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Effect of radiation on human comfort

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ABSTRACT. An attempt has been made to study the influence of radiation on human comfort in India. It is known that the major weather elements which control human comfort are temperature of air, relative humidity and air movement. In a broad sense, temperature and humidity are related to radiation intensity. Discomfort indices for various cities in India have been worked out using a new formula as a function of radiation intensity. The results obtained by this method are found to be in good agreement with those obtained by other workers except for monsoon months, where they deviate much from the reality due to the inherent defect these methods suffer.

Using the discomfort index formula suggested, 'discomfort indices' maps are prepared employing uniform data of 70 stations widely distributed throughout India, for the different months, seasons and the annual.

1. Introduction

Climate plays an important role in every sphere of human activity. The tourist is interested in the degree of comfort he expects to experience at various resorts over the seasons. The human body reacts to various ranges of temperature and humidity and diseases like plague, bronchial asthma, filiaria, tuberculosis etc show variations in incidence associated with the variations of weather elements. The essence of human comfort (or discomfort) can be understood fully only by the reaction of the human body and in terms of sensation. This has led Lee (1953) to put forward a strain formulation for the study of human comfort. From the point of view of meteorological elements (ASHRAE 1967) have presented a nomogram as functions of thermal discomfort index for (or effective temperature) dry and wet bulb temperatures and wind speed. As Thom (1959) and U. S. Weather Bureau (1959) suggested empirical formulae which are derived from the nomogram by correlative study under the assumption of low wind speed. On this assumption these two formulae are not giving satisfactory results in monsoon months (*vide* infra). Hendrick (1959) has added the effects of wind and total solar radiation to produce a more complete comfort index. As Hendrick himself notes, however, in reality there can be no precise numerical measure of as subjective a concept as comfort. But his method is too complicated compared to the above two methods. Malhotra (1967) defined the environmental comfort scale in warm and humid atmosphere based on chamber experiments.

In the present study the authors have made an attempt to give a new method of estimation of discomfort index using radiation intensity (*i.e.*, both total solar and net radiation), an important factor having major influence over human comfort. It is known that net radiation intensity (R_N) is a fairly good indicator of 'night' climate and the total solar radiation (R_t) and net radiation (R_N) intensities together represent the 'day' climate over a region. Using this formula 'discomfort indices' maps are prepared using 70 stations data over India for 12 months, 3 seasons and the annual.

2. Data and Analysis

In the present study mean daily meteorological data for the period 1959-68 were considered for 70 stations evenly distributed over the country for each of 12 calendar months, three seasons and annual. Table 1 gives the stations with their location. As only a few stations are recording radiation elements R_t and R_N are estimated using the formulae of Reddy (1971) and Reddy and Rao (1973) which will give satisfactory estimates in the absence of observed data.

It is seen that 'day' and 'night' climates mainly depend upon total solar radiation and net radiation intensities (R_t and R_N) and net radiation intensity (R_N) respectively. These two are the main factors which could be taken as indicators of the heat and moisture content at earth's surface in any season. The net radiation intensity depends upon moisture content of the surface soil, temperature of the air, humidity and to

