PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

A Field Survey of Thermal Stress in New Guinea Villagers

G. M. Budd, R. H. Fox, A. L. Hendrie and K. E. Hicks

Phil. Trans. R. Soc. Lond. B 1974 **268**, 393-400
doi: 10.1098/rstb.1974.0037

Phil. Trans. R. Soc. Lond. B. **268**, 393–400 (1974) [393]
Printed in Great Britain

A field survey of thermal stress in New Guinea villagers

By G. M. Budd, R. H. Fox, A. L. Hendrie and K. E. Hicks
School of Public Health and Tropical Medicine, The University of Sydney, N.S.W. 2006, Australia
and Division of Human Physiology, National Institute for Medical Research, Holly Hill, London NW3 6RB

A survey to assess the thermal stress experienced by New Guinea villagers during everyday life was conducted on about 30 adults of each sex at each of two places – the villages of Kaul, on Karkar Island, and Lufa in the highlands. An observer accompanied each subject throughout the day, continuously recording his activity, his adjustments of clothing, and the time he spent in sunshine and in shade. Every 20 min, measurements of air temperature, humidity, and wind speed, and the mean radiant temperature in sunshine and shade, were made near the subject. Air temperature in the villagers' houses was continuously recorded by thermograph.

A preliminary analysis of the results indicates that people at Lufa were exposed to lower air temperature, humidity, and wind speed, but greater radiant heat, than those at Kaul. The average thermal stress, as calculated by the method of Belding & Hatch, was only slightly less at Lufa than at Kaul. At Kaul the air temperature indoors was much the same as that outdoors, but at Lufa it was 2 °C higher than outdoors. Air temperature and mean radiant temperature at Kaul were considerably higher in houses built of galvanized iron than in those of traditional bush materials. Men working in a copra drier were intermittently exposed to air temperatures over 71 °C, and to globe-thermometer temperatures as high as 110 °C. Kaul people engaged in their normal pursuits were found to lose an average of 2196 g of sweat in 7.5 h and to replace about half of it by drinking, thus incurring a fluid deficit of 1172 g, equivalent to 2.1 % of body mass.

Introduction

The thermal physiology project of the New Guinea multidisciplinary study, in the Human Adaptability Section of the International Biological Programme, was divided into two parts. One part was a laboratory investigation of temperature regulation in New Guinea villagers, as described in the accompanying paper (Fox, Budd, Woodward, Hackett & Hendrie, this volume). The other part, described below, was a field survey to assess the thermal stress experienced by the same people during everyday life.

The villagers studied were the inhabitants of Kaul, on Karkar Island, and Lufa, in the eastern highlands. Kaul is about 150 m, and Lufa about 1900 m, above sea-level. The weather at each village is generally similar to that at the nearby towns of Madang and Goroka, respectively, where meteorological observations have been made for many years. Table 1 shows that Goroka has a cooler and less humid climate than Madang, with only half as much rainfall. There is little seasonal variation in temperature at either place, but more rain falls between November and May than at other times of the year. The wind in both places is described as light and variable.

From these observations it might be thought that the villagers of Kaul would be exposed to a good deal more heat stress than those of Lufa. However, thermal stress depends on other factors besides air temperature and humidity. It depends also on sunshine and wind, the influence of which can be greatly modified by the use of shade and shelter; on the metabolic heat produced by exercise; and on the clothing worn.

We have therefore attempted to measure these various factors in about 30 young adults of each sex at Kaul and Lufa. The field work was undertaken at Kaul from July to October 1969, and at Lufa from February to June 1970. At each place the survey was immediately followed by the laboratory investigation of temperature regulation, in which most of the subjects took part. In this paper we present a preliminary report of the results of the field survey.

Table 1. Weather at Madang and Goroka: annual mean values

Data by courtesy of Commonwealth Bureau of Meteorology.

	Madang	Goroka
air temperature/°C		
maximum	30.0	25.6
minimum	23.1	14.4
vapour pressure/kPa	3.00	1.67
rainfall/m	3.48	1.90

Methods

Subjects

The subjects (table 2) were men and women aged from 16 to 30 years; they were generally short in stature, lean, and of good physique.

Clothing

At Kaul the men wore cotton shorts, and a sleeveless cotton shirt which they removed when feeling too hot. The women wore a loose-fitting cotton dress, or a skirt and blouse. Similar clothing was worn at Lufa by most of the men and a few of the women, but the remainder wore traditional clothing which provided little more insulation than a loincloth. In calculating indices of heat stress, subjects wearing traditional clothing, or shorts only, were assumed to be naked, and the insulation of the clothing worn by the remainder was assumed to be 0.3 clo units (Fanger 1970), where 1 clo is equivalent to the insulation provided by a conventional business suit as worn in cool climates (Fourt & Hollies 1970).

