A SIMPLE METHOD FOR ESTIMATING AVAILABLE WIND ENERGY FROM AVERAGE MONTHLY WINDSPEEDS

by

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Introduction

In order to facilitate the application of wind data to the use of wind for power, the Atmospheric Environment Service (AES) has published "Climatic Data Sheet",CDS 3-76 (1). This publication gives the mean number of hours of wind and associated energy (theoretical) for each of various speed classes for 137 Canadian stations. Data are given for the year and for selected months, viz. January and for the windiest and least windy months, at each station. In addition, because most wind machines do not generate power from winds of lower speeds and are feathered at higher speeds, the circular gives cumulative totals of energy for speed in ranges greater than 6 mph (10 km/h) and less than 36 mph (58 km/h).

While considering the possibilities of utilizing the wind as a source of energy at a suburban or farm location, it was recognized that estimates of the monthly average total daily energy would be useful. This led to a linear regression analysis of the relationship between the monthly cumulative energy totals given in CDS 3-76 and the corresponding monthly average windspeeds given in "Canadian Normals" (2). As a result, an empirical formula for estimating the energy available from the wind using the monthly mean windspeed has been derived.

Basic Theory

As discussed in the circular, CDS 3-76, the kinetic energy associated with any given vertical cross-sectional area, α, of a wind with speed, v, is given by the formula:

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

where ρ = atmospheric density. For example, using international (SI) units and taking ρ as 1.2923 kg m^{-3}, i.e. atmospheric density at standard pressure, 101.325 kPa and standard temperature 0 degrees C, we obtain:

$$K.E. = \frac{1.2923}{2}(1)v^3 = 0.64615\ v^3,$$ where v is expressed in metres per second ($m\ s^{-1}$).

Thus, since 1 mph = 0.44704 m s^{-1}, the kinetic energy in 1 m^2 cross-sectional area of wind having a speed of 1 mph is:

$$K.E. = 0.64615\ (0.44704)^3$$

$$= 5.7726 \times 10^{-2} \text{ (watts)}$$

If this energy is equated to power and converted to kilowatts, we have

P = 5.7726×10^{-5} kilowatts as the power theoretically available from 1 m^2 cross-sectional area of a 1 mph wind. The total cumulative power for a 1 hour period would be 5.7726×10^{-5} kilowatt-hours (KWH's). Since P is related to the cube of the windspeed, the cumulative power during 1 hour in a 10 mph wind is not 10 times but is 10^3 times that in a 1 mph wind, i.e. 5.7726×10^{-2} KWH's.

Data

Using the foregoing theoretical basis, circular CDS 3-76 provides averages of cumulative energy for various speed ranges according to the average number of hours of wind in each range. The hours are distributed equally to each speed within a given speed range. It also gives, as mentioned previously, the total average cumulative energy for all the speed ranges between 6 and 36 mph (10 and 58 km/h) for the month of January and for the windiest and the least windy month at each station.

In order to test a possible linear relationship between the average monthly total cumulative energy, $\bar{E}_m$, and the average monthly wind speed, $\bar{V}_m$, a linear regression analysis of the relationship between $\bar{E}_m$ and $\bar{V}_m$ was done. Wind data were abstracted from published normals (2).

Since it is evident that no wind machine is likely to be located where the winds are generally weak, only stations at which the average annual windspeed is greater than 10 mph (16 km/h) were used. The data obtained are shown in Table 1, below.

Table 1 - Monthly Averages of Windspeed, $\bar{V}_m$, and Corresponding Total Cumulative Energy, $\bar{E}_m$, for the Speedrange, 7 - 35 mph (11 - 56 km/h).

