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Estimation of monsoon wind characteristics in India

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सार - समूचे भारत में फैले हुए 57 केन्द्रों के मानसून ऋतु (जून से सितंबर) के पवन गति के वर्ष 1921 से 1990 तक की अवधि के औसत मासिक आँकड़ों के व्यापक साँख्यिकी विश्लेषणों की सूचना प्राप्त की गई है। प्रत्येक केन्द्र की संभावित सघनताओं, औसत पवन गतियों, मानक परिवर्तनों, ककुदता और पवन गति की आवृत्ति के वितरण की विषमता का विवरण तैयार किया गया है। इस संबंध में औसत पवन गति की सापेक्षिक आवृत्ति के विवरण को दर्शाने वाले आयत चित्र (हिस्टोग्राम) भी तैयार किए गए हैं। विभिन्न आयत-चित्रों में परस्पर कोई समानता नहीं पाई गई है जिससे यह पता चला है कि सभी केन्द्रों में एकल वितरण समान रूप से नहीं पाया गया है। भारत के मुख्य भागों में मानसून ऋतु के समय पवन की औसत गति 7 से 14 किलोमीटर प्रति घंटा के बीच रहने का भी पता चला है। इसके अतिरिक्त मानसून पवन की औसत गति अधिकांश स्थानों में पवन की औसत वार्षिक गति से प्रायः उच्चतर रही है। यह भी द्रष्टव्य है कि गुजरात के तटीय क्षेत्रों और प्रायद्वीपीय भारत के दक्षिणी भागों में पवन की गति अधिकतर 10 किलोमीटर प्रति घटा से अधिक होती है। प्राप्त हुई इन सूचनाओं के बहुउद्देशीय अनुप्रयोग हैं। (*i*) पवन उर्जा परिवर्तन प्रणाली स्थापित करने के लिए उपयुक्त स्थान का निर्धारण, (*ii*) परिचालन वर्षा सूचकांक का विकास और (*iii*) पर्यावरण की दृष्टि से आरामदेह भवनों के निर्माण हेतु उनका डिजायन तैयार करना।

ABSTRACT. A detailed statistical analysis of monthly average wind speed data of monsoon period (June-September) for the year 1921-90 for 57 stations spread all over India have been reported. Probability densities, average wind speeds, standard deviations, kurtosis and skewness of wind speed frequency distribution for each station have been worked out. Histograms depicting relative frequency distribution of average wind speeds have also been prepared. It is observed that the different histograms do not exhibit any similarity among themselves indicating thereby that no single distribution is uniformly applicable for all the stations. It is also seen that the average wind speeds during monsoon period over major part of India varies from 7 to 14 kmph. Further, at most of the stations average monsoon wind speed is generally higher than average annual wind speeds. It is also noted that most of the time the wind speed exceeds 10 kmph in coastal regions of Gujarat and southern parts of the peninsular India. The information generated is of multi fold application such as (*i*) Identification of sites suitable for installation of Wind Energy Conversion Systems (*ii*) Development of Driving Rain Index and (*iii*) Design of buildings for creating comfortable environment indoors.

Key words – Monsoon, Wind data, Probability densities, Histograms, Most probable wind.

1. Introduction

Estimation of annual wind speed characteristics has been of interest to several investigators working on the problems related to use of non conventional sources of energy with particular reference to the wind power generation and design of buildings for adequate natural ventilation therein.. Wind plays a significant role in creating comfortable environment in and around buildings and in design of energy efficient buildings. In early nineties Mani (1990,1992,1994) reported detailed results of her studies of quantitative assessment of wind potential at the sites which were pre identified as windy sites. Since India is a vast country, further investigations