Table 2. Physical characteristics of the subjects

Data by courtesy of Mr R. G. Harvey,

	Kaul		Lufa	
	men	women	men	women
number of subjects	26	30	29	29
age/years	23.1	20.2	25.4	23.6
height/cm	163.9	155.5	162.2	152.5
mass/kg	57.4	52.2	59.0	51.1
skinfold* thickness/mm	5.91	10.67	5.86	8.09

* Mean of triceps, subscapular and suprailiac sites.

Housing

All the houses at Lufa, and most of those at Kaul, were of traditional construction. At Lufa the inhabitants warmed themselves around the cooking fire on the earthen floor in the main living-room. The walls were of woven cane, or of bark packed with grass for insulation, and the roofs were of grass thatch. Besides a house in the village, most families had, nearer their gardens, a second house which they shared with their pigs.

At Kaul the houses stood on piles 1–2 m in height. The floor was of split palm-trunks, the walls of woven bamboo, and the roof of sago thatch. Cooking was done in a well-ventilated kitchen. The houses were cool and airy, but had the disadvantage that damage by insects made it necessary to rebuild them every 3–5 years, and more permanent materials were sometimes preferred. One house had walls and roof of galvanized iron, and two others had iron roofs.

The thermal environment indoors was assessed by leaving a thermograph or thermo-hygrograph in each subject's house for a week. In certain houses observations of air movement and radiation were also made throughout the day.

Activity

The activities of the subjects were mainly those of subsistence agriculture, such as gardening, clearing bush, making fences, and building houses. Most villagers also grew cash crops, which were mainly coconuts and cocoa at Kaul, and coffee at Lufa. Several of the men at Lufa worked intermittently as paid labourers on road maintenance.

Thermal-stress survey

The thermal stress experienced throughout the working day was determined by direct observation. The observers would meet a particular subject (or subjects) in the early morning, usually before he had left his house, and would accompany him throughout the day as he went about his customary activities.

Every 20 min an observer measured the air temperature, humidity, radiation and wind speed near the subject, and made general notes on cloud cover, rain, and other aspects of the weather. The wet-bulb and dry-bulb air temperatures were measured with a sling psychrometer, and the wind speed was measured with a cup anemometer, vane anemometer or katathermometer. The cup and vane anemometers were sensitive to wind speeds as low as 0.15 m/s, and a fine woollen thread was used as a wind vane to ensure that the vane anemometer was always pointed into the wind. Radiation was assessed by observing the globe-thermometer temperature, using standard black globes of 15 cm diameter (Bedford 1946), in sunshine and in shade, and subsequently calculating a weighted average by the method described below. Thermometers and anemometers were calibrated before and after the survey.

Every minute throughout the day, another observer recorded the subject's activity on a timed-activity card, using the same categories of activity as were used in the survey of energy expenditure (Durnin *et al*., this volume) which was then in progress. He also recorded, each minute, whether the subject was in sunshine or in shade, and made notes on other relevant factors such as adjustments of clothing.

Subsequently the various activities in each 20 min period were multiplied by their respective energy-equivalents, using data kindly provided by Dr Durnin and his colleagues, to estimate the subject's metabolic rate. The globe-thermometer temperatures in sunshine and in shade were multiplied by the time spent in each place to obtain a weighted average, which was then used to calculate the mean radiant temperature of the subject's surroundings (Bedford 1946). Finally, the metabolic rate and mean radiant temperature were combined with the observations of air temperature, humidity, wind speed and clothing, to calculate the Belding–Hatch 'heat-stress index' (Belding & Hatch 1955; Hertig & Belding 1963; Hatch 1963). In computing this index one first calculates the heat gained from metabolism, and the heat gained or lost by radiation and convection. These are then added together to provide an estimate of E_{req}, the evaporation required for thermal balance. The heat stress index is E_{req} expressed as a percentage of E_{max}, the maximum evaporative cooling possible in the given environment.

Physiological responses

At the same time as the thermal stress experienced by the villagers was being assessed, certain physiological responses to it were also investigated. At Lufa, the subject's thermal comfort, skin temperature, sweating and shivering were recorded at the time of each weather observation, and the results will be reported separately. At Karkar, most subjects were weighed, on a beam-balance sensitive to 50 g (Herbert & Sons, Edmonton, London N. 18), at the beginning and end of the day's observations. Throughout the day all food eaten was weighed on a Salter dietary balance sensitive to 5 g, which was periodically calibrated by weighing objects of known mass, and the volume of all fluid drunk and urine passed was measured. From these observations the subject's sweat loss (more exactly, the mass loss attributable to the evaporation of water from the skin and respiratory tract, to gas exchange, and to the loss of sweat by dripping) was calculated by standard methods (Consolazio, Johnson & Pecora 1963).

