Printed from INDIAN JOURNAL OF POWER & RIVER VALLEY DEVELOPMENT, December 1985

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Estimation of Weibull's parameters and evaluation of wind data for utilisation of wind energy for natural ventilation in buildings in India

The paper presents the results of analysis of ten years hourly wind data recorded by India Meteorological Department at 38 places in the country. Weibull's distribution function has been made use of for simulation of wind speed frequency distribution. The Weibull's parameters, power law exponent, average wind speeds, most probable wind speeds, the duration for which wind speed is equal to or exceeds the most probable speed, energy pattern factors, and wind energy densities have been computed for the whole year and also for the period May to August when ventilation is needed primarily for comfort purposes. Such data were computed for the different heights of anemometers and were subsequently converted to the standard anemometer height of 10 metre above the ground.

Introduction

Provision of adequate air motion for thermal comfort indoors is an important consideration in the design of buildings in tropics. Among the two motive forces, viz, temperature differential and wind, the latter is a predominating contributor towards inducement of air motion in unconditioned buildings. Utilisation of wind energy for amelioration of thermal environment in buildings in tropics had been a common practice since time immemorial. However, researches aimed at evolution of design guidelines for optimum utilisation of outdoor wind indoors were initiated about three decades ago. Since then several investigations have been carried out into these aspects in India[1] and abroad[2] as well. Most of these studies concern with the design of openings for natural ventilation, and the results are presented in terms of the free wind speed as a reference value. Obviously, utilisation of these findings in the building design necessitates knowledge of free wind speeds at the site in question. Since permanent ventilation is the year round requirement in buildings, the design need to be based on the most probable wind speed of the year. On the other hand, comfort ventilation is needed during hot and hot humid conditions (say from May to Aug.) and as such ventilation design is to be worked out based on the most probable wind speeds of this period. Further, in the present days of energy crisis it would be in tune with the need of the time to develop simple wind operated devices which could be made use of for inducing air motion indoors. Such gadgets would help save energy consumed in running fans. Evolution of cost effective and energy efficient design of the envisaged devices will have a bearing on the most probable wind speeds, the duration during which wind speed is equal to or exceeds the most probable speed and also the average energy content of the prevailing wind. Data concerning these aspects of wind characteristics are not available in the studies carried out on Indian wind data by other investigators[3,4] in the past. Recently, Mani and Mooley[5] have brought out data on average monthly and annual wind speeds and also on wind energy factors and wind energy densities for 235 places in the country. However, further analysis of data is needed to procure information on various other wind characteristics which are prerequisite for utilisation of wind energy in buildings. Such data have been evolved and presented in this paper.

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Data used for computation

Average hourly wind speeds computed from the latest 10 years data collected by India Meteorological Department, are available in published form[5,6] for 38 places in the country. The data do not provide

detailed time series information in respect of wind spectrum at these places. However, for ventilation design of buildings, data on commonly prevalent wind are of importance, and short spells of high winds are not of much interest. As such average hourly wind data of a place is good enough to represent the wind conditions of the site in question. Hence the average hourly values of wind speeds were used for computation of the various wind parameters.

Weibulls distribution and computation of Weibull's parameters

Weibull's distribution can adequately model the wind speed frequency distribution at a place, and because of inherent computational advantages, it has been used by several investigators[7-10] for wind load studies and wind energy computations as well. The Weibull's probability distribution function for wind speed V is given by

$$p(v) = \frac{k}{C}\left(\frac{V}{C}\right)^{k-1} \exp\left[-\left(\frac{V}{C}\right)^{k}\right] \quad (1)$$

where k is a dimensionless shape factor and C is a scale factor with units of speed.

The cumulative probability function for a velocity V_1 is given by

$$p_1 = \int_0^{V_1} p(V)\, dV.$$

$$\text{or} \quad p_1 = 1 - \exp - \left(\frac{V_1}{C}\right)^{k} \quad (2)$$

This equation may be written in the linear form, as

$$Y = a + bx \quad (3)$$

where $Y = \log[-\log(1-p_1)]$

$$X = \log V_1 \quad (4)$$

$$k = b$$

$$\text{and} \quad C = \exp\left(-\frac{a}{b}\right) \quad (5)$$

The coefficients a and b of equation 3 were computed using least square method. To accomplish this, the average hourly wind speeds were divided into 10 frequency ranges and corresponding frequencies of occurrence were counted and cumulative frequencies (P_1) were determined. The data was processed through a computer program, and the values of a and b so obtained were made use of for computation of Weibull's parameters k and c given by equations 4 and 5. The raw data used for computational work were based on the records of anemometers mounted at different heights at different places. Therefore, values of Weibull's parameters were converted to the standard anemometer height of 10 m above the ground. The equations used are,