TABLE 1

Monsoon (June - September) wind speed data

S. No.	Station	Average wind speed (kmph)	Standard deviation (kmph)	Coefficient of skewness	Coefficient of kurtosis	Most probable wind speed (kmph)	Duration of most probable wind speed (% of total period)
1.	Agra	5.17	1.62	0.20	3.72	4.94	43
2.	Ahmedabad	7.89	1.29	0.73	4.57	7.50	30
3.	Ahmednagar	9.49	1.51	- 0.49	3.38	9.50	36
4.	Asansol	6.97	0.94	- 0.69	2.91	7.44	30
5.	Bahraiach	6.56	1.55	- 0.83	2.94	6.50	29
6.	Balasore	8.07	1.54	- 1.00	3.62	9.50	31
7.	Bangalore	12.72	3.42	- 0.41	1.77	15.43	29
8.	Bareilly	4.94	1.51	- 0.10	3.22	5.50	28
9.	Barmer	10.95	1.49	0.03	3.27	10.50	33
10.	Baroda	7.64	1.93	- 0.21	2.75	7.56	29
11.	Belgaum	7.77	2.10	- 0.48	3.38	8.94	29
12.	Bellary	12.52	1.69	- 0.70	3.09	13.18	30
13.	Bijapur	6.26	3.13	1.65	4.55	4.62	51
14.	Bikaner	9.93	2.20	- 0.19	2.81	10.18	27
15.	Bombay	11.74	1.96	- 0.36	2.52	12.81	24
16.	Chandrapur	8.95	1.64	1.17	8.30	8.75	41
17.	Coimbatore	13.43	3.02	- 0.44	2.74	14.81	26
18.	Cuddalore	9.64	1.12	- 0.50	2.88	9.37	29
19.	Cuddapah	8.06	2.11	- 0.24	2.51	7.63	27
20.	Daltonganj	3.86	1.52	1.11	4.39	3.56	39
21.	Darbhanga	5.71	1.98	- 0.35	2.12	5.56	33
22.	Delhi	9.02	2.67	- 0.06	2.36	10.31	27
23.	Hissar	7.87	1.39	- 0.48	2.63	8.82	31
24.	Jagdalpur	6.29	1.97	0.56	3.69	5.50	40
25.	Jalpaiguri	5.28	1.73	- 0.92	2.84	5.50	30
26.	Jamshedpur	6.73	1.07	- 0.64	2.66	7.87	31
27.	Jhalwar	9.11	1.26	- 1.07	4.01	9.81	39
28.	Khandwa	11.98	1.79	- 0.48	3.15	12.06	34
29.	Kodaikanal	12.63	2.40	0.35	2.46	12.37	26
30.	Kurnool	14.70	4.84	- 0.48	2.11	16.75	30
31.	Kozhikode	8.21	1.90	- 1.42	5.64	8.94	40
32.	Ludhiana	3.89	0.72	- 0.11	2.60	3.75	31
33.	Madras	12.37	3.23	0.31	2.02	10.01	20
34.	Masulipatnam	9.59	3.46	- 0.46	1.94	11.62	30
35.	Midnapore	4.85	1.10	- 0.15	2.78	5.44	30
36.	Nagapattinam	10.76	1.31	0.29	5.71	9.81	20
37.	Nellore	8.83	1.75	- 0.65	2.37	9.88	24
38.	Nizamabad	7.54	1.73	- 0.41	2.26	8.06	33
39.	Nowgong	5.45	1.48	- 0.57	2.70	6.50	36
40.	Pune	9.00	1.98	- 0.26	1.98	9.50	36
41.	Purnea	4.93	0.83	- 0.24	2.82	4.81	30
42.	Raipur	8.08	2.09	- 0.31	2.16	8.06	20
43.	Roorkee	5.06	0.92	- 1.08	3.95	5.44	39
44.	Sagar	11.40	4.19	0.63	2.33	9.31	36
45.	Salem	7.04	1.46	- 0.85	3.45	8.50	31
46.	Sambalpur	6.23	1.56	0.35	3.13	6.94	26
47.	Satna	7.24	0.77	- 0.65	4.32	7.37	39
48.	Seoni	6.78	0.96	- 0.81	3.45	6.81	29
49.	Shillong	3.85	0.89	- 0.88	4.40	3.81	43
50.	Simla	2.85	1.09	1.71	6.44	2.12	36
51.	Surat	10.45	1.58	- 0.81	3.40	11.19	41
52.	Tezpur	2.74	0.70	0.43	3.06	2.75	40
53.	Trivandrum	9.67	1.46	- 0.83	4.02	10.18	39
54.	Varanasi	6.61	2.15	- 0.11	1.88	9.32	23
55.	Vellore	8.67	1.27	- 0.38	3.89	8.94	41
56.	Veraval	23.00	3.91	- 0.29	2.50	25.37	24
57.	Vishakhapatnam	11.48	2.32	0.14	2.50	8.81	26

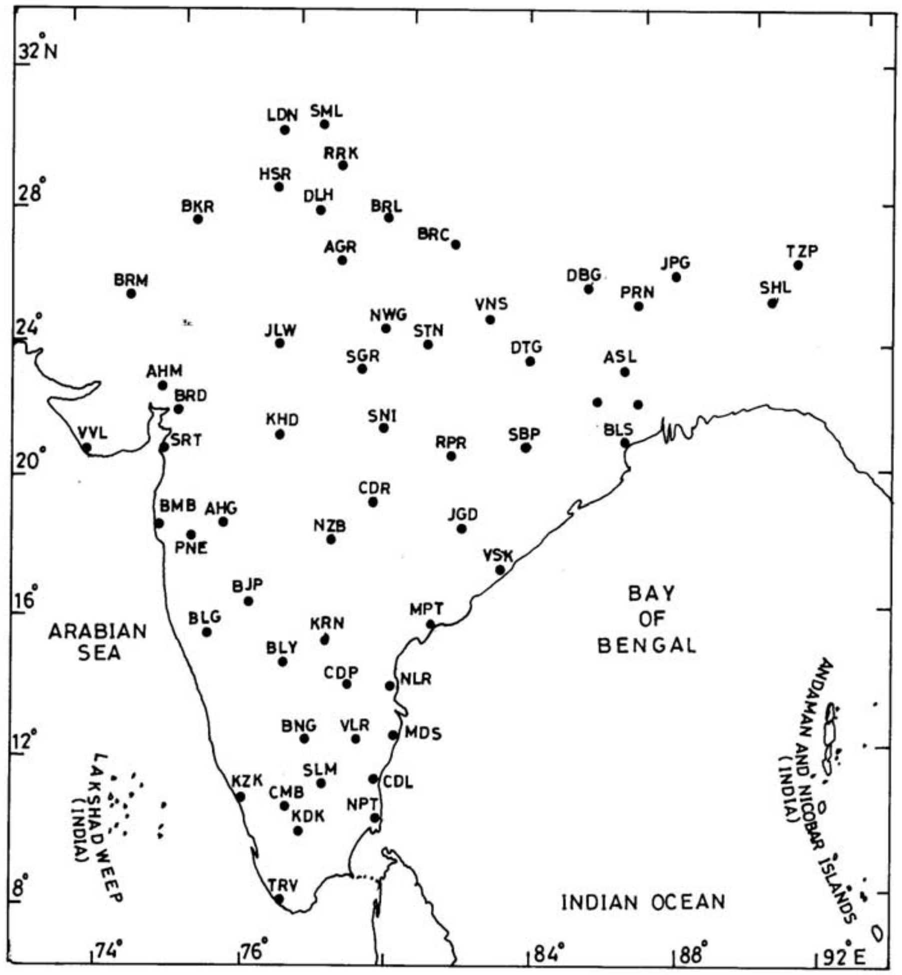

Fig. 1. Network of observation stations

were desired to determine wind characteristics at several other stations which were left uncovered in earlier studies. Therefore, at the Central Building Research Institute, Roorkee, earlier studies carried out in this direction were aimed at exploring annual wind characteristics of 92 stations spread all over India for the year 1931-90 . The findings of these studies are reported in an earlier publication of Bhargava *et al*. (1999). In context with climatic design of buildings, specially in hot humid climate where high rates of air motion are desired for thermal comfort of occupants, availability of data on wind speeds for monsoon period is a prerequisite for evolution of functionally efficient design of buildings. Mooley (1983) has carried out such analysis of wind data for monsoon period utilising hourly wind data for the period 1969-73 only for a few stations in the country. Hence it was considered imperative to carry out such studies for monsoon period when wind plays a prominent role in creating comfortable environment in the interior of buildings. The findings of these studies form the subject matter of the present paper.

