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Bioclimatic classification of 19 stations in India in terms of cumulative heat stress

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ABSTRACT. The paper makes an attempt to outline a rational approach towards bioclimatic classification of the climates of Indian stations, in relation to human comfort and efficiency, keeping in view the nature and quantum of relevant available meteorological data. A simple and practical index of monthly cumulative heat stress has been defined and termed as Monthly Excess Maximum Effective Temperature-days (MEMET), which has been found to correlate very well with Excess Discomfort Index-Hour-Days based on mean hourly values of dry and wet bulb temperatures during daylight hours. This index has been utilised for grading 19 Indian stations in descending order of cumulative discomfort for (*i*) the hottest month of the year, (*ii*) average of the three hottest months of the year, and (*iii*) average of eight months from March to October. Tentative assessment of the air-conditioning needs has also been made on a monthly basis in terms of MEMET values. Findings are applicable to average acclimatised Indian adult males in normal summer clothing, resting or engaged in sedentary duties indoors with an average wind speed of 150 ft/min (2·7 km/hr).

1. Introduction

Classification of climates is important for many fields of human activity, although the criteria chosen for such classification are determined by the specific field of application. Subrahmanyam *et al.* (1968) have produced a voluminous report on "Climatic Zonation of India and the adjoining areas" on the basis of Thornthwaite's rational scheme. Their approach is essentially that of an agricultural meteorologist, the chief criterion being heat and moisture balance of the soil.

It is only in recent years that attempts have been directed towards bioclimatic classification of climates in relation to human comfort and efficiency. The United States Weather Bureau has been reporting the hot days in terms of "Discomfort Index" (D.I.) which is a simplified version (Thom 1959) of the widely popular Effective Temperature (E.T.) Scale (Yaglou & Miller, 1925). Buettner (1962) has defined a "Desert Equivalent Temperature" (D.E.T.) and produced a tentative bioclimatic map of the USA for the hottest month (July) in terms of D.E.T. This, in his opinion, appears to be a promising first approach for the mapping of areas of discomfort.

In India, no serious attempt seems to have been made so far in this direction, as evidenced by available literature on the subject. However Venkiteshwaran and Swaminathan (1967) have made estimates of thermal comfort on the basis of mean hourly values of Thom's Discomfort Index, in respect of 5 Indian Stations. The data cover a priod of 3-5 years. Whatever be its merits and limitations, their method, being based on hourly values of dry and wet bulb temperatures, cannot be of much practical use, since a very limited number of observatories in India are equipped with autographic instruments. What is actually needed is a rational and practical system of classification in terms of routine meteorological data that are readily available for all Indian Stations.

The object of the present paper is, therefore, to outline a practical and realistic solution of the above problem, keeping in view the nature and quantum of meteorological data available at present with the India Meteorological Department. The findings have been utilised to classify the climates of 19 stations* in terms of cumulative heat stress for which relevant meteorological data were collected from five Regional Meteorological

*Stability of the ranking of 19 stations with different period (with/without overlap), according to the authors, should be the subject of another paper for which meteorological data over a much longer peroid, say 15-20 years should be made available—*Editor*.

Centres under the India Meteorological Department. The scope of the present study has been limited to average acclimatised Indian adult males in normal summer clothing, who are resting or engaged in sedentary activity. Further, the entire analysis has been confined to 8 months of the year, *i.e.*, from March to October, so that the four months from November to February which are relatively cold have not been taken into account.

The findings of the present study may be useful in planning for environmental protection and for deciding the air conditioning needs of living and working spaces. As a matter of fact, this problem was taken up for study, since the existing criteria for air-conditioning of military hospitals on the basis of dry-bulb temperatures alone proved to be inadequate, and often led to anomalous recommendations.

2. Criteria for rational classification of climates

The first step towards the solution of the problem is to define the upper limit of comfort in terms of meteorological parameters, since discomfort due to heat manifests itself above this limit with the onset of active sweating.