$$C_{10} = C_a\left(\frac{10}{Z_a}\right)^{n}$$

$$K_{10} = k_a\left[1 - 0.088 \ln.\left(\frac{Z_a}{10}\right)\right]$$

where C_{10} and K_{10} are the Weibull's parameters at 10 m height and C_a and k_a at the anemometric height Z_a (m). The power law exponent, n, is given by

$$n = [0.37 - 0.088 \ln C_a]/[1 - 0.88 \ln (Z_a/10)]$$

The results of computation for the annual and May-Aug. data are summarised in Table 1 and Table 2 respectively. These values of Weibull's parameters were used for computation of desired wind parameters at the anemometric heights and also at height of 10 m above the gound.

Relationship used for computation of wind data

Expressions for the average and most probable wind speeds, and the duration for which wind blows at speeds equal to or more than the most probable value as derived from equation 1, are given as

$$\bar{V} = C\,\Gamma\left(1 + \frac{1}{k}\right)$$

$$Vmp = C\left(\frac{k-1}{k}\right)^{\frac{1}{k}}$$

$$T \geqslant Vmp = \exp\left[-\left(\frac{Vmp}{C}\right)^{k}\right]$$

where $\bar{V}$ is the average wind speed and Vmp is the most probable wind speed

$T \leqslant Vmp$ is the time (fraction of the total period of observation) during which wind speed $\geqslant Vmp$, and Γ denotes the function.

Similarly, the expression for energy pattern factor (EPF) which is a ratio of total energy available in the wind to the energy calculated by cubing the mean wind speed, is given by

$$EPF = \frac{\bar{V}^3}{(\bar{V})^3} = \frac{\Gamma\left(1 + \frac{3}{k}\right)}{\left[\Gamma\left(1 + \frac{1}{k}\right)\right]^3}$$

Also, the energy density of the wind, i.e., the energy contained in the air stream passing through 1 m² area of cross section in a day is given by

$$E_d = 0.00031\ \bar{V}^3 \times EPF$$

Where E_d, the nergy density is expressed in units of kWh/m² per day

By making use of these equations and using the Weibull's parameters given in Table 1 and Table 2, desired wind data were computed. The results are given in Tables 3 to 6. The average wind speeds determined by this method were compared with average speeds arrived at by taking simple arithmatic mean of 288 values of average hourly wind speed of the years (Table 7). It is seen that in most of the cases the values do not differ by more than 5 per cent. This amply testifies the fitness of the data on Weibull's distribution,

TABLE 1—WEIBULL'S PARAMETERS (ANNUAL DATA)

