MEASUREMENTS OF TEMPERATURE AND HUMIDITY BETWEEN THE CLOTHES AND THE BODY*

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(With 2 Figures in the Text)

It is evident that a knowledge of the conditions of temperature and humidity which prevails beneath the clothes is essential to a proper understanding of several important problems. For instance, such information is required if one wishes to study the loss of heat from individuals exposed to trying climates, either those prevailing in hot countries or those under which certain occupations are pursued in temperate countries: a study of climatic conditions on the surface of the clothed body might also form a part of an investigation into the factors which control populations of body lice.

It is remarkable how little has been recorded in view of the importance of the subject. Indeed, it seems that nothing has been published since the work of K. Mellanby (1932); before that date only two or three papers had dealt with this matter. It seems, therefore, that even the rather small collection of data here recorded has some value. The figures were collected in south-west Persia by one author (F. Marsh), and worked up in London by the two authors together.

Mellanby (1932) has already pointed out that the methods used by previous authors were open to objections. In particular, no method based on wet-bulb temperatures is appropriate, because the bulb cannot be ventilated, and because evaporation from it adds water to the atmosphere which is being studied. Mellanby himself used a chemical hygrometer. Into this a sample of air was aspirated from the place to be studied and its volume measured at atmospheric pressure. The air was then dried with sulphuric acid and the volume again measured. The method gave satisfactory results, but the apparatus is fragile and rather cumbersome, and it seemed better in the present investigation to make use of a small dew-point apparatus. The temperature and humidity of the air of the room in which the investigation was carried out were measured by whirled dry- and wet-bulb thermometers, and the dew-point of the air in the room was determined at the same time as a check on the accuracy of that method. A sample of air was then drawn from beneath the clothes of the investigator and its dew-point determined. The apparatus used appears to be an improvement on most others in that the mirror is flat and of

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stainless steel: the thermometer is immediately behind the mirror, in front of which is a chamber containing air under study. The formation of dew on the mirror is observed through a wide glass window giving good illumination. The apparatus was made at our suggestion by Messrs Casella, who have been good enough to provide the drawing shown in Fig. 1.

The data were recorded at Masjid-i-Sulieman, in south-west Persia (Iran), at an altitude of approximately 600 ft. above sea-level. The climatic conditions are those of a tropical desert. There is a long, very hot, dry summer extending from early May to mid-October, the period of intense heat (max. 124–127° F., min. 80–105° F.: 51–53 and 27–41° C.) including the latter half of June, July

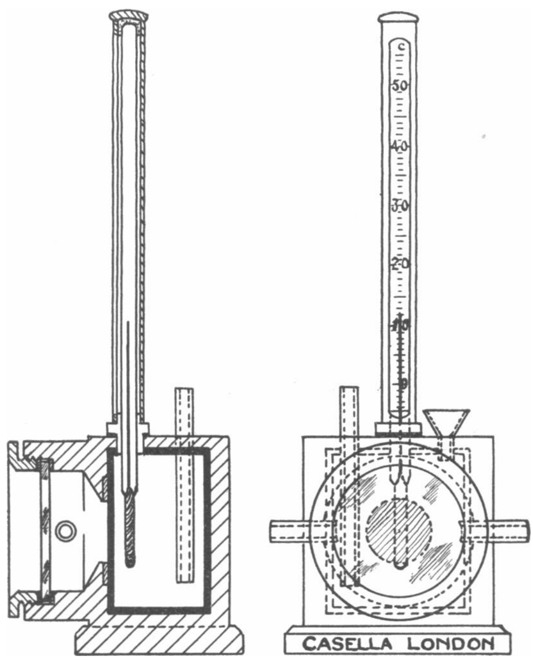

Fig. 1. Side and front view of dew-point apparatus.