2.1. *Upper limit of comfort zone*

For the purpose of the present study, the upper limit of comfort zone is defined as the combination of meteorological parameters, such as ambient dry bulb temperature, humidity and wind speed (radiation may be ignored under ordinary indoor conditions), which is the critical limit for the onset of active sweating. Average wind speed under ordinary indoor conditions, as observed in several wards of the Base Hospital, Delhi Cantt, with ceiling fans on, was about 150 ft/min.

Under comfortable conditions in the absence of sensible perspiration, the evaporative heat loss in respiration and diffusion through skin is reasonably constant and amounts to about 25 per cent metabolic heat production, whence the heat balance equation under indoor conditions may be put in the form (Majumdar 1953) :

$$12\cdot15 \; MI = T_s - T_a \qquad (1)$$

where

M=metablolic rate in met units (one met = 50 kcal/m^2 hr)

I = Total thermal insulation of air *plus* clothing in clo units (one clo = 0·18°C per kcal/m^2 hr=0·324°F/kcal/m^2 hr;

T_s = Mean skin temperature °F

T_a = Ambient dry bulb temperature °F

The following numerical values have been taken for the various parameters in Eq. (1) :

(*i*) Air insulation near sea level at wind speed of 150 ft/min = 0·5 clo (Majumdar 1953).

(*ii*) Average insulation of ordinary Indian summer clothing = 0·4 clo.

(*iii*) Average metabolic rate of resting Indian male adults (age 20-50 years) = 0·9 met (45 kcal/m^2 hr), which is about 10 per cent below the European value.

(*iv*) Mean skin temperature, T at the upper limit of comfort = 95°F or 35°C (Hardy 1970).

Substitution of the above values in Eq. (1) yields a value of 85·2°F for T_a, the ambient dry bulb temperture at wind speed of 150 ft/min at the upper limit of comfort. This is in agreement with earlier observations on upper limit of comfort of Indian subjects (Malhotra 1955). Brooks (1950) has stated that the British comfort zones lie from about 50°F to 69°F, in the USA from 69°F to 80°F, and in the tropics, the range is from about 74°F to 85°F, between 30-70 per cent relative humidity lines.

2.2. *Choice of comfort index*

It will be clear from Eq. (1) that dry bulb temperature alone is a poor index of comfort, which is also influenced by air movement and activity. Although within the zone of vasomotor thermo regulation, comfort is little influenced by humidity over a wide range (Nevins and Hardy 1965), it assumes an increasingly important role with increased heat stress. Among the various indices of heat stress in current use, the predicted four-hour sweat rate (P4SR) of Mc Ardle *et al.* (1947) appears to be the best, since it reliably reflects the effects of various environmental parameters and level of activity. However, for the present purpose, with regard to resting or sedentary, clothed subjects and within the range of natural indoor conditions, the normal scale of effective temperature (E.T.) (Yaglou & Miller 1925) with an assumed wind speed of 150 ft/min is considered to be reasonably satisfactory, particularly because its computation with the help of standard chart is much simpler and less time consuming. Thom's (1959) Discomfort Index (D.I.) which is a simplified version of E.T. is of doubtful reliability because it gives equal weightage to dry and wet bulb temperatures under all conditions. It was, therefore, decided to use the normal E.T. scale with wind speed of 150 ft/min for natural indoor conditions. According to this scale, the upper limit of comfort for Indian sedentary subjects in summer clothing is 80·0°F (E.T.) (Malhotra 1955). At a dry bulb temperature of 85·2°F and wind speed of 150 ft/min this corresponds to a wet bulb temperature 79·0°F or 75 per cent relative humidity.

2.3. *Cumulative heat stress as a measure of climatic severity*

It is well known that the degree of discomfort caused by a particular hot environment is determined jointly by the intensity of heat stress and the duration of continuous exposure to it, the product of the two being termed as "Cumulative heat stress" (Sohar *et al.* 1962 a), on the basis of data collected during an experimental march in Israel, demonstrated how daily water intake could be reliably predicted from the daily values of Cumulative Discomfort Index (Cum. D.I.) and daily work schedule. They computed D.I. from Thom's formula, modified in the form—

$$D.I. = T_a + T_w$$

where T_a and T_w are the dry and wet bulb temperatures in °C. According to Sohar *et al.* (1962 b), discomfort due to heat began when temperature exceeded 24°C (75.2°F) with 100 per cent relative humidity (*i.e.*, $T_a = T_w = 24$°C). They, therefore, chose a D. I. of 48 as the upper limit of comfort which corresponds to 24°C E.T.