Sl. no.	Station	Height of anemometer (Metre)	Weibull's parameters at				Power law exponent
			Anemometer Height		10 Metre Height		
			K	C	K	C	n
1.	Ahmedabad (AP)	14.8	2.44	11.83	2.35	11.12	0.158
2.	Amritsar (AP)	19.8	2.02	8.88	1.97	6.89	0.372
3.	Bangalore (AP)	14.6	2.50	15.63	2.42	15.22	0.153
4.	Bangalore City	19.2	2.66	11.22	2.59	9.32	0.285
5.	Baroda	22.8	2.02	9.12	1.95	7.15	0.295
6.	Bhopal	11.7	2.44	14.31	2.38	13.78	0.139
7.	Bombay Colaba	18.5	2.47	12.75	2.33	11.58	0.154
8.	Bombay Santacruz	15.3	1.81	10.28	1.74	9.56	0.171
9.	Calcutta Alipore	26.4	1.83	9.29	1.67	7.73	0.190
10.	Calcutta Dumdum	20.0	1.31	7.39	1.23	6.40	0.207
11.	Gaya	12.5	1.42	8.12	1.39	7.78	0.190
12.	Goa	10.7	1.96	9.54	1.95	9.36	0.284
13.	Gopalpur	10.3	3.08	15.47	3.07	15.41	0.129
14.	Hyderabad (AP)	18.5	2.55	12.31	2.49	18.36	0.280
15.	Indore (AP)	10.9	3.50	21.17	3.47	20.99	0.101
16.	Jagdalpur	15.6	1.19	4.35	1.14	3.89	0.250
17.	Jaipur (AP)	18.3	2.56	6.44	2.50	5.35	0.306
18.	Jamnagar	13.0	2.74	16.22	2.73	15.70	0.125
19.	Jamshedpur	15.5	1.24	4.49	1.19	4.03	0.248
20.	Jharsuguda	10.0	1.75	9.24	1.75	9.24	0.174
21.	Jodhpur	18.3	2.47	10.81	2.41	9.09	0.285
22.	Kandla Port	33.3	3.43	23.32	3.07	20.58	0.104
23.	Kodaikanal	15.2	3.18	13.65	3.13	12.17	0.274
24.	Lucknow (AP)	13.7	2.11	11.27	2.05	10.71	0.161
25.	Madras Harbour	30.0	3.62	17.97	3.27	15.61	0.128
26.	Madras Minambakam	26.3	1.86	10.89	1.70	9.19	0.175
27.	Mangalore Port	16.5	1.16	6.11	1.11	5.47	0.220
28.	Nagpur (AP)	15.6	2.02	9.04	1.98	7.95	0.290
29.	New Delhi Palam	16.0	2.53	10.76	2.48	9.41	0.284
30.	New Delhi Safdarjung	19.8	1.64	8.90	1.54	7.83	0.188
31.	Port Blair	16.8	1.69	10.25	1.61	9.37	0.173
32.	Pune	7.5	1.31	9.12	1.34	9.58	0.172
33.	Raipur	12.0	1.15	3.84	1.12	3.66	0.258
34.	Sagar Island	17.0	1.38	7.48	1.32	6.72	0.202
35.	Tiruchirapalli (AP)	23.0	2.51	17.04	2.33	15.28	0.131
36.	Tuticorin Harbour	9.9	3.48	22.58	3.48	22.60	0.096
37.	Veraval	14.9	3.45	19.19	3.33	18.34	0.110
38.	Vishakhapatnam	12.2	1.41	9.80	1.38	9.47	0.170

TABLE 2—WEIBULL'S PARAMETERS (MAY–AUGUST DATA)

Sl. no.	Station	Height of anemometer (Metre)	Weibull's parameters at				Power law exponent
			Anemometer Height		10 Metre Height		
			K	C	K	C	n
1.	Ahmedabad (AP)	14.8	4.30	14.59	4.15	13.81	0.134
2.	Amritsar (AP)	19.8	1.69	8.59	1.59	7.53	0.193
3.	Bangalore (AP)	14.6	5.54	21.97	5.36	21.14	0.101
4.	Bangalore City	19.2	4.40	14.95	4.15	13.65	0.140
5.	Baroda	22.8	2.88	12.88	2.67	11.32	0.156
6.	Bhopal	11.7	5.18	20.09	5.06	19.50	0.109
7.	Bombay Colaba	18.5	4.44	16.60	4.20	15.32	0.130
8.	Bombay Santacruz	15.3	3.36	14.96	3.24	14.11	0.137
9.	Calcutta Alipore	26.4	2.14	10.71	1.96	9.02	0.177
10.	Calcutta Dumdum	20.0	2.18	11.22	2.05	9.98	0.168
11.	Gaya	12.5	1.96	10.54	1.92	10.15	0.166
12.	Goa	10.7	3.65	14.87	3.63	14.74	0.134
13.	Gopalpur	10.3	3.80	16.67	3.79	16.60	0.123
14.	Hyderabad (AP)	18.5	4.49	18.02	4.29	16.74	0.120
15.	Indore (AP)	10.9	6.73	25.61	6.68	25.42	0.085
16.	Jagdalpur	15.6	2.39	6.61	2.30	6.02	0.212
17.	Jaipur (AP)	18.3	2.80	7.78	2.65	6.89	0.201
18.	Jamnagar	13.0	3.25	22.33	3.24	21.76	0.098
19.	Jamshedpur	15.5	2.48	5.87	2.38	5.32	0.223
20.	Jharsuguda	10.0	3.20	13.35	3.20	13.35	0.142
21.	Jodhpur	18.3	4.44	15.05	4.17	13.84	0.138
22.	Kandla Port	33.3	5.21	30.48	4.66	27.74	0.078
23.	Kodaikanal	15.2	4.77	15.24	4.59	14.40	0.136
24.	Lucknow (AP)	13.7	2.65	12.53	2.58	11.94	0.152
25.	Madras Harbour	30.0	4.07	18.53	3.68	16.15	0.125
26.	Madras Minambakam	26.3	3.57	14.98	3.27	13.03	0.144
27.	Mangalore Port	16.5	3.18	8.23	3.04	7.47	0.193
28.	Nagpur (AP)	15.6	2.53	11.97	2.43	11.16	0.157
29.	New Delhi Palam	16.0	2.94	12.85	2.82	11.97	0.151
30.	New Delhi Safdarjung	19.8	1.61	8.79	1.51	7.72	0.189
31.	Port Blair	16.8	2.86	15.23	2.73	14.19	0.136
32.	Pune	7.5	4.40	16.97	4.51	17.55	0.117
33.	Raipur	12.0	3.50	6.51	3.41	6.27	0.210
34.	Sagar Island	17.0	4.19	14.02	3.99	12.99	0.144
35.	Tiruchirapalli (AP)	23.0	5.48	24.15	5.08	23.96	0.097
36.	Tuticorin Harbour	9.9	5.16	24.97	5.16	24.97	0.087
37.	Veraval	14.9	6.19	25.97	5.97	15.09	0.086
38.	Vishakhapatnam	12.2	1.94	12.42	1.91	12.05	0.151