2. Wind data

Wind data at various stations of IMD is collected at 0800 IST and mean of the day is calculated from the total run of the wind during the 24 hours period. Thence the mean monthly wind speed for each month is worked out. Wind speed data is random in nature and different distributions have been proposed to fit the observed data. According to several researchers, Weibull's distribution

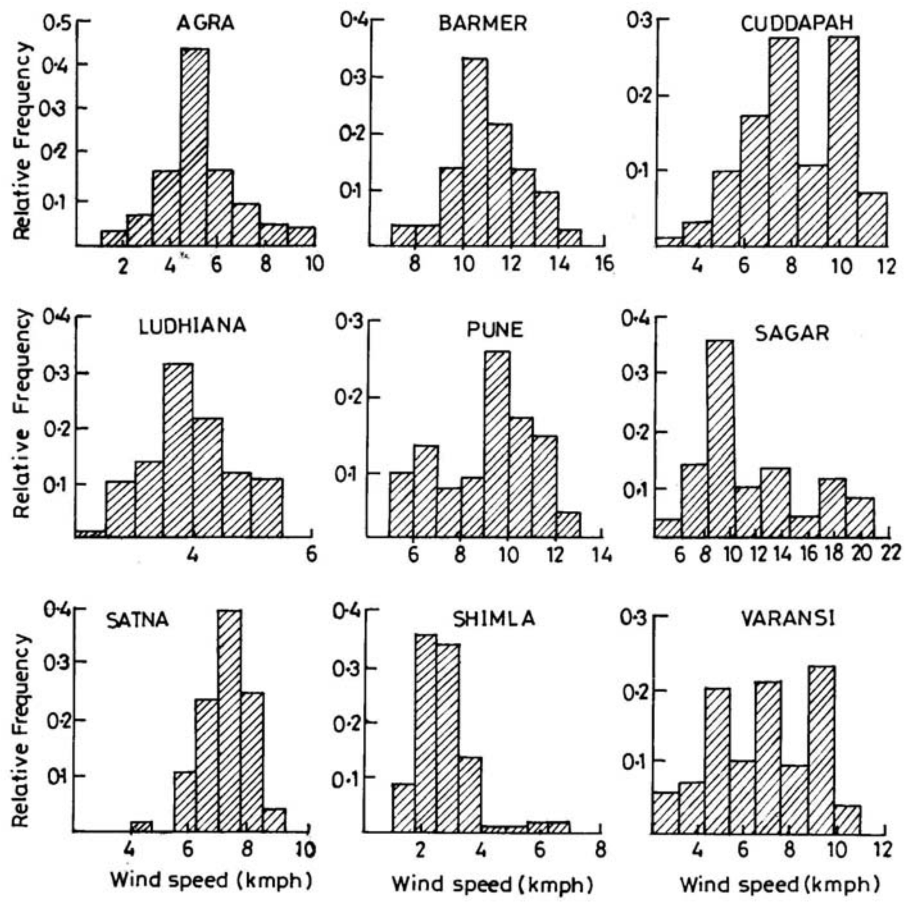

Fig. 2. Frequency distribution of average monsoon wind speeds (1921-90) at various stations

gives a good fit to observed wind speed distributions in most of the cases reported by Chand and Bhargava (1985) and Justus *et al*. (1978). Since, it does not fit in all the cases, hence histograms depicting relative frequency distribution of wind speeds were prepared. The network of observation stations for which characteristics of monsoon wind have been studied is depicted in Fig.1.

3. Data analysis

The analysis of data was undertaken following the standard methods and formulae. Average monsoon wind speeds for each year were calculated by taking average of wind speeds recorded in rainy season (June to September). Then the various parameters depicting the wind characteristics were computed using the following expressions :

Mean of monsoon average wind speeds, $V_M = \Sigma V_i / N$

Standard Deviation, $\sigma = [\Sigma (V_i - V_M)^2 / N]^{1/2}$

Coefficient of Skewness = $[\Sigma (V_i - V_M)/\sigma]^3 / N$

Coefficient of Kurtosis = $[\Sigma (V_i - V_M) / \sigma]^4 / N$

Where

V_i = average monsoon wind speed during a year *i*.

N = number of years for which wind speed data has been utilised.

The average wind speed, standard deviation, coefficient of skewness, coefficient of kurtosis and most probable wind speeds at various stations were calculated for all the 57 stations. The results of computation are listed in Table 1. Frequency distribution analysis of

