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Wind Atlas for Australasia and the Pacific Region

I. Kamal* & P. Freere**

**INST, Bangladesh Atomic Energy Commission, GPO Box 3787, Dhaka, Bangladesh.*
***Department of Electrical and Computer Systems Engineering,, Monash University, Victoria, Australia*
Email: imtiazk@connectbd.com

Abstract

Of the ten sites of Australia, two had a mean wind speeds at 10m height of about 8m/s and eight of the sites had a mean wind speeds about 6m/s. The sites at Kilcunda North, Toora, Apollo Bay and Bridgewater recorded the highest annual average wind speeds. The sites at Apollo Bay recorded the highest wind energy harvest potential. However, Kilcunda Toora and Bridgewater would probably be better sites than Apollo Bay for harvesting the wind energy because their velocity is more consistent throughout the year.

Wind velocity was higher during winter and spring compared to during summer and autumn. Also they were higher during day. There is a trend to higher wind velocity with the increasing altitude.

The part of the Victoria coast from the South Australia border to Cape Otway and from Portsea to Wilsons, s Promontory appear to be most prospective for wind energy. [1] The wind speeds measured along the Victorian coast have good potential for electricity generation.

Introduction

The State Electricity Commission of Victoria (SECV) and the Victorian Solar Energy Council (VSEC) are investigating jointly to determine the prospects of electricity generation in Victoria using wind energy. The wind monitoring studies have carried out only two years at ten exposed sites along the Victorian coastal line. The site locations are shown in Fig.1. Data collection for joint wind monitoring study is completed and the results are presented in this report covering from February 1985 to January 1987. The site locations extend from near Lakes Entrance in the east to near Portland in the west.

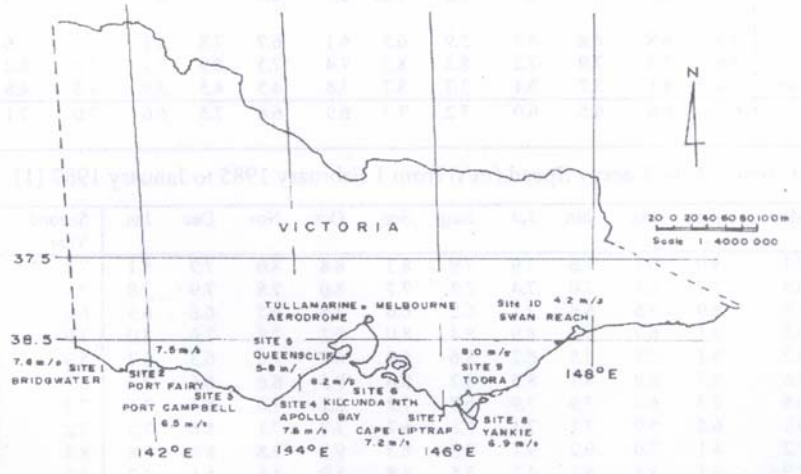


Fig. 1 Wind Monitoring Sites in Victoria (1)

Table 1: Locations of different sites and elevation above mean sea level [1]

Site number	Site name	Latitude (S)	Longitude (E)	Elevation(m ASL)
1	Bridgewater	$38^0 19'$	$141^0 25'$	105
2	Port Fairy	$38^0 22'$	$142^0 06'$	65
3	Port Campbell	$38^0 39'$	$143^0 06'$	85
4	Apollo Bay	$38^0 45'$	$143^0 38'$	287
5	Queenscliff	$38^0 15'$	$144^0 36'$	64
6	Kilcunda North	$38^0 31'$	$145^0 29'$	165
7	Cape Liptrap	$38^0 54'$	$145^0 58'$	110
8	Yanakie	$38^0 50'$	$146^0 11'$	45
9	Toora	$38^0 39'$	$146^0 20'$	257
10	Swan Reach	$38^0 51'$	$147^0 48'$	10

Wind Speed in Victoria

The average monthly wind speeds at the 10 sites are given in Table 2 and Table 3 [1,2] and Figs. 2-21. These results show that the annual average speed was 8m/s or more at Kilcunda North.

Table 2: First year - Wind Energy Speed (m/s) from 1 February 1985 to January 1987 [1]

