G. E. Glock.

No 1

AN INVESTIGATION OF THE EFFECTS OF AIR CONDITIONS VARYING IN TEMPERATURE, AIR MOVEMENT AND HUMIDITY ON CERTAIN ASPECTS OF RESPIRATION, CIRCULATION AND EXCRETION AND ALSO THE RELATION OF THESE CONDITIONS TO MUSCULAR AND MENTAL EFFICIENCY.

Thesis submitted for the Degree [illegible]
Nov 1932 by Miss G E Glock

The present investigation was carried out in order to obtain some quantitative indications of the effect of air conditions varying in temperature, air movement and humidity, on certain aspects of respiration, circulation and excretion and also the relation of these conditions to muscular and mental efficiency.

Adverse atmospheric conditions, such as occur in mines and various industries (e.g. cotton and linen weaving) have been shown by numerous workers to have profound effects both on the health and efficiency of the industrial worker.

In this country, Leonard Hill's katathermometer is now used extensively to determine the suitability or non-suitability of the atmospheric conditions in factories, since the "cooling power" (C.P.) serves as a fairly reliable index of bodily comfort. But, as will be shown later, the katathermometer is not strictly comparable to the human body. Vernon attempted the very tedious task of calibrating the katathermometer in terms of human sensation, Workers in factories were asked if they found the atmospheric conditions "comfortable", "too cold" or "too hot". Taking the average of these observations, Vernon found that a comfortable sensation of warmth was experienced in Winter at a C.P. of 6.6 and in Summer at a C.P. of 6.4. Hence the sensation of warmth is not directly proportional to the C.P. but varies with the season, Acclimatisation is also a very important factor. In spite of these anomalies, the katathermometer has been used extensively in testing atmospheric conditions in industry; as a method for the comparison of methods of heating and ventilation (by Bedford and Angus principally); in ventilation tests on board of liners (Angus); and in cinemas, theatres and other places of public amusement.

In using the C.P. as a standard for atmospheric conditions in industry, Leonard Hill suggests that a :-

Dry	C.P.	of 6	and	a Wet	C.P.	of 18	is	suitable	for	sedentary workers,
"	"	8	"	"	"	25	"	"	"	light manual work,
"	"	10	"	"	"	30	"	"	"	heavy " " .

The cooling power standard, however, is only used in England and her Colonies (especially in South Africa). In America a different standard, the "effective temperature" (E.T.) has been resorted to. Two chambers are used with different combinations of temperature, air movement and humidity. One is kept constant at a given E.T. and the other adjusted until the subject, who steps from one chamber to the other, experiences the same degree of comfort or discomfort. From charts it is possible to convert any combination of these three atmospheric factors into an E.T. (An atmospheric condition has e.g. an E.T. of 65 if it is comparable to an air temperature of 65°F, saturated with moisture and with no air movement.)

This method is obviously more accurate than the katathermometer, which depends on empirical graduations made at different times of the day and year, and on varying clothing etc. But the great disadvantage to the E.T. method, is that it takes no account of acclimatisation. The subject cannot become acclimatised to either set of conditions in the two chambers and therefore experiences the changes to the maximum degree. It is also improbable that the E.T. standard will ever have more than a very restricted use in industry, since the dry and wet bulb temperatures and the air velocity must all be taken, whereas if the katathermometer is used only one reading need be taken.

The adverse effects of high temperatures and humidities on the efficiency of the industrial worker is most marked when the work is of a strenuous physical character.

In 1922 Orensein and Ireland made a number of experimental observations on the relation between atmospheric conditions and the production of fatigue in mine labourers in the Rand Mines. The following table shows the values of the C.P. and the corresponding physiological effects observed.

Cooling power		Physiological effects on men stripped
Wet kata.	Dry kata.	to the waist.
5	1.5	Extremely oppressive; profuse sweating; rise of body temperature and pulse rate especially when work performed. Very small evaporation from respiratory tract.
10	3.5	Distinctly oppressive; body temperature can be kept nearly normal only by profuse sweating. Skin flushed and wet. Pulse rate high.

Cooling Power		Physiological Effects
Wet kata.	Dry kata.	
15	5.5	Lower limit for comfort.
20	8	Quite comfortable for work.
25	10	Cool and refreshing for work; too cold for resting, especially after being heated.

The output of work was registered in foot-lbs per day by a suitable ergometer and these workers found that, assuming the working efficiency to be 100% at a dry C.P. of 6.0, the following relationship exists between the efficiency and the dry C.P. (But it is possible that the efficiency will increase with C.P. up to 8.0)

Dry C.P.	1	2	3	4	5	6
Working efficiency %	50	60	70	80	90	100

Sayers and Harrington (1925) also made extensive observations on subjects at rest in hot and deep metal mines, and the blood pressure, pulse rate and body temperature of the worker were taken. They found that if the subject remained at rest in saturated air at 91°F - 95°F, there was an increase in body temperature, increased pulse rate, profuse sweating and after effects of dizziness and weakness, but these conditions were considerably mitigated by air movement. But at 98°F - 100°F, there was a very marked rise in body temperature which reached 102°F, a marked rise in pulse rate (the pulse rate varying from 152 - 175), profuse sweating and very early appearance of dizziness and weakness. No beneficial effects were obtained by air movement even at velocities as great as 800 feet per minute and in many cases the air movement aggravated the condition of the subject, and in no case was the subject able to remain a full hour under these conditions.

In regard to the best temperatures for working efficiency, Vernon concluded from a study of different occupations, that a temperature of 65°F - 69°F is probably the most suitable for ordinary machine work.

The question as to whether the commonly experienced disinclination to perform muscular work in a hot and humid atmosphere is accompanied by an actual diminution in the working power, was studied by the New York State Commission on Ventilation. They found that when the men were urged to work they accomplished 28% less total work in a day in an atmosphere of

86°F and 80% relative humidity

than at 68°F and 50% " " ,

and also the workers were capable of performing four times more work in a temperature of 100°F with a % relative humidity of 30, than in a saturated condition of 100°F.

Vernon found that the minimum accident rate in both men and women was between 65°F and 69°F. Above 69°F, the accident rate increases slowly in women, (probably because the work is less severe than the men) but increases rapidly with men and at 79°F is 39% greater than at 65°F - 69°F. There is also an increased accident rate at low temperatures; at 50° - 54°F, it is 35% higher than at 65°F - 69°F.

Reed has shown that a moderate increase of temperature (within physiological limits) would augment the action of drugs, whether harmful or not. Thus at high temperatures and humidities, there would be a more rapid combination of CO with Hb than at normal temperatures and humidities, with the same concentration of CO. Also, heat and humidity produce a greater susceptibility to Pb poisoning, because the Pb powder is absorbed on the surface of the wet body. (There is also often no clothing.)

The relation of sex to susceptibility to abnormal atmospheric conditions seems not to have been given much consideration although statements are frequently made that women react more readily than men to variations in temperature, air movement and humidity.

Thus, although a considerable amount of work has been done in connection with the effects of abnormal atmospheric conditions on the industrial worker, most of the work is qualitative in nature and has all been done on male subjects. Consequently, the present investigation was carried out in order to obtain more quantitative data in this connection. Also, all the subjects were women.

All the following experiments were carried out in the air-conditioning hut at the Home Office Industrial Museum, which can be adjusted to practically any atmospheric condition. This consists of a central corridor open at both ends and separated on either side by a metal partition from an outer corridor which extends right round the inner part. The walls of the central corridor are provided with four radiant heat panels of different intensities and each side corridor has two convected heating panels. Near one end of the central corridor is a large electric fan screened by a wire meshwork on the outside and by a metal perforated screen in front, composed of separate metal partitions riveted together so that the air currents set up are unidirectional and parallel. The air can thus be circulated down the central corridor and back by the outer corridors and hence recirculated. The air can also be artificially humidified by steam or water jets.

In all the experiments quoted, convected heat alone was used, the radiant heating panels only being used to warm up the hut prior to any experiment and were always turned off some time before the commencement of the experiment.

When high, still temperatures were required, it was found necessary to keep the convected heating panels on the whole time, and since these could only be used in conjunction with the fan, the subject had to be surrounded by screens, which proved to shield her very effectively from any air movement.

The following physical measurements were made:

1. Wet and Dry Bulb Temperatures by means of a sling psychrometer.

2. % Relative Humidity by means of a recording hygrometer. (When high, still temperatures, and consequently a screen to shield the subject, were employed, the % Relative Humidity was calculated from the wet and dry bulb temperatures via the dew point.)

3. Air Movement by means of a vane anemometer. The air velocity was adjusted from 100 to 400 feet per minute. An air velocity of 200 feet per minute was the highest to be used in the later experiments, a higher value being considered incomparable to any indoor atmospheric condition.

4. Cooling Power (C.P.) The dry cooling power, and in some cases the wet cooling power, in addition, was determined. A self-recording katathermometer (Schuster's modification) was employed. In this apparatus, current is passed through the heating coil in the bulb until a temperature of 100°F is reached. It is then switched off automatically and the temperature of the bulb falls at a rate depending on the C.P. of the air, to 95°F. The current is then switched on automatically and the temperature again rises to 100°F, and so the cycle of operations repeated. A recording instrument is included, in which a lever traces an arc on a roll of paper for each cooling period of the katathermometer. The length of these lines is not in simple proportion to, but varies with the cooling time. The instrument is calibrated and a chart devised, showing the relationship between the length of the lines and the cooling power of the atmosphere, so that

by comparing the record obtained in any one experiment with the chart, the average cooling power over that experimental period can be obtained.

This katathermometer does not register cooling powers below 3.0 and hence at these low cooling powers the ordinary alcohol katathermometer of Leonard Hill was employed. At air temperatures of 90°F, the great length of time taken by this instrument in cooling from 100°F to 95°F renders it inaccurate, and hence at this temperature the 'high temperature kata' was also employed. This cools from 130°F to 125°F. The cooling powers obtained with the two instruments are not, however, comparable.

The cooling power exerted by the air on the kata is estimated at what is approximately the mean body temperature (100°F - 95°F) and it is sometimes supposed that its readings can be applied directly to the cooling action which the air exerts on the human body. But this direct comparison cannot hold for several reasons. The kata, by reason of its small bulk, exposes a relatively much larger surface to the air than the human body; it exposes an uncovered surface, whilst most portions of the human body are usually covered with clothing, which causes it to react differently to atmospheric conditions at different times and seasons. Under a few conditions only may the rate of cooling of the katathermometer between 100°F and 95°F be taken as an index of the cooling of the body itself. The rate of cooling of the naked body when the skin is covered with moisture is directly comparable with the wet katathermometer, and when the skin is dry the

the rate of cooling is to some extent comparable to the dry kata, but not wholly so, as there is always a considerable loss of heat at the body surface from insensible perspiration. But when the body is clothed, it is practically impossible to obtain closely comparable conditions of cooling in the katathermometer. In spite of this, the dry katathermometer readings are of extreme importance and form a fair index of comfort for ordinary atmospheric conditions.

Great difficulties arise in using the cooling power as a standard for the comparison of atmospheric conditions. The katathermometer tends to overestimate air movement and to underestimate humidity. The dry kata cooling power is in fact practically unaltered by increased humidity, and according to Leonard Hill is entirely uninfluenced. Thus, in attempting to plot various physiological factors against cooling powers, it is obvious that many discrepancies will appear. As will be seen in some of the following graphs these discrepancies are particularly emphasized at high humidities. The cooling power does, in fact, afford a much better qualitative than quantitative index of physiological reactions, but unfortunately there is no other single factor which is even as good as this.

The three subjects used in the following experiments were all females varying in age from 18 to 23 years.

The duration of each experiment at any one given atmospheric condition was 2 hours. During this time 4 blood samples were taken at intervals of 30 minutes, and 3 samples of expired air, the subject breathing into a Douglas bag for 15 minute periods, during which time the respiration rate and pulse rate were also taken. The blood pressure, mouth temperature and skin temperature were taken at 40 minute intervals and also the mental efficiency tested for 5 minute periods at the same time intervals.

Soon after the subject arrived at the hut in the morning a normal blood sample was taken and the normal mental efficiency on that day tested as will be described later.

The profound influence of clothing on the physiological responses of a subject to any air condition has long been recognised and hence in order to eliminate this clothing factor as far as possible, a standard uniform was worn by all the subjects. This consisted of a navy blue, woollen stockinette pyjama suit.

The diet of the subject was also partly controlled, no breakfast being taken apart from a drink and the subject neither ate nor drank during the whole period of the day's experiments.

A normal sample of urine was collected immediately before the experiment began and also over each two hour experimental period.