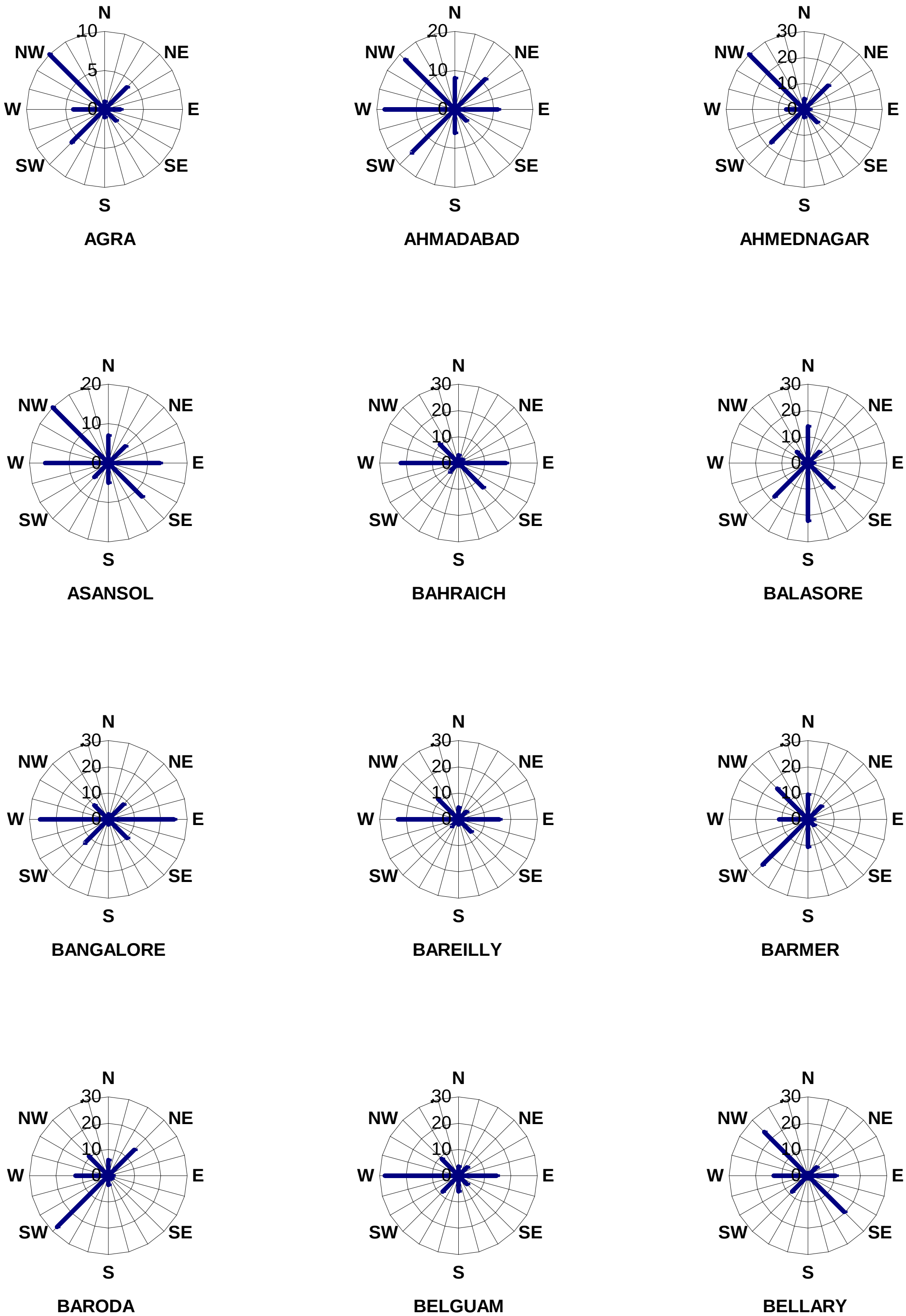

Fig. 3. Annual wind roses

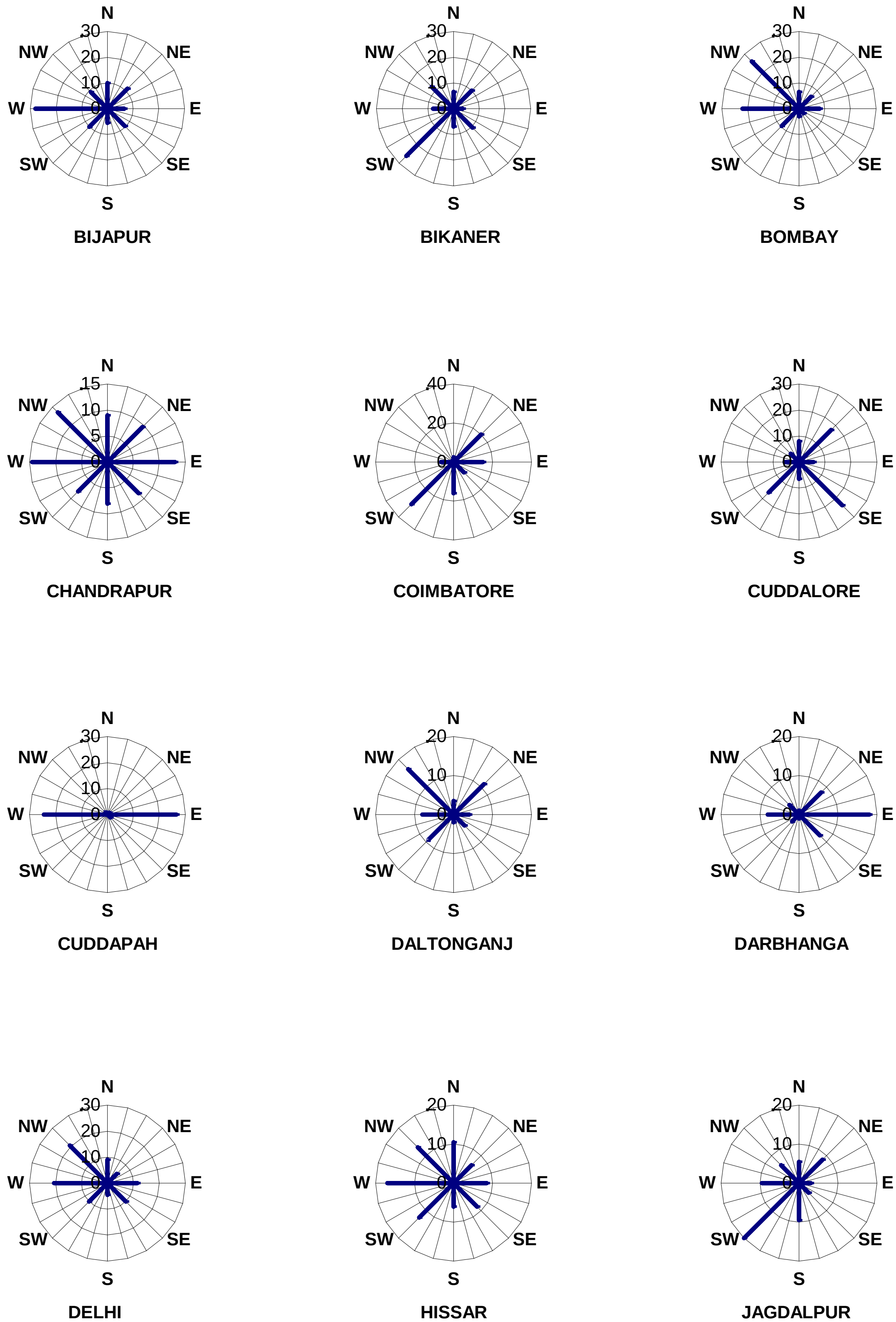

Fig. 3 (*Contd.*). Annual wind roses

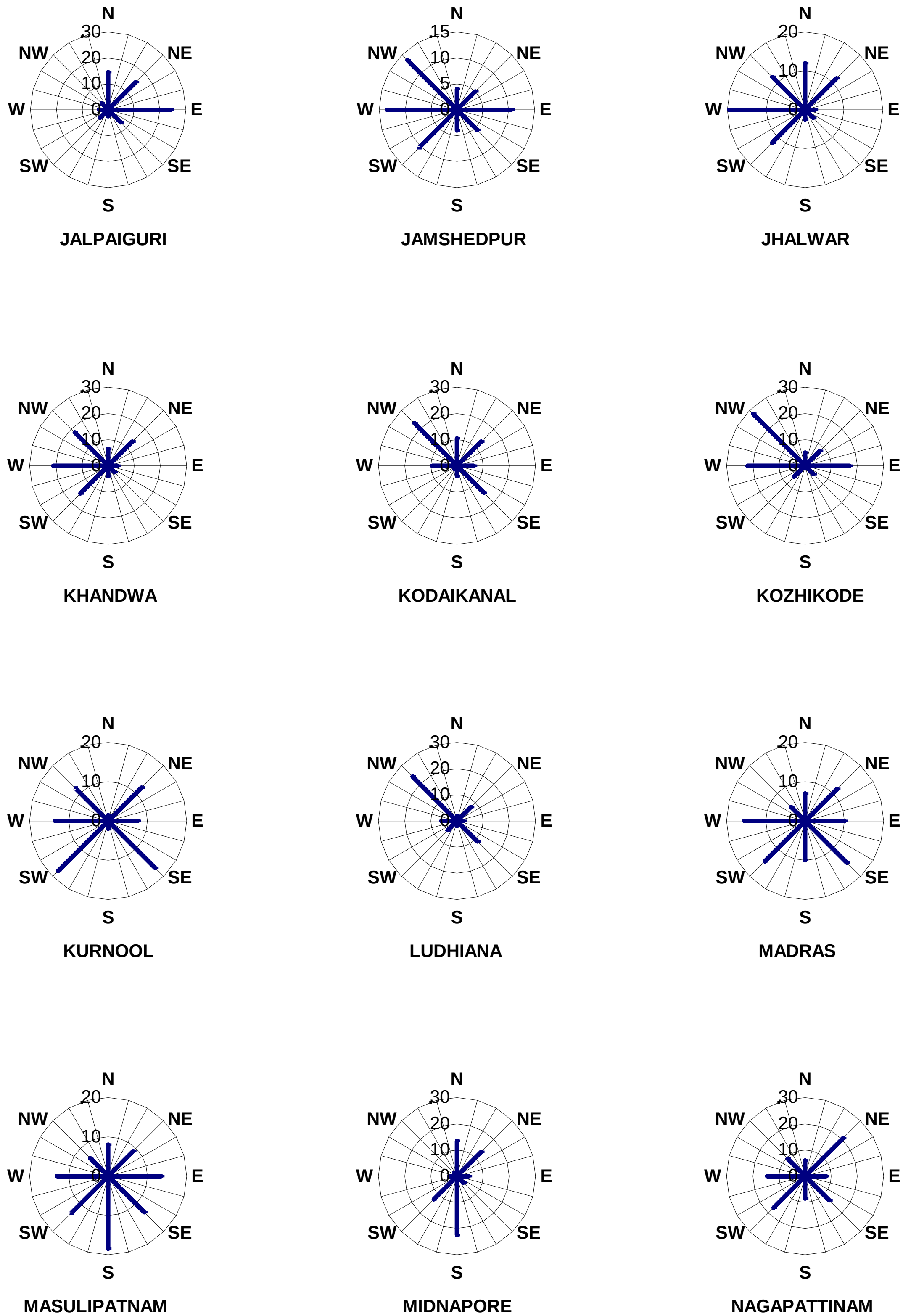

Fig. 3 (*Contd.*). Annual wind roses

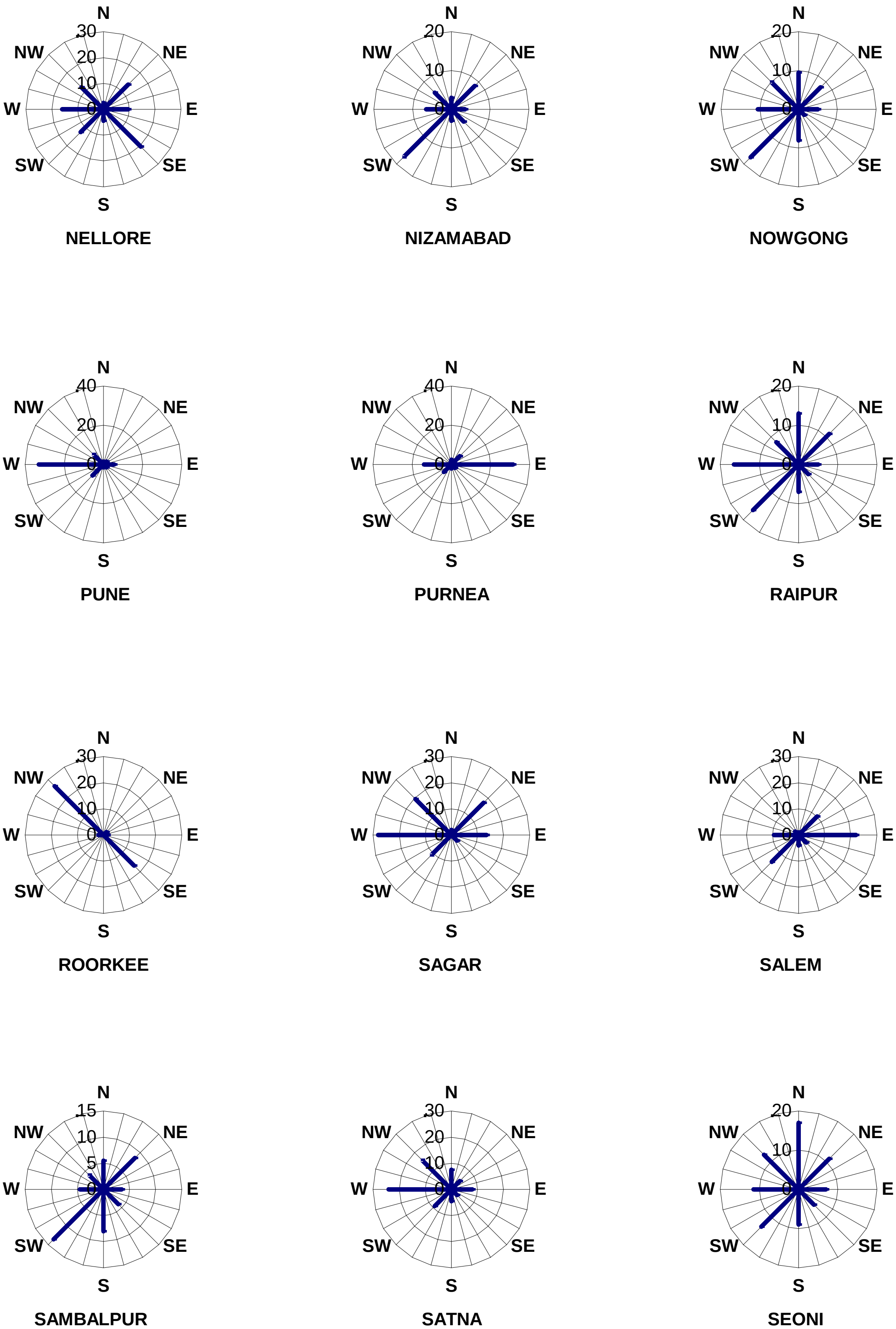

Fig. 3 (*Contd.*). Annual wind roses

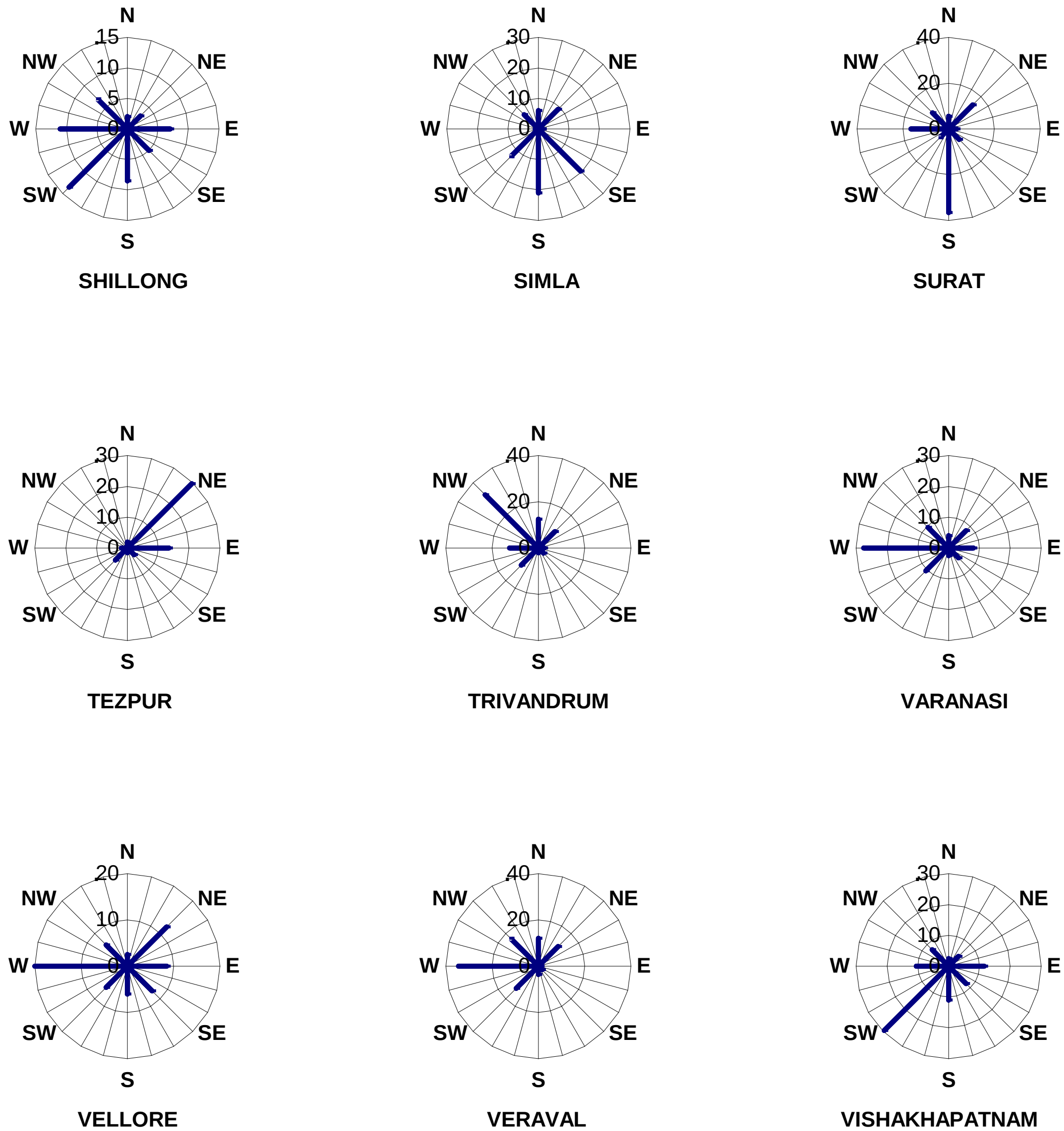

Fig. 3 (*Contd.*). Annual wind roses

monsoon average wind speed data was also worked out and histograms depicting monsoon relative frequency distribution of wind speed were prepared for all the stations. It was noted that all the histograms are not identical in nature. Because of limited space, presentation of all the histograms is not possible hence only few histograms representing positively skewed and negatively skewed distribution; platykurtic, normal and leptokurtic nature of distribution are included in this paper. These are depicted in Fig. 2.

4. Wind Roses