TABLE 3—AVERAGE ANNUAL WIND DATA AT ANEMOMETRIC HEIGHT

Sl. no.	Station	Average wind speed (Km/hr)	Most probable wind speed (Km/hr)	Duration of speed equal to or exceeding most probable wind speed (per cent of total period)	Energy pattern factor (E.P.F.)	Wind energy densities (kW h/m²/day)
1.	Ahmedabad (AP)	10.49	9.53	55	1.60	0.573
2.	Amritsar (AP)	7.86	6.33	60	1.90	1.885
3.	Bangalore (AP)	13.87	12.75	55	1.56	1.290
4.	Bangalore City	10.08	9.39	54	1.50	0.377
5.	Baroda	8.10	6.50	60	1.90	0.279
6.	Bhopal	12.69	11.54	55	1.60	1.014
7.	Bombay Colaba	11.31	10.35	55	1.59	0.713
8.	Bombay Santacruz	9.14	6.60	64	2.16	0.511
9.	Calcutta Alipore	8.26	6.03	64	2.13	0.372
10.	Calcutta Dumdum	6.81	2.47	79	3.41	0.334

(*Continued*)

TABLE 3—(*Continued*)

11. Gaya	7.38	3.46	74	2.94	0.366
12. Goa	8.46	6.63	62	1.95	0.414
13. Gopalpur	13.83	13.63	51	1.38	1.132
14. Hyderabad (AP)	10.92	10.13	54	1.56	0.643
15. Indore (AP)	19.04	19.24	49	1.29	2.782
16. Jagdalpur	1.10	0.95	85	4.20	0.090
17. Jaipur (AP)	5.72	5.30	54	1.57	0.093
18. Jamnagar	14.43	13.75	53	1.48	1.379
19. Jamshedpur	4.19	1.20	82	3.75	0.086
20. Jharsuguda	8.23	5.70	65	2.21	0.382
21. Jodhpur	9.59	8.25	55	1.59	0.391
22. Kandla Port	20.96	21.09	49	1.32	3.768
23. Kodaikanal	12.22	12.12	50	1.36	0.785
24. Lucknow (AP)	9.98	8.31	59	1.84	0.567
25. Madras Harbour	16.20	16.43	49	1.28	1.687
26. Madras Minambakam	9.67	7.20	63	2.08	0.583
27. Mangalore Port	5.80	1.11	87	4.48	0.271
28. Nagpur (AP)	8.01	6.44	60	1.90	0.274
29. New Delhi Palam	9.55	8.82	54	1.56	0.324
30. New Delhi Safdarjung	7.96	4.99	68	2.38	0.372
31. Port Blair	9.15	6.03	67	2.28	0.542
32. Pune	8.41	3.07	79	3.41	0.629
33. Raipur	3.65	0.66	88	4.50	0.068
34. Sagar Island	6.83	2.94	76	3.14	0.310
35. Tiruchirapalli (AP)	5.12	13.93	55	1.55	1.661
36. Tuticorin Harbour	20.31	20.49	49	1.32	3.428
37. Veraval	17.25	17.38	49	1.32	2.100
38. Vishakhapatnam	8.92	4.09	75	3.02	0.665