Blood counts were also made on subject A, but the small variations noticed in these did not warrant continuing estimations with subject B.

Subject C, who did muscular and mental work only, did not conform to the above conditions apart from wearing the standard uniform.

PULSE RATE

The pulse rate was taken over 5 minute periods every 40 minutes, while the subject was breathing into the Douglas bag, and the average value taken. The pulse rate was plotted against the cooling power.

The results obtained with subject A showed that:

1. The pulse rate (P.R.) is approximately inversely proportional to the cooling power (C.P.), increased C.P. producing a decrease in the P.R., and decreased C.P. an increase in the P.R.
2. Air movement produces a decrease in the P.R. except at very high air temperatures (90°F), when there was practically no difference, or if anything a slight increase.
3. Increasing the humidity has no noticeable effect on the P.R.

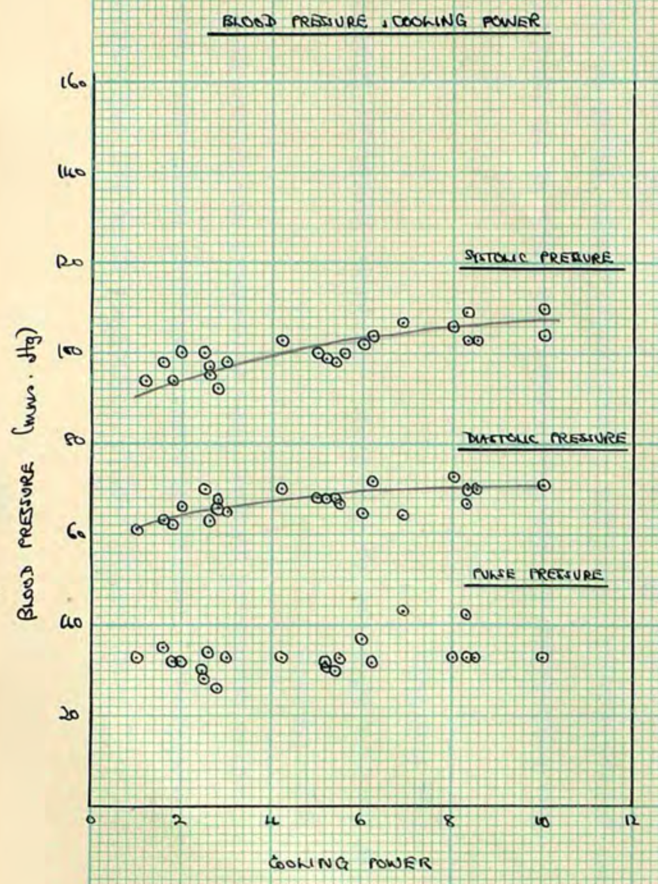
The results with subject B were slightly different and showed that:

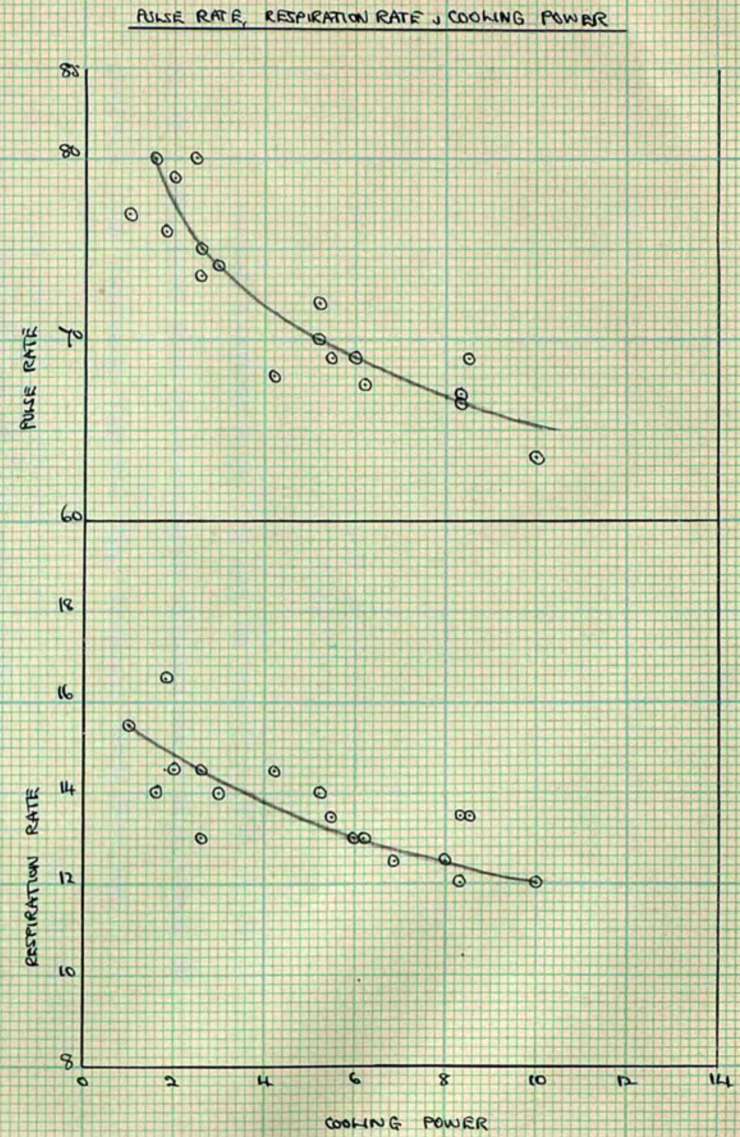
1. There is no direct relation between C.P. and P.R.
2. The P.R. increases with increasing air temperature and there is also a very slight increase at very high cooling powers (i.e. at a C.P. of 16.5)
3. At and below 70°F, the P.R. is decreased by air movement, but at and above 75°F air movement has no influence on the P.R. and at 90°F and 100% saturation even increases the

Subject A

Date	Air Condition °F	Percentage Relative Humidity	Air Velocity in Feet per Min.	Cooling Power	Respiration Rate	Pulse Rate	Blood Pressure Systolic	Diastolic	Pulse
Nov.16	50		0	8.0	12-13	63	106	73	33
	60		0	6.2	13	68	104	72	32
Nov.11	60		100	8.3	12	67	109	67	42
Nov.19	60		200	10.0	12	63-64	110	69	41
Nov.12	70		0	4.2	14-15	68	103	70	33
Nov.19	70		200	8.3	13-14	66-67	103	70	33
Nov.30	75		0	3.0	14	74	98	65	33
	75		100	5.5	13-14	69	100	67	33
Jan.11	75		200	6.9	12-13	69	107	68	39
	80		0	2.6	14-15	75	96	68	28
	80		200	5.2	14	72-73	99	68	31
Nov.26	80		400	8.5	13-14	69-70	103	70	33
Nov.5	80	100	0	1.8	16-17	76	94	62	32
Dec.10	80	78	0	2.6	13	73	97	63	34
	80	63	200	6.0	13	69	102	65	37
Dec.2	90		0	1.1	14-15	77	94	61	33
	90		100	1.6	14	80	98	63	35
Nov.26	90		200	2.0	14-15	79	100	66	34

SUBJECT A


BLOOD PRESSURE v COOLING POWER
BLOOD PRESSURE (mms. Hg)
SYSTOLIC PRESSURE
DIASTOLIC PRESSURE
PULSE PRESSURE
COOLING POWER


PULSE RATE, RESPIRATION RATE v COOLING POWER
PULSE RATE
RESPIRATION RATE
COOLING POWER

rate. This latter result coincided with the subjective sensations. Subject B found that wind under such conditions increased rather than decreased the discomfort experienced.

4. The P.R. is affected by humidity, increased humidity increasing the P.R.

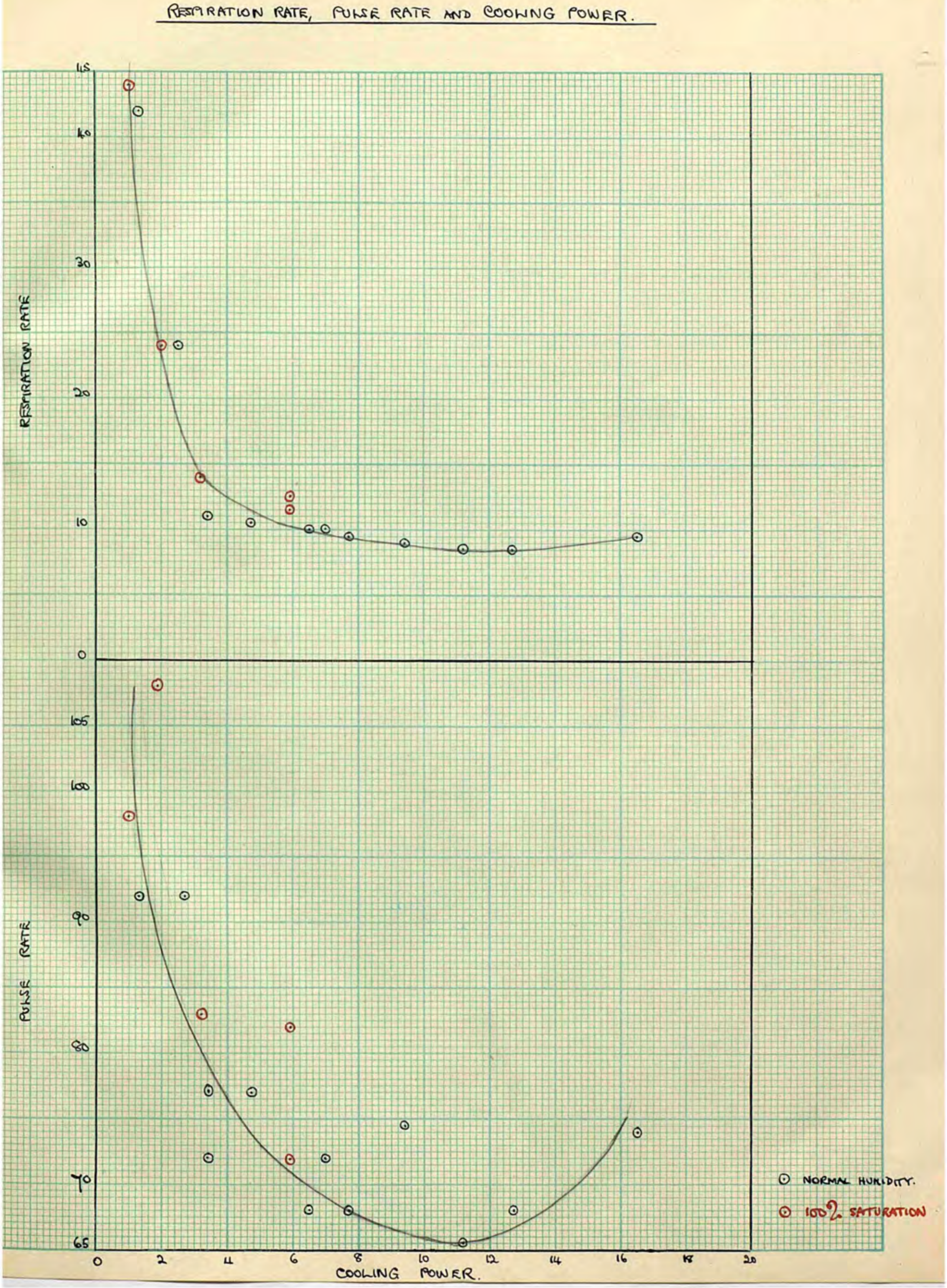
The variations in the pulse rate, as well as in most of the other physiological reactions investigated, were found to be connected very closely with the subjective sensations experienced. Subject A, who was not incapacitated either by high temperatures or humidities, only showed a range of P.R. from 63 to 80, whereas subject B, who was very susceptible to both increased air temperatures and particularly to increased humidity, showed a much wider range of from 65 to 108.

Disregarding, however, the results obtained with subject B at high humidities, the results with both do show that the P.R. is approximately proportional to the dry kata cooling power.