Table 3. Exposure climate at Kaul and Lufa

Mean ± standard error of mean. The number of observations is shown in parentheses.

	Kaul		Lufa	
	men	women	men	women
air temperature/°C	27.81 ± 0.06 (647)	27.71 ± 0.07 (696)	21.49 ± 0.06 (2655)	21.87 ± 0.07 (2268)
vapour pressure/kPa	2.792 ± 0.007 (548)	2.866 ± 0.006 (583)	1.889 ± 0.006 (1801)	1.958 ± 0.006 (1559)
wind speed/m s^{-1}	1.176 ± 0.037 (647)	1.284 ± 0.040 (695)	0.753 ± 0.013 (2654)	0.729 ± 0.015 (2284)
mean radiant temperature/°C	44.55 ± 0.60 (548)	43.34 ± 0.58 (583)	46.46 ± 0.37 (1801)	47.02 ± 0.39 (1559)

Results and discussion

Thermal stress

The averages of all the weather observations made near the subjects – that is, the climate to which they were actually exposed – are shown in table 3. The average air temperature and humidity were lower at Lufa than at Kaul, but to balance this, at Lufa there was less wind and a higher mean radiant temperature.

The heat exchanges of the subjects, as estimated by the components of the Belding–Hatch heat stress index, are shown in table 4. The heat gained by radiation was greater at Lufa than at Kaul, but so was the heat lost by convection, and the losses very nearly balanced the gains. The net result was a small heat gain from the environment at Kaul, and an equally small heat loss at Lufa. Since the metabolic rate was virtually the same in both places, the small difference in the environmental heat load was reflected in the evaporative requirement (E_{req}), which at Lufa was 91 % of the Kaul value. In the less humid climate of Lufa the maximum evaporative capacity (E_{max}) was higher than at Kaul, and so the heat stress index (the ratio of E_{req} to E_{max})

was lower there. In most components of the heat stress index the values for women were somewhat lower than those for men.

One of the assumptions made in calculating heat exchange by the Belding–Hatch equation is that the mean skin temperature is 35 °C. At Kaul this assumed value was probably not far from the correct value, but at Lufa it seems likely to have been too high at the cooler times of day. Such an error would cause heat loss to the environment to be over-estimated, and heat gain from it to be under-estimated; hence correcting for the error would tend to reduce the already small difference in E_{req} between Kaul and Lufa.

TABLE 4. COMPONENTS OF BELDING–HATCH HEAT STRESS INDEX

Mean ± standard error of mean.

	Kaul		Lufa	
	men	women	men	women
number of observations	548	583	1801	1559
radiation/W	91.85 ± 5.80	70.86 ± 4.79	110.04 ± 3.52	104.33 ± 3.33
convection/W	−80.11 ± 1.22	−71.26 ± 1.12	−121.84 ± 1.31	−106.90 ± 1.36
radiation + convection/W	11.74 ± 5.93	−0.40 ± 4.92	−11.80 ± 3.76	−2.57 ± 3.60
metabolism/W	170.44 ± 2.79	171.72 ± 3.03	179.38 ± 1.90	157.26 ± 1.82
E_{req}/W	182.18 ± 6.55	171.32 ± 5.78	167.58 ± 4.21	154.69 ± 4.03
E_{max}/W	509.65 ± 8.88	439.32 ± 7.90	567.75 ± 6.33	493.83 ± 6.13
heat stress index	35.75 ± 1.43	39.00 ± 1.49	29.52 ± 0.81	31.32 ± 0.90

The similarity of the evaporative requirement of the subjects at Kaul and Lufa would seem to provide a satisfactory explanation for their close similarity in sweating capacity, as determined by the thermoregulatory function test (Fox *et al.*, this volume). That the evaporative requirement was less for the women than for the men is also in agreement with the finding that the women's sweating capacity was lower than that of the men.