Daily values (*i.e.*, over 24 hour periods) of cumulative heat stress are obtained by adding hourly values of D.I. above the upper limit of comfort, *i.e.*, 48, while ignoring the rest as they do not contribute to heat stress. Values reported by Sohar *et al.* (1962 b), of Cum. E.T. and Cum. D.I. for 24 days, are plotted in Fig. 1, which indicates a very high degree of correlation between the two indices. The observed scatter is presumably due to the fact that the effect of air movement does not enter the formula for D.I.

Venkiteswaran and Swaminathan (1967) have computed the monthly average values of number of hour-days of discomfort index of different ranges in each month for five Indian stations, *viz.*, New Delhi, Calcutta, Poona, Madras and Trivandrum. The hourly D.I. values were computed with the help of Thoms' (1959) original formula, namely—

$$D.I. = 0·4\,(T_a + T_w) + 15\ °F,$$

where T_a and T_w are the dry and wet-bulb temperatures in °F. In this form, the D.I. was found to be in reasonably close agreement with corresponding E.T. The mean D.I. was calculated for

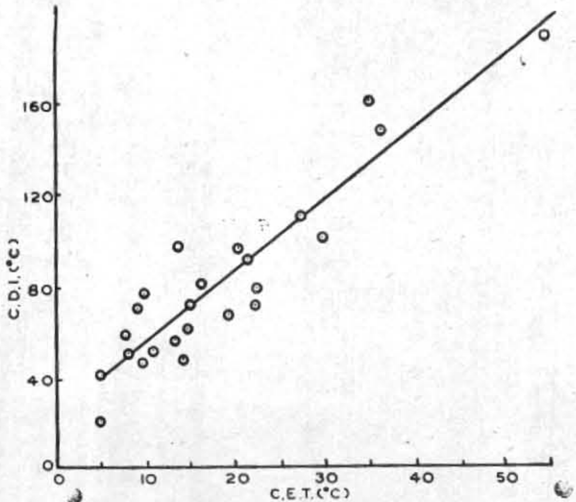

Fig. 1. Comparison between cumulative discomfort index and effective temperature (Data : Sohar *et al.* 1962 b)

these stations for each hour of the day in each month. The ranges considered were, < 70, 70-75, 76-80, 81-85 and 86-90. By adding up the number of hours D.I. was in a particular range for all the days in a month, the numbr of hour-days of D.I. in that range for that month was obtained.

To evaluate the cumulative heat stress, the upper limit of comfort has to be defined in relation to clothing and level of activity. For average, Indian adult males in light summer clothing and engaged in sedentary activity, the upper limits as established by Malhotra (1955), are E.T's of 80°F and about 81°F, on the basis of 70 and 60 per cent comfort votes respectively. The latter value *i.e.* 81°F (E.T.) has been used in the present study.

2.4. *Monthly excess DI-hour-days as measure of cumulative heat stress over a month*

Whereas Sohar *et al.* (1962 b) computed Cum. D.I. on a daily basis, we need a measure of cumulative heat stress characteristic of each month. For this purpose we have introduced the term "Excess DI-hour-days". In case hourly records of dry and wet-bulb temperatures are available, it can be rigorously computed in the following manner.

Let D.I. be any hourly value in excess of 81°F. Then we have :

$$\text{Monthy excess DI-hour-days} = \Sigma(\text{DI}-81) \quad (2)$$

the summation extending over all the hours of all the days in a month for any given station.