Site No.	Location	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	First Year
1	Bridgewater	7.6	7.7	7.0	7.1	8.8	8.3	7.9	7.3	8.3	7.6	7.8	7.4	7.7
2	Port Fairy	7.4	7.3	7.1	6.3	7.5	8.0	7.5	7.8	8.0	7.6	7.7	7.9	7.5
3	Port Campbell	5.2	6.3	6.1	5.9	6.9	7.2	7.0	6.2	6.5	5.9	6.4	6.4	6.4
4	Apollo Bay	6.2	6.4	6.9	7.2	9.4	9.2	8.3	6.5	8.4	7.2	7.8	7.0	7.6
5	Queenscliff	5.9	5.5	5.3	4.7	5.6	6.2	6.0	5.4	6.0	5.7	5.8	6.3	5.7
6	Kilcunda North	8.2	7.8	7.5	7.1	8.2	9.0	8.5	7.7	8.4	7.8	7.6	8.3	8.0
7	Cape Liptrap	6.9	6.7	6.3	6.1	7.2	7.2	6.7	6.5	8.2	6.6	7.3	7.3	7.0
8	Yanakie	7.3	6.8	6.8	5.7	5.9	6.3	6.1	6.7	7.8	6.5	7.3	7.6	6.7
9	Toora	7.6	7.2	7.9	7.2	8.3	8.2	7.4	7.5	8.9	7.1	7.8	8.2	7.8
10	Swan Reach	4.4	4.1	3.7	3.1	3.7	3.7	3.8	4.5	4.5	3.9	4.5	4.8	4.1
Average		6.7	6.6	6.5	6.0	7.2	7.3	6.9	6.6	7.5	6.6	7.0	7.1	6.9

Table 3: Second year - Wind Energy Speed (m/s) from 1 February 1985 to January 1987 [1]

Site No.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Second Year	Two Years
1	7.7	7.1	8.0	6.7	7.6	7.9	7.9	8.3	8.8	8.0	7.9	8.1	7.8	7.8
2	7.4	6.9	7.7	6.1	7.0	7.4	7.2	7.7	8.0	7.8	7.9	7.8	7.4	7.5
3	6.6	5.9	6.9	5.5	6.6	7.1	6.2	6.6	7.5	6.5	6.8	6.9	6.6	6.5
4	8.1	6.5	8.1	6.7	8.0	8.9	8.4	8.0	9.2	7.9	7.6	8.0	7.9	7.8
5	6.0	5.5	6.1	4.7	5.5	6.2	5.6	5.9	6.5	7.0	6.3	5.7	5.9	5.8
6	8.4	7.6	9.3	6.9	8.1	8.5	8.2	8.6	9.5	8.6	8.5	7.7	8.3	8.2
7	8.4	6.6	7.3	6.3	7.9	7.9	6.8	7.2	8.1	7.0	8.3	7.4	7.4	7.2
8	8.6	6.9	6.5	5.9	7.1	7.1	5.8	6.7	7.7	7.1	8.6	7.5	7.2	6.9
9	8.8	7.2	8.1	7.0	9.2	9.1	8.0	8.3	9.2	7.8	8.8	7.8	8.3	8.0
10	4.8	3.9	4.1	3.1	4.1	4.3	3.5	3.8	5.0	4.6	5.1	4.7	4.2	4.2
Average	7.5	6.4	7.2	5.9	7.1	7.4	6.8	7.1	8.0	7.2	7.6	7.2	7.1	7.0

AVERAGE MONTHLY WIND SPEED AT DIFFERENT LOCATIONS OF VICTORIA (1986)