TABLE 5. INDOOR AIR TEMPERATURE (°C) AT KAUL AND LUFA

Maxima and minima from weekly thermograph charts, in houses of traditional construction. The number of charts is shown in parentheses.

place	maxima	minima
Kaul (45)		
mean	29.9	21.3
extremes	31.1	20.0
Lufa (25)		
mean	27.8	17.3
extremes	32.2	13.9

Thermal environment indoors

Comparison of Kaul and Lufa

Table 5 shows the averages of the highest and lowest temperatures recorded on each subject's weekly thermograph chart, together with the extreme values recorded for Kaul and Lufa. The maximum and minimum temperatures were lower, by 2 and 5 °C respectively, at Lufa than at Kaul. A comparison with the temperatures recorded outdoors in the same months at the nearest meteorological observatories (table 6) shows that at Kaul the temperature indoors was virtually the same as that outdoors, whereas at Lufa it was 2 °C higher than outdoors. Thus the traditional houses in both places appear to be well adapted to their respective climates. At Kaul they provide shelter and privacy without adding to the environmental heat load, whereas those at Lufa, which are less well-ventilated and are warmed by fire, partly reduce the cold stress of the mornings and evenings.

TABLE 6. COMPARISON OF INDOOR AND OUTDOOR AIR TEMPERATURES (°C)

Indoor temperatures are as in table 5; outdoor temperatures are means of the daily maxima and minima recorded by the Commonwealth Bureau of Meteorology at Madang and Goroka, in the same months as the corresponding thermograph records at Kaul and Lufa.

place	maximum	minimum
coast		
Kaul (indoors)	29.9	21.3
Madang (outdoors)	29.4	22.8
highlands		
Lufa (indoors)	27.8	17.3
Goroka (outdoors)	25.6	15.0

Comparison of traditional and iron houses

The thermograph records illustrate the thermal penalty paid by those villagers at Kaul who have built with galvanized iron in place of the traditional sago-palm and woven bamboo. Table 7 shows that although the minimum temperatures were the same in both kinds of house, the maximum temperatures were 4 °C higher in the iron houses. Half-hourly observations throughout the day (table 8) in a house with iron walls and roof, and in the two adjacent houses of traditional construction, showed that although good ventilation in the iron house prevented the air temperature from rising more than 2 °C above that in the other houses, the mean radiant temperature was 8 °C higher throughout the day, and at times was as much as 13 °C higher. In the traditional houses, by contrast, air temperature and mean radiant temperature remained the same as in the shade outdoors.

TABLE 7. COMPARISON OF TRADITIONAL AND IRON HOUSES AT KAUL

Maximum and minimum air temperatures (°C) from weekly thermograph charts, the number of which is shown in parentheses.

type of house	maximum	minimum
traditional (45)		
mean	29.9	21.3
extremes	31.1	20.0
iron (3)		
mean	33.9	21.1
extremes	35.0	20.6

Copra driers

The heat stress of a semi-industrial process in the tropics, and an effective behavioural adaptation to such stress, are exemplified by observations made in a copra drier, built of traditional bush materials, which was operated by some of the Kaul villagers. The drier was of the Ceylon type, in which heat to dry the copra is provided by burning trains of coconut shells on the earthen floor 2 m below the copra trays. The shells are tended, and periodically replaced, by two firemen, who have to enter the fire room to do so. The thermal environment in the fire room is shown in table 9. Globe-thermometer temperatures were as high as 110 °C, and air temperature was mostly above 71 °C, which was the upper limit of the psychrometer that was used. Nevertheless the evaporative mass losses of the two firemen over $2\frac{1}{2}$ h were only 137 and 196 g/h – less than that (214 g/h) of the observer who was reading the thermometers. No doubt the reason for the firemen's comparatively low sweat loss was that they did not linger in the fire room, remaining there only 15s on the average and rarely more than 40s.

TABLE 8. COMPARISON OF TRADITIONAL AND IRON HOUSES AT KAUL. AIR TEMPERATURE AND MEAN RADIANT TEMPERATURE (M.R.T.) (°C)

Means of half-hourly observations from 08h30 to 17h30.

place	air temperature		m.r.t.	
	mean	maximum	mean	maximum
outdoors	28.3	30.0	60.0†	73.9†
iron house	29.4	32.2	37.2	44.4
traditional houses (mean of 2)	28.3	30.0	29.4	31.7

† Globe-thermometer exposed to sun.

TABLE 9. THERMAL ENVIRONMENT IN A COPRA DRIER

Temperatures (°C) in fire room.†

temperature	number of observations	mean	range
wet bulb	4	35.0	31.7–40.0
dry bulb	4	—	52.8 to > 71
globe-thermometer	11	96.7	70.6–110.6

† Temperature outside fire room: wet bulb 26.7°, dry bulb 30.6°.