However, since Venkiteshwaran and Swaminathan (1967) have reported the number of hour-days of D.I. in various ranges for each month, the

TABLE 1

Comparison between monthly excess DI-hour-days and monthly excess max. ET-days (MEMET) for 5 stations for 8 months from March to October

	New Delhi		Calcutta		Madras		Poona		Trivandrum	
	Monthly excess DI hour days (1950-54)	Monthly excess Max. ET days (1965-70)	Monthly excess DI hour days (1950-52)	Monthly excess Max. ET days (1965-70)	Monthly excess DI hour days (1953-55)	Monthly excess Max. ET days (1965-70)	Monthly excess DI hour days (1950-54)	Monthly excess Max. ET days (1965-70)	Monthly excess DI hour days (1953-55)	Monthly excess Max. ET days (1965-70)
March	12	00	110	12	310	23	132	7	218	9
April	176	16	676	71	698	77	304	43	288	21
May	1059	64	1072	130	1321	128	388	53	274	13
June	1257	116	873	94	877	95	124	17	28	1
July	932	94	479	64	411	63	0	1	0	0
August	572	61	514	52	548	51	4	1	2	0
September	435	34	460	48	393	38	36	0	0	0
October	90	2	274	14	212	13	36	0	0	0

NOTES— 1. Excess DI-hour-days have been computed from the data of Venkiteswaran and Swaminathan (1967) corresponding to hours of day light (0700 to 1800 hr).

2. Excess maximum ET days have been computed from data compiled by present authors from records maintained by Regional Meteorological Centres under I.M.D.

computation can be performed in the following modified form—

$$\text{Monthly Excess DI-hour-days} = \Sigma\ [(\overline{DI}-81) \times \text{corresponding hr. days}] \quad (3)$$

Where, $\overline{DI}$ is the mid-point value of any range, and the summation extends over all the ranges from 81°F above. It may be pointed out that while Eq. (2) is exact, Eq. (3) is only approximate.

It will be seen that computation of monthly excess DI-hour-days requires hourly values of dry and wet-bulb temperatures which are not available for most of the observatories under the India Meteorological Department.

2.5. *Monthly Excess Maximum ET-Days—A practical substitute for cumulative heat stress over a month*

It is now quite apparent that any rational system for bioclimatic classification of stations with regard to human comfort and efficiency, must take into account the daily cumulative heat stress summed up over each month. In the absence of hourly records of dry and wet-bulb temperatures, it becomes imperative that a practical alternative index be evolved which can be derived from routine meteorological data.

From a study of the monthly average diurnal temperature and humidity curves in respect of a few stations for which hourly records were available, it appeared that the daily maximum E.T. should serve the purpose well, at least during the hours of day light.

In order to test the validity of the above assumption, we introduce the term "Monthly Excess Maximum ET-days" as a practical substitute for cumulative heat stress over a month which may be computed from the formula :

$$\text{Monthly Excess Max. ET-days} = \Sigma\ (\text{max. ET} - 81) \quad (4)$$

the summation extending over all the days in a month. Here max. ET stands for all daily max. ET values exceeding 81°F.

Daily max. ET is computed from daily max. dry bulb temperature and the corresponding wet bulb temperature at the average indoor wind speed of 150 ft/min, with the help of standard ET chart on Normal Scale (Yaglou and Miller 1925). However, the records maintained at the Regional Meteorological Centres give hourly values of dry bulb temperature (t_d) and relative humidity (%), from which it is possible to compute the corresponding hourly value of wet bulb temperature (t_w) as follows.

The standard psychrometric equation (List 1971) may be put in the form,

$$e = e_w - Ap\ (t_d - t_w)\ \text{mb} \quad (5)$$

where,

e = vapour pressure in the air in mb

e_w = saturation vapour pressure in mb at temp. t_w ,

p = barometric pressure in mb and

A = psychrometric constant varying slightly with t_w and depending on the condition of exposure of the wet bulb thermometer.

If e_s be the saturation vapour pressure in mb, at temperature t_d the relative humidity (RH) is given by

$$\mathrm{RH} = (e/e_s) \times 100\,\% \qquad (6)$$

The saturation vapour pressures e_s and e_w corresponding to temperature t_d and t_w respectively can be read from any standard table (List 1971). With the given values of RH(%) and e_s , e can be obtained from Eq. (6), whence t_w, the wet bulb temperature, can be computed from Eq. (5), from given barometric pressure, p, and prescribed value of A, for given conditions of exposure. Since the present study has been confined to stations near sea level, p has been taken to be 1000 mb. Tedious computational work has been avoided by making use of standard hygrometric tables of I.M.D. for 1000 mb, applicable to wet bulb thermometers exposed in Stevenson's screen.