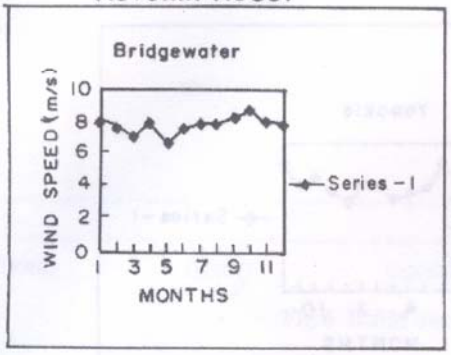


Fig. 2

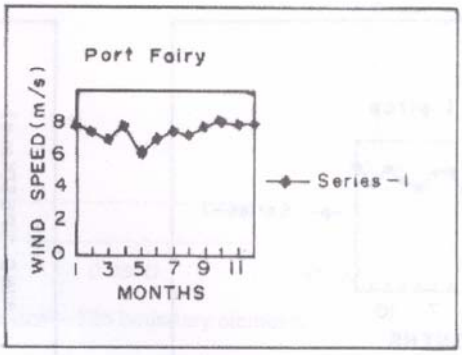


Fig. 3

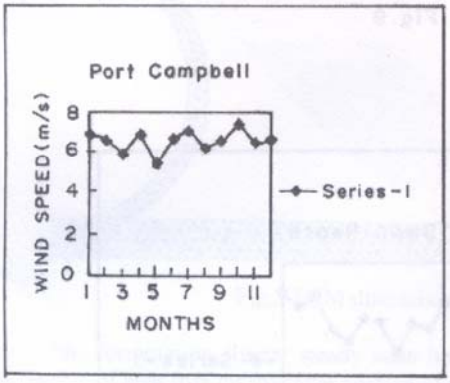


Fig. 4

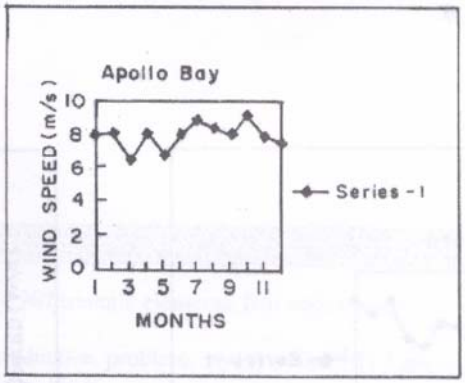
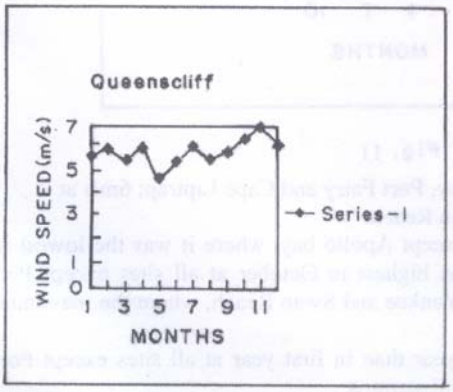


Fig. 5



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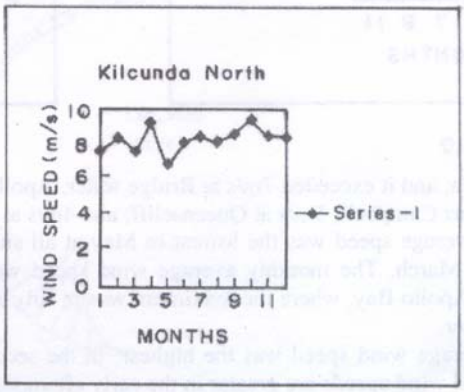


Fig. 7

AVERAGE MONTHLY WIND SPEED AT DIFFERENT LOCATIONTS OF VICTORIA (1986)

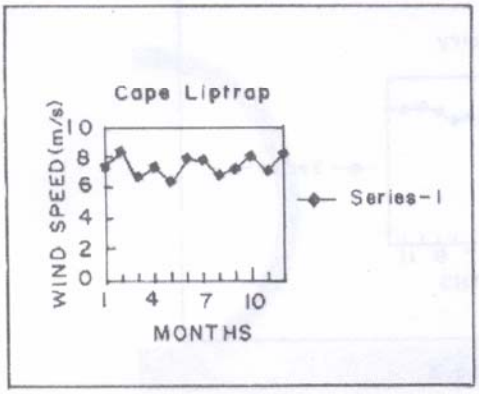


Fig. 8

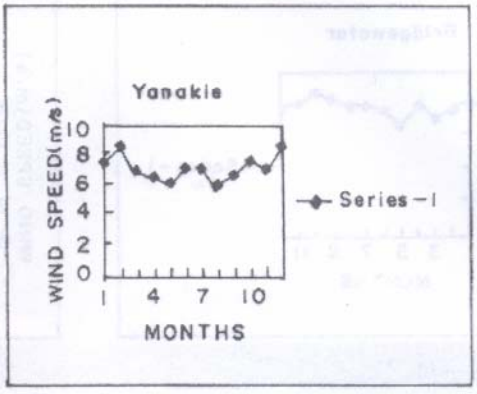
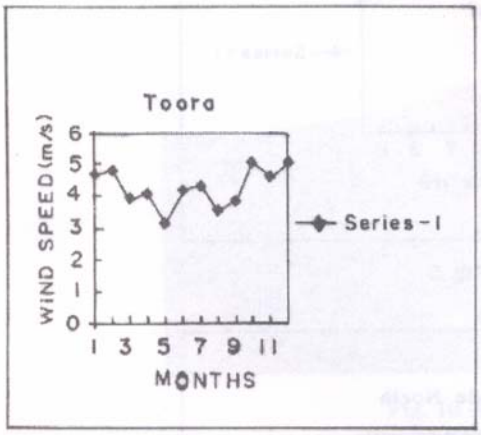


Fig. 9



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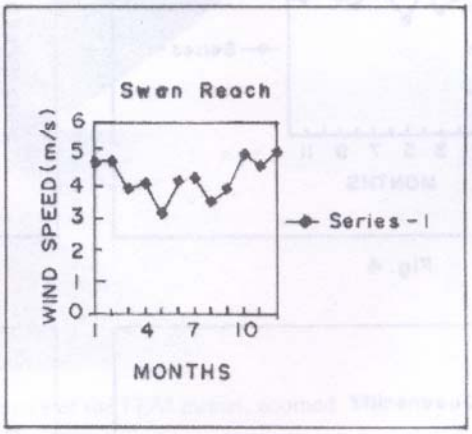

Fig. 11

North and Toora; and it exceeded 7m/s at Bridge water, Apollo Bay, Port Fairy and Cape Liptrap; 6m/s at Yanakie and Port Campbell; 5m/s at Queenscliff; and 4m/s at Swan Reach.

The monthly average speed was the lowest in May at all sites except Apollo bay, where it was the lowest in February and March. The monthly average wind speed was the highest in October at all sites except Port Campbell and Apollo Bay, where the maximum was in July and Yankee and Swan Reach, where the maximum was in December.

The annual average wind speed was the highest in the second year than in first year at all sites except Port Fairy. In general wind speeds are greater in the early afternoon at all stations.