and August. This is followed by a short winter, of which the coldest portion extends from mid-December to mid-February, during which the minimum temperature frequently falls several degrees below freezing-point. Rainfall, to the extent of 7–14 in. a year (17–35 cm.), occurs during the winter. The undershirt figures were collected in the office attached to the pathological laboratory, a small room about 10 ft. by 20 ft. with thick stone walls, a door opening on to a verandah, and one small window: both the door and the window were kept shut and shaded during the heat of the day. An electric ceiling fan was provided, but was stopped during each experiment, except where the contrary is shown by an asterisk in Table I. The samples of air from beneath the clothes were obtained with a long glass capillary pipette, initially filled with mercury, inserted through the anterior mid-line buttoned seam of the shirt, so that the point of the pipette came to rest in the cavity under the left armpit. Clothing worn by experimenter (F. M.) was a white cellular cotton shirt and drawers (the shirt having a permanent collar of the same material), a long white laboratory cotton coat, white cotton trousers, and a leather belt. The subject was a well acclimatized healthy European adult male, engaged in sedentary work. He was of regular habits, and the samples were taken approximately $2\frac{1}{2}$ hours after the first meal of the day. The experimental procedure was repeated in exactly the same order on every occasion. Each figure is the mean of at least six observations.

The crude data obtained formed the basis of some simple calculations which can be readily understood if a particular example is followed out. It has seemed best to reduce the figures to saturation deficiencies, which are appropriate to studies on the physiology of man or insect, rather than to work on the relative humidity scale. On 12 February, at 11.30 a.m., the readings obtained with a whirled dry and wet bulb were 17·2 and 15·5° C. Reference to the appropriate tables shows that the vapour pressure of water was 12·4 mm. of mercury: as the saturation vapour pressure corresponding to 17·2° C. is 14·7 mm., the saturation deficiency was 2·3 mm. (i.e. the difference between 14·7 and 12·4). As it was proposed to use the dew-point method for studying the climate beneath the clothes, it seemed best to take a reading of the dew-point of the air of the room as a check on the accuracy of the method. On this occasion the dew-point was found to be 13·3° C., so that the vapour pressure as determined by this method was 11·4 mm., but as the saturation vapour pressure was 14·7 mm. the saturation deficiency was 3·3 mm. (i.e. 14·7 − 11·4). The discrepancy between readings obtained by the two methods is discussed below. Climatic conditions between the clothes and the body were studied at the same time, a reading of the dry bulb being made by a thermometer, the bulb of which was not allowed to come in actual contact with the skin. The dew-point was determined on samples of air sucked out from beneath the clothes. The dry-bulb temperature was 30·0° C., the dew-point 11·6° C. From these figures we deduce a saturation vapour pressure of 31·7 mm. and an actual vapour pressure of 10·2 mm. The saturation deficiency was therefore 21·5 mm.

Reference has been made to the fact that in a series of observations on the humidity of the room taken by whirled thermometers and by dew-point a small error was found on nearly every occasion. This error was always in the same direction, the measurement by dew-point tending to make the humidity appear lower (that is to say, the saturation deficiency greater), than the more reliable whirled thermometers. This error is clearly due to the difficulty in observing the first deposit of dew. Now it is familiar to workers with the dew-point apparatus that it is particularly difficult to obtain satisfactory readings when the dew-point is many degrees below the temperature of the room, that is to say, when the air is hot and dry. The present series of figures shows that under these conditions the observer's error was greatest: when the air was less hot the error was present, but less. A consideration of the original data suggests that the following corrections might be applied to our dew-point readings of saturation deficiency:

Saturation deficiency under 20 mm., subtract 2 mm.
Saturation deficiency 20–35 mm., subtract 4 mm.
Saturation deficiency over 35 mm., subtract 5 mm.

It will be seen that the correction is not in any case a very great one.

Table I. *Giving readings of whirled psychrometer in room, uncorrected readings of dew-point of air aspirated from beneath clothes, and certain figures calculated from the above readings*