Knowledge of prevailing wind direction at the building site is quite important to derive maximum benefit from wind for passive design of buildings, which are functionally efficient. Installation of gadgets for harnessing wind energy and integration of these devices with design of buildings also require knowledge of prevailing wind directions. Further, prevailing wind direction is a criterion of utmost importance in planning

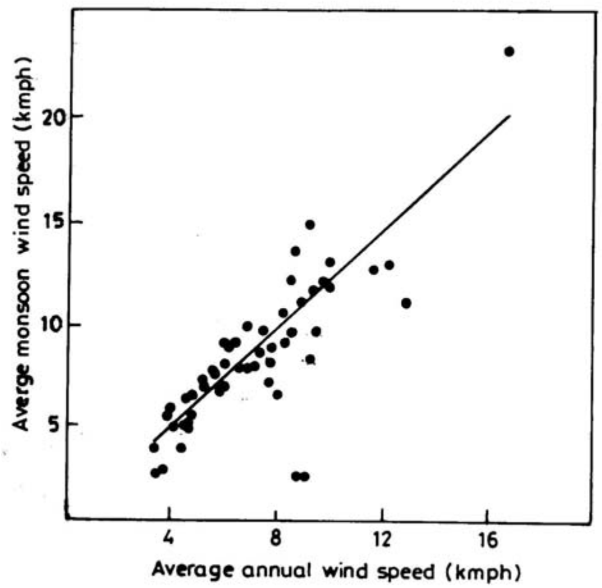

Fig. 4. Relation between average annual wind speed and average monsoon wind speed for various stations

and layout of new cluster of buildings, particularly in the vicinity of industrial areas where pollution dispersal is of great concern. To accomplish this, frequency analysis of wind direction was carried out for all the twelve months and also for the whole year. However, due to paucity of space, only the data pertaining to annual frequency distribution is depicted in the form of wind roses in Fig 3. The