AVERAGE MONTHLY WIND SPEED AT DIFFERENT LOCATIONS OF VICTORIA (1985)

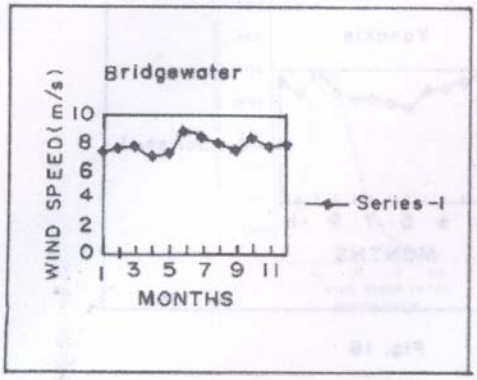

Fig. 12

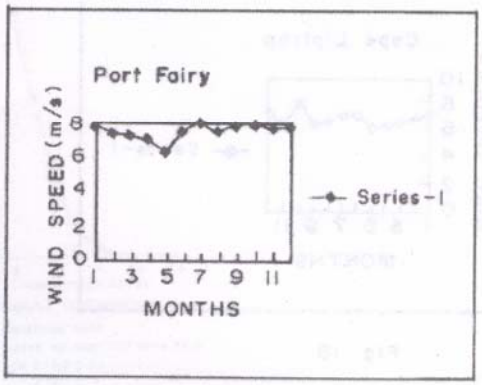

Fig. 13

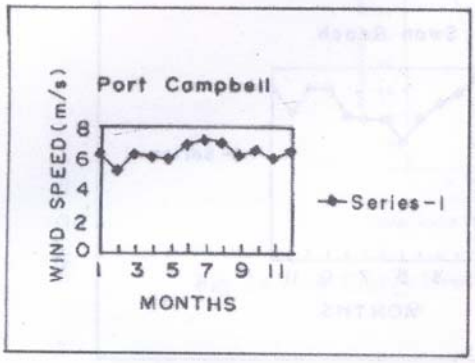

Fig. 14

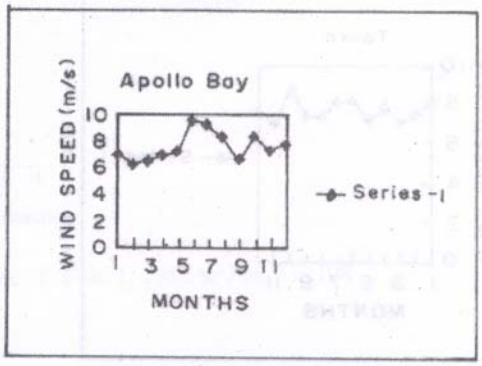

Fig. 15

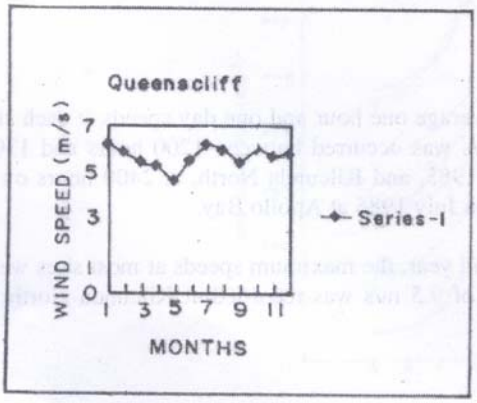

Fig. 16

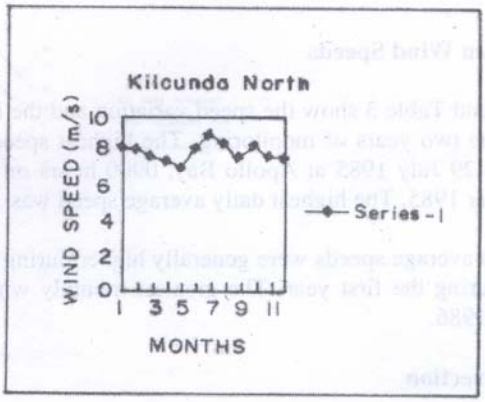

Fig. 17

AVERAGE MONTHLY WIND SPEED AT DIFFERENT LOCATIONS OF VICTORIA (1985)