		Conditions in room			Conditions beneath clothes		
Hour	Date	Dry bulb ° C.	Wet bulb ° C.	Saturation deficiency mm. Hg	Dry bulb ° C.	Dew-point ° C.	Saturation deficiency mm. Hg
9.15	10 Feb.	18·3	15·5	4·0	27	12·7	15·6
10.45	11 Feb.	19·7	17·5	3·3	31	13·3	22·0
11.30	12 Feb.	17·2	15·5	2·3	30	11·6	21·5
10.30	13 Feb.	17·7	14·4	4·6	28	11·6	18·2
11.45	15 Feb.	17·5	13·9	4·9	29·5	12·7	19·8
11.30	16 Feb.	16·6	13·3	4·4	30	12·7	20·7
10.00	17 Feb.	18·6	14·4	5·9	28	13·3	16·6
13.30	17 Feb.	19·7	14·4	7·6	28	12·7	18·2
11.45	18 Feb.	18·0	14·4	5·0	28·5	11·6	18·8
11.50	19 Feb.	18·0	14·4	5·0	29	13·3	18·5
11.25	7 May	26·1	19·2	12·2	32	12·8	24·4
13.30	20 May†	29·4	19·4	19·1	32	14·4	23·2
11.15	11 June†	34·4	20·6	29·4	32	12·8	24·4
11.30	12 June	35·0	20·6	31·0	31	11·1	23·7
10.00	15 June*†	35·0	19·2	33·2	30	10·0	22·5
11.40	22 June†	35·6	20·6	32·3	31·5	13·3	22·7
13.00	26 June*†	36·1	20·0	35·0	31	11·7	23·2
12.00	6 July*	35·6	20·0	33·3	33	11·7	27·2
12.20	13 July*	36·7	20·6	35·7	29	11·7	19·5
12.30	20 July*†	37·2	20·6	37·1	29	12·8	18·8

* Fan running. † Subject sweating.

In Table I particulars will be found of twenty sets of observations on conditions in the room and beneath the clothes at the same time. The readings of the dew-point in the room are omitted as being irrelevant and having value only as a test of the accuracy of the method. The figures for saturation deficiency beneath the clothes have been calculated from the dry-bulb temperature and dew-point in that position, and are presented without corrections. The same figures are made use of in Fig. 2, but in this instance corrections defined above have been applied to the saturation deficiency readings beneath the clothes. From Table I and Fig. 2, it is apparent that the work was done at two directly contrasted seasons, ten observations having been made in February and ten in the summer, between 7 May and 20 July. The contrast between these two readings in the climate of the room, and the great similarity of the figures for the climate beneath the clothes is brought out by the following mean figures:

	Mean temperature ° C.	Mean saturation deficiency mm. Hg (corrected)
Beneath shirt, February	28·9	16·4
Beneath shirt, summer	31·0	19·4

