Sleeping % Time	Sitting % Time	Walking Inside % Time	Standing Inside % Time	Light Work Inside % Time	Walking Outside % Time	Light Work Outside % Time	Heavy Work Outside % Time
M.A.S.	February	33	50	6	1	3	7	1	-
	March	28	22	6	6	6	6	5	22
	April	29	50	6	3	6	7	-	-
	May	35	43	7	7	3	3	3	-
	June	43	22	1	21	10	1	1	-
	July	43	40	3	8	6	-	-	-
	August	26	60	6	3	3	3	-	-
	September	33	54	1	7	3	1	-	-
	October	29	51	4	3	4	7	1	-
	November	33	42	3	-	3	18	1	-
	December	33	51	7	4	1	4	-	-
	Annual Mean	33	44	5	6	4	5	1	2

APPENDIX I contd.

Subject	Month	Sleeping % Time	Sitting % Time	Walking Inside % Time	Standing Inside % Time	Light Work Inside % Time	Walking Outside % Time	Light Work Outside % Time	Heavy Work Outside % Time
J.A.S.	February	31	29	7	6	7	7	10	4
	March	33	42	4	8	7	4	1	-
	April	33	31	1	17	13	3	-	3
	May	49	31	4	4	10	3	-	-
	June	33	33	4	13	7	4	4	1
	August	31	50	3	4	8	3	1	-
	September	26	53	3	7	6	4	1	-
	October	33	49	3	1	8	3	3	-
	November	33	26	8	3	8	6	3	14
	December	33	42	3	-	4	15	3	-
	Annual Mean	33	39	4	6	8	5	3	2

APPENDIX I contd.

Subject	Month	Sleeping % Time	Sitting % Time	Walking Inside % Time	Standing Inside % Time	Light Work Inside % Time	Walking Outside % Time	Light Work Outside % Time	Heavy Work Outside % Time
N.A.H.	February	35	32	4	6	6	6	4	8
	March	49	36	3	1	3	3	4	1
	April	35	50	3	-	4	3	3	3
	May	35	40	6	6	4	3	4	3
	July	36	50	3	1	1	3	6	-
	August	32	51	3	7	4	-	-	3
	September	31	46	3	4	8	8	-	-
	October	40	35	3	7	7	4	4	1
	December	35	44	1	-	3	3	4	10
	Annual Mean	36	43	3	4	4	4	3	3

APPENDIX I contd.

Subject	Month	Sleeping % Time	Sitting % Time	Walking Inside % Time	Standing Inside % Time	Light Work Inside % Time	Walking Outside % Time	Light Work Outside % Time	Heavy Work Outside % Time
G.M.A.	February	33	33	6	1	14	1	13	-
	March	33	43	4	-	3	3	14	-
	April	49	39	4	3	3	1	1	-
	May	54	26	1	8	7	1	-	2
	July	35	35	3	11	8	4	-	4
	August	36	28	4	14	14	3	1	-
	September	38	39	4	6	4	1	1	7
	October	40	35	4	3	4	7	-	7
	December	33	36	1	3	14	13	-	-
	Annual Mean	39	35	3	6	8	4	3	2

APPENDIX I contd.

b. ENERGY EXPENDITURE

The sources of the energy expenditure values.