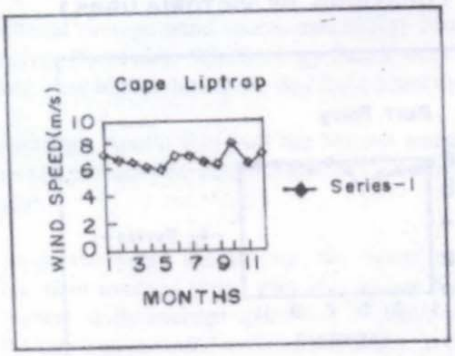

Fig. 18

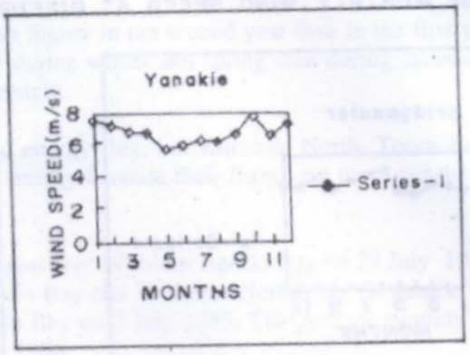

Fig. 19

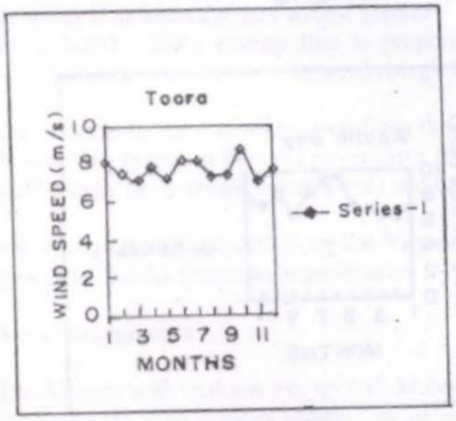

Fig. 20

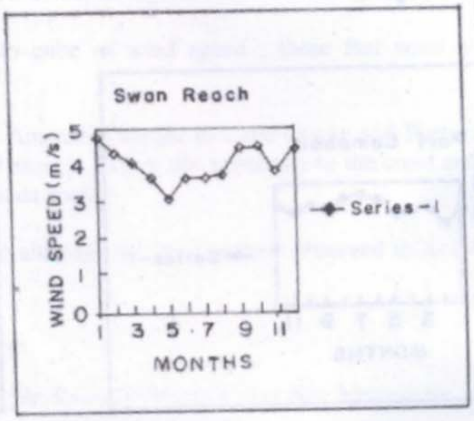

Fig. 21

Maximum Wind Speeds

Table 2 and Table 3 show the speed variation and the highest average one hour and one day speeds at each site during the two years of monitoring. The highest speed of 39m/s was occurred between 1200 hours and 1300 hours on 29 July 1985 at Apollo Bay, 0900 hours on 11 June 1985, and Kilcunda North, at 2400 hours on 1 September 1985. The highest daily average speed was 19.3m/s on July 1985 at Apollo Bay.

Although average speeds were generally higher during the second year, the maximum speeds at most sites were higher during the first year. The greatest monthly wind speed of 9.5 m/s was recorded at Kilcunda North in October 1986.

Wind Direction

The occurrence frequency of wind direction for each site is shown graphically in Fig. 11 the wind velocity for the two-year monitoring period is divided into four broad groups.

Reasonably uniform distribution of directions

Bridgewater had the most uniform distribution of directions, with a small peak in occurrence of west-northwesterlies and a compensating minimum occurrence of winds from easterly octant.

Prevalence of wind from the north and south

The regime was exhibited by four of six sites in Western and Central Victoria -Port Fairy, Port Campbell, Queenscliff and Kilcunda North. Port Fairy , Port Campbell and Kilcunda North winds blew most frequently from the northern octant and also from the southwestern quadrant. The least frequent winds are easterlies at port fairy and port Campbell and westerlies at Kilcunda north. At Kilcunda North the greatest frequency of occurrence of winds with a southerly component was associated with southwesterlies. Unlike Kilcunda North, Queenscliff had a high incidence of winds from the South and north also although Westerlies occurred most frequently.

Prevalence of wind from east and west

The regime was displayed by the four most southern sites -Cape Liptrap, Yankie, Toora and Apollo Bay-the last two sites have the highest elevations. There was a predominance of winds from both the east-northeastern and the west southern octants,. The former is most frequent at Yankie and the later most frequent at Cape Liptrap.

If we compare to Kilcunda North, the occurrence of southerly and northerly winds were generally very low at these four sites. This probably caused by the blocking effect of the Otway and Strzeslecki Ranges immediately north of these sites. [1]

Prevalence of wind from the north and west

Swan Reach, which is the furthest east and north site experienced a wind regime with the most frequent winds prevailing from the western and north northeastern octants. If we compare the winds of this site with the other nine sites , the winds are much lower and calm.

If we compare the wind velocity for the first and second years at the ten sites, we can see that the wind velocity were fairly similar during both year at seven of ten sites. There is a significant difference of wind velocity at Bridge water, Port Fairy and Queenscliff during the year.