2.6. *Comparison between monthly excess max. ET-days and monthly excess DI-hour-days*

As mentioned earlier, Venkiteshwaran and Swaminathan (1967) have computed the number of hour- days of DI in various ranges for each month in respect of five Indian stations. However, they have reported the values for (*i*) all the 24 hours of the day, as well as (*ii*) for the hours of day light (0700-1800 hr). Since higher E.T. or D.I. values occur, as a rule, during hours of day light, the same have been utilised in the present study, for comparison between monthly excess max. ET-days and Monthly excess DI-hr-days.

Values of monthly excess-max. ET-days for the same stations have been computed with the help of Eq. (4) from data compiled by the present authors from records maintained by the Regional Meteorological Centres under I.M.D. These have also been shown in Table 1 together with data period of each station.

Fig. 2 reveals an excellent correlation between monthly excess max. ET-days and monthly excess DI-hour-days, not withstanding the fact that there is a gap of about 15 years between the two sets of data, and also that monthly excess DI-hour-days was evaluated with the help of the approximate Eq. (3).

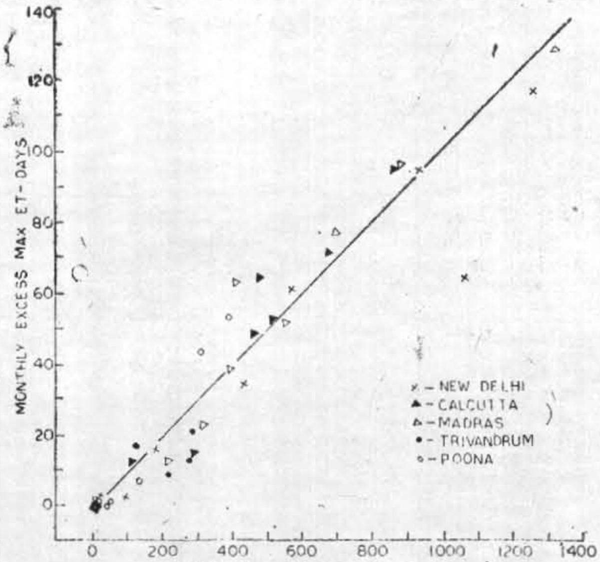

Fig. 2. Comparison between monthly excess max. ET-days and DI-hour days for five stations

It may be reasonably concluded, therefore, that bioclimatic classification in terms of monthly cumulative heat stress, can be undertaken for all stations for which routine meteorological data are available. The monthly cumulative heat stress is closely represented by the monthly axcess ET-days, which can be easily computed from routine meteorological data.

2.7. *Practical application of "monthly excess maximum ET-days" in classifying the Bioclimates of 19 Indian stations*

Meteorological data compiled from the records maintained by the Regional Meteorological Centres under India Meteorological Department (I.M.D). consisted of daily maximum dry-bulb temperature and corresponding wet-bulb temperature, the latter being computed from relative humidity readings with the help of standard hygrometric tables prepared by I.M.D. as explained earlier. Data were obtained for 19 stations in India as indicated in Table 2, which also shows the data period for each station. The stations have been listed in alphabetical order.

Daily maximum E.T. was computed in the usual way with the help of standard ET chart (Normal Scale) for average wind speed of 150 ft/min.