TABLE 4—AVERAGE ANNUAL WIND DATA AT 10 METRE HEIGHT ABOVE THE GROUND

Sl. no.	Station	Average wind speed (Km/hr)	Most probable wind speed (Km/hr)	Duration of speed equal to or exceeding most probable wind speed (per cent of total period)	Energy pattern factor (E.P.F.)	Wind energy densities ($kWh/m^2.day$)
1.	Ahmedabad (AP)	9.85	8.79	56	1.70	0.504
2.	Amritsar (AP)	8.08	6.58	60	1.91	0.312
3.	Bangalore (AP)	13.49	12.20	56	1.64	1.248
4.	Bangalore City	9.76	8.91	55	1.59	0.458
5.	Baroda	8.08	6.53	60	1.92	0.314
6.	Bhopal	12.20	10.96	56	1.64	0.951
7.	Bombay Colaba	10.26	9.11	56	1.70	0.569
8.	Bombay Santacruz	8.32	5.85	65	2.22	0.396
9.	Calcutta Alipore	6.90	4.48	67	2.33	0.237
10.	Calcutta Dumdum	5.28	1.63	83	3.85	0.176
11.	Gaya	7.10	3.12	75	3.10	0.344
12.	Goa	9.96	8.48	58	1.75	0.536
13.	Gopalpur	13.78	13.56	51	1.39	1.128
14.	Hyderabad (AP)	11.46	10.91	53	1.48	0.690
15.	Indore (AP)	18.58	19.03	49	1.32	2.625
16.	Jagdalpur	3.71	0.63	88	4.60	0.073
17.	Jaipur (AP)	6.80	6.41	54	1.49	0.145
18.	Jamnagar	13.97	13.28	53	1.48	1.259
19.	Jamshedpur	3.80	0.87	85	4.20	0.071
20.	Jharsuguda	8.23	5.70	65	2.21	0.382
21.	Jodhpur	9.97	9.31	34	1.53	0.470
22.	Kandla Port	18.40	18.09	51	1.39	2.684
23.	Kodaikanal	12.93	13.06	49	1.29	0.864
24.	Lucknow (AP)	9.49	7.73	60	1.90	0.503
25.	Madras Harbour	14.00	13.97	50	1.33	1.140
26.	Madras Minambakam	8.20	5.46	66	2.26	0.386

TABLE 4—(*Continued*)

27. Mangalore Port	5.26	0.68	91	4.62	0.208
28. Nagpur (AP)	8.57	7.10	59	1.86	0.363
29. New Delhi Palam	10.23	9.72	53	1.49	0.495
30. New Delhi Safdarjung	7.05	3.97	70	2.60	0.282
31. Port Blair	8.40	5.14	68	2.46	0.452
32. Pune	8.77	3.47	77	3.20	0.674
33. Raipur	3.51	0.51	90	4.60	0.062
34. Sagar Island	6.19	2.27	79	3.41	0.231
35. Tiruchirapalli (AP)	13.54	12.00	56	1.71	1.316
36. Tuticorin Harbour	20.33	20.51	49	1.32	3.438
37. Veraval	16.46	16.47	50	1.33	1.839
38. Vishakhapatnam	8.66	1.29	76	3.10	0.624

TABLE 5—WIND DATA AT ANEMOMETER HEIGHT (MAY TO AUGUST DATA)