Wind Energy Flux in Victoria

The wind is in motion carries with it energy in the form of Kinetic energy. The kinetic energy of the wind passing through the vertical cross sectional area in unit time, termed the wind energy flux (WEF) The wind energy flux is calculated from the wind speed using the formula

$$E=1/2\ \rho\ V^3 \qquad \text{..... .....} \qquad (1)$$

Where E is the wind energy flux (W/m^2), V is the wind speed (m/s) and ρ is the air density (average value of 1.255 kg /m^3)

The wind energy flux is primarily dependent on wind speed, being proportional to its third power. However, the density of air can vary by some 20% over the range of temperature and pressure along the coast of Victoria. At high temperature the density is low (1.1 kg/m at 30^0 C) and at low temperature the density is high (1.3 kg/ m at 0^0 C) i. e. some 10% in hourly determinations of wind energy flux. Uncertainties in annual average wind energy fluxes will be much less than 10% as seasonal changes will tend to cancel out the effects of the density variations.[1] Equations has been used to calculate wind energy flux with no allowance being made for density

variations. The monthly wind energy fluxes at 10m for all sites are listed in Table 4 and plotted in figure. The discussions of two years monitoring are given below:

1 The annual average flux at 10m exceeded 500 W/m^2 at Apollo bay, Kilcunda North and Toora; 400 W/m^2 at Bridgewater and Port Fairy; 300 W/m^2 at Cape Liptrap and Yankie; 200 W/m^2 at Port Campbell; and 100 W/m^2 at Queenscliff and Swan Reach.

2 As with the speeds, the annual average wind energy density was higher for the second year than for the first year at all sites except Port Fairy. The difference was most pronounced (60 w/m^2 to 100 w/m^2) at the three site of South Gippsland (Yanakie, Toora and Swan Reach)

3 Throughout the both years, monthly wind fluxes at 10m exceeded 300 W/m^2 at Kilcunda North and Toora; 200 W/m^2 at Bridge Water, Port Fairy and Apollo Bay; J100 W / m^2 at Port Campbell, Cape Liptrap and Yankie; while at Queenscliff and Swan Reach, were below 100 W/m^2

Table 4: Maximum Wind Speeds from the study for different averaging periods [1]

Rank	Site Name	Maximum Gust(m/s)	Maximum One hour Average Speed(m/s)	Maximum Daily Average Speed (m/s)	Ratio of Max./ Average
1	Apollo Bay	39	26.1	19.3	1.49
2	Kilcunda North	35	26.1	19.1	1.34
3	Toora	37	23.4	17.9	1.58
4	Bridgewater	32	22.5	18.6	1.42
5	Port Fairy	33	22.9	16.1	1.44
6	Cape Liptrap	29	19.5	15.6	1.48
7	Yanakie	30	19.7	15.8	1.52
8	Port Campbell	28	19.1	14.8	1.47
9	Queenscliff	25	16.7	13.1	1.49
10	Swan Reach	28	20.4	11.3	1.37

4 The monthly wind energy flux was highest in July or October at all sites, except Queenscliff, where it was highest in November, and Yankie, where it was highest in February. The monthly wind Energy fluxes was lowest in may at all sites except Apollo Bay where it was lowest in March. From the Table 4 we can conclude that wind energy is greater in winter and spring, and less in summer and autumn.

5 Wind energy being proportional to the cube of wind speed, that is why the wind energy flux shows much greater variations from month to month are shown in Table 4. The ratio of the maximum and minimum monthly wind energy fluxes at 10m during the two years was lowest at Toora (2.5),and also less than three at Bridgewater 2.6, Port Fairy (2.6), Kilcunda North (2.8) and Cape Liptrap (2.8); and also less than four at Yankie (3.0), Queenscliff 3.3) and Port Campbell (3.5); less than five at Apollo Bay (4.4); and highest at Swan Reach(5.4).

Table 5 First year - Wind Energy Flux (W/m^2) at 10m from ground level during February 1985 to January 1987 [1]

Site No.	Location	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	First Year
1	Bridgewater	354	412	337	357	591	717	452	362	519	368	414	347	436
2	Port Fairy	346	380	395	250	391	579	419	507	500	383	423	424	417
3	Campbell	126	326	273	196	275	438	311	264	294	210	245	248	274
4	Apollo Bay	253	365	456	520	945	999	695	348	712	475	548	342	569
5	Queenscliff	181	201	157	120	158	264	216	188	220	194	178	223	193
6	Kilcunda North	488	525	488	376	566	810	602	575	634	551	426	480	544
7	CapeLiptrap	307	316	237	199	352	429	254	256	507	317	359	353	329
8	Yanakie	379	378	337	193	2-05	320	238	315	448	312	370	412	326
9	Toora	424	415	480	392	598	713	390	414	656	406	430	483	485
10	Swan Reach	135	131	81	39	65	84	92	122	147	88	119	140	103
Average		299	345	324	264	415	547	367	335	466	330	351	345	368

Table 6 Second year - Wind Energy Flux (W/m^2) at 10m from ground level during February 1985 to January 1987 [1]

Site No.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Second . Year	Two Years
1	417	315	525	274	444	428	421	587	698	416	440	476	453	445
2	362	292	436	220	387	406	349	419	479	404	465	433	388	402
3	314	204	336	153	315	303	216	289	404	253	301	309	283	279
4	585	350	644	363	598	689	650	656	914	541	429	655	588	579
5	197	164	245	95	160	219	173	201	265	318	246	194	202	198
6	574	430	818	305	546	678	510	626	848	687	577	469	583	563
7	566	270	403	218	449	437	296	354	514	340	476	374	390	361
8	584	327	313	210	397	415	210	303	462	381	578	446	393	358
9	676	380	619	325	715	717	505	609	803	532	595	496	580	533
10	158	92	103	38	99	125	61	90	204	148	197	157	123	113
Aver age	443	282	444	220	411	442	339	413	559	402	430	401	398	383