Activity	Value	Source	Mean
1. Sleeping	0.66 Cal/M^2/min 0.68 Cal/M^2/min	Adam Rennie	0.67 Cal/M^2/min 1.31 Cal/min
2. Sitting			
Sitting eating	1.6 Cal/min	Passmore & Durnin	
Sitting at rest	1.6 Cal/min	"	
Sitting eating	1.5 Cal/min	"	
Listening to radio	2.0 Cal/min	"	
Listening to radio	2.5 Cal/min	"	
Writing	1.9 Cal/min	"	1.9 Cal/min
Writing	2.2 Cal/min	"	
Playing cards	1.9 Cal/min	"	
Playing cards	2.1 Cal /min	"	
3. Standing			
Standing at ease	1.7 Cal/min	Passmore & Durnin	
Standing at ease	1.9 Cal/min	"	2.1 Cal/min
Conducting orchestra	2.5 Cal/min	"	
4. Light work inside			
Ablutions	2.20 Cal/M^2/min	Adam	
Blancoing	2.48 Cal/M^2/min	"	
Bed making	1.96 Cal/M^2/min	"	
Cleaning rifle	1.42 Cal/M^2/min	"	
Dressing	2.20 Cal/M^2/min	"	
Floor sweeping	2.95 Cal/M^2/min	"	2.08 Cal/M^2/min
Ironing	2.31 Cal/M^2/min	"	or
Laying fire	2.09 Cal/M^2/min	"	4.12 Cal/min.
Laying out kit	1.25 Cal/M^2/min	"	
Polishing (kneeling)	1.58 Cal/M^2/min	"	
Scrubbing	2.48 Cal/M^2/min	"	

5. Walking inside	4.8 Cal/min	Passmore & Durnin	4.8 Cal/min
6. Walking outside	3.32 Cal/Kg/hr.	Rennie	4.53 Cal/min
7. Light work outside Light work Medium work	 3.2 Cal/min 5.6 Cal/min	 Lewis & Masterton "	4.4 Cal/min
8. Heavy work outside	12.5 Cal/min	Lewis & Masterton	12.5 Cal/min

APPENDIX II

a. MET CLIMATE

The percentage of time during which the various temperature arrays of the met climate occurred. The year's observations are contained in two tables.

Temp. Range °C	Jan. % Time	Feb. % Time	March % Time	April % Time	May % Time	June % Time	July % Time
0 - -5	73	21			<1		
-6 - -10	16	46	4	10	19		
-11 - -15	11	24	28	16	19	4	6
-16 - -20		8	36	22	23	11	11
-21 - -25		1	17	29	30	16	20
-26 - -30			11	13	7	19	23
-31 - -35			4	7	2	17	22
-36 - -40				1		21	13
-41 - -45				2		11	5
-46 - -50						1	

APPENDIX II (contd.)

Met climate

Temp. Range ^{o}C	August % Time	Sept. % Time	Oct. % Time	Nov. % Time	Dec. % Time	The Year % Time
0 - -5				10	65	14
-6 - -10			10	26	35	15
-11 - -15	2	2	25	40	<1	15
-16 - -20	15	8	23	15		14
-21 - -25	23	8	17	9		14
-26 - -30	26	22	18			12
-31 - -35	24	35	6			9
-36 - -40	4	21	1			5
-41 - -45	6	4				2
-46 - -50						<1

b. WIND VELOCITY

The percentage of time during which the various wind velocities of the met climate occurred.

Knots	Jan. % Time	Feb. % Time	Mar. % Time	Apr. % Time	May % Time	June % Time	July % Time	Aug. % Time	Sept. % Time	Oct. % Time	Nov. % Time	Dec. % Time	The Year % Time
0-5	18	37	25	17	5	30	10	19	9	21	20	18	19
6-10	22	38	45	35	13	66	27	36	48	26	27	20	34
11-15	28	12	15	20	25	3	23	24	18	16	15	15	18
16-20	13	9	8	10	13	1	13	7	12	8	7	13	9
21-25	8	4	5	6	14		10	7	5	9	10	16	8
26-30	5		2	1	13		7	4	1	9	13	6	5
31-35	6			4	10		6	3		6	8	7	4
36-40	<1			3	3		2		3	4		3	2
41-45				3	3		2		2	1		1	1
46-50				1					1				<1
51-56					1				1			1	<1

APPENDIX III

a. EXPOSURE CLIMATE

The percentage of time during which the various temperature arrays of the exposure climate occurred. The year's observations are contained in two tables.