*Expired on 7 February 1974

TABLE 1

Stations names and their locations

Station	Co-ordinates			Station	Co-ordinates		
	Ht. (m)	Lat. (°N)	Long. (°E)		Ht. (m)	Lat. (°N)	Long. (°E)
		° ′	° ′			° ′	° ′
Adhartal	411	23 09	79 58	Kayangulam	3	09 08	76 31
Aduthurai	19	11 01	79 32	Kodaikanal	2443	10 14	77 28
Agra	169	27 10	78 05	Kovilpatti	92	09 12	77 53
Ahmadabad	55	23 04	72 38	Kotah	257	25 11	75 30
Akola	281	20 42	77 02	Labhandi	289	21 16	81 36
Allahabad	98	25 27	81 44	Madras	16	13 00	80 11
Amritsar	234	31 38	74 52	Mangalore	102	12 55	74 53
Babbur		13 57	76 37	Nagpur	310	21 06	79 03
Bangalore	897	12 58	77 35	Nagrikatta	229	26 54	88 55
Baroda	34	22 18	73 15	Nagrifarm	1158	26 55	88 12
Begumpet	545	17 27	78 28	New Delhi	216	28 35	77 12
Bellary	448	15 09	76 51	Niphad	550	20 03	74 07
Bhopal	523	23 17	77 21	Okha	07	22 29	69 07
Bhubaneswar	26	20 15	85 50	Ootacamond	2218	11 24	76 44
Bombay	11	18 54	72 49	Parbhani	408	19 16	76 47
Calcutta	06	22 32	88 20	Patna	52	25 30	85 15
Chensurah	09	22 52	88 24	Pattambi	25	10 48	76 12
Coimbatore	409	11 02	77 03	Phoolbhag	233	29 00	79 30
Cuttack	24	20 29	85 52	Poona	559	18 32	73 51
Dharwar	679	15 26	75 06	Pusa	52	25 59	85 40
Dehra Dun (F.R.I.)	640	30 20	77 52	Raichur	389	16 12	77 21
Gannavaram	24	16 32	80 48	Saharanpur	275	29 58	77 33
Gauhati	54	26 06	91 35	Samalkot	09	17 03	82 13
Gorakhpur	79	27 00	83 27	Shakkaranagar		18 39	77 45
Gwalior	208	26 15	78 14	Shillong	1598	25 34	91 53
Hagari		15 10	77 04	Sholapur	476	17 40	75 54
Hebbal	899	13 00	77 38	Sileuri	40	24 50	92 52
Jaipur	390	26 49	75 48	Srinagar	1587	34 05	74 50
Jalgaon	201	21 03	75 34	Surat	11	21 12	72 52
Jodhpur	217	26 18	73 01	Tiruchirapalli	88	10 46	78 43
Jullundur	238	31 25	75 38	Titabar	99	26 35	94 10
Kanke (Ranchi)	675	23 25	85 20	Tocklai	87	26 47	94 12
Karimganj	16	24 40	92 30	Tirvandrum	64	08 29	76 57
Karjat	52	18 55	73 18	Viramgam	27	23 03	72 09
Kasrgod	11	12 30	74 59	Visakhapatnam	03	17 43	83 18

some extent on air movement and total solar radiation. Therefore, using radiation intensities (Rt and R_N) a method of estimation of 'discomfort indices' (DI) is suggested as follows :

$$DI = (DI_{\text{night}} + DI_{\text{day}})/2 \qquad (1)$$

where, $$DI_{\text{night}} = a\ R_N \qquad (2)$$

$$DI_{\text{day}} = b\ R_N + c\ R_N/R_t \qquad (3)$$

and a, b, c being constants to be determined. The results of discomfort indices are obtained using Thom's formula for solving a, b and c (The details of the correlative study are not presented). Hence, the above three equations can be written as :

$$DI_{\text{night}} = 34 \times 10^{-4} R_N \qquad (4)$$

$$DI_{\text{day}} = R_N\,(26 \times 10^{-4} + 1/R_t) \qquad (5)$$

$$DI = R_N\,(30 \times 10^{-4} + 0{\cdot}5/R_t) \qquad (6)$$

Using the Eq. (6) discomfort indices are obtained at few stations (for the above mentioned data) and compared with the results of Venkiteswaran *et al.* (1967) and Parthasarthy *et al.* (1972) and also results of nomogram (1967), which are shown in Table 3. For the comparison of these results (obtained by the authors) with others the criterion followed is as follows: If 60 per cent of calculated hourly values in a month lie in the limit Discomfort Index ≤ 75, that particular month is considered as comfortable (cold side uncomfortable is possible).