Sl. no.	Station	Average wind speed (Km/hr)	Most probable wind speed (Km/hr)	Duration of speed equal to or exchanging most probable wind speed (per cent of total period)	Energy pattern factor (E.P.F.)	Wind energy densities (kWh/m²/day)
1.	Ahmedabad (AP)	13.28	13.72	46	1.21	0.879
2.	Amritsar (AP)	7.67	5.04	67	2.28	0.319
3.	Bangalore (AP)	20.29	21.19	44	1.21	2.900
4.	Bangalore City	13.62	14.10	45	1.20	0.940
5.	Baroda	11.48	11.11	52	1.43	0.671
6.	Bhopal	18.48	19.27	45	1.13	2.211
7.	Bombay Colaba	15.14	15.68	46	1.19	1.280
8.	Bombay Santacruz	13.43	13.47	50	1.32	0.991
9.	Calcutta Alipore	9.48	7.98	59	1.79	0.473
10.	Calcutta Dumdum	9.94	8.47	58	1.78	0.542
11.	Gaya	9.34	7.31	62	1.95	0.492
12.	Goa	13.39	13.62	48	1.28	0.953
13.	Gopalpur	15.00	15.38	48	1.26	1.320
14.	Hyderabad (AP)	16.44	17.04	46	1.19	1.377
15.	Indore (AP)	23.90	25.00	43	1.10	4.656
16.	Jagdalpur	5.86	5.26	56	1.68	0.105
17.	Jaipur (AP)	6.93	6.65	53	1.46	0.151
18.	Jamnagar	20.02	19.95	50	1.34	3.333
19.	Jamshedpur	5.20	4.77	55	1.58	0.068
20.	Jharsuguda	11.96	11.88	50	1.35	0.716
21.	Jodhpur	13.72	14.21	46	1.19	0.953
22.	Kandla Port	28.05	29.25	45	1.13	2.731
23.	Kodaikanal	13.95	14.51	45	1.17	0.985
24.	Lucknow (AP)	11.14	10.47	54	1.50	0.643
25.	Madras Harbour	16.81	17.28	47	1.23	1.811
26.	Madras Minambakam	13.49	13.66	49	1.29	0.982
27.	Mangalore Port	7.37	7.31	50	1.38	0.171
28.	Nagpur (AP)	10.62	9.82	55	1.54	0.572
29.	New Delhi Palam	11.46	11.16	52	1.41	0.658
30.	New Delhi Safdarjung	7.88	4.81	68	2.46	0.373
31.	Port Blair	13.57	13.10	52	1.44	1.116
32.	Pune	15.45	16.00	46	1.20	1.372
33.	Raipur	5.86	5.91	49	1.29	0.081
34.	Sagar Island	12.74	13.14	47	1.22	0.782
35.	Tiruchirapalli (AP)	22.29	23.28	44	1.12	3.845
36.	Tuticorin Harbour	22.97	23.94	45	1.13	4.245
37.	Veraval	24.13	25.24	43	1.11	4.835
38.	Vishakhapatnam	11.01	8.53	62	1.98	0.819

TABLE 6—WIND DATA AT 10 METRE HEIGHT (MAY TO AUGUST DATA)

Sl. no.	Station	Average wind speed (Km/hr)	Most probable wind speed (Km/hr)	Duration of speed equal to or exceeding most probable wind speed (per cent of total period)	Energy pattern factor (E.P.F.)	Wind energy densities (kWh/m²/day)
1.	Ahmedabad (AP)	12.54	12.92	47	1.22	0.746
2.	Amritsar (AP)	6.76	4.04	69	2.48	0.237
3.	Bangalore (AP)	19.45	20.34	44	1.12	2.560
4.	Bangalore City	12.40	12.77	47	1.22	0.721
5.	Baroda	10.06	9.50	53	1.49	0.470
6.	Bhopal	17.92	18.67	45	1.14	2.030
7.	Bombay Colaba	13.92	14.36	47	1.22	1.020
8.	Bombay Santacruz	12.65	12.59	50	1.34	0.840
9.	Calcutta Alipore	7.99	6.27	62	1.95	0.310
10.	Calcutta Dumdum	8.84	7.20	60	1.90	0.407
11.	Gaya	9.00	6.91	62	2.00	0.452
12.	Goa	13.23	13.48	48	1.28	0.919
13.	Gopalpur	15.00	15.30	45	1.26	1.320
14.	Hyderabad (AP)	15.23	15.74	46	1.21	1.330
15.	Indore (AP)	23.74	24.81	43	1.10	4.560
16.	Jagdalpur	5.23	4.70	57	1.71	0.076
17.	Jaipur (AP)	6.12	5.76	54	1.50	0.107
18.	Jamnagar	19.50	19.41	50	1.34	3.080
19.	Jamshedpur	4.72	4.23	56	1.68	0.055
20.	Jharsuguda	11.96	11.88	50	1.35	0.716
21.	Jodhpur	12.57	12.96	47	1.22	0.751
22.	Kandla Port	25.37	26.34	46	1.18	5.970
23.	Kodaikanal	13.16	13.54	46	1.18	0.834
24.	Lucknow (AP)	10.60	9.87	54	1.53	0.565
25.	Madras Minambakam	11.68	11.65	50	1.33	0.657
26.	Madras Harbour	14.57	14.82	48	1.27	1.217
27.	Mangalore Port	6.67	6.55	51	1.39	0.128
28.	Nagpur (AP)	9.89	8.97	56	1.62	0.486
29.	New Delhi Palam	10.66	10.25	52	1.45	0.545
30.	New Delhi Safdarjung	6.96	3.76	88	2.70	0.282
31.	Port Blair	12.62	12.00	53	1.48	0.922
32.	Pune	16.01	16.60	46	1.18	1.501
33.	Raipur	5.63	5.66	49	1.32	0.073
34.	Sagar Island	11.77	12.08	47	1.24	0.627
35.	Tiruchirapalli	21.96	22.95	45	1.14	3.743
36.	Tuticorin Harbour	22.97	23.95	45	1.13	4.245
37.	Veraval	23.27	24.33	44	1.12	4.375
38.	Vishakhapatnam	10.68	8.75	62	2.00	0.755