As the wind speed varies a great deal with time it is commonly summarized by its frequency distribution representing the distribution of the winds speed over a specific period. The mean WEF expressed in terms of the probability, P(v), that the wind speed lies between v and v+dv over this period is

$$E = 1/2\rho \int^{\infty} P(v)\, v^3 dv \quad \ldots\ldots \quad \ldots\ldots \quad (2)$$

where,

$$\int^{\infty} p(v)dv = 1.0 \quad \ldots\ldots \quad \ldots\ldots \quad (3)$$

In practice the mean wind speed over a finite time interval is recorded and not the instantaneous wind speed. This mean wind speed , V is related to P(v) by

$$v = \int^{\infty} v\, P(v)\, dv \quad \ldots\ldots \quad \ldots\ldots \quad (4)$$

Because the WEF is a function of the cube of the wind speed and because the wind speed is varying continuously , the WEF computed from the mean wind speed is less than true integral equation 2 . The ratio between the true mean WEF and the mean WEF computed from a mean wind speed is called the Energy Pattern Factor (EPF), K

$$K = 1/v^3 \int V^3\, P(v)\, dv \quad \ldots\ldots \quad \ldots\ldots \quad (5)$$

Hence,

$$E = 1/2\, \rho\, K\, v^3 \quad \ldots\ldots \quad \ldots\ldots \quad (6)$$

K is greater than unity because the mean of the cubes of any series of numbers (not all equal) is greater than the cube of their mean. Annual or monthly EPF,s can be as high 4 or 5.

Table 7 Average Wind Speed (m/s), Standard Deviation of Wind Speed, Energy Density and ratio of maximum and minimum monthly wind energy fluxes at different locations in Victoria (from 1985 to 1986).

Site No.	Location	Monthly Mean Wind Speed (1985)	Monthly Standard Deviation (1985)	Monthly Mean Wind Speed (1986)	Monthly Standard Deviations (1986)	Average Wind Density ($w/m^{2)}$)	Ratio of Fluxes
1	Bridgewater	7.73	0.507	7.83	.515	445	2.6
2	Port Fairy	7.51	0.452	7.41	.520	402	2.6
3	Campbell	6.34	0.523	6.59	.512	279	3.5
4	Apollo Bay	7.54	1.03	7.95	.736	579	4.4
5	Queenscliff	5.70	0.422	5.91	.559	198	3.3
6	Kilcunda North	8.0	0.497	8.32	.681	563	2.8
7	Cape Liptrap	6.91	0.541	7.43	.658	361	2.8
8	Yanakie	6.73	0.642	7.12	.852	358	3.0
9	Toora	7.78	0.523	8.24	.723	533	2.6
10	Swan Reach	4.06	0.470	4.25	.589	113	5.4

The absolute difference between the highest and lowest monthly fluxes at Apollo Bay was 860 w/m^2.

Wind Speed Distribution

The wind speed distributions at the sites are fitted to Weibull distribution. The Weibull distribution is given by -

$$P(v)= \exp -(v/c)^k \quad \ldots\ldots\ldots \quad \ldots\ldots\ldots \quad (7)$$

Where V is the wind speed, P(v) is the probability that the wind speed is greater than a particular velocity v, c is the Weibull scale parameter and k is the Weibull shape parameter. The Weibull parameters c and k determined from the wind speed data at all monitoring sites are given in Table 6. Weibull distributions fit the two years of data with correlation coefficients between 0.9 and 0.93. The parameter c and to a lesser extent k are proportional to the wind speed at the site. The parameter c and k versus v are determined by using least squares method. The results are:

$$c= 1.159v -0.262 \quad \ldots\ldots\ldots \quad \ldots\ldots\ldots \quad (8)$$

$$k= 0.41 (v-2)^{0.61}+1 \quad \ldots\ldots\ldots \quad \ldots\ldots\ldots \quad (9)$$

A correlation coefficient of 0.93 was obtained for an alternative form of equation (9) which was [1]

$$k= 0.967(v-4.15)^{0.155} + 1 \quad \ldots\ldots\ldots \quad \ldots\ldots\ldots \quad (10)$$

Equations (8) and (9) could be used to generate wind speed distributions using equation (7) at Victorial coastal sites where mean wind speeds are available.

Table 8 Weibull parameters c and k for the two years study period

Site no.	Site name	c	k
1	Bridgewater	8.8	2.3
2	Port Fairy	8.5	2.3
3	Port Campbell	7.2	2.1
4	Apollo Bay	8.9	2.0
5	Queenscliff	6.5	2.1
6	Kilcunda North	9.2	2.2
7	Cape Liptrap	8.1	2.2
8	Yanakie	7.7	2.1
9	Toora	8.9	2.1
10	Swan Reach	4.6	1.6

Fig. 22 shows wind speed distributions (histogram, cumulative frequency distribution and Weibull distribution curves) for Bridgewater sites for two years of monitoring.