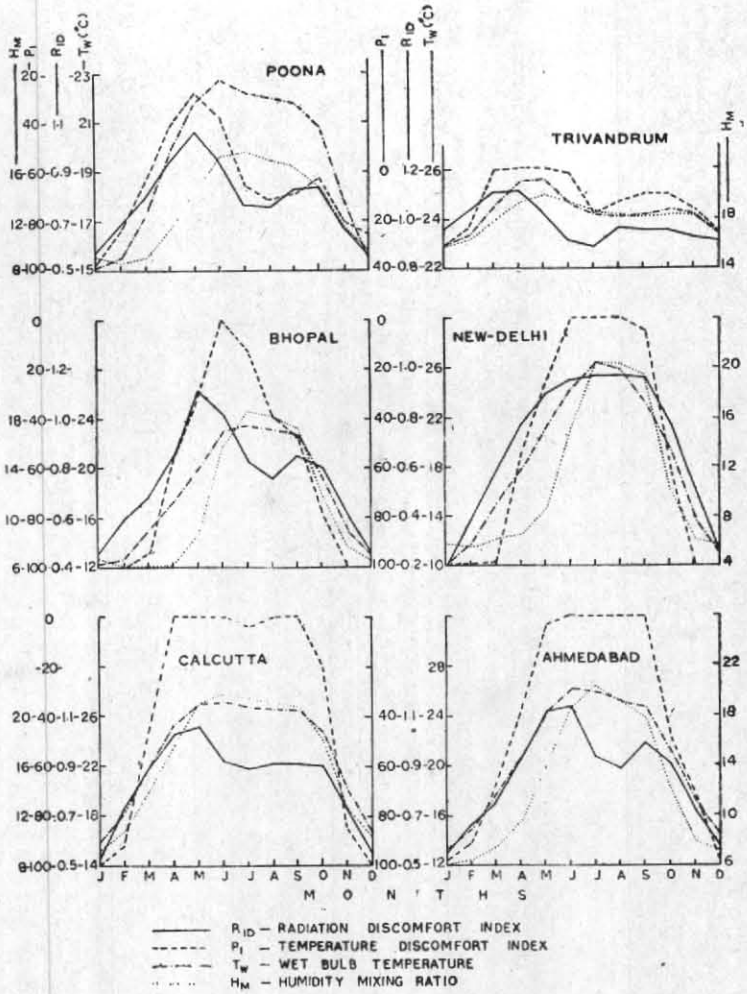

Fig. 1(a). Variation of R_{ID}, P_I, T_W and H_W with months

TABLE 2

Radiation discomfort index zones

DI	Type of comfort	Effect of population
< 0·30	Most uncomfortable	All people feel uncomfortable, cold waves
0·30-0·60	Uncomfortable	Cold 60 per cent of population feels uncomfortable.
0·60-0·95	Comfortable	90 per cent of population feels comfortable
0·95-1·05	Uncomfortable	Hot, 60 per cent of population feels uncomfortable.
>1·05	Most uncomfortable	All people feel uncomfortable, heat strokes are possible.

A table is presented for the ranges of comfort and discomfort (Table 2) for the understanding of the 'Discomfort Index' values obtained by Eq. (6).

This is drawn on the basis of tentative ranges presented by other workers.

The stations considered in Table 3 represent the different climatological types in India. Radiation discomfort indices are obtained using above mentioned data for 70 stations for 12 months, 3 seasons (*i.e.*, Winter — Nov to Feb, Summer — Mar to Jun and Monsoon — Jul to Oct), and annual. These are shown in Fig. 1.

3 Discussion

Table 3 gives the discomfort indices of 0-24 hours (whole day) obtained by using (*i*) present formula suggested by authors, (*ii*) Thom's formula by Venkiteswaran *et al.* (*iii*) U. S.

TABLE 3

Discomfort indices for 0-24 hours at 12 stations over India

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BANGALORE	C	0·67	0·80	0·94	1·03	1·02	0·82	0·70	0·74	0·74	0·77	0·66	0·63
	P	100	99	75	57	54	79	93	96	94	97	98	100
MADRAS	C	0·82	0·95	1·02	1·23	1·24	1·09	1·00	1·05	1·05	1·02	0·85	0·80
	P	69	45	09	00	00	00	00	00	00	00	29	60
	V	74	57	25	00	00	00	04	02	04	16	65	82
	N	100	92	53	00	00	13	17	25	33	25	100	100
HYDERABAD	C	0·63	0·74	0·84	0·98	1·09	0·95	0·84	0·85	0·87	0·83	0·68	0·59
	P	100	95	60	24	04	17	46	50	55	68	95	100
VISAKHAPATNAM	C	0·74	0·92	1·05	1·14	1·19	0·98	0·91	0·98	1·01	1·01	0·86	0·70
	P	89	57	20	00	00	00	00	00	00	01	58	92
BOMBAY	C	0·80	0·89	0·99	1·08	1·13	0·96	0·82	0·83	0·93	1·04	0·96	0·85
	P	84	69	31	00	00	00	00	00	00	00	27	57
NAGPUR	C	0·56	0·68	0·76	0·91	1·04	1·02	0·86	0·82	0·91	0·81	0·63	0·52
	P	100	91	65	38	07	02	00	06	21	61	92	100
CALCUTTA	C	0·53	0·73	0·90	1·03	1·06	0·92	0·89	0·91	0·91	0·90	0·73	0·55
	P	100	92	43	00	00	00	04	00	00	20	85	100
AHMEDABAD	C	0·54	0·65	0·75	0·93	1·12	1·14	0·94	0·89	0·99	0·91	0·72	0·57
	P	99	91	67	38	03	00	00	00	00	48	72	99
JODHPUR	C	0·43	0·56	0·68	0·83	0·99	1·12	1·03	0·98	1·03	0·85	0·62	0·46
	P	100	100	100	64	29	08	00	42	17	62	100	100
NEW DELHI	C	0·21	0·39	0·59	0·77	0·90	0·95	0·97	0·97	0·96	0·77	0·48	0·23
	P	100	100	99	54	25	00	00	00	05	62	100	100
	V	100	100	90	61	10	02	00	00	12	77	100	100
POONA	C	0·58	0·69	0·79	0·94	1·06	0·94	0·76	0·75	0·82	0·83	0·67	0·58
	P	98	84	65	43	29	39	66	72	69	63	81	86
	V	96	87	65	50	43	57	90	85	75	73	88	96
	N	96	83	79	58	58	91	100	100	100	87	96	96
TRIVANDRUM	C	0·95	1·02	1·10	1·11	1·02	0·91	0·88	0·96	0·95	0·95	0·92	0·91
	P	31	24	01	00	00	02	19	14	11	11	17	27
	V	39	38	11	07	11	31	52	33	32	36	37	44