TABLE 7—COMPARISON OF AVERAGE ANNUAL WIND SPEEDS

Sl. no.	Station	Average wind speed (Km/hr)	
		Computed by taking simple arithmatic mean	Computed using Weibulls' distribution
1.	Ahmedabad	9.7	10.49
2.	Amritsar (AP)	7.7	7.86
3.	Bangalore (AP)	14.0	13.87
4.	Bangalore City	9.4	10.08
5.	Baroda	8.0	8.10
6.	Bhopal	13.1	12.69
7.	Bombay Colaba	11.3	11.31
8.	Bombay Santacruz	9.6	9.14
9.	Calcutta Alipore	7.7	8.26
10.	Calcutta Dumdum	7.3	6.81
11.	Gaya	7.6	7.38
12.	Goa	8.9	8.46

TABLE 7—(*Continued*)

13. Gopalpur	13.4	13.83
14. Hyderabad (AP)	11.0	10.92
15. Indore (AP)	19.2	19.04
16. Jagdalpur	4.1	4.10
17. Jaipur (AP)	5.8	5.72
18. Jamnagar	14.8	14.43
19. Jamshedpur	4.3	4.19
20. Jharsuguda	8.1	8.23
21. Jodhpur	9.3	9.59
22. Kandla Port	21.4	20.96
23. Kodaikanal	12.2	12.22
24. Lucknow (AP)	9.5	9.98
25. Madras Harbour	16.1	16.20
26. Madras Minambakam	10.4	9.67
27. Mangalore Port	6.4	5.8
28. Nagpur (AP)	7.8	8.01
29. New Delhi Palam	8.8	9.55
30. New Delhi Safdarjung	7.9	7.96
31. Port Blair	9.4	9.15
32. Pune	9.0	8.41
33. Raipur	3.5	3.65
34. Sagar Island	7.5	6.83
35. Tiruchirapalli (AP)	15.5	15.12
36. Tuticorin Harbour	20.3	20.31
37. Veraval	18.8	17.25
38. Vishakhapatnam	9.4	8.92

and also establishes the correctness of the parameters evolved.

Discussion

Wind data for 38 places have been analysed specifically from the view point of utilisation of wind energy for inducing air motion for thermal comfort in buildings. Because of simplicity and economic considerations in the design of wind operated air moving systems it is desired to make direct utilisation of wind energy without going into the provision of an energy storage system. Hence, high wind speeds of short duration were not used for computation of total energy content, rather average hourly values were used. This is why EPF values are lower than those reported by Mani et al[5]. However, the average values are in agreement with those obtained by taking simple arithmatic mean of the hourly data. The values of power law exponent are also given, which make it possible to compute the values of K and C at any desired height. These values in turn can be used for determination of Vmp, $T \geqslant Vmp$, E.P.F. and wind energy density at any desired height above the ground.

Acknowledgement

The study forms a part of the normal research programme of CBRI, Roorkee and the paper is published with the permission of the Director.

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