Subject B

Date	Air Condition °F.	Air Condition Percentage relative humidity.	Air Condition Air velocity in feet per min.	Cooling Power.	Respiration Rate.	Pulse Rate.	Blood Pressure Systolic	Blood Pressure Diastolic	Blood Pressure Pulse
Jan,25	50	41	0	7.7	9-10	68	113	70	43
	50	56	100	12.7	8-9	68	117	75	42
Feb.15	50	52	200	16.5	9.10	74	119	75	44
Feb.1	60	53	0	6.5	10	67-68	110	68	42
Feb.15	60	50	100	6.4	10	68	110	68	42
Feb.1	60	51	200	11.2	8-9	65	115	72	43
Feb.29	60	100	0	5.9	13	72	102	68	34
Feb.4	70	45	0	4.7	10-11	77	108	66	42
	70	40	200	9.4	9	74-75	115	72	43
Feb.8	75	37	0	3.4	11	72	107	63	44
	75	33	200	7.0	10	72	111	68	43
Feb,11	75	100	0	3.2	14	83	102	64	48
	75	100	200	5.9	11-12	82	110	66	44
Feb.25	90	45	0	1.3	42	98	94	60	34
	90	35	200	2.7	24	92	116	70	46
Mar.14	90	100	0	1.0	(CHEYNE-STOKES BREATHING) 44	98	115	82	33
	90	100	200	1.9	24	108	98	62	36

SUBJECT B


RESPIRATION RATE, PULSE RATE AND COOLING POWER.
RESPIRATION RATE
PULSE RATE
COOLING POWER.
45
40
30
20
10
0
105
100
90
80
70
65
0
2
4
6
8
10
12
14
16
18
20
NORMAL HUMIDITY.
100% SATURATION

BLOOD PRESSURE

The blood pressure (both systolic and diastolic) was determined by the auscultatory method every 40 minutes.

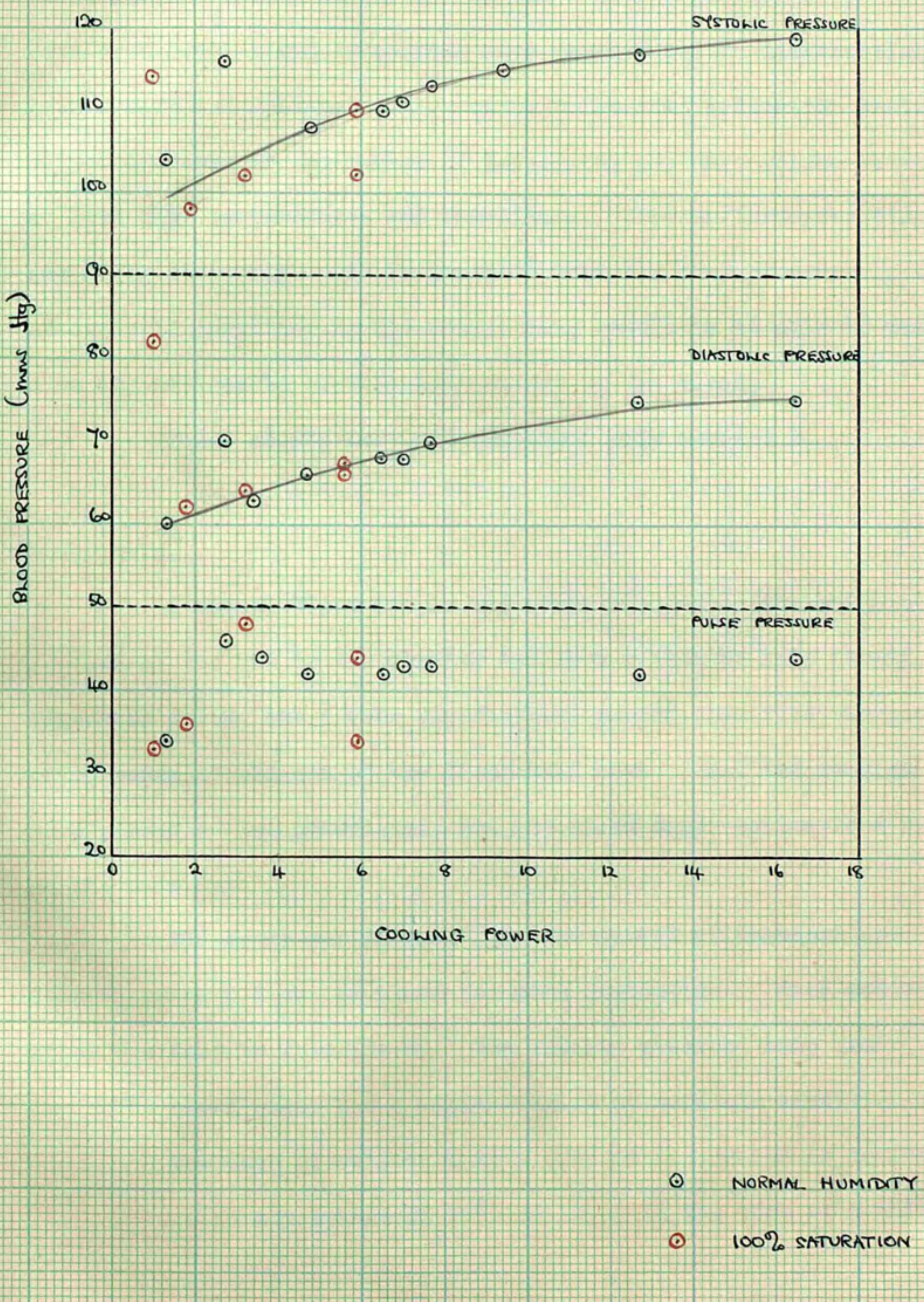
The results obtained with subject A showed that:

1. The blood pressure (B.P.) is not greatly affected by variations in the air conditions. The systolic B.P. only increased from 94 to 109 over a cooling power range of 1 to 11.0.
2. High temperatures decrease the B.P. probably chiefly because of dilatation of the cutaneous vessels, and low temps. increase it because of vasoconstriction of the skin vessels and also as has been shown by Barcroft, because of a increase in the minute volume and systolic output of the heart.
3. Air movement produces a slight increase in both systolic and diastolic blood pressures.
4. The diastolic B.P. follows the systolic B.P. so that the pulse pressure is approximately constant. Air movement tends to produce a slight increase in the pulse pressure.
5. Increased humidity produces no noticeable effect on the B.P.

In the case of subject B it was shown that:

1. The systolic and diastolic B.P. are roughly proportional to the C.P. (excluding air conditions with high humidities), both increasing with an increase in the dry kata C.P.
2. The pulse pressure is approximately constant.
3. Increased humidity produces a fall of B.P. except at high temperatures (90°F). But all the values of the B.P. at 90°F seem to be discrepant and can only be assigned to the individual idiosyncracies of the subject.

SUBJECT B



SYSTOLIC PRESSURE
DIASTOLIC PRESSURE
PULSE PRESSURE
BLOOD PRESSURE (mms Hg)
120
110
100
90
80
70
60
50
40
30
20
0
2
4
6
8
10
12
14
16
18
COOLING POWER
NORMAL HUMIDITY
100% SATURATION

BLOOD COUNTS

Blood counts were made in the case of subject A on the blood sample removed at the end of the 2 hour experimental period. Both erythrocytes and leucocytes were counted but no differential counts were undertaken. There seems to be some indication that a slight decrease in the number of leucocytes per unit volume occurs at both high temperatures and humidities. The erythrocytes did not alter obviously. It is probable that a 2 hour exposure to any atmospheric condition is not nearly long enough to be able to produce any noticeable histological effect on the blood.

These counts were not continued with subject B.

BLOOD SUGAR

A normal blood sample was taken soon after the subject arrived at the hut in the morning and four others at half hourly intervals during the 2 hour experimental period, the first sample being taken at the end of the first half hour. All the samples were placed on ice immediately and the blood sugar estimations done on the same day.

The sugar was estimated by the method of Hagedorn and Jensen, using 0.1 cc. of blood for each estimation. Each estimation was done in triplicate. The results obtained show that:

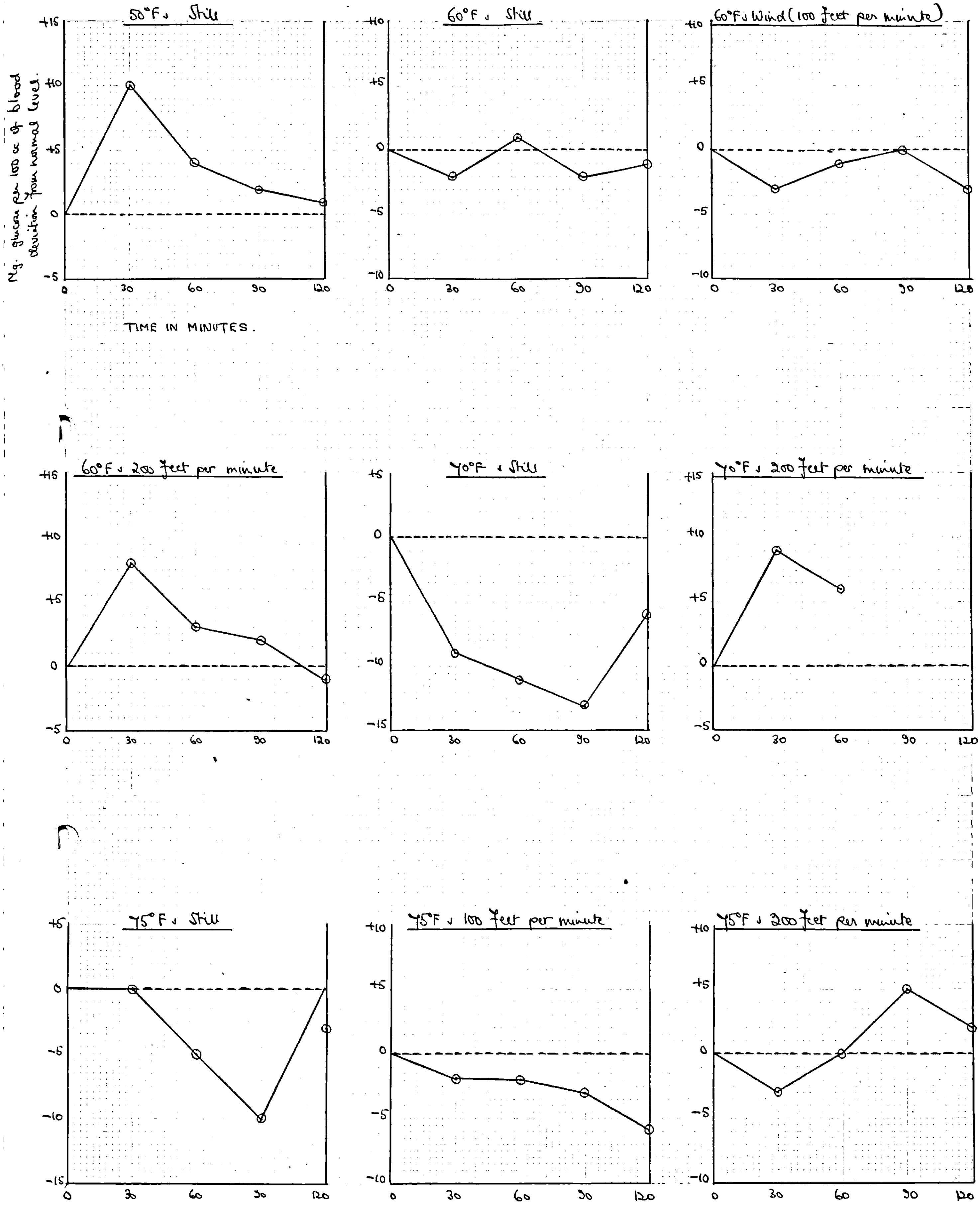
1. The blood sugar has a minimum value at some air condition (in the case of subject A at a C.P. of 3.4, which is equivalent to an atmosphere of 75°F still. In the case of B this

Subject A

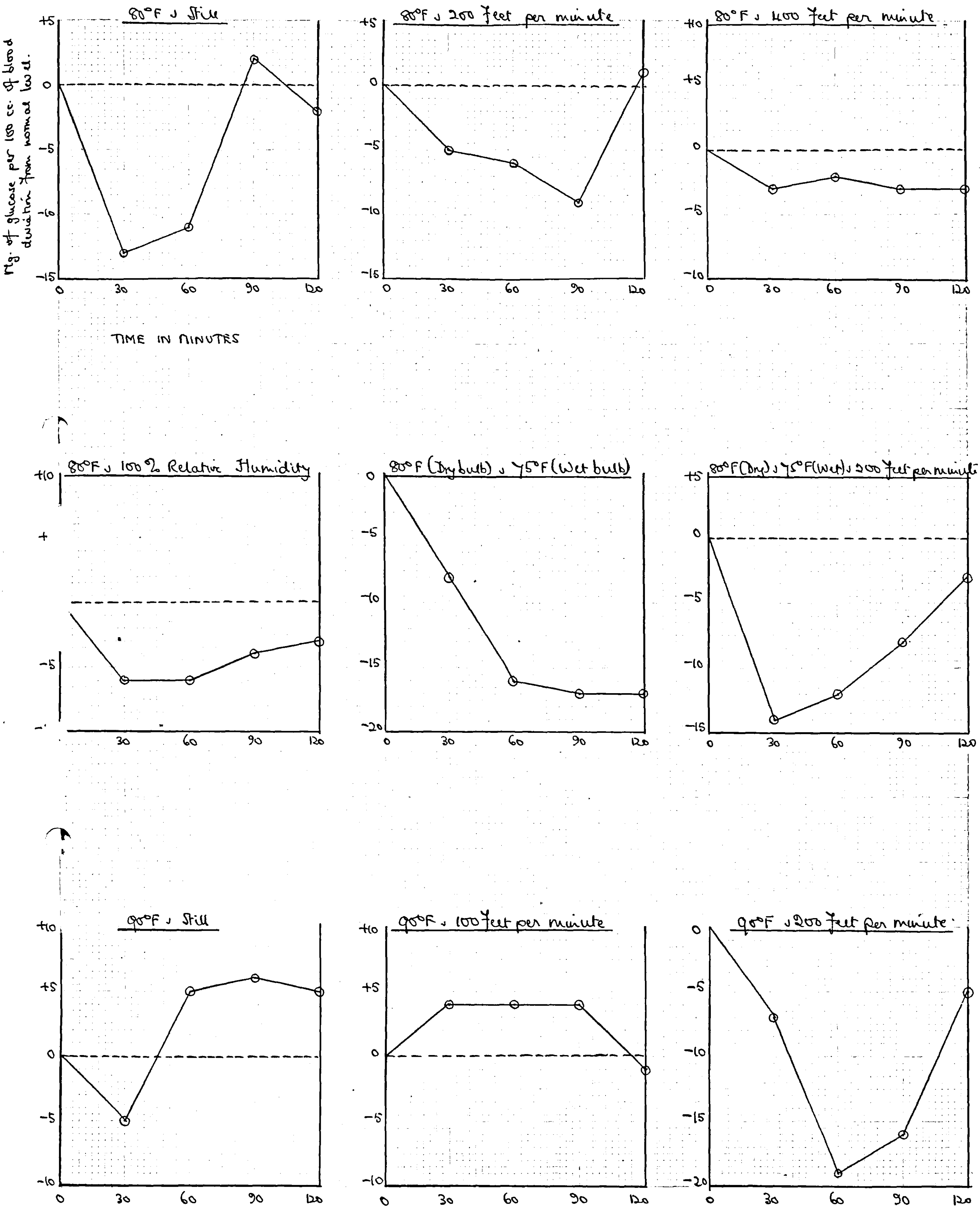
BLOOD SUGARS

	Date	Air Condition: Percentage of relative humidity		Air velocity in feet per min.	Cooling Power	Normal Blood Sugar	Mg Glucose per 100 cc Blood: 30	60	90	120
	Nov.16	50		0	8.0	89	99 (+10)	93 (+4)	91 (+2)	90 (+1)
	Oct.26	60		0	6.5	100	98 (-2)	101 (+1)	98 (-2)	99 (-1)
	Jan.11	60		100	8.3	101	98 (-3)	100 (-1)	100 (-1)	98 (-3)
	Nov.19	60		200	10.0	100	108 (+8)	103 (+3)	102 (+2)	99 (-1)
	Nov.12	70		0	4.2	104	95 (-9)	93 (-11)	91 (-13)	98 (-6)
	Nov.19	70		200	7.8	91	100 (+9)	97 (+6)	146 ?	139 ? (visitor!)
	Nov.26	75		0	3.3	110	110 (±0)	105 (-5)	100 (-10)	107 (-3)
		75		100	5.2	110	108 (-2)	108 (-2)	107 (-3)	104 (-6)
	Jan.11	75		200	6.9	101	98 (-3)	101 (±0)	106 (+5)	103 (+2)
	Nov.9	80		0	2.5	98	85 (-13)	87 (-11)	100 (+2)	96 (-2)
	Nov.24	80		200	5.0	100	95 (-5)	94 (-6)	91 (-9)	101 (+1)
	Nov.26	80		400	8.5	102	99 (-3)	100 (-2)	99 (-3)	99 (-3)
	Nov.5	80	100	0	1.8	105	99 (-6)	99 (-6)	101 (-4)	102 (-3)
...on in cotton mill	Nov.10	80	78	0	2.6	107	99 (-8)	91 (-16)	90 (-17)	90 (-17)
...n mill ventilated		80	63	200	6.0	107	93 (-14)	95 (-12)	99 (-8)	104 (-3)
	Dec.2	90		0	1.07	105	100 (-5)	110 (+5)	111 (+6)	110 (+5)
		90		100	1.6	105	109 (+4)	109 (+4)	109 (+4)	104 (-1)
	Nov.26	90		200	2.0	102	95 (-7)	83 (-19)	86 (-16)	97 (-5)

DEVIATIONS OF BLOOD SUGAR FROM NORMAL LEVEL. SUBJECT A.



SUBJECT A.


80°F , Still
80°F , 200 feet per minute
80°F , 400 feet per minute
Mg. of glucose per 100 cc. of blood deviation from normal level.
TIME IN MINUTES
80°F , 100% Relative Humidity
80°F (Dry bulb) , 75°F (Wet bulb)
80°F (Dry) , 75°F (Wet) , 200 feet per minute
90°F , Still
90°F , 100 feet per minute
90°F , 200 feet per minute
0
30
60
90
120
+5
+10
-5
-10
-15
-20

minimum value was at a C.P. of 2.5 - 4.2, (i.e. between 70°F and 80°F still.), and increases at both higher and lower cooling powers.

The increase in blood sugar on exposure to cold has long been recognised and is attributed to an increased output of adrenaline and a consequently increased glycogenolysis in the liver.

Flinn (1925) subjected dogs to very high temperatures and found a similar increase in the blood sugar which he showed could not be attributed to an increased concentration of the blood solids. The increased blood sugar at high temperatures is probably due to an emergency mechanism which mobilises sugar.

2. At and above the C.P. at which blood sugar is at a minimum, air movement produces an increase in the blood sugar. At lower cooling powers (i.e. at 90°F) wind decreases the blood sugar; that is, it tends to restore it to its normal level.

3. In the case of subject B, increased humidity increases the blood sugar. This increase was in most cases preceded by an initial fall. The results obtained with subject A seem to be rather discrepant in connection with increased humidity.

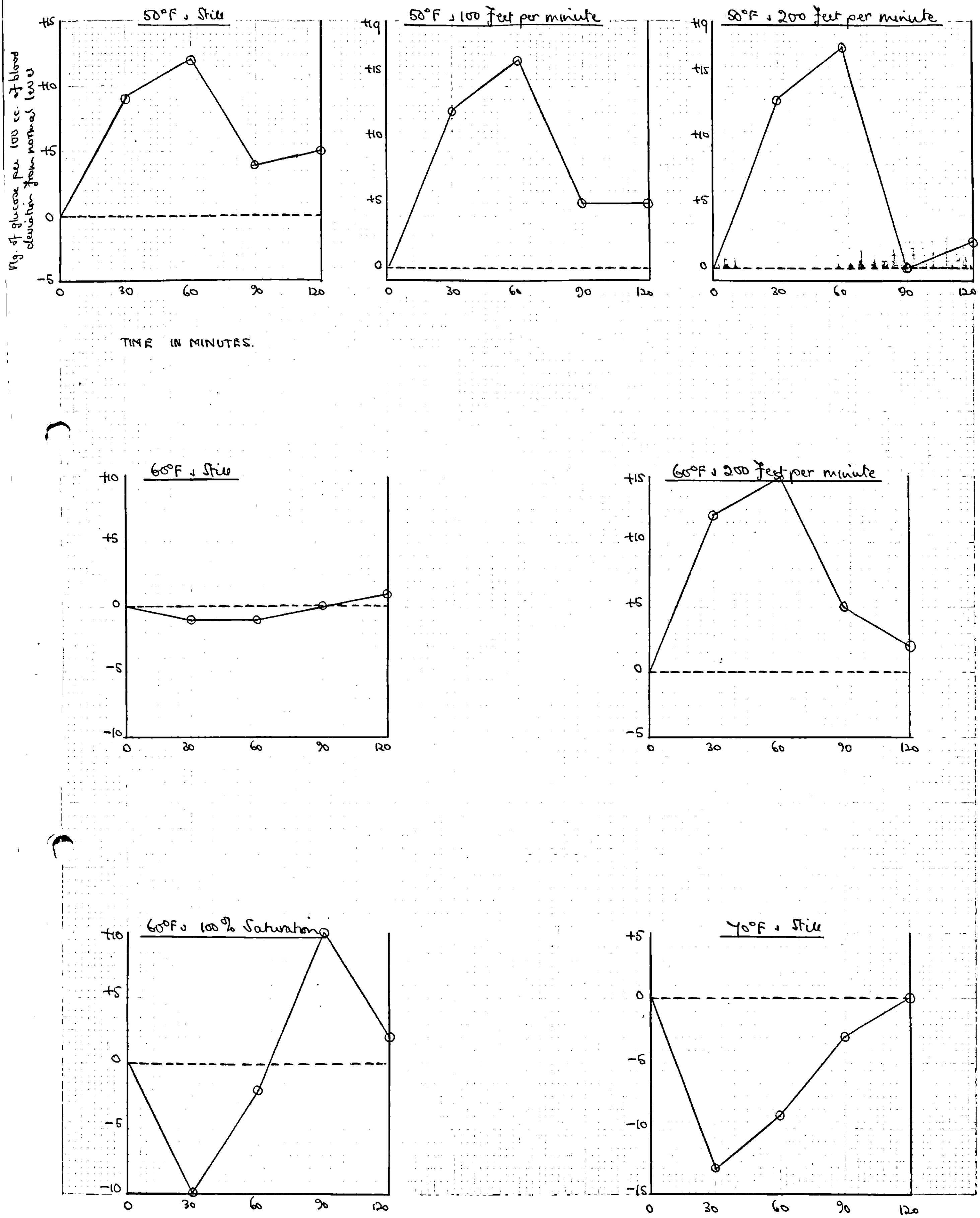
Subject B

BLOOD SUGARS

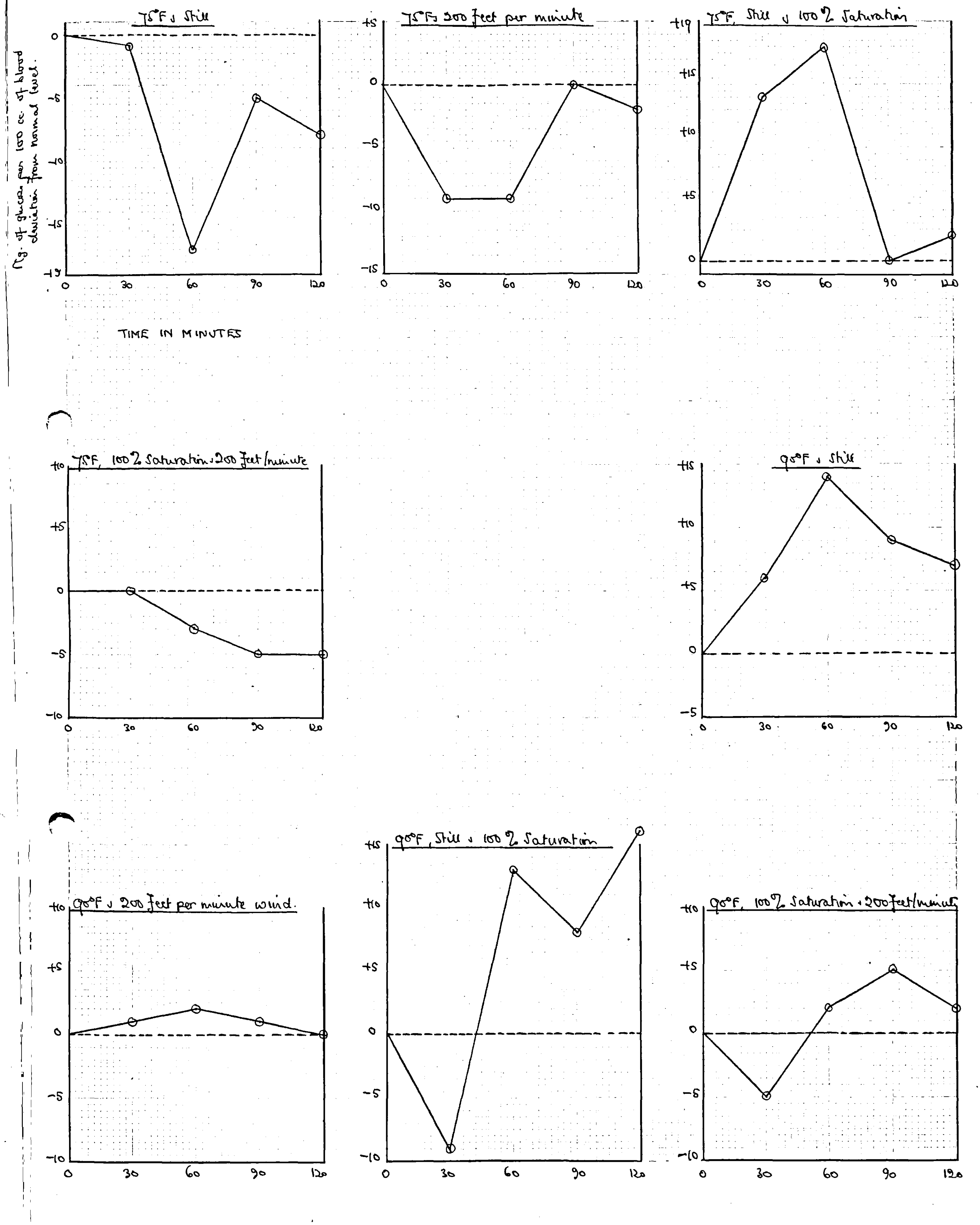
Date	Air Condition °F	Percentage Relative Humidity	Air Velocity in Feet per Min:	Cooling Power	Normal Blood Sugar	Mg Glucose per 100 cc Blood 30	60	90	120
Jan.25	50	61	0	7.7	108	117 (+9)	120 (+12)	112 (+4)	113 (+5)
	50	58	100	12.7	108	120 (+12)	124 (+16)	113 (+5)	113 (+5)
Feb.15	50	52	200	16.5	115	128 (+13)	132 (+17)	115 (±0)	117 (+2)
Feb.1	60	53	0	6.5	110	112 (+2)	112 (+2)	110 (±0)	113 (+3)
Feb.18	60	90	0	6.4	121	120 (-1)	120 (-1)	121 (±0)	122 (+1)
Feb.1	60	51	200	11.2	110	122 (+12)	125 (+15)	115 (+5)	112 (+2)
Feb.29	60	100	200	5.9	118	108 (-10)	116 (-2)	128 (+10)	120 (+2)
Feb.4	70	45	0	4.7	115	102 (-13)	106 (-9)	112 (-3)	115 (±0)
	70	40	200	9.4	115	100 (-15)	100 (-15)	103 (-12)	116 (+1)
Feb.8	75	37	0	3.4	114	113 (-1)	97 (-17)	109 (-5)	106 (-8)
	75	33	200	7.0	114	105 (-9)	105 (-9)	114 (±0)	112 (-2)
Feb.11	75	100	0	3.2	115	128 (+13)	132 (+17)	115 (±0)	117 (+2)
	75	100	200	5.9	115	115 (±0)	112 (-3)	110 (-5)	110 (-5)
Feb.25	90	45	0	1.3	114	120 (+6)	128 (+14)	123 (+9)	121 (+7)
	90	40	200	2.7	114	115 (+1)	116 (+2)	115 (+1)	114 (±0)
Mar.25	90	100	0	1.0	116	107 (-9)	129 (+13)	124 (+8)	132 (+16)
	90	100	200	1.9	116	111 (-5)	118 (+2)	121 (+5)	118 (+2)

DEVIATIONS OF BLOOD SUGAR FROM NORMAL LEVEL

SUBJECT B



SUBJECT B.


75°F, Still
75°F, 200 feet per minute
75°F, Still, 100% Saturation
Mg. of glucose per 100 cc. of blood deviation from normal level.
TIME IN MINUTES
75°F, 100% Saturation, 200 feet/minute
90°F, Still
90°F, 200 feet per minute wind.
90°F, Still, 100% Saturation
90°F, 100% Saturation, 200 feet/minute

RESPIRATION RATE

The respiration rate was taken while the subject was breathing into the Douglas bag and hence those observed at high temperatures were probably higher than those that would occur normally.

The results showed that:

1. The respiration rate (R.R.) does not alter very considerably except under very hot conditions. With subject A the R.R. only altered from 12 to 16 within a range of C.P. of 1-11.0, but in the case of subject B it rose from 8 to 44. All the high values, however, were obtained at 90°F, at which temperature the subject experienced great discomfort.

   Low cooling powers produce a high R.R.

   High " " " low R.R.

2. High temperatures result in an increased rate of respiration but also a decreased depth, so that the ventilation of the lungs is probably not increased.

3. Air movement produces a decreased R.R. This is most marked in B, especially at high temperatures and humidities; in fact at 90°F, a wind of 200 feet per minute almost halved the R.R.

4. Increased humidity produces an increased R.R. with B but no noticeable effect with A. Cheyne Stokes' breathing was noticed with subject B at 90°F and 100% saturation, but this only occurred when breathing into the Douglas bag. The discomfort experienced by B under these conditions is

is accentuated when breathing against such a resistance. The very quick and shallow breathing probably produces a lack of O_2 supply to the respiratory centre.

RESPIRATORY EXCHANGE

Both O_2 consumption and CO_2 output increase at high and low environmental temperatures. In the case of subject A the respiratory exchange was minimum at a C.P. of 3.0, and in the case of B at a C.P. of 6.5

The respiratory exchange is not noticeably affected by humidity.

RESPIRATORY QUOTIENT

Marked variations in the R.Q. were noticed, but there is no relation between the R.Q. and the C.P. or between the R.Q. and the temperature and humidity. The American workers Mc Connell and Yagloglou, however, found that there was a direct relation between the R.Q. and the "effective temperature", the R.Q. increasing with an increasing E.T.

METABOLIC RATE

Three metabolic rate determinations were made for each 2 hour experimental period. The subject breathed into a Douglas bag for 15 minute periods at 40 minute intervals. The average of the

Subject A

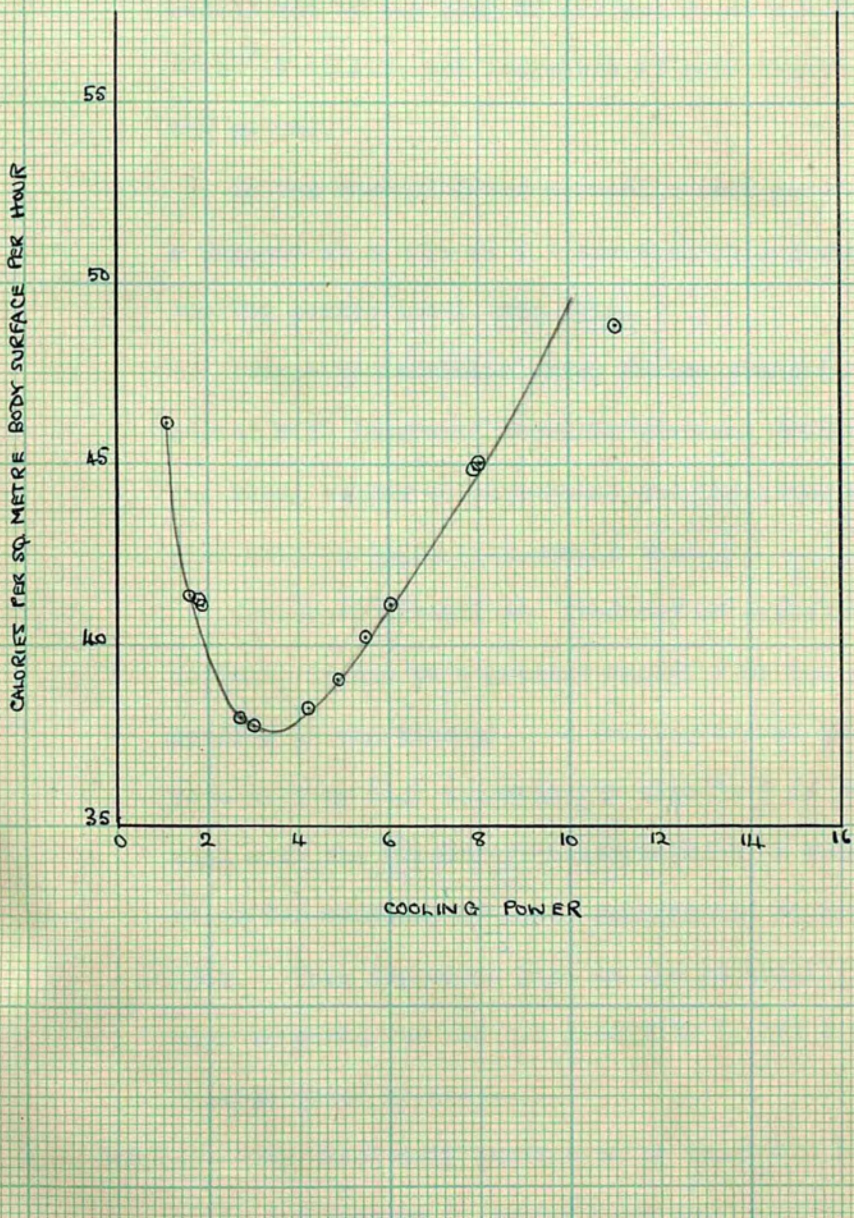
Weight = 70.37 kilos. Height = 164.6 cms.

Surface Area = 1.79 sq. metres.

Air Condition	Expired Air			Volume of expired air in 15 mins. (in litres)	Volume of expired air in 1 min. at N.T.P.	cc O_2/ minute.	cc CO_2/ minute.	R.Q.	Metabolic Rate.	Cooling Power.
	% CO_2	% O_2	% N_2							
50°F, Still.	4.121	16.37	79.509	87.2	5.504	276.1	224.5	0.770	44.98	8.0
60°F, Still.	4.011	16.62	79.367	87.2	5.504	258.36	209.9	0.821	41.18	6.1
60°F, 200 feet/min.	4.135	15.935	79.93	89.45	5.968	309.5	225.0	0.728	48.87	11.0
70°F, Still.	3.556	16.62	79.824	91.5	5.686	242.4	177.0	0.731	38.3	4.2
70°F, 200 feet/min.	4.232	16.17	79.598	85.7	5.713	275.7	220.0	0.798	44.9	7.9
75°F, Still	4.115	16.43	79.455	76.0	4.670	230.2	177.1	9.808	37.8	3.0
75°F, 100 feet/min.	4.086	16.43	79.484	81.3	4.984	254.9	182.7	0.809	40.19	5.5
80°F, Still.	3.556	16.62	79.824	91.5	5.05	242.4	177.0	0.731	38.30	2.8
80°F, 200 feet/min.	4.129	16.80	79.794	87.0	5.15	242.6	191.4	0.866	38.93	4.9
80°F, Still, 100% Saturation.	3.593	16.79	79.617	92.83	5.513	259.4	193.9	0.748	41.21	1.8
80°F, (Dry bulb), 75°F (Wet)	3.574	17.19	79.236	90.5	5.375	233.9	195.4	0.762	37.61	2.7
80°F (D), 75°F (W), 200 feet/min.	3.899	16.33	79.771	89.3	5.304	275.8	204.3	0.742	43.92	5.8
90°F, Still.	4.737	16.43	78.833	88.2	5.86	277.0	253.6	0.919	46.1	1.1
90°F, 100 feet/min.	4.027	16.37	79.603	85.1	5.055	256.1	201.4	0.780	41.30	1.6
90°F, 200 feet/min.	4.326	16.36	79.312	86.85	5.037	251.9	195.0	0.857	41.06	2.0

SUBJECT A

METABOLIC RATE AND COOLING POWER



three metabolic rates was taken for each air condition.

The results show that:

1. The metabolic rate is at its minimum at a certain air condition; in the case of subject A, at a cooling power of 3.0 (≡ 75°F still) and in the case of subject B, at a C.P. of 6.5 (≡ 60° F still), and increases at both higher and lower cooling powers.

   In the case of B the metabolic rate was found to attain a maximum at a C.P. of 2.7 and then to decrease again at cooling powers lower than this.

   Increased metabolic rates at low temperatures is concerned with increased muscular movement including shivering, increased output of adrenaline and thyroxine and probably also with variations in muscle tone.

   Increased metabolism, produced on exposure to warm conditions, is due to a greater velocity of the chemical reactions in the tissues. A falling off of the metabolic rate at very high temperatures seen in B is probably associated with the discomfort accompanied by a general disinclination for muscular movement experienced at a temperature of 90°F. This secondary rise in the metabolic rate at very high temperatures was not seen with A, but A was in no way incapacitated by heat.

2. Subject A was absolutely unaffected by increased humidity, whereas in the case of B, at 60°F and 100% saturation an increase in the metabolic rate was produced, and at 75°F there was no

Subject B

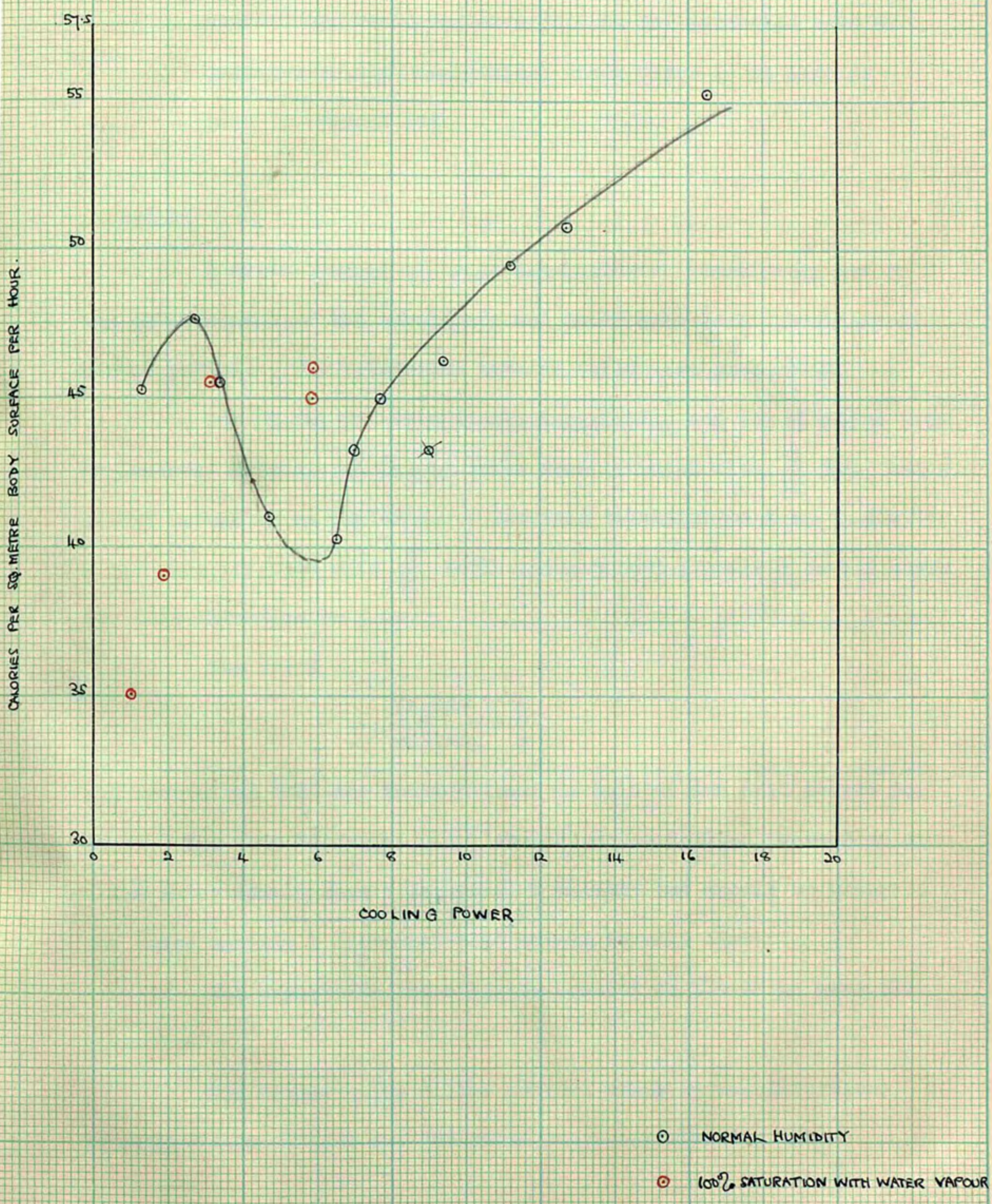
Weight = 75.42 kilos. Height = 168 cms.

Surface Area = 1.85 sq. metres.

Air Condition	Expired Air			Volume of expired air in litres/ 15 mins.	Volume of expired air in 1 min. at N.T.P.	cc O_2 retained per min.	cc CO_2 per min.	R.Q.	Metabolic Rate.	Cooling Power.
	% CO_2	% O_2	% N_2							
50°F, Still.	4.236	16.24	79.624	90.83	5.875	283.3	248.4	0.8813	44.93	7.7
50°F, 100 feet/min.	3.551	16.783	79.706	116.5	7.534	325.4	263.3	0.8065	50.70	12.7
50°F, 200 feet/min.	3.198	17.49	79.312	154.0	9.850	345.7	314.6	0.9102	55.32	16.5
60°F, Still.	3.974	16.562	79.464	88.05	5.746	252.5	222.5	0.893	40.21	6.5
60°F, 200 feet/min.	3.450	16.995	79.555	124.2	7.685	313.9	265.3	0.848	49.45	11.2
60°F, Still, 100% Saturation.	3.506	16.82	79.674	108.4	6.842	292.8	239.8	0.8101	45.96	5.9
70°F, Still.	3.943	16.28	79.77	89.43	5.514	266.4	217.4	0.8244	41.00	4.7
70°F, 200 feet/min.	3.874	16.17	79.95	96.9	5.974	298.7	231.2	0.774	46.15	9.4
75°F, Still.	3.799	16.38	79.821	100.9	6.141	291.7	233.0	0.799	45.40	3.4
75°F, 200 feet/min.	3.924	15.90	80.176	88.87	5.407	283.3	211.9	0.732	43.31	7.0
75°F, Still, 100% Saturation.	3.395	17.23	79.375	126.0	7.410	286.7	251.2	0.876	45.55	3.2
75°F, Wind, 100% Saturation.	3.326	16.78	79.894	113.5	6.673	292.3	221.7	0.758	44.95	5.9
90°F, Still.	3.096	17.24	79.864	124.85	7.547	292.1	235.5	0.799	45.18	1.3
90°F, 200 feet/min.	3.494	16.53	79.976	113.2	6.798	316.8	237.2	0.749	47.66	2.7
90°F, Still, 100% Saturation.	3.061	17.45	79.480	105.7	6.160	222.4	186.3	0.847	35.04	1.0
90°F, Wind, 100% Saturation.	2.886	17.81	79.304	130.1	7.505	247.2	209.7	0.912	38.95	1.9

SUBJECT B.

METABOLIC RATE AND COOLING POWER



effect, and at 90°F there was a fall. Theoretically, of course, one would expect a fall in the metabolic rate on exposure to high humidities, since there is no loss of heat by evaporation.

EXCRETION

A normal sample of urine was collected immediately before the commencement of the experiment and again over each 2 hour experimental period. The volume and time of collection were noted.

The pH was determined colorimetrically and the alkaline tide by Leathes' method. 5 cc. of urine were titrated with $\frac{N}{10}$ HCl, using methyl orange as an indicator. Let this titration be x cc. Another 5 cc. were titrated with $\frac{N}{10}$ NaOH, using phenol phthalein as indicator. Let this titration be y cc.

The ratio

$$\frac{Na_2HPO_4}{NaH_2PO_4} = \frac{x}{y}$$

was determined and also the % titratable acidity and acid output per hour. The term "alkaline tide" should not be applied to samples of urine which merely show a decreased % acidity but should be reserved for those showing a decreased acid output in unit time.

The creatinine and chloride content of the urine were also determined.

The normal urine of the subject under normal laboratory atmospheric conditions was collected over corresponding time intervals. By this means it should be possible to decide whether the changes in the urine could be ascribed to alterations in the atmospheric conditions, or whether they were the normal variations which occur at different times of the day under ordinary atmospheric conditions.

It was found almost impossible to deduce any facts from these results. They do, however, tend to show that the volume of urine increases with decreased air temperature and decreases with increased air temperature, but is not affected by increased humidity. These slight changes in the urinary volume are probably due to variations in the blood pressure.

There seems to be no connection between the reaction of the urine, creatinine and chloride content and the atmospheric condition.

It is probable that a 2 hour exposure to any one given atmospheric condition is not long enough to produce any marked changes in the composition of the urine. Difficulties also arise in using human subjects as it is generally impossible to control the diet absolutely and this seems to be an essential in all urinary observations.

MENTAL EFFICIENCY

The mental efficiency of the subject was tested by the Woodworth and Wells efficiency tests. These involved adding up four single integer figures at a time, which were read out to the subject fairly rapidly and as soon as an answer was received, four others given. The number of groups of figures (each group thus comprising 4 figures) added per minute, and also the number incorrectly added, were noted.

The normal mental efficiency was tested each day soon after the subject arrived at the hut in the morning, in the main building of the Museum, which is kept at a practically constant temperature of 65°F. The subject added up for two 5 minute periods and the average was taken. The mental efficiency was tested three times at 40 minute intervals over each 2 hour experimental period, and the subject added up for 5 minutes each time, as above.

The results of these tests seem to follow extraordinarily closely the subjective sensations experienced.

Only a few observations were made with subject A, but these show that her mental efficiency decreases under cold atmospheric conditions and increases under hot conditions and especially in hot and humid atmospheres. Subject A dislikes cold intensely and enjoys heat and increased humidity and did in fact find an atmospheric condition of 90°F and 100% saturation extraordinarily pleasant.

In the case of subject B, it was found that her maximum efficiency was at 65°F still, the normal atmospheric condition in the Museum. It decreased very slightly under colder conditions but considerably under hotter conditions. Humid conditions, even at 60°F produced a marked diminution in her mental capacity, and at 75°F and 100% saturation, this decrease was even greater than that observed at

Subject A

Date	°F.	Air Condition: Percentage relative humidity.	Air Condition: Air velocity in feet per min.	Number added/ 5 mins.	Number added/ wrongly.	Normal Number/ 5 mins.	Normal Number Wrong.	% Deviation from Normal.
Nov.30	60		100	35	2	38	5	-8
Nov.30	75		0	34	2	37	3	-8
	75		100	32	2	37	3	-13
Nov.11	75		200	35	2	38	5	-8
Dec.12	80	78	0	42	1	39	1	+7.7
	80	63	200	39	1	39	1	±0
Dec.2	90		0	40	3	35	2	+14
	90		100	42	2	35	2	+20

Subject B

Date	Air Condition °F.	Percentage relative humidity.	Air velocity in feet per min.	Number added/ 5 mins.	Number added wrongly.	Normal Number/ 5 mins.	Normal Number wrong.	% Deviation from Normal.
	50	64	0	74	1-2	76	0	-3
	50	62	200	67	4	68	0	-1½
	60	50	0	74	2-3	75	2	-1½
	60	48	200	67	1	68	0	-1½
	60	100	0	74	2	79	1	-6
	75	34	0	69	2-3	73	2	-5½
	75	31	200	72	1	73	2	-1½
	75	100	0	66	2	79	1	-16
	90		0	65	4	75	1	-14
	90		200	67	1	72	1	-8

Subject C

Date	Air Condition °F.	% relative humidity.	Air velocity in feet per min.	Number added/ 5 mins.	Number added wrongly.	Normal Number/ 5 mins.	Normal Number wrong.	% Deviation from Normal.
	50	64	0	62	6	63	2	− 2
	50	62	200	62	5	63	2	− 2
	60	50	0	65	2	65	1	± 0
	60	48	200	61	2	63	2	− 3
	60	100	0	82	2	77	1	+ 7
	75	34	0	63	3	60	0	+ 5
	75	31	200	65	1–2	65	1	± 0
	75	100	0	83	3	77	1	+10
	90		0	79	2	75	1	+ 6
	90		200	69	2	64	0	+ 8

$90^{o}F$ and still. Subject B is very averse to hot atmospheric conditions and found hot and humid atmospheres almost unbearable.

Subject C showed a slight decrease in mental efficiency at atmospheric conditions colder than $65^{o}F$ (i.e. at cooling powers 6.5) but showed a decided increase under hotter conditions but a decrease again at $90^{o}F$ still. $90^{o}F$ and 200 feet per minute seemed to be the limit for comfort. As in the case of subject A, an increased efficiency was observed under saturated air conditions.

Although both A and C were subjectively uninfluenced by increased humidity, it is very difficult to explain why there should be an actual increase in the mental efficiency under humid conditions.

It is also interesting to note that the mental efficiency seems to run almost parallel with the muscular efficiency, as will be seen in the next section.

MUSCULAR EFFICIENCY

The muscular efficiency of the subject was tested on a bicycle ergometer. Since muscular fatigue is due principally to some kind of circulatory failure, it was thought permissible to take the pulse rate, or rather the pulse index, as an index of muscular efficiency. The pulse index was taken as the

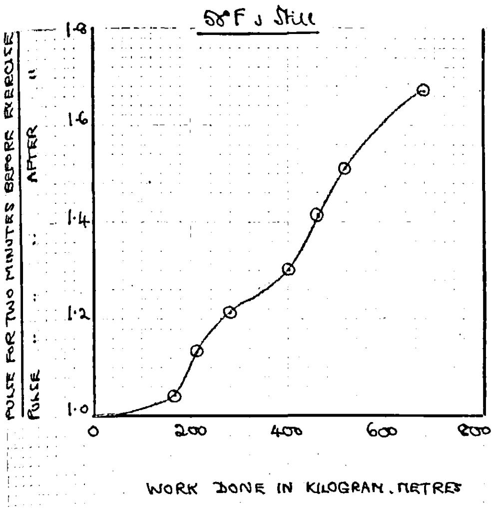
$$\frac{\text{Pulse rate for 2 minutes before exercise}}{\text{Pulse rate for 2 mins. immediately after exercise}}$$

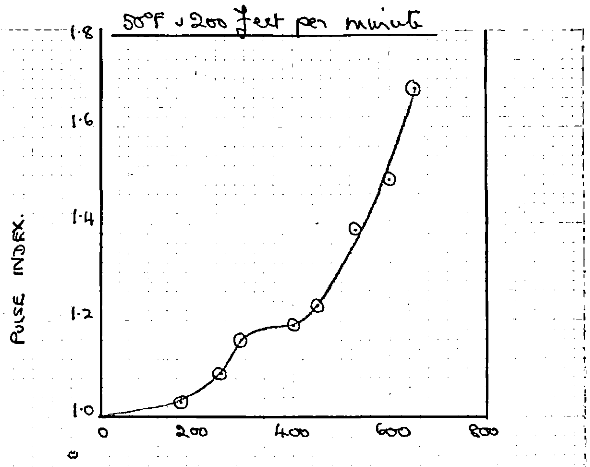
At the beginning of the experiment the subject sat in the resting position on the bicycle for about 10 minutes, and the pulse rate was

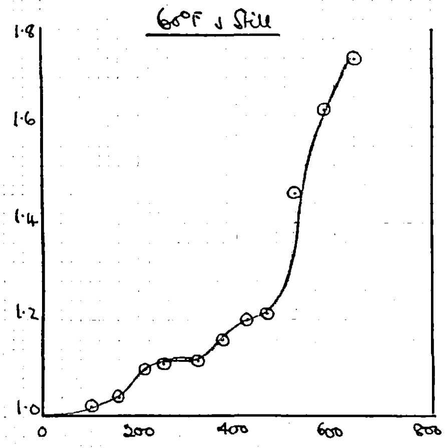
Subject B

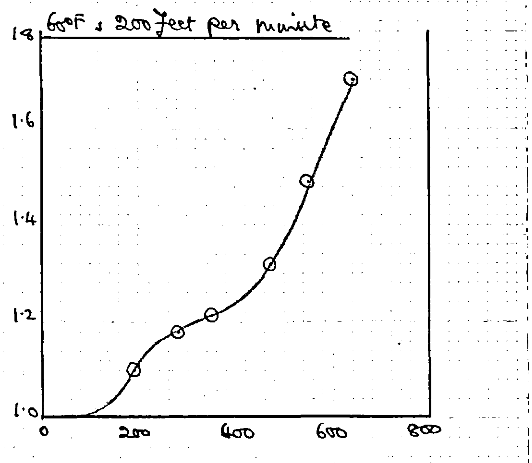
AIR CONDITION °F.	Percentage relative humidity.	Air velocity in feet per min.	COOLING POWER	WORK DONE IN KILOGRAM-METRES TO GIVE A PULSE INDEX OF 1.3	1.4	1.5	1.6	1.7
50		0	7.8	400	455	505	580	670
50		200	13.8	490	540	590	626	670
60		0	6.2	500	515	535	580	640
60		200	11.2	500	530	555	600	650
60	100	0	5.9	385	425	455	486	520
60	100	200	11.0	510	570	600	606	615
75		0	3.4	350	470	516	540	600
75		200	6.0	493	530	566	586	610
75	100	0	3.3	407	430	450	468	480
75	100	200	4.9	405	445	500	570	660
90		0	1.3	353	455	506	555	610
90		200	2.7	345	370	435	525	645
90	100	0	1.0	340	390	420	430	440
90	100	200	2.4	255	335	415	500	580

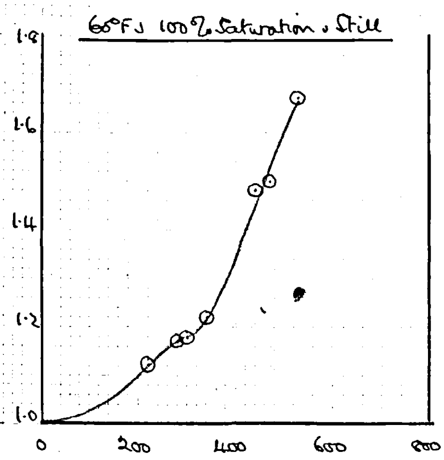
SUBJECT B

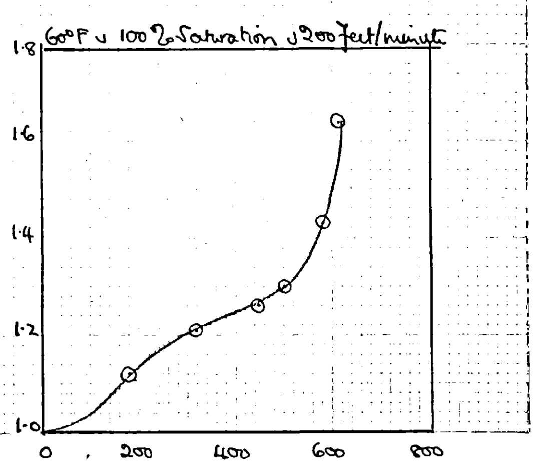

58°F, Still
PULSE FOR TWO MINUTES BEFORE EXERCISE
PULSE " " " AFTER "
1·0
1·2
1·4
1·6
1·8
0
200
400
600
800
WORK DONE IN KILOGRAM.METRES


58°F, 200 feet per minute
PULSE INDEX.
1·0
1·2
1·4
1·6
1·8
0
200
400
600
800

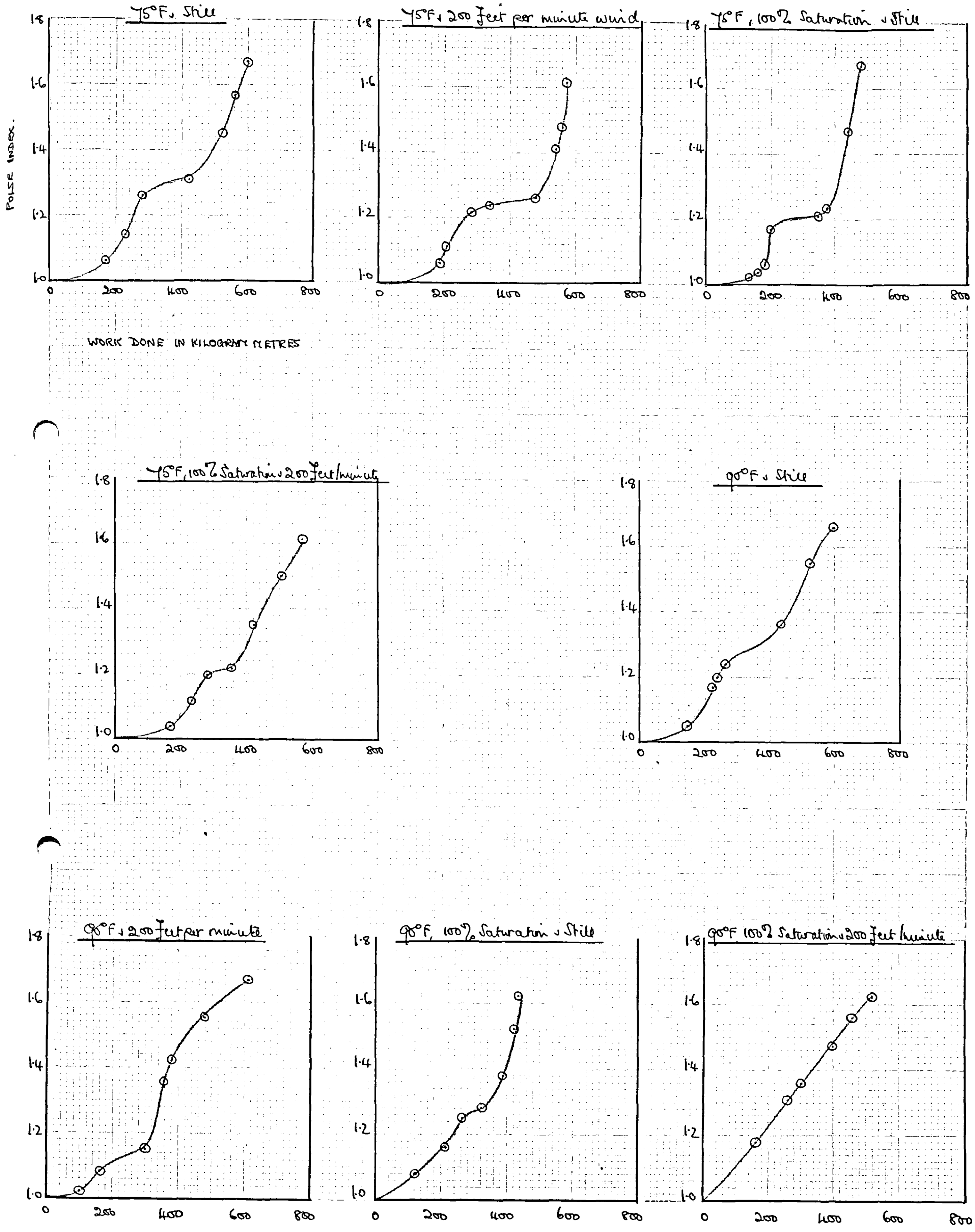

60°F, Still
1·0
1·2
1·4
1·6
1·8
0
200
400
600
800


60°F, 200 feet per minute
1·0
1·2
1·4
1·6
1·8
0
200
400
600
800


60°F, 100% Saturation, Still
1·0
1·2
1·4
1·6
1·8
0
200
400
600
800


60°F, 100% Saturation, 200 feet/minute
1·0
1·2
1·4
1·6
1·8
0
200
400
600
800

SUBJECT B



75°F, Still
75°F, 200 feet per minute wind
75°F, 100% Saturation, Still
75°F, 100% Saturation, 200 feet/minute
90°F, Still
90°F, 200 feet per minute
90°F, 100% Saturation, Still
90°F 100% Saturation, 200 feet/minute
PULSE INDEX.
WORK DONE IN KILOGRAM METRES
1·0
1·2
1·4
1·6
1·8
0
200
400
600
800

taken until it became constant. Three-minute periods of work were done and the pulse rate counted for each $\frac{1}{2}$ minute immediately after the exercise until it returned to normal. The work was varied by altering both the load and the speed of the exercise so that about 6 to 10 different degrees of work were performed at each atmospheric condition.

Graphs were drawn plotting the pulse index against the work done in kilogram-metres. This method was used by Barcroft in connection with the effect of high altitude on muscular efficiency. From these graphs, the work done in kilogram-metres to give a pulse index of 1.2, 1.3, 1.4, 1.5, 1.6, and 1.7 was read off and tabulated.

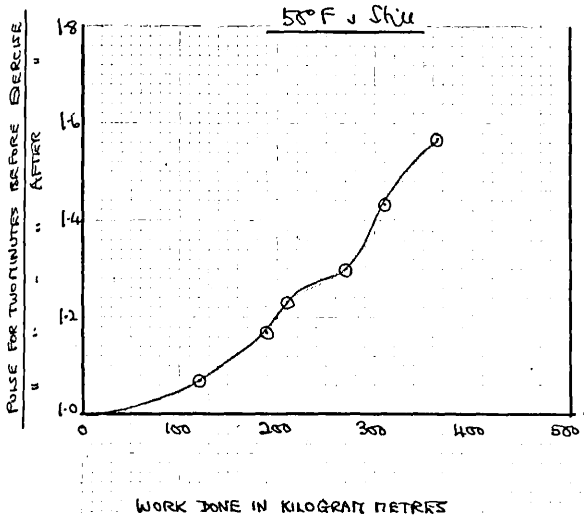
In this way it was possible to compare the efficiency at different air conditions i.e. to find the work which has to be done to produce a certain pulse index at each different atmospheric condition.

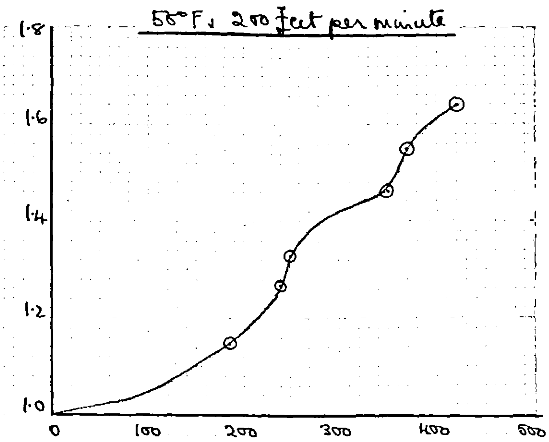
It is seen that all these curves exhibit a certain flattening. This flattening probably corresponds to an optimum period for muscular work, over which period the pulse rate is practically unaffected by increased work.

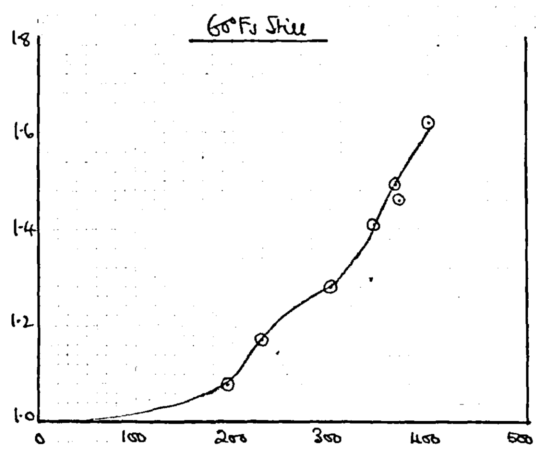
Taking, in the case of subject C, the work done to produce a pulse index of 1.6, to serve as an index of the muscular efficiency, it seems that the efficiency is scarcely affected over a range of cooling power of 3.6 to 16.2, but at high temperatures (90°F) the efficiency is increased. A slight decrease is seen at 90°F still,

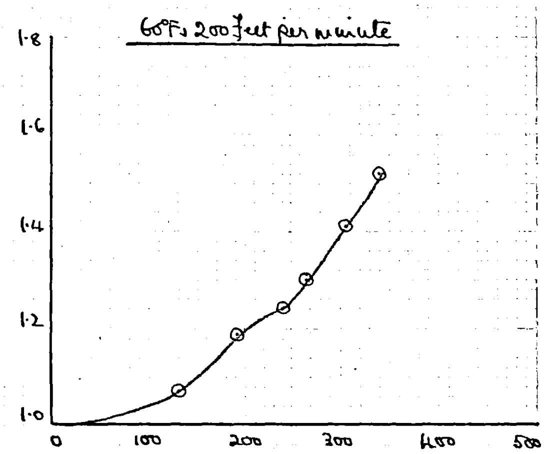
Subject C

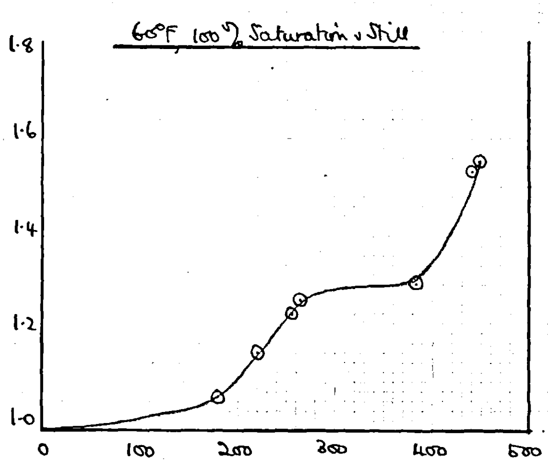
Air condition: °F.	Percentage relative humidity.	Air velocity in feet per min.	Cooling power	Work done in kilogram-metres to give a pulse index of 1.2	1.3	1.4	1.5	1.6
50		0	7.8	206	270	302	344	380
50		200	16.2	210	247	300	360	398
60		0	6.3	240	313	343	360	395
60		200	12.7	200	364	300	351	358
60	100	0	6.0	236	384	406	425	447
75		0	3.6	212	262	340	363	386
75		200	5.7	200	260	330	360	410
75	100	0	3.2	264	296	327	410	437
90		0	1.3	243	277	404	472	(>500)
90		200	2.7	263	364	404	496	(>500)


50°F v Still
PULSE FOR TWO MINUTES BEFORE EXERCISE
AFTER
1·8
1·6
1·4
1·2
1·0
0
100
200
300
400
500
WORK DONE IN KILOGRAM METRES


50°F v 200 feet per minute
1·8
1·6
1·4
1·2
1·0
0
100
200
300
400
500

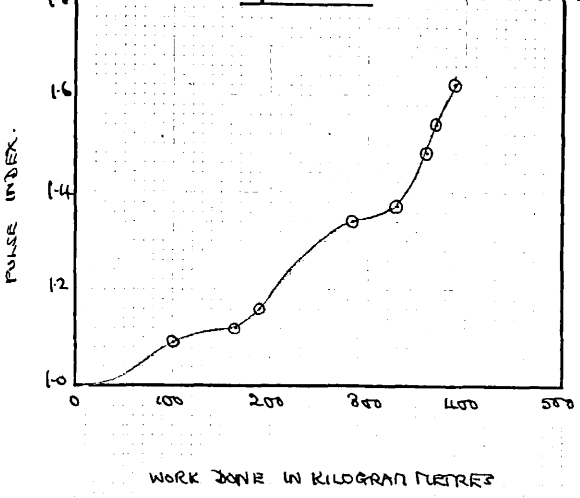

60°F v Still
1·8
1·6
1·4
1·2
1·0
0
100
200
300
400
500


60°F v 200 feet per minute
1·8
1·6
1·4
1·2
1·0
0
100
200
300
400
500

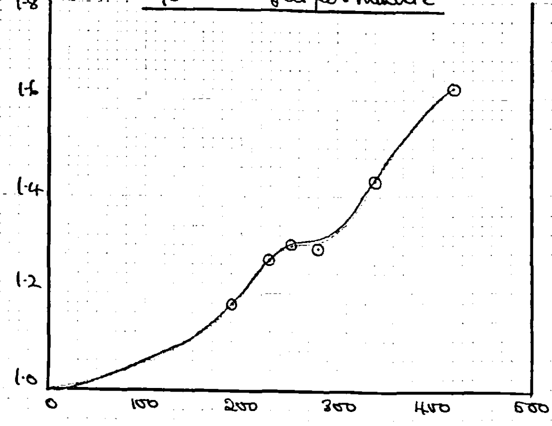

60°F, 100% Saturation v Still
1·8
1·6
1·4
1·2
1·0
0
100
200
300
400
500

SUBJECT C

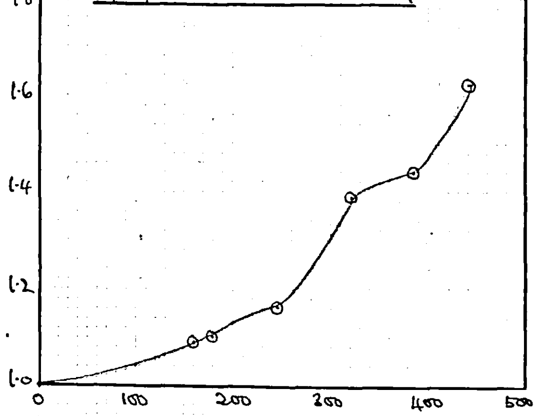
75°F, Still



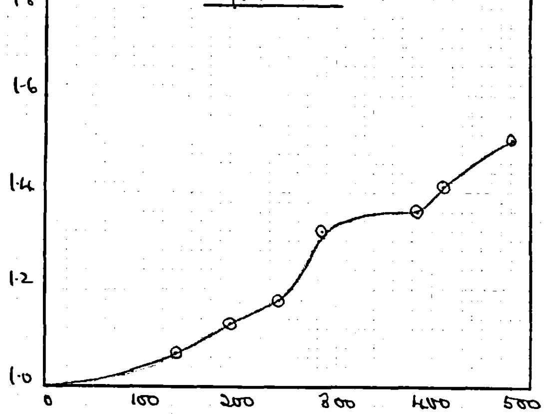
75°F, 200 feet per minute



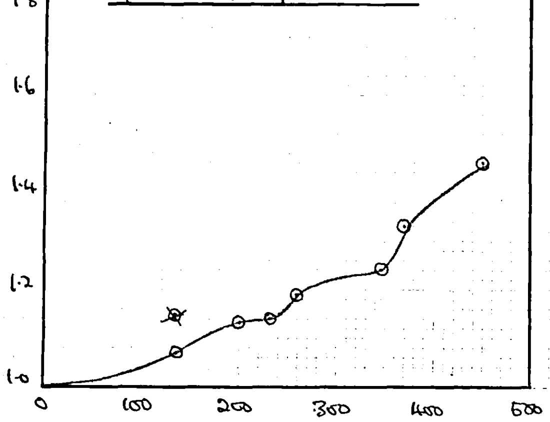
75°F, Still & 100% Saturation



90°F, Still



90°F, 200 feet per minute



90°F with a wind being the upper limit for comfort. (See also mental efficiency) (Subject C was not very strong and was unable to perform more than 500 kilogram-metres of work and hence no values of the work done at 90°F to produce a pulse index of 1.6 were obtained, but it is obvious from the graphs that this figure must be greater than 500 kilogram-metres.)

In the case of subject B, taking the work done to produce a pulse index of 1.7 as a criterion of the efficiency, it is seen that the efficiency is very slightly increased at high cooling powers and there is also a decrease in the efficiency at 75°F and about the same decrease at 90°F. The efficiency at these dry atmospheric conditions is practically uninfluenced by air movement although there is a slight increase in the efficiency at 90°F when there is a wind.

The efficiency is greatly reduced by increased humidity even at temperatures as low as 60°F, and in every case the efficiency is increased by air movement of 200 feet per minute and restored practically to normal.

CONCLUSION

It is seen that different subjects react differently to varying atmospheric conditions and hence it is impossible to lay down any hard and fast rules as to the effects which will be produced by any one atmospheric factor, such as increased humidity or air movement.

Some subjects are entirely uninfluenced by increased humidity of the air, whereas others are greatly incapacitated by it. The majority of people indeed, find that air which is saturated or nearly saturated with moisture is very oppressive. This is probably chiefly due to the unaccustomed sensations which it produces. In this country the humidity very seldom corresponds to a saturation of more than 60% and consequently the body has got accustomed to relatively dry air. But in moist climates it would soon get equally accustomed to humid air and it is possible that it would then experience discomfort if suddenly exposed to dry air.

In the case of all three subjects, the physiological reactions produced by alterations in the atmospheric conditions follow very closely the subjective sensations experienced. Thus subject A, who liked hot air conditions and was in no way incapacitated by atmospheres saturated with moisture, showed minimum values for the pulse rate, respiration rate, metabolic rate and blood sugar etc. at a cooling power of 3.5 ($\equiv$ 75^{o}F still). Subject B, however, who preferred cooler air conditions than A, showed minimum values at a cooling power of 6.5

(≡ 60°F). Moreover, the range of the variations of these factors with subject B were much greater than with A, probably because A experienced no discomfort at any atmospheric condition to which she was subjected, whereas B found all hot and humid air conditions most disagreeable.

Also, when the subject was uninfluenced by humidity, the physiological factors were also generally uninfluenced. Thus increased humidity had no effect on the pulse rate, respiration rate, blood pressure, metabolic rate and blood sugar etc. of A, whereas these were markedly influenced in B. But in spite of the fact that both A and C were subjectively unaffected by humidity, they both showed an increased mental and in the case of C also an increased muscular efficiency on exposure to atmospheres saturated with moisture. It is difficult to advance any explanation of this phenomenon.

Whenever discomfort was experienced, whether due to increased air temperature or to increased humidity, this was always considerably mitigated by air movement. (Except in the case of subject B at high temperatures and humidity, i.e. 90°F and 100% saturation.)

[illegible]

Thesis

[illegible]

(1) [illegible]