length of the petal represents the percentage frequencies of wind direction corresponding to eight cardinal directions *viz*., N, NE, E, SE, S, SW, W, NW. With the help of these wind roses, prevailing wind direction for a station can be straightaway determined.

5. Results and discussion

Based on the analysis of data, wind speeds of different stations can be grouped into three categories (*i*) Stations having wind speed less than 5 kmph (*ii*) Stations with wind speed ranging from 5 to 10 kmph and (*iii*) Stations with wind speed exceeding 10 kmph. It is observed that at Bareilly, Daltonganj, Ludhiana, Midnapur, Purnea, Shillong, Shimla, Tezpur and Varansi, the annual average wind speed is weak, as it remains less than 5 kmph. Therefore, these 9 stations may be considered areas of weak wind speeds. It is also noted that Agra, Ahmedabad, Ahmednagar, Asansol, Bahraiach, Balasore, Baroda, Belgaum, Bijapur, Bikaner, Chandrapur, Cuddalore, Cuddapaha, Darbhanga, Delhi, Hissar, Jagdalpur, Jalpaiguri, Jamshedpur, Jhalwar, Kozhikode, Masulipatnam, Nellore, Nizamabad, Nowgang, Pune, Raipur, Roorkee, Salem, Sambalpur, Satna, Seoni, Trivandrum and Vellore have average annual wind speed varying from 5 to 10 kmph. Some of these 34 locations are suitable for installation of low speed wind mills for extraction of power from wind. At Bangalore, Barmer, Bellary, Bombay, Coimbatore, Khandwa, Kodaikanal, Kurnool, Madras, Nagapattinam, Sagar, Surat and Visakhapatnam the monsoon average wind speed varies from 10 to 15 kmph. These 13 stations may be characterised as stations with good wind potential and suitable for installation of large size wind mill. Further, at Veraval, average monsoon wind speed is 23 kmph, and also the wind speed exceeding 15 kmph are achieved for about 93% duration or more. This station, therefore, has tremendous wind potential and is extremely suitable for power generation .