Fig. 23 shows that the variation of wind energy flux by time of day for stations of the study. All stations show maximum wind energy fluxes between 0900h and 1500h, during the time of peak electricity. The availability of wind energy by hour of day coincides well with demand for the easterly stations and westerly stations of Fig. 22 apart from Apollo Bay and Bridgewater.

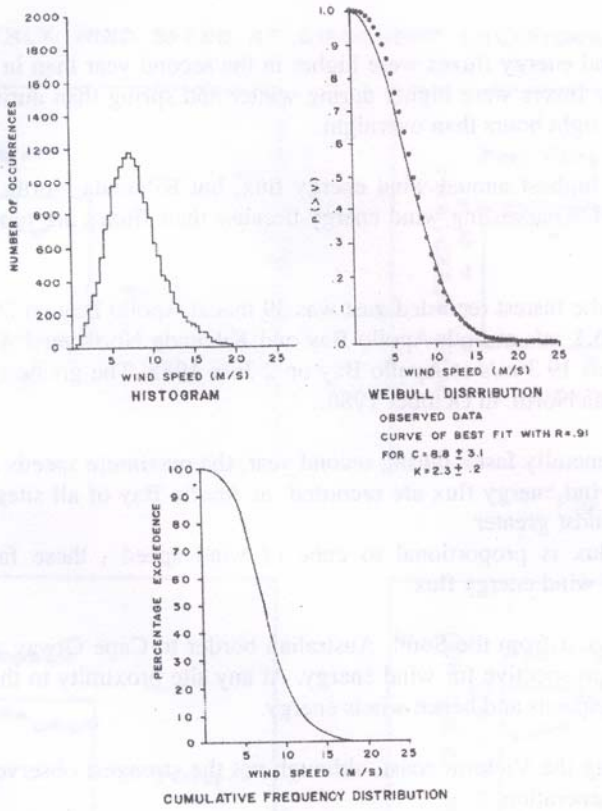

Fig. 22 Wind Energy Distribution Site -1. Feb. 1, 1985 to Jan. 31, 198

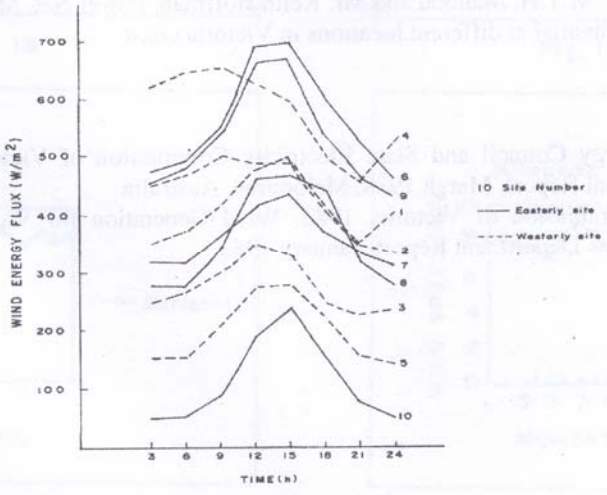

Fig. 23 Variation of Wind Energy Flux by Time of Day

Conclusions

Annual average wind speeds and energy fluxes were higher in the second year than in the first year at all sites except Port Fairy. Wind energy fluxes were higher during winter and spring than during summer and autumn, and were higher during the day light hours than overnight.

Although Apollo Bay had the highest annual wind energy flux, but Kilcunda North, Toora and Bridgewater would probably be better sites for harvesting wind energy because their fluxes are more consistent throughout year.

In the two years monitoring , the fastest recorded gust was 39 m/s at Apollo Bay on 29 July 1985, the highest one hour average speed was 26.1 m/s at both Apollo Bay and Kilcunda North on 1 September 1985, and the highest daily average speed was 19.3 m/s at Apollo Bay on 2 July 1985. The greatest monthly wind speed of 9.5 m/s was recorded at Kilcunda North in October 1986.

Although average speeds are generally faster during second year, the maximum speeds at most sites were faster during fast year. The highest wind energy flux are recorded at Apollo Bay of all sites because it experienced the greatest incidence of fast winds(greater
than 15m/s) . Since energy flux is proportional to cube of wind speed , these fast wind speed made a disproportionate contribution to wind energy flux.

The sections of the Victorian coast from the South Australian border to Cape Otway and Portsea to Wilson's Promontory appear to be most prospective for wind energy. At any site proximity to the coast and elevation of wind energy favor greater wind speeds and hence winds energy.

The wind speeds measured along the Victoria coast, although not the strongest observed in Australia but have good potential for future wind generation.

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[2] State Electricity Commission of Victoria, 1983. Wind Generation for Victoria, Volumes 1 to 3. Planning Investigations Department Report, January 1983