Temp. Range °C	Feb. % Time	March % Time	April % Time	May % Time	June % Time	July % Time	Aug. % Time
26 - 30		4		1			
21 - 25	10	12	13	14	1	2	9
16 - 20	72	34	41	27	42	40	45
11 - 15	2	21	13	36	26	54	37
6 - 10	1	12	26	19	26	1	5
1 - 5			1				1
0 - -5	2		1				
-6 - -10	10	5					
-11 - -15	3	9	1				
-16 - -20		1	2				1
-21 - -25		1	2	3			
-26 - -30		1					
-31 - -35					2		
-36 - -40				1		1	2
-41 - -45					3	2	

APPENDIX III contd.

EXPOSURE CLIMATE

Temp Range °C	September % Time	October % Time	November % Time	December % Time	The Year % Time
26 - 30					0.4
21 - 25	12	10	9	10	10
16 - 20	49	65	69	57	49
11 - 15	27	10	1	19	23
6 - 10	4	7		2	9
1 - 5	2				0.2
0 - -5			3	7	1
-6 - -10			18	4	3
-11 - -15	1	1		1	2
-16 - -20	1	4			1
-21 - -25	1	3			1
-26 - -30					
-31 - -35					0.4
-36 - -40	2				
-41 - -45	1				

b. RELATIVE HUMIDITY

The percentage of time during which the various arrays of relative humidity occurred within the hut. The year's observations are contained in one table.

Relative Humidity %	Feb. % Time	Mar. % Time	April % Time	May % Time	June % Time	July % Time	Aug. % Time	Sept. % Time	Oct. % Time	Nov. % Time	Dec. % Time
15 - 19	1	1	1	4			1	<1	<1	1	
20 - 24	1	2	2	3	1	2	4	5	4	1	1
25 - 29	<1	4	12	9	9	8	16	17	8		2
30 - 34	5	8	8	11	13	26	33	26	19		5
35 - 39	10	9	8	7	11	25	17	22	12	5	15
40 - 44	10	11	7	11	19	19	17	16	22	7	18
45 - 49	35	12	14	15	17	8	6	6	16	17	12
50 - 54	26	27	21	14	6	9	5	6	15	57	26
55 - 59	9	13	10	15	18	2	1	1	2	7	14
60 - 64	2	11	13	8	6	1		<1	2	3	7
65 - 69	1	2	4	3						2	1

APPENDIX IV

MICRO-CLIMATE

The frequency of occurrence of the sub-clothing temperatures (expressed as percentage of time), The temperature array differences are due to conversion from the electrical resistance recordings. One table is devoted to the results of each subject.

G.M.A.

Temp. °C	Feb. % Time	Mar. % Time	Apr. % Time	May % Time	July % Time	Aug. % Time	Sept. % Time	Oct. % Time	Dec. % Time	Sledging % Time	The Year % Time
19.0								3			0.4
21.2								4		3	0.4
21.8								2			0.1
22.3							3	2		3	0.5
22.9	1	3				1				12	0.6
23.4					1	3	1	1		14	0.6
24.0	1	1			1	1	1			15	0.6
24.5				2				2		6	0.2
25.1					1	1				11	0.2
25.6				2	3		3	1		3	0.6
26.2							1	3		7	0.5
26.7							4	1		1	0.6
27.3	1	1				1		4		7	0.5
27.8		1	2	2	9	6	3	3		7	2.9
28.4	1			2	4	7	4	4		2	1.6
28.9	1	1			16	18	1	7	1		6.3
29.5	4	3		3	8	14	3	11	4	4	5.6
30.0				2	6	10	7	6	1	2	3.7
30.6	3	6	5		4	3	7	7	3	4	4.4
31.1	3	1		2	4		6	1	3		3.3
31.7	13	17	9	3	9	1	14	6	4		8.7
32.2	18	18	7	13	27	31	35	17	28		23.7
32.8	17	21	25	3	6	3	6	11	35		12.0
33.3	24	17	19	20	1		1	4	21		12.0
33.9	4	4	12	22							4.4
34.4	6	3	7	8							2.6
35.0	3	3	14	16							3.7
35.5											

APPENDIX IV contd.