C=Discomfort indices calculated using formula (6).

P.V.N.=Total percentage hours in a month lie in the limit of discomfort index <75, calculated using formula of U. S. Weather Bureau, Thom and from nomogram (ASHRAE 1967) respectively.

P=Calculated using monthly mean hourly values of temperature and humidity.

V=Calculated using daily hourly values of dry bulb and wet bulb temperatures.

N=Calculated using monthly mean hourly values of dry and wet bulb temperatures and wind speed.

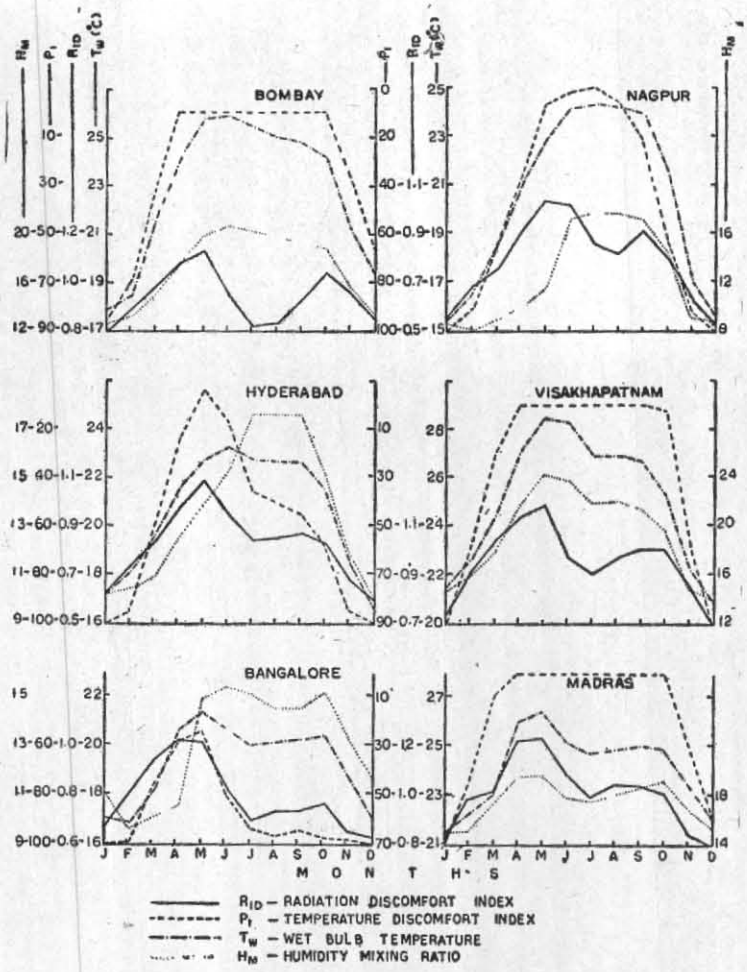

Fig. 1 (b). Variation of R_{ID}, P_I, T_W and H_W with months

Weather Bureau formula by Parthasarathy *et al.* and (*iv*) nomogram (ASHRAE 1967) by present authors. The results of (*i*) and (*iv*) are fairly agreeing. The results of (*ii*) and (*iii*) are also fairly agreeing with the results of (*i*), except in most cases of monsoon months. This is due to high humidity values contributing high *DI* values in (*i*) and (*iii*) which otherwise would have been reduced, by taking actual wind condition into consideration (seen in *iv*). Moreover, the results obtained by the present method and nomogram are more or less in line with the practical experience. But the estimation of discomfort indices from nomogram is a tedious job. Therefore, using the Eq. (6), mean discomfort indices can be obtained for each month or season with the same accuracy as otherwise would have been obtained using nomogram.