Monthly excess max. ET-days for each month was evaluated with the help of Eq. (4). The

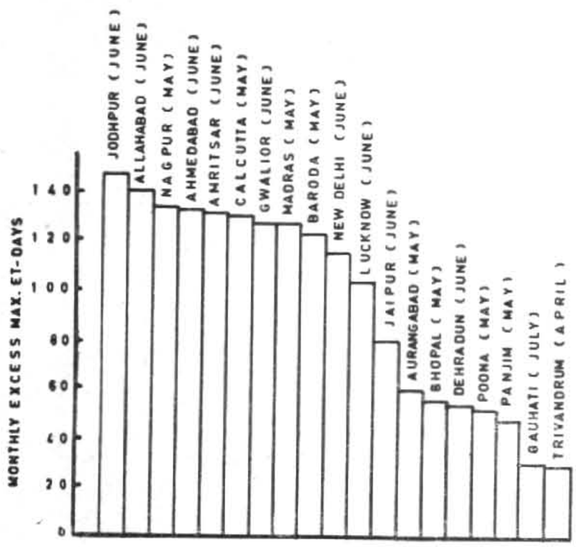

Fig. 3. For the hottest month of the year

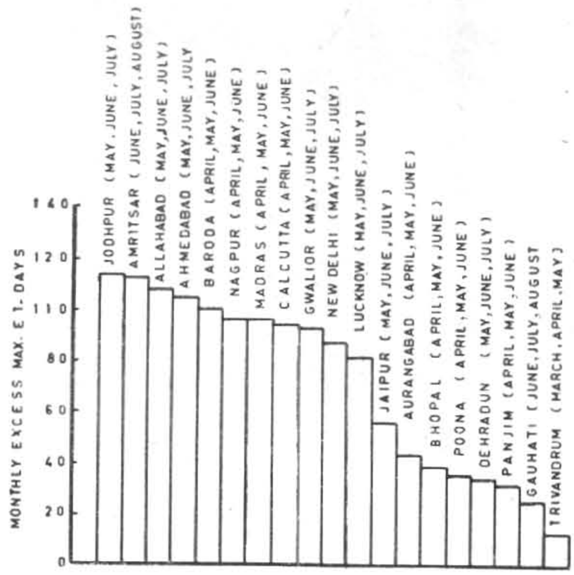

Fig. 4. For the average of three hottest months of the year

Figs. 3 & 4. Grading of 19 stations in terms of monthly excess maximum ET-days

TABLE 2

Monthly excess maximum ET-days (MEMET) at 19 Indian stations for 8 months from March to October

Sl. No.	Station	Monthly excess max. ET days (MEMET)								Hottest month of the year	Average of 3 hottest months	Average of all 8 months
		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct			
1	Ahmedabad	10	57	114	132	78	34	37	43	132 (June)	108	63
2	Allahabad	6	56	117	139	80	51	41	11	139 (June)	112	63
3	Amritsar	0	7	47	131	122	97	59	2	131 (June)	117	58
4	Aurangabad	10	43	59	35	8	1	2	0	59 (May)	46	20
5	Baroda	22	82	123	108	57	29	44	57	123 (May)	104	65
6	Bhopal	1	26	56	41	14	3	4	0	56 (May)	41	18
7	Calcutta	12	71	130	94	64	52	48	14	130 (May)	99	61
8	Dehradun	0	5	43	54	15	7	2	0	54 (June)	37	16
9	Gauhati	0	1	16	21	31	28	18	1	31 (July)	27	15
10	Gwalior	0	26	93	128	74	27	14	1	128 (June)	98	45
11	Jaipur	0	8	48	80	48	20	8	1	80 (June)	58	27
12	Jodhpur	1	21	79	147	126	54	61	32	147 (June)	117	65
13	Lucknow	0	15	65	103	86	61	38	1	103 (June)	85	46
14	Madras	23	77	128	95	63	51	38	13	128 (May)	100	61
15	Nagpur	20	74	133	93	25	14	17	6	133 (May)	100	48
16	New Delhi	0	16	64	116	94	61	34	2	116 (June)	91	48
17	Panjim	12	40	48	19	4	1	2	16	48 (May)	36	18
18	Poona	7	43	53	17	1	1	0	0	53 (May)	38	15
19	Trivandrum	9	21	13	1	0	0	0	0	21 (April)	14	6