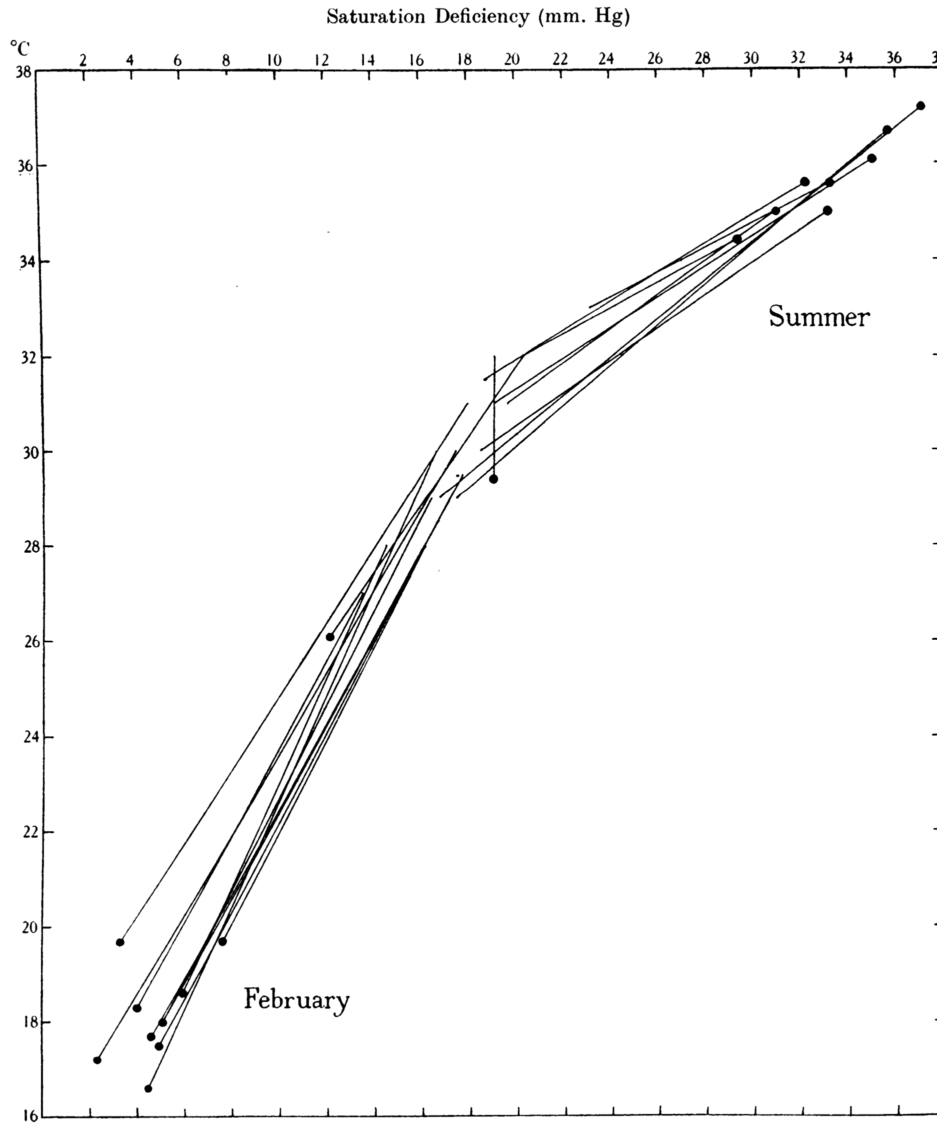

Fig. 2. Conditions of temperature and saturation deficiency, in laboratory and beneath clothes. Each line connects a pair of simultaneous observations, the black circle showing conditions in the laboratory, the other end of the line those beneath the clothes.

The remarkable diversity of the readings in the room, and the great consistency in those taken beneath the clothes, is also shown by a consideration of the following, based on Table I:

	In room			Beneath shirt		
	Max.	Min.	Range	Max.	Min.	Range
Temperature, ° C.	37·2	16·6	20·6	33·0	27·0	6·0
Saturation deficiency mm. (corrected)	37·1	2·3	34·8	23·2	13·6	9·6

From these figures it appears that the range of conditions in the room was three or four times as great as that beneath the clothes. One may suppose that the range of conditions in the open air, even in the shade, would have been still greater.

The figures show that the subject possessed considerable ability to regulate the conditions on the surface of his clothed body, though climatic conditions in the room varied so widely: it may also be observed that the running of the fan appears to have had little effect. At the time when most of the observations were made the subject was not in perspiration, but as Table I shows, even when he was in profuse perspiration diffusion of water vapour through his clothes was sufficient to keep the saturation deficiency at about a normal figure. Dr T. Bedford has made an interesting comment on our data: there is a tendency for dry-bulb temperatures beneath shirt and in room to rise together, till the room temperature reaches about 30° C.: but at higher room temperatures the temperature beneath the clothes falls, presumably owing to sweating. It would be interesting and valuable to supplement these figures by some taken beneath the clothes of a man carrying out light physical work or standing in the sun: it would also be particularly interesting, in relation to the problem of heat stroke, to collect figures from patients suffering from fever and suppression of sweating.

The results obtained by one of us in south-west Persia show remarkable consistency with those obtained by a different observer working in London with a different type of apparatus (Mellanby, 1932). Mellanby carried out his experiments at air temperature ranging from 0 to 40° C. and at a range of saturation deficiency from 1·5 to 37 mm., but beneath the clothes the extreme range of temperature was only 23–37° C. and of saturation deficiency from 13 to 18 mm.

Summary

The paper describes a series of observations made in a well-built room in south-west Persia. A study was made of conditions of temperature and humidity in the room, and between the clothes and the body.

Observations were made in the cold and the hot seasons. In spite of the great contrast which prevailed in the room at these two seasons, there was very little difference on the surface of the body.

The observations are consistent with those published by Mellanby, who worked under a wide range of artificially produced climatic conditions.

REFERENCE

MELLANBY, K. (1932). The conditions of temperature and humidity of the air between the skin and shirt of man. *J. Hygiene*, **32**, 268–73.

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