Fig. 1 shows the isolines of discomfort indices obtained using Eq. (6), with the aid of Table 2. It can be easily seen that the comfort or discomfort zones in different months and seasons over India, will help the tourist and air conditioners in different parts of the country quite satisfactorily. Some of the salient features observed in Fig. 1 are presented below :

(*i*) Precautionary measures to protect the body from cold should be taken in winter months (*i.e.*, from round about November and to first few days in March) beyond 25°N in India.

(*ii*) Precautionary measures like air conditioning etc should be taken :

(*a*) Along west coast—end of March to May last ;

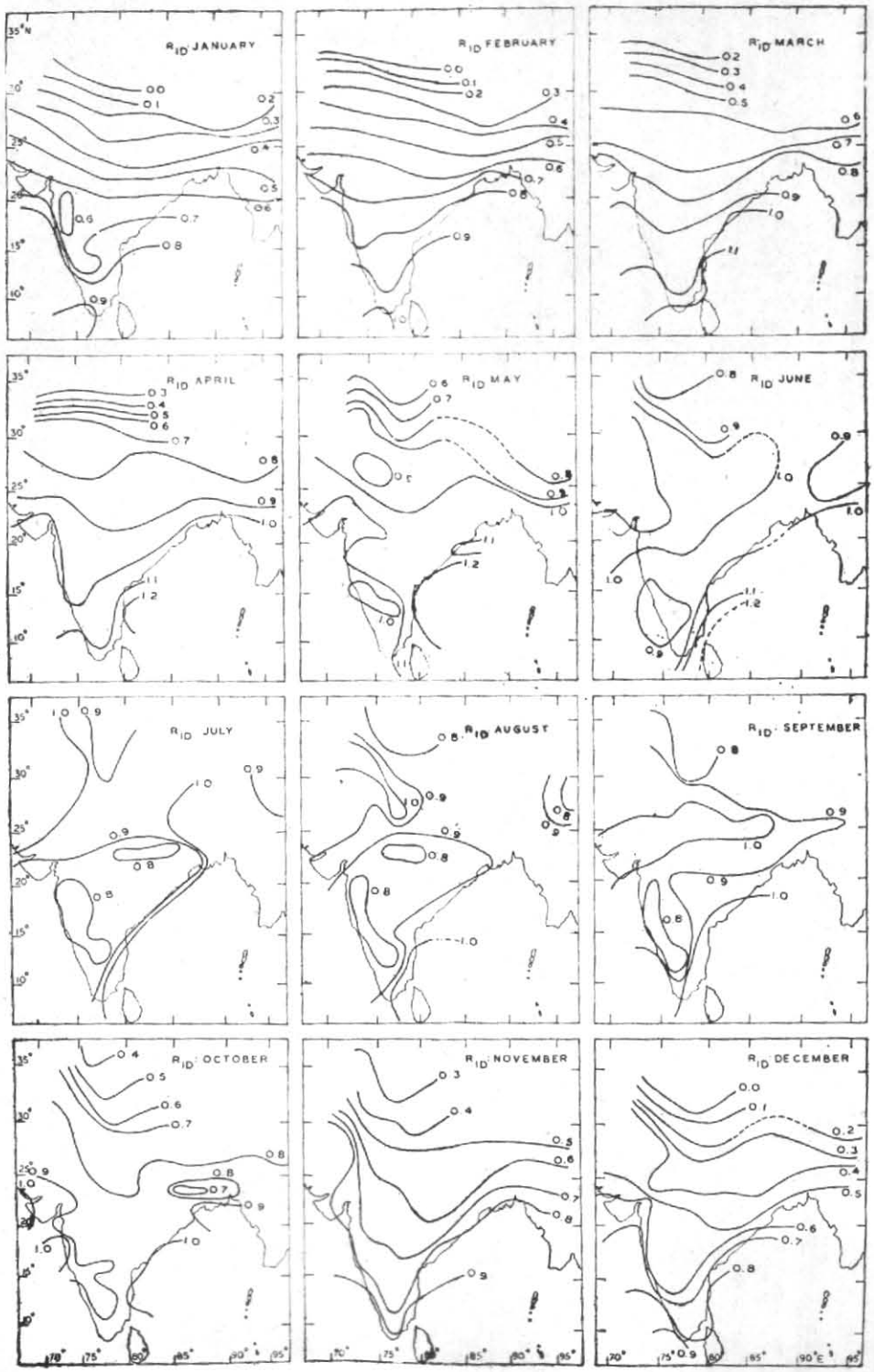

Fig . 2 (a). R_{ID} for each month

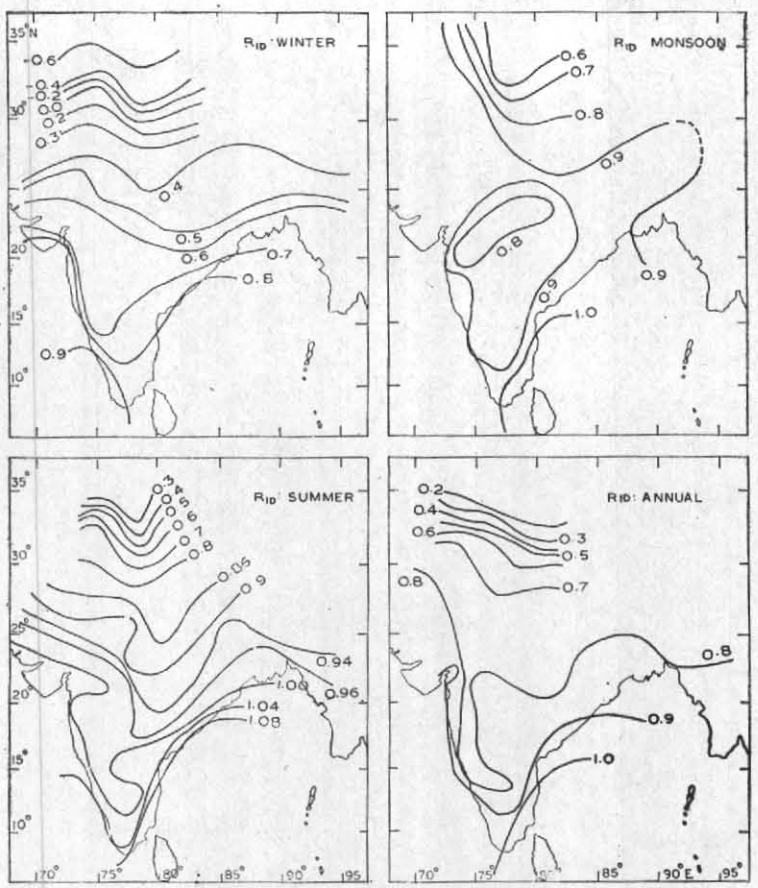

Fig. 2 (b). R_{ID} for winter, monsoon, summer seasons and annual

(*b*) Along east coast—round about second week of March to July end and in addition September and October along coastal Andhra Pradesh and Madras,

(*c*) South inland region end of March to June end,

(*d*) Gujarat region—end of April to July end,

(*e*) Rajasthan region—May end to July end,

and (*f*) Other parts of northwest India (except Jammu and Kashmir region) and central parts of India—end of May to first week of July.

4. Conclusion

1. The results obtained using the Eq. (6) are generally in good agreement with the results of nomogram, and Thom and U. S. Weather Bureau formulae, except for monsoon months with the latter two formulae. It is due to inherent defect that these two formulae are suffering (as explained earlier). The results of the Eq. (6) is also generally agreeing with the experience of the people living in those areas (obtained information from few people regarding their experience in respective regions). Therefore, the mean zones of discomfort or comfort can be made by using the Eq. (6) which will enable the tourist to take precautions and also help the air conditioners.

2. From the annual discomfort map (Fig. 1) it may be seen that the east coast of the country, south of Masulipatnam and the extreme northern parts over Kashmir and adjoining Himachal Pradesh have the maximum discomfort over the year, the former in relation to higher temperatures and the latter in relation to low temperatures. This is only a very general assessment spread over the year. Seasonwise, the area north of Lat. 25°N is uncomfortable in winter, the Peninsular area south of about Lat. 20°N, parts of Gujarat and parts of West Bengal has maximum discomfort for the summer period taken as a whole and the east coast south of Visakhapatnam, parts of Gujarat, Bihar, Orissa and West Bengal is uncomfortable in the monsoon period also.

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