MICRO-CLIMATE

N.A.H.

Temp. °C	Feb. % Time	Mar. % Time	Apr. % Time	May % Time	July % Time	Aug. % Time	Sept. % Time	Oct. % Time	Dec. % Time	Sledging % Time	The Year % Time
20.1										2	
20.7	3									2	0.4
21.2	1									12	0.1
21.8	1				1					12	0.2
22.3										5	
22.9										14	
23.4					1						0.1
24.0										13	
24.5	1				1					8	0.2
25.1										15	
25.6			4		1					3	0.5
26.2	3		2		3					3	0.9
26.7	4	1				1				2	0.7
27.3	1	3	2							3	0.6
27.8	3					3				3	0.7
28.4	3	4				7	1				1.8
28.9		1			1	6	6	1	1	2	1.9
29.5	6			2	1	1	6	7	7		3.5
30.0	3	1	7	2	6	4	1	4	4		3.6
30.6	15	4	4	10	8	1					4.5
31.1	6	3	5	2	14	7	9	13	11	2	8.1
31.7	14	8	22	8	24	22	14	8	8		13.8
32.2		22	13	12	3	19	28	22	23		17.8
32.8	18	18	14	23	1	3	9	6	6		7.4
33.3	1	8	5	12	3	20	20	7	7		10.0
33.9		13	5	16	31	6	6	32	33		16.0
34.4	14	10	2	10							4.2
35.0	1	3	12	2							2.7
35.5											

APPENDIX IV contd.

MICRO-CLIMATE

M.A.S.

Temp °C	Feb. % Time	Mar. % Time	Apr. % Time	May % Time	June % Time	July % Time	Aug. % Time	Sept. % Time	Oct. % Time	Nov. % Time	Dec. % Time	The Year % Time
25.6		2	2									0.2
26.2		2	2			1	1	2		3		0.8
26.7										1		0.1
27.3		2								6		0.8
27.8		2	2						1	3		0.6
28.4	1	2	2						1			0.4
28.9	3	4			2		3	2				1.1
29.5		9			3				1			1.1
30.0	7	9		4	8	3			10	1		2.9
30.6	6	23	14	4	14	4				4	10	7.6
31.1	13	5		10	3	3	1	2		10	5	4.8
31.7	25	5	2	21	23	22	28	26	1	9	13	16.6
32.2	8	5	33	8		22	14	17	18	18	15	14.4
32.8	26	5		21	5	3	17	11	26	13	10	13.1
33.3	4	14	42	15	2	4	13	14	33	28	33	17.9
33.9	4	2		13	25	1	16	21	8	4	7	9.2
34.4		5		4	15	17	6	4			7	5.6
35.0	1	4				17	1	1				2.4
35.5												

APPENDIX IV contd.

MICRO-CLIMATE

J.A.S.

Temp °C	Feb. % Time	Mar. % Time	Apr. % Time	May % Time	June % Time	Aug. % Time	Sept. % Time	Oct. % Time	Nov. % Time	Dec. % Time	The Year % Time
26.7					1						0.2
27.3											
27.8											
28.4	1				1			1			0.5
28.9	1						2	1	1		0.8
29.5		1						1			0.3
30.0		1									0.2
30.6	11	3			1				11	4	3.2
31.1	11	7	2	1	3	1	3	1	13	7	5.3
31.7	20	11	8	2	7	23	9	6	19	12	12.2
32.2	14	6	12	10	32	24	14	4	11	3	13.0
32.8	6	16	14	15	20	32	23	21	3	24	17.0
33.3	8	13	30	21	14	11	29	28	16	18	19.2
33.9	14	14	8	18	14	9	18	14	22	22	15.1
34.4	14	3	13	10	7		2	22	3	10	8.5
35.0		13	12	17							2.7
35.5		11	2	6							2.4