Sweat loss and fluid balance

Tables 10 and 11 show that the average sweat loss of 40 Kaul subjects (15 men and 25 women) engaged in their habitual activities was 2196 g over a period of 7.5 h, which corresponds to an hourly sweat rate of 293 g. The results for each sex separately were very similar. The highest sweat loss was 3560 g in 8.8 h, and the highest sweat rate was 451 g/h over a period of 5.7 h.

TABLE 10. SWEAT RATE AND FLUID BALANCE AT KAUL

Subjects who did not eat, drink, or urinate have been excluded from the calculations for food, drink, and urine.

	no. of subjects	mean	range
duration/h	40	7.5	4.8–9.0
sweat rate/g h^{-1}	40	293	123–451
food/g	37	467	12–1425
drink/ml	39	1129	260–2310
urine/ml	15	205	50–400

Only 15 of the subjects urinated, and the average volume of urine they passed was 205 ml. Almost all of them ate or drank: they ate 467 g of food, usually coconuts, and drank 1129 ml of coconut milk or water. They drank only half as much fluid as they had lost by sweating, and so ended the working day with a fluid deficit of 1172 g, which is equivalent to 2.1 % of body mass. The amount they drank, and their final fluid deficit, were both significantly ($P < 0.001$) correlated with their sweat loss: the heaviest sweaters drank the most, yet still became the most dehydrated. Thus the villagers of Kaul exhibited the phenomenon of 'voluntary dehydration', in the same way that people of Caucasian origin, such as soldiers in the desert (Adolph 1947) and workers in hot industries (Henschel & Coppola 1972), have been shown to do.

Table 11. Sweat loss and fluid balance at Kaul

Observations on 40 subjects (15 men, 25 women). In the calculations for mean volume of drink and urine, subjects who did not drink or urinate have been included and treated as zero values.

	mean	range
duration/h	7.5	4.8–9.0
sweat loss/g	2196	612–3560
urine/ml	77	0–400
total fluid loss/g	2273	752–3910
drink/ml	1101	0–2310
final fluid deficit/g	1172	5–1985
as % of body mass		
sweat loss	3.9	1.1–6.3
total fluid loss	4.1	1.4–6.8
final fluid deficit	2.1	0–3.4

It is a pleasure to acknowledge the help given by many people throughout the investigation. We would particularly like to thank Dr R. W. Hornabrook and his staff of the New Guinea Institute of Medical Research, and also Mr John Middleton, Mr Roger Middleton, and Mr Fred Rimmer, of Karkar Island, for their support during the field work; Miss Josephine Bastian for her invaluable help in both the field survey and the laboratory investigation; Mr Barry McDowall, Mrs Jan Bubb, and their colleagues in the Division of Computing Research, Commonwealth Scientific and Industrial Research Organization, and Dr John Robinson, Department of Mathematical Statistics, University of Sydney, for their generous help with the analysis of the results; Professor R. K. Macpherson, Principal of the School of Public Health and Tropical Medicine, and Dr O. G. Edholm, Head of the Division of Human Physiology, for their advice and encouragement; and most especially the villagers of Kaul and Lufa, for their unfailing helpfulness and courtesy as assistants, subjects, and neighbours.

References (Budd *et al.*)

Adolph, E. F. *et al.* 1947 *Physiology of man in the desert*. New York: Interscience.

Bedford, T. 1946 Environmental warmth and its measurement. *Med. Res. Counc. War Memo.* no. 17.

Belding, H. S. & Hatch, T. F. 1955 Index for evaluating heat stress in terms of resulting physiological strains. *Heat. Pip. Air Condit.* 27, 129–136.

Consolazio, C. F., Johnson, R. E. & Pecora, L. J. 1963 *Physiological measurements of metabolic functions in man.* New York: McGraw-Hill.

Fanger, P. O. 1970 Conditions for thermal comfort – introduction of a general comfort equation. In *Physiological and behavioral temperature regulation* (ed. J. D. Hardy, A. P. Gagge and J. A. J. Stolwijk), pp. 152–172. Springfield: Thomas.

Fourt, L. & Hollies, N. R. S. 1970 *Clothing – comfort and function*. New York: Dekker.

Hatch, T. F. 1963 Assessment of heat stress. In *Temperature, its measurement and control in science and industry*, vol. 3, part 3 (ed. J. D. Hardy), pp. 307–318. New York: Reinhold.

Henschel, A. & Coppola, S. A. 1972 *Occupational exposure to hot environments – criteria for a recommended standard.* U.S. Dept. of Health, Education and Welfare.

Hertig, B. A. & Belding, H. S. 1963 Evaluation and control of heat hazards. In *Temperature, its measurement and control in science and industry*, vol. 3, part 3 (ed. J. D. Hardy), pp. 347–355. New York: Reinhold.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES