AN INVESTIGATION OF THE EFFECTS OF ADVERS ATMOSPHERIC CONDITIONS SUCH AS ARE EN-COUNTERED IN VARIOUS INDUSTRIES ON MENTAL AND MUSCULAR EFFICIENCY

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(With 1 Graph)

ADVERSE atmospheric conditions, such as occur in mines and various industrie have been shown by numerous workers to have profound effects on both tl health and efficiency of the industrial worker.

In this country, Leonard Hill's katathermometer is now extensively use to determine the suitability or non-suitability of the atmospheric conditioi in factories, since the cooling power (C.P.) serves as a fairly reliable index (bodily comfort. But, as will be shown later, the katathermometer is n(strictly comparable to the human body. Vernon (1926–8) and Bedfor(Vernon and Warner (1926) attempted the very tedious task of calibrating tl katathermometer in terms of human sensation. Workers in factories wei asked if they found the atmospheric conditions "comfortable," "too cold" ("too hot." Taking the average of these observations, these workers foun that a comfortable sensation of warmth was experienced in winter at a C.P. (6·6 and in summer at a C.P. of 6·4. Hence the sensation of warmth is n(directly proportional to the C.P., but varies with the season. Acclimatisatio is also a very important factor.

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

A dry C.P. of 6 and a wet C.P. of 18 is suitable for sedentary workers,
A dry C.P. of 8 and a wet C.P. of 25 is suitable for light manual work, an(
A dry C.P. of 10 and a wet C.P. of 30 is suitable for heavy manual work.

The C.P. standard, however, is only used in England and her colonies. I America a different standard, the "effective temperature" (E.T.) has bee resorted to. This depends on the fact that the same feeling of warmth is give by very different combinations of temperature, air movement and humidit Atmospheric conditions producing the same subjective sensations are know as "equivalent conditions," and these equivalent conditions have the sam "effective temperature." (An atmospheric condition has an E.T. of, fc example, 65, if it is comparable to an air condition of 65° F., saturated wit

https://doi.org/10.1017/S0022172400019008 Published online by Cambridge University Press

moisture and with no air movement.) An E.T. chart has been constructed whereby it is possible to convert any combination of the above three atmospheric conditions into an E.T. It is improbable, however, that the E.T. standard will ever attain more than a very restricted use in industry, since the wet- and dry-bulb temperatures and the air velocity must all be determined, 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 are most marked when the work is of a strenuous physical character.

Orenstein and Ireland (1921–3) made a number of experimental observations on the relation between atmospheric conditions and the production of fatigue in mine labourers in the Rand Mines, and in 1923 Sayers and Harrington also made extensive observations on subjects at rest in deep metal mines.

Campbell and Hill (1922) found that during muscular exertion a definite relationship can ordinarily be demonstrated between the pulse rate (P.R.) and the dry C.P. If the load is kept constant, then the P.R. varies inversely as the dry C.P. These workers also showed that the efficiency of a trained man on a bicycle ergometer was not altered by raising the dry kata C.P. from 3·9 to 11·2. It is probable, however, that this is not true of the untrained individual.

Bauer and co-workers (1931), in their study of men working on a bicycle ergometer in a cold (54° F.) and a hot (93° F.) room, found that the O_2 usage was only very slightly modified. They conclude that the mechanical efficiency does not vary significantly with alterations in temperature between 54 and 93° F.

Amongst the most trying atmospheric conditions in England are those encountered in certain textile industries, such as the weaving of cotton and linen goods, in which it is important to have a hot and humid atmosphere, otherwise breakages of the yarn are very frequent and the quality of the woven material is depreciated. In addition to the textile industries, where a high temperature is desirable in the interests of production, there are other industries, such as laundry work, in which the incidental heat can scarcely be avoided.

The relation of sex to susceptibility to abnormal atmospheric conditions seems to have been given very little consideration, although statements are frequently made that women are more susceptible than men to variations in temperature, air movement and humidity. Since women are principally employed in textile industries and in laundries, and since it is in these industries that the most trying atmospheric conditions are encountered, it seems of importance to obtain some quantitative data as to the effect of abnormal atmospheric conditions on women. Consequently, the present investigation was carried out, all the subjects being women varying in age between 18 and 23 years.

The observations were made 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 heating 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 following experiments convected heat alone was used.) The following physical measurements were made:

(1) *Wet- and dry-bulb temperatures* by means of a sling psychrometer.

(2) *Percentage relative humidity* by means of a recording hygrometer.

(3) *Air movement* by means of a vane anemometer. The air velocity was adjusted from 100 to 400 ft. per min. An air velocity of 200 ft. per min. 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 C.P. and in some cases the wet C.P., in addition, was determined. A self-recording katathermometer (Schuster's modification) was used whenever possible, but since this katathermometer does not register C.P.'s below 3·0, the ordinary alcohol katathermometer of Leonard Hill was employed at low C.P.'s. At air temperatures of 90° F., the high-temperature katathermometer was, in addition, used, since the great time taken for the ordinary kata to cool at this temperature renders it inaccurate. The high-temperature kata cools from 130° to 125° F. The C.P.'s obtained with the two instruments are not, however, comparable.

The C.P. exerted by the air on the kata is estimated at what is approximately the mean body temperature (100–95° 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 kata between 100 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 to the wet katathermometer, and when the skin is dry the rate of cooling is to some extent comparable to the dry katathermometer, 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 kata readings are of extreme importance and form a fair index of comfort for ordinary atmospheric conditions.

Great difficulties arise in using the C.P. as a standard for the comparison of atmospheric conditions. The katathermometer tends to overestimate air movement and to underestimate humidity. The dry kata C.P. 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 C.P.'s, it is obvious that many discrepancies will arise, and these discrepancies are particularly emphasised at high humidities. The C.P. does, in fact, afford a much better qualitative than quantitative index of physiological reactions, but unfortunately there is no other single index, apart perhaps from the effective temperature, which is even as good as this.

The duration of each experiment at any one given atmospheric condition was 2 hours. During this time four blood samples were taken at intervals of 30 min. and three samples of expired air, the subject breathing into a Douglas bag for 15-min. periods, during which time the respiration rate and P.R. were also taken. The blood pressure, mouth temperature and skin temperature were taken at 40-min. intervals and also the mental efficiency tested for 5-min. periods at the same time intervals. The mouth and skin temperatures showed very small and insignificant variations, and hence these results are not tabulated.

After arriving at the hut in the morning the subject rested for about 20 min. and then a normal blood sample was taken and the normal mental efficiency on that day tested, as will be described later. Except when performing work for the determination of muscular efficiency, the subject rested during the whole of the 2-hour experimental period.

The profound effect of clothing on the physiological responses of a subject to any air condition has long been recognised, and hence in order to eliminate this 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 experiment.

The following results were obtained with two of the subjects. Subject A preferred hot to cool atmospheres, and subject B disliked both hot and humid atmospheres profoundly. It will be seen from the results presented that there are very definite reasons for these likes and dislikes.

PULSE RATE

The P.R. was taken over 5-min. periods every 40 min., while the subject was breathing into the Douglas bag and the average value taken (see Tables I and II). The results obtained with both subjects show that:

(1) The P.R. is approximately inversely proportional to the C.P.; increased C.P. resulting in a decrease in the P.R. and decreased C.P. in an increase in the P.R.

(2) Air movement produces a decrease in the P.R. except at high air temperatures, when in the case of subject A, air movement at 90° F. produced no alteration in the P.R., and in the case of B at 90° F. and 100 per cent. saturation, air movement even increased the P.R. (Subject B found that under these conditions wind increased rather than decreased the discomfort experienced.)

(3) Increased humidity may or may not increase the P.R. In the case of A, the P.R. was unaffected by increased humidity, whereas with B increased humidity resulted in a marked increase in the P.R.

The variations in the P.R., 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 over a C.P. range 1 to 10, whereas subject B, who was very susceptible to both increased air temperatures and particularly to increased humidity, showed a much wider range of P.R. under the same air conditions, namely from 65 to 108.

Table I. *Subject A. Registration rate, pulse rate and blood pressure*

	Air condition						Blood pressure		
Date	° F.	Percentage relative humidity	Air velocity in feet per min.	Cooling power	Respiration rate	Pulse rate	Systolic	Diastolic	Pulse
Nov. 16	50	71	0	8·0	12–13	63	106	73	33
Nov. 12	60	61	0	6·2	13	68	104	72	32
Nov. 11	60	60	100	8·3	12	67	109	67	42
Nov. 19	60	63	200	10·0	12	63–64	110	69	41
Nov. 12	70	53	0	4·2	14–15	68	103	70	33
Nov. 19	70	48	200	8·3	13–14	66–67	103	70	33
Nov. 30	75	45	0	3·0	14	74	98	65	33
	75	40	100	5·5	13–14	69	100	67	33
Jan. 11	75	44	200	6·9	12–13	69	107	68	39
Oct. 29	80	50	0	2·6	14–15	75	96	68	28
Nov. 4	80	50	200	5·2	14	72–73	99	68	31
Nov. 26	80	42	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	80	0	2·6	13	73	97	63	34
	80	63	200	6·0	13	69	102	65	37
Dec. 2	90	30	0	1·1	14–15	77	94	61	33
	90	26	100	1·6	14	80	98	63	35
Nov. 26	90	31	200	2·0	14–15	79	100	66	34

Blood pressure

Both systolic and diastolic blood pressures were measured every 40 min. by the auscultatory method (for results see Tables I and II). The results showed that:

(1) Both systolic and diastolic blood pressure (B.P.) are roughly proportional to the C.P. (excluding air conditions with high humidities in the case of B), both increasing slightly with an increase in the dry C.P.

High temperatures decrease the B.P. probably chiefly because of dilation of the cutaneous vessels, and low temperatures increase it because of vasoconstriction of the skin vessels, increased output of adrenaline from the suprarenals and also, as has been shown by Barcroft, because of an increase in the minute volume and systolic output of the heart.

(2) Increased humidity produced no noticeable effect on the B.P. in the case of A. With B, increased humidity resulted in a fall of B.P. except at high temperatures (90° F.). But all the values of the B.P. at 90° F. with B seem to be discrepant and can only be attributed to the individual idiosyncracies of the subject.

(3) The pulse pressure remains approximately constant.

Table II. *Subject B. Respiration rate, pulse rate and blood pressure*

	Air condition						Blood pressure		
Date	° F.	Percentage relative humidity	Air velocity in feet per min.	Cooling power	Respiration rate	Pulse rate	Systolic	Diastolic	Pulse
Jan. 25	50	61	0	7·7	9–10	68	113	70	43
	50	58	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	0	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	72	34
Feb. 4	70	55	0	4·7	10–11	77	108	66	42
	70	50	200	9·4	9	74–75	115	72	43
Feb. 11	75	37	0	3·4	11	72	107	63	42
	75	33	200	7·0	10	72	111	68	43
Feb. 8	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	92	94	60	34
	90	35	200	2·7	24	92	116	70	46
				(Cheyne-Stokes' breathing)					
Mar. 14	90	100	0	1·0	44	98	115	82	33
	90	100	200	1·9	24	108	98	62	36

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 blood sugar was estimated by the method of Hagedorn and Jensen, using 0·1 c.c. of blood for each estimation. Each estimation was done in triplicate. (For results see Tables III and IV.) The results obtained show that:

(1) The blood sugar has a minimum value at some air condition (in the case of A at a C.P. of 3·4, which is equivalent to an atmosphere of 75° F. still). In the case of B, this minimum value was at a C.P. of 2·5–4·2 (*i.e.* between 70 and 80° F. still) and increases at both higher and lower C.P.'s.

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.

Table III. *Subject A. Blood glucose*

	Air condition					Deviations of blood glucose in mg. % from initial level, measured at the following time intervals from the beginning of the experiment			
Date	° F.	Percentage relative humidity	Air velocity in feet per min.	Cooling power	Initial blood glucose mg. %	30	60	90	120
Nov. 16	50	71	0	8·0	89	+10	+ 4	+ 2	+ 1
Oct. 28	60	61	0	6·5	100	− 2	+ 1	− 2	− 1
Jan. 11	60	60	100	8·3	101	− 3	− 1	± 0	− 3
Nov. 19	60	63	200	10·0	100	+ 8	+ 3	+ 2	− 1
Nov. 12	70	53	0	4·2	104	− 9	−11	−13	− 6
Nov. 19	70	48	200	7·8	91	+ 9	+ 6	*	*
Nov. 26	75	45	0	3·3	110	± 0	− 5	−10	− 3
	75	40	100	5·2	110	− 2	− 2	− 3	− 6
Jan. 11	75	44	200	6·9	101	− 3	± 0	+ 5	+ 2
Nov. 9	80	50	0	2·5	98	−13	−11	+ 2	− 2
Nov. 24	80	50	200	5·0	100	− 5	− 6	− 9	+ 1
Nov. 26	80	42	400	8·5	102	− 3	− 2	− 3	− 3
Nov. 5	80	100	0	1·8	105	− 6	6	− 4	− 3
Nov. 10	80	78	0	2·6	107	− 8	−16	−17	−17
	80	63	200	6·0	107	−14	−12	− 8	− 3
Dec. 2	90	30	0	1·1	105	− 5	+ 5	+ 6	− 5
	90	26	100	1·6	105	+ 4	+ 4	+ 4	− 1
Nov. 26	90	31	200	2·0	102	− 7	−19	−16	− 5

* Results discrepant; omitted because of psychological disturbance due to visitor.

Table IV. *Subject B. Blood glucose*

	Air condition					Deviations of blood glucose in mg. % from initial level, measured at the following time intervals from the beginning of the experiment			
Date	° F.	Percentage relative humidity	Air velocity in feet per min.	Cooling power	Initial blood glucose mg. %	30	60	90	120
Jan. 25	50	61	0	7·7	108	+ 9	+12	+ 4	+ 5
	50	58	100	12·7	108	+12	+16	+ 5	+ 5
Feb. 15	50	52	200	16·5	115	+13	+17	± 0	+ 2
Feb. 1	60	53	0	6·5	110	+ 2	+ 2	± 0	+ 3
Feb. 18	60	50	0	6·4	121	− 1	− 2	± 0	+ 1
Feb. 1	60	51	200	11·4	110	+12	+15	+ 5	+ 2
Feb. 29	60	100	0	5·9	118	−10	− 9	+10	+ 2
Feb. 4	70	55	0	4·6	115	−13	− 9	− 3	± 0
	70	40	200	9·4	115	−15	−15	−12	+ 1
Feb. 8	75	37	0	3·4	114	− 1	−17	− 5	− 8
	75	33	200	7·0	114	− 9	− 9	± 0	− 2
Feb. 11	75	100	200	3·2	115	−13	−17	± 0	+ 2
	75	100	200	5·9	115	± 0	− 3	− 5	− 5
Feb. 25	90	45	0	1·3	114	+ 6	+14	+ 9	+ 7
	90	35	200	2·7	114	+ 1	+ 2	+ 1	± 0
Mar. 14	90	100	0	1·0	116	− 9	+13	+ 8	+16
	90	100	200	1·9	116	− 5	+ 2	+ 5	+ 2

Flinn (1924–5) 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 the blood sugar is at a minimum, air movement increases the blood sugar. At lower C.P.'s (*i.e.* at 90° F.) wind decreases the blood sugar, that is, it tends to restore it to its normal level. The beneficial effect of air movement is seen particularly well in the case of subject B. At high temperatures and humidities (*i.e.* at 90° F. and 100 per cent. saturation still) the blood-sugar level is still considerably above normal even after 2 hours' exposure, whereas when air movement is employed the blood sugar has returned practically to normal after 2 hours.

(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.

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 (see Tables I and II) show that:

(1) The respiration rate (R.R.) does not alter very considerably except under very hot air conditions. With subject A, the R.R. only altered from 12 to 16 within a range of C.P. of 1 to 11, but in the case of 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.

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

(3) Air movement produces a decrease in the R.R. This is most marked with B, especially at high temperatures and humidities, in fact at 90° F., a wind of 200 ft. per min. almost halved the R.R.

(4) Increased humidity produces an increase in the R.R. with B, but no noticeable effect with A. Cheyne Stokes' breathing was noticed with subject B at 90° F. and 100 per cent. saturation, but this only occurred when breathing into the Douglas bag. The discomfort experienced by B under these conditions was accentuated when breathing against such a resistance. The very quick and shallow breathing probably results in a deficient O_2 supply to the respiratory centre.

Respiratory quotient

Marked variations in the R.Q. were noticed (Tables V and VI), 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 McConnell and Yagloglou (1924, 1926 *b*), however, found that there was a direct relationship between the R.Q.

Table V. *Subject A. Metabolic rate*

Weight=70·37 kg. Height=164·6 cm. Surface area=1·79 sq. m.

Air condition	Expired air % CO_2	Expired air % O_2	Expired air % N_2	Vol. of expired air in 15 min. (in litres)	Vol. of expired air in 1 min. at N.T.P.	c.c. O_2 retained per min.	c.c. CO_2 per min.	R.Q.	Metabolic rate	Cooling power
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 ft. per min.	4·135	15·935	79·93	89·45	5·963	309·5	225·0	0·728	48·87	11·0
70° F. still	3·556	16·62	79·824	91·5	5·666	242·4	177·0	0·731	38·3	4·2
70° F. 200 ft. per 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	238·2	177·1	0·808	37·8	3·0
75° F. 100 ft. per min.	4·086	16·43	79·484	81·3	4·964	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 ft. per min.	4·129	16·80	79·794	87·0	5·15	242·6	191·4	0·868	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 bulb)	3·574	17·19	79·236	90·5	5·375	233·9	195·4	0·762	37·61	2·7
80° F. (dry bulb), 75° F. (wet bulb), 200 ft. per 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	5·88	277·0	253·6	0·919	46·1	1·1
90° F. 100 ft. per min.	4·027	16·37	79·603	85·1	5·055	258·1	201·4	0·780	41·30	1·6
90° F. 200 ft. per min.	4·328	16·36	79·312	86·85	5·037	251·9	195·0	0·857	41·06	2·0

Table VI. *Subject B. Metabolic rate*

Weight=75·42 kg. Height=168 cm. Surface area=1·85 sq. m.

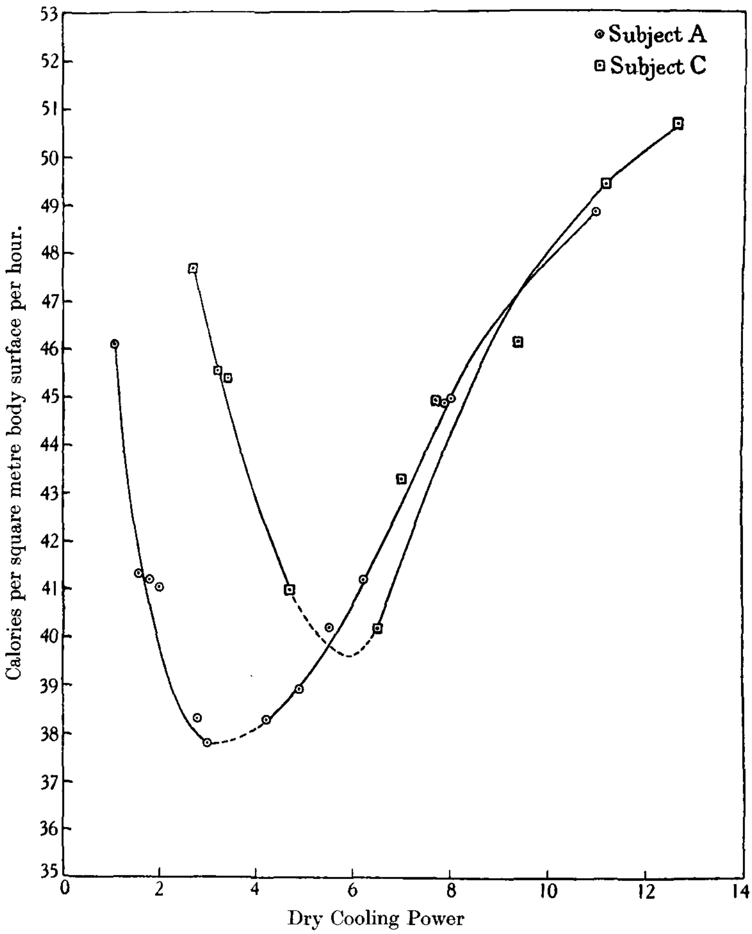
Air condition	Expired air % CO_2	Expired air % O_2	Expired air % N_2	Vol. of expired air in 15 min. (in litres)	Vol. of expired air in 1 min. at N.T.P.	c.c. O_2 retained per min.	c.c. CO_2 per min.	R.Q.	Metabolic rate	Cooling power
50° F. still	4·236	16·24	79·624	90·83	5·875	283·3	248·4	0·8813	44·93	7·7
50° F. 100 ft. per min.	3·551	16·783	79·706	116·5	7·534	325·4	263·3	0·8085	50·70	12·7
50° F. 200 ft. per 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 ft. per 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	0·8181	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 ft. per 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 ft. per 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	77·375	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	79·664	124·85	7·547	292·1	233·5	0·799	45·18	1·3
90° F. 200 ft. per 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	188·3	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

and the E.T., the R.Q. increasing with an increasing E.T. Since the R.Q. is mainly a combustion quotient, it would mean that the E.T. could alter the fuel that was being used. This is very unlikely.

METABOLIC RATE

Three metabolic rate determinations were made during each 2-hour experimental period. The subject breathed into a Douglas bag for 15-min. periods at 40-min. intervals. The average of the three metabolic rates was taken for each air condition. The results (Tables V and VI) show:

(1) The metabolic rate is at its minimum at a certain air condition, in the case of A, at a C.P. of 2·7 (*i.e.* at 80° F. still) and in the case of B, at a C.P. of



Graph 1.

6·5 (*i.e.* 60° F. still) and increases at both higher and lower C.P.'s. The results obtained with B at high humidities seem to be very discrepant and hence are not discussed here nor are they plotted on Graph 1 above.

Increased metabolic rate at low temperatures is connected with increased muscular movement, including shivering, increased output of adrenaline, increased activity of the thyroid and probably also with variations in muscular tone.

Increased metabolic rate at high temperatures shows that under such conditions the regulative functions of the body have ceased to function, since the body is then behaving like a chemical reaction, increased temperature resulting in an increased velocity of reaction in the tissues. Under such air conditions there must be considerable unnecessary energy production, chiefly in the form of heat, and this under conditions in which it is difficult to dissipate the heat. The consequent necessity for increased energy intake in the form of food under such adverse air conditions is obviously of great importance to the industrial worker.

(2) With subject A the metabolic rate was absolutely unaffected by increased humidity, whereas in the case of B, at 60° F. and 100 per cent. saturation, an increase in the metabolic rate was produced, at 75° F. there was no 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 reduced loss of heat by evaporation.

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 four figures) added correctly 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-min. periods and the average was taken. The mental efficiency was tested in this way three times at 40-min. intervals over each 2-hour experimental period (for results see Tables VII and VIII).

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 per cent. 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 per cent. saturation this decrease was even greater than that observed at 90° F. still. Subject B is very averse to hot atmospheric conditions and found hot and humid atmospheres almost unbearable.

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

Table VII. *Subject A. Mental efficiency*

Date	Air condition: ° F.	Air condition: Percentage relative humidity	Air condition: Air velocity in feet per min.	Number added per 5 min. correctly	Number added wrongly	Normal number added per 5 min. correctly	Normal number added wrongly	% deviation from normal
Nov. 30	60	61	100	35	2	38	5	− 8
Nov. 30	75	45	0	34	2	37	3	− 8
	75	40	100	32	2	37	3	−13
Nov. 11	75	44	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	30	0	40	3	35	2	+14
	90	26	100	42	2	35	2	+20

Table VIII. *Subject B. Mental efficiency*

Date	Air condition: ° F.	Air condition: Percentage relative humidity	Air condition: Air velocity in feet per min.	Number added per 5 min. correctly	Number added wrongly	Normal number added per 5 min. correctly	Normal number added wrongly	% deviation from normal
Mar. 16	50	64	0	74	1–2	76	0	− 3
,,	50	62	200	67	4	68	0	− 1½
Mar. 20	60	50	0	74	2–3	73	2	− 1½
,,	60	48	200	67	1	68	0	− 1½
,,	60	100	0	74	2	79	1	− 6
Mar. 23	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
Mar. 27	90	45	0	65	4	75	1	−14
,,	90	35	200	67	1	72	1	− 8

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 P.R., or rather the pulse index, as a criterion of muscular efficiency. The pulse index was taken as:

$$\frac{\text{P.R. for 2 min. immediately after exercise}}{\text{P.R. for 2 min. before exercise}}.$$

At the beginning of the experiment the subject sat in the resting position on the bicycle for about 10 min. and the P.R. was taken until it remained constant. Three-minute periods of work were done and the P.R. counted for each ¼ min. 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 six to ten 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 altitudes 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 how much work has to be done to produce a certain pulse index at each different atmospheric condition.

These results (see Table IX) show that the optimum temperature for the performance of muscular work is at 60° F. At higher temperatures, the same amount of work produces a higher pulse index. At lower temperatures, when the work is not of a severe character (*i.e.* consider the work necessary to produce a pulse index of 1·3 to 1·5), the heat first produced in the performance of muscular work is utilised to overcome the internal friction (or viscosity) of the muscles.

Table IX. *Subject B. Muscular efficiency*

	Air condition				Work done in kilogram-metres in 3 min. to give a pulse index of				
Date	° F.	Percentage relative humidity	Air velocity in feet per min.	Cooling power	1·3	1·4	1·5	1·6	1·7
Mar. 16	50	61	0	7·8	400	455	505	580	670
,,	50	62	200	13·8	490	540	590	626	670
Mar. 20	60	63	0	6·2	500	515	535	580	640
,,	60	50	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
Mar. 23	75	37	0	3·4	350	470	516	540	600
,,	75	33	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
Mar. 27	90	45	0	1·3	353	455	506	555	610
,,	90	35	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

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 C.P.'s. There is 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 ft. per min. 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 due to interference with the loss of heat by evaporation from the body surface.

In all cases, 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 by moisture, showed minimum values for the pulse rate, respiration rate, metabolic rate and blood sugar, etc., at a cooling power of 3·5 ($\equiv 75°$ F. still). Subject B, however, who preferred cooler air conditions, showed minimum values at a cooling power of 6·5 ($\equiv 60°$ F. still). Moreover, the range of the variations of these factors with B was 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 atmospheres most disagreeable.

Also, when the subject was subjectively 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 subject B.

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

It has long been realised that a consideration of atmospheric conditions is of great importance in connection with industry. In the air conditions such as would be encountered in an unventilated cotton mill, for example, most people would show an increased pulse rate, respiration rate and metabolic rate; decreased blood pressure and decreased muscular and mental efficiency, whereas if the mill were ventilated by a wind of 200 ft. per min. (although this amount of air movement is rather more than could be borne with comfort by most people) all of these factors would return almost to the normal level.

Furthermore, since in the interests of efficiency workers are often grouped according to their suitability for certain tasks as shown by their performance in vocational tests, it would seem that a simple physiological test could be devised, based on the pulse index, which would assist in determining a worker's optimum working conditions or his or her suitability for work under air conditions of low- or high-cooling powers.

I am greatly indebted to the Home Office for allowing me to carry out this work in the air-conditioning hut of the Home Office Industrial Museum and also to Mr E. Murray for his valuable help in connection with the physical measurements.

REFERENCES

BAUER, P. S., DILL, D. B., EDWARDS, H. T. and LEVENSON, E. J. (1931). *Arbeitsphysiol.* **4**, 508.

BEDFORD, T., VERNON, H. M. and WARNER, C. G. (1926). *Sp. Rep. Ser. Med. Res. Coun.* No. 100.

—— —— —— (1926 *a*). *Ind. Fat. Res. Board,* Rep. No. 35.

CAMPBELL, J. A. and HILL, L. (1922). *J. Ind. Hyg.* **4**, 246.

FLINN, F. B. (1924). *Amer. J. Physiol.* **70**, 194.

—— (1925). *Pub. Health Rep.* **40**, 868.

HILL, L. (1919). *Sp. Rep. Ser. Med. Res. Coun.* No. 32.

—— (1920). *Ibid.* No. 52.

HILL, L. *et al.* (1923). *Ibid.* No. 73.

MCCONNELL, W. J. and YAGLOGLOU, C. P. (1924). *Pub. Health Rep.* Reprint No. 977, 3075.

—— —— (1926). *J. Amer. Soc. Heat. and Vent. Eng.* **31**, 35.

—— —— (1926 *b*). *Ibid.* **32**, 27.

ORENSTEIN, A. J. and IRELAND, H. J. (1921). *J. S. Afric. Instit. Eng.* March, p. 767.

—— —— (1922). *J. Ind. Hyg.* **4**, 30.

—— —— (1923). *Pub. Health Rep.* Reprint No. 607, 97.

SAYERS, R. R. and HARRINGTON, D. (1923). *Ibid.* Reprint No. 639, 116.

VERNON, H. M. (1926). *J. Ind. Hyg.* **8**, 392.

—— (1927). *Ibid.* **9**, 287.

—— (1928). *Physiol. Reviews,* **8**, 130.

(*MS. received for publication* 1. XII. 1934.—Ed.)