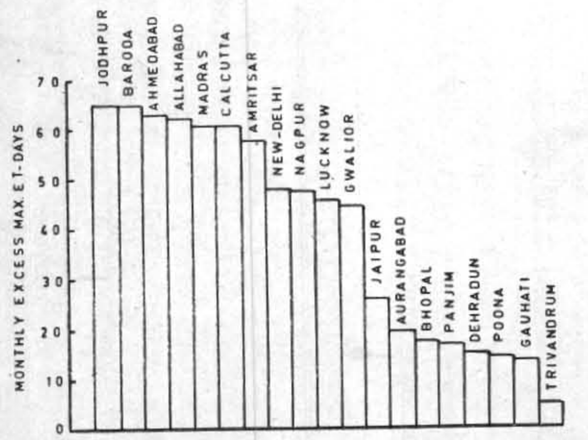

Fig. 5. Grading of 19 stations for the average of ei ht months (Mar-Oct) in terms of monthly excess max. ET-days

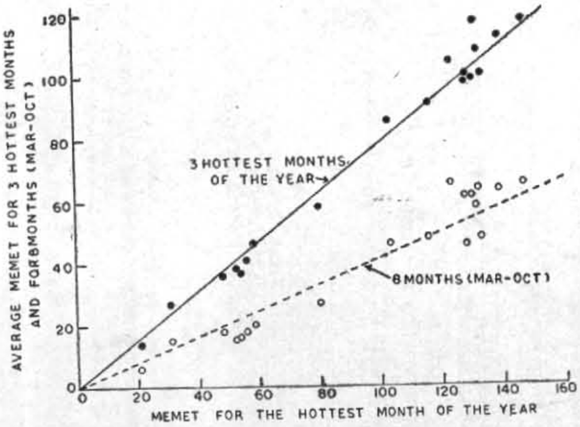

Fig. 6. MEMET values of 19 stations averaged over 3 hottest months and 8 months (Mar-Oct) as compared to corresponding MEMET values for the hottest month of the year

average values are presented in Table 2, which also shows the average values for all the 8 months as well as for the hottest 3 months.

The stations have been graded in Fig. 3 for the hottest month of the year for each station, in Fig. 4, for the average of the three hottest months of the year, and in Fig. 5, for the average of all the eight months from March to October.

3. Discussion

It may be emphasised again that the findings of the present study on cumulative heat stress, are applicable to average Indian adults in light summer clothing, resting or engaged in sedentary duties indoors, with an average wind speed of 150 ft/min. ET of 81°F has been accepted as the upper limit of comfort, as found by Malhotra (1955) on the basis of 60 per cent comfort votes.

Fig. 2 appears to demonstrate convincingly, the applicability of monthly excess max. ET-(MEMET) days as a practical index of cumulative heat stress, for the purpose of classifying the bioclimates of stations for the hours of day light. It seems reasonable to conclude that similar study can be undertaken for all the 24 hours of the day, provided that the diurnal range of ET is also taken into consideration.

With regard to the hottest month of the year, it will be seen from Fig. 3 that Jodhpur is the hottest (MEMET : 147, Jun) among the 19 stations studied, closely followed by Allahabad (MEMET : 139, Jun). The other hot stations (MEMET $>$ 100) in descending order are Nagpur, Ahmedabad, Amritsar, Calcutta, Gwalior, Madras, Baroda, New Delhi and Lucknow. Relatively cool stations (MEMET $<$ 60) in descending order, are Aurangabad, Bhopal, Dehradun, Poona, Panjim, Gauhati and Trivandrum. Jaipur is the only station lying mid-way between the two groups (MEMET : 80). It may be pointed out, however, that while data of all the other 18 stations cover a period of 5-6 years, those of Jaipur cover only 3 years.

With regard to the three hottest months of the year, Fig. 4 reveals a few interesting changes from the hottest month. While Jodhpur retains its 1st place, Amritsar jumps up to the 2nd place from the 5th and Barola, to the 5th from the 9th. Nagpur, on the other hand, recedes to the 6th place from the 3rd. This shows that the heat stress during the 3 hottest months is more persistent at Amritsar and Baroda than at other stations, while that at Nagpur is relatively short lived.