It is also revealed that average monsoon wind speeds exceeding 5 kmph occur at about 85% of the stations covered in the study. The wind speeds of this order are considered good enough for inducing natural ventilation in buildings. Natural flow of outdoor wind through buildings makes important contribution towards creation of comfort condition indoors in hot-humid and hot-dry climates and thus helps in saving energy consumed in cooling and ventilation of buildings. This can be achieved with optimum orientation of buildings *w.r.t.* prevailing wind, proper location and size of openings, planning and lay out of buildings etc. Another way of direct utilisation of wind energy in buildings is through wind towers and wind catchers. These are important architectural features of naturally ventilated buildings in hot arid regions of India and Middle East. Through these systems, the prevailing wind is harnessed and circulated through the building. Development of all the above devices need information of the magnitude of the prevailing wind speeds at the station in question. The desired data on wind speed can be derived from Table 1 and information related to prevailing wind direction may be deduced from the wind roses depicted in Fig.3.

It is also of interest to examine the variations in the average monsoon wind speeds of various stations over a period of 70 years covered in the study. The standard deviation is minimum 0.70 kmph at Tezpur and maximum 4.84 kmph deviations occur at Kurnool. This clearly indicates that the speed of wind has maximum uniformity at Tezpur and large scale variations in wind speed occur at Kurnool.

Skewness is another important parameter defining the wind characteristics. It is found (Table 1) that coefficient of skewness is positive at 15 stations whereas it is negative for 42 stations. The positive coefficient of skewness is minimum (0.03) for Barmer and maximum (1.71) for Shimla while the negative coefficient of skewness is minimum (−0.10) for Bareilly and maximum (−1.42) for Kozhikode .

Kurtosis is a measure of sharpness of the curve representing frequency distribution of wind speeds. The value of coefficient of Kurtosis is minimum (1.77) for Bangalore and maximum (8.30) for Chandrapur. This indicates that Bangalore wind speed distribution during monsoon season is most platykurtic and Chandrapur is most leptokurtic. The value of coefficient of kurtosis for Bellary and Tezpur are 3.09 and 3.06 respectively which are very close to the value known for normal frequency distribution curves.

6. Wind speed variation with height

Investigations carried on problems related to wind loads on buildings by Baines (1963) have revealed that variation of wind speed with height is an important parameter governing the pressure distribution on tall buildings. Hence for structural design of buildings in respect of wind loads, it is desired to determine the wind speeds at different height above the ground. The data referred in the paper is based on the wind data recorded at normal height of 10 m at various meteorological stations. Using the above data, wind velocity gradient at these stations can be easily worked out by using the following power law :

$$\frac{\overline{V}_Z}{\overline{V}_{ZG}} = \left[\frac{Z}{Z_G}\right]^{\alpha}$$

Where

α = Power law exponent.

$\overline{V}_Z$ = Mean speed at height Z

Z_G = Gradient height

$\overline{V}_{ZG}$ = Mean speed at gradient height

Z_G and α are functions of ground roughness. The gradient height varies from about 250m over open sea or ice field to 400-500m over extremely rough terrain like city. The power law exponent varies from about 0.11 for open sea or ice field to 0.36 for city centres and well developed industrial area.

7. Relationship between average annual wind speeds and average monsoon wind speeds

A comparison of average wind speeds of monsoon period with the annual average wind speeds, which was reported in an earlier publication Justus *et al.* (1978) is depicted in Fig. 4. The relationship derived on the basis of linear regression analysis of data is given by

$$V_M = 1.2\ V_A + 0.046$$

Where

V_M = Average monsoon wind speed (kmph)

V_A = Average annual wind speed (kmph)

The standard error and coefficient of correlation in derivation of above expression between observed and calculated values of data are 1.549 and 0.894 respectively. It is noted that the value of average monsoon wind speeds are generally 20% higher than the average annual wind speeds. Bijapur, Daltanganj, Kozhikode, Nagapattinam, Salem, Shilong and Tezpur are the only 7 stations where average monsoon wind speed remains less than the average annual wind speeds. Since data on wind speeds during rainy season are more realistic in constructing Driving Rain Maps hence the above relationship may be helpful to assess the average monsoon wind speeds for those stations for which detailed data on monsoon wind speeds are not available. The importance of such information was also emphasized by Lacy (1962) during his investigations on development of Driving Rain Index for U.K. He estimated that the ratio of average monsoon wind speeds to the average annual wind speeds is more or less constant and vary from 1.2 to 1.4.

8. Application of the findings

The information generated in the present study have followings applications ;

(*i*) The distribution of wind in space and time is essential for precise and reliable estimate of India's total wind potential and to identify high wind areas for power generation.

(*ii*) The knowledge of the duration and average energy content of the prevailing wind is helpful for design of energy efficient buildings. This information also provides a basis for assessing the ventilation rates in buildings for creating comfortable environment indoors and also for estimation of energy loss in conditioned buildings.

(*iii*) The wind characteristics are also used in wind load studies on structures and other wind engineering applications such as dispersion and transportation of air pollutants.

(*iv*) Studies on monsoon wind characteristics is useful for development of driving rain index which is a measure of the rain water derived by wind on walls of buildings.

9. Conclusion

The monsoon wind characteristics of 57 stations spread all over India have been studied and average wind speed, standard deviation, coefficient of skewness, coefficient of kurtosis, most probable wind speed, duration of most probable wind speed etc. for all the stations have been worked out. It has been found that wind speed exceeding 5 kmph during monsoon period occur at about 85% stations covered in the present study. Wind speeds in coastal areas of Gujarat and southern part of the peninsula exceeds 10 kmph for most of the time during monsoon period. The findings help identifying locations which are windy and have sufficient potential for inducing natural ventilation and power generation. However, the studies do not provide precise information about the quantum of power available at these sites. This needs further analysis of data based on hourly observation of wind records. Further, the information generated is of immense practical applications as it provides useful tool to the architects and building designers for design of buildings for adequate natural . Knowledge of monsoon wind characteristics is also helpful for development of Driving Rain Index map of the country.

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