The over-all picture for all the eight months can be seen from Fig. 5. Baroda now joins Jodhpur at the top of the list, indicating the highest degree of persistence of heat stress. Amritsar drops down to the 7th place showing that the 5 months other than the three hottest months of the year, are relatively much cooler. Nagpur recedes further to the 9th place thus confirming that summer at Nagpur is short lived.

Fig. 6 shows that the average MEMET values for the 3 hottest months and for all the 8 months (Mar to Oct) are remarkably well correlated with the MEMET values for the hottest month, being on the average 78·8 per cent and 41·8 per cent of the latter respectively.

3.1. *Application of MEMET to assessment of airconditioning needs*

As noted earlier, relatively cool stations have

MEMET values in the hottest month below 60. It is therefore proposed to fix the limit of MEMET as 60, above which a station will require air-conditioning in order to bring down the ET within the comfort zone, *i.e.*, below 81°F. On this basis, it will be seen from Table 2 that 5 stations require 4 month's air-conditioning, *viz.*, Madras, Calcutta (Apr, May, Jun, Jul), New Delhi, Lucknow (May, Jun, Jul, Aug), and Jodhpur (May, Jun, Jul, Sep.) Six stations require 3 months air-conditioning, *viz.*, Baroda, Nagpur (Apr, May, Jun), Allahabad, Ahmedabad, Gwalior (May, Jun, Jul) and Amritsar (Jun, Jul, Aug). Jaipur needs air-conditioning only for one month (Jun). None of the remaining 7 stations require air-conditioning. These stations except Aurangabad and Poona, have typical monsoon climate, annual rainfall ranging from 1208 to 2314 mm.

In conclusion, it may be pointed out that the above findings, being based on daily maximum ET values, pertain to air-conditioning needs during hours of day light. It would be worthwhile to evolve a similar practical index of monthly cumulative heat stress over a 24-hour period.

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REFERENCES

Brooks, C. E. P. 1950 *Climate in Every day Life*, Ernest Benn, London.

Buettner, K. J. K. 1962 *Biometeorology*, Proc. 2nd International Bioclimatological Congress., Pergamon Press, London, p. 135.

Hardy, J. D. 1970 *Physiological and Behavioural Temperature Regulation*, Edited by J. D. Hardy, *et al.* Spring- field, Illionois, p. 862.

List, R. J. 1971 *Smithsonian Meteorological Tables*, Smithsonian Publication, Washington, p. 365.

Majumdar, N. C. 1953 *Indian J. Physiol. & Appl. Sci.*, 7, p. 205.

Malhotra, M. S. 1955 *J. Sci. Ind. Res.*, **14A**, 10, pp. 469-473.

Mc Ardle, B., Dunham, W., Holling, H. E., Ladell, W. S. S., Scott, J. W., Thomson, M. L. and Weiner, J. S. 1947 Med. Res. Council (London), R. N. P. Rep., 47 : 391.

Nevins, R. G. and Hardy, J. D. 1965 *Humidity and Moisture, Measurement and control in Science and Industry*, **2**, Arnold Wexler, Publ. Corp, New York, p. 10.

Sohar, E., Tennebaum, J. and Yaski, D. 1962a *Biometeorology*, Proc. 2nd International Bioclimatological Congress, Pergamon Press, London, pp. 401-405.

Sohar, E., Tennebaum, J. and Robinson, N. 1962b *Ibid.*, pp. 395-400.

Subrahmanyam, V.P., Murty, P. S. N. and Ramasastry, K. S. 1968 Tech. Rep. No. 19 (Restricted) Vols. I to IV, Dep. of Met. and Oceanogr., Andhra University Waltair, and Terrain Evaluation Cell, Dte. of Engineering, Defence R & D Orgn. New Delhi.

Thom, E. C. 1959 *Weatherwise*, **12**, 2, pp. 57-60.

Venkiteshwaran, S. P. and Swaminathan, M. S. 1967 *Indian J. Met. Geophys.*, **18**, pp. 27-38.

Yaglou, C. P. and Miller, W. E. 1925 *Trans. ASHVE*, **31**, p. 89.