STATION	JANUARY		WINDIEST MONTH			LEAST WINDY MONTH		
	$\bar{V}_m$ (mph)	$\bar{E}_m$ (KWH/m^2)	$\bar{V}_m$ (mph)		$\bar{E}_m$ (KWH/m^2)	$\bar{V}_m$ (mph)		$\bar{E}$ (KWH/m^2)
Baker Lake	16.2	323	16.6	Feb.	292	11.8	Aug.	149
Cambridge Bay	13.5	212	14.4	Oct.	249	11.8	Mar.	158
Cape Parry	11.8	170	13.9	Oct.	215	10.7	Feb.	126
Chesterfield	14.2	218	17.4	Oct.	360	10.0	July	93
Coral Harbour	12.8	132	14.5	Nov.	214	11.0	Mar.	143
Hall Beach	13.5	200	15.9	Oct.	298	10.8	July	106
Resolute	13.5	220	15.9	Sept.	282	12.3	Apr.	198
Edmonton (Namao)	10.9	119	11.9	May	184	11.8	Aug.	104
Lethbridge	14.0	230	15.1	Oct.	267	10.9	July	134
Estevan	13.4	190	13.4	Jan.	190	11.2	July	127
Moose Jaw	14.3	248	14.3	Jan.	248	11.4	Aug.	153
Regina	14.0	217	14.6	Apr.	225	11.4	July	136
Saskatoon	10.8	111	12.6	May	176	10.2	Feb.	90
Swift Current	16.4	290	16.5	Dec.	293	12.8	July	166
Yorkton	11.4	134	12.7	May	181	10.2	Aug.	105
Churchill	15.4	258	16.5	Nov.	283	12.6	July	162
Dauphin	11.5	162	12.6	May	183	10.0	Aug.	98
Rivers	11.6	139	13.6	May	191	10.6	July	105
Winnipeg	12.1	154	13.5	Apr.	198	10.1	July	95

The linear regression equation based on these data is:

$\bar{E}_m' = 32.22\ \bar{V}_m - 229.87$ ...... (2)

where $\bar{E}_m'$ is the estimated monthly average total energy per unit cross-sectional area of wind. The correlation coefficient is 0.97 and the standard error of estimate is 16.53 KWH's.

Figure 1 shows the plotted values of the data in Table 1 as well as the line of best fit given by equation (2). Table 2 is a tabulation of estimated values, $\bar{E}_m'$ based on given values of $\bar{V}_m$ and found by using equation (1).

Table 2 - Estimated Values of Monthly Total Wind Energy, $\bar{V}_m'$ Corresponding to Given Values of Monthly Average Windspeeds, $\bar{V}$.

$\bar{V}_m$ (mph)	$\bar{V}$(km/h)	$\bar{E}_m'$ (KWH)	$\bar{V}_m$ (mph)	$\bar{V}_m$(km/h)	$\bar{E}_m'$ (KWH)
10.0	16.1	92.4	14.0	22.5	221.3
10.5	16.9	108.5	14.5	23.3	237.4
11.0	17.7	125.0	15.0	24.1	253.5
11.5	18.5	140.7	15.5	24.9	269.5
12.0	19.3	156.8	16.0	25.7	285.6
12.5	20.1	172.9	16.5	26.5	301.8
13.0	20.9	189.0	17.0	27.3	317.9
13.5	21.7	205.1	17.5	28.2	334.0

As an illustration, estimates $\bar{E}_m'$ corresponding to the observed monthly average windspeeds, $\bar{V}$, have been made for the four Manitoba stations shown in Table 3. The same information is given in Figure 2, which illustrates graphically the seasonal variation in wind energy at different localities.

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Table 3 - Monthly Average Estimated Cumulative Energy, $\bar{E}_m'$, In $1m^2$ of Wind

MONTH	Winnipeg $\bar{V}_m$ mph	km/h	$\bar{E}_m'$ (KWH)	Rivers $\bar{V}_m$ mph	km/h	$\bar{E}_m'$ (KWH)	Dauphin $\bar{V}_m$ mph	km/h	$\bar{E}_m'$	Churchill $\bar{V}_m$ mph	km/h	$\bar{E}_m'$ (KWH)
Jan.	12.1	19.5	160	11.6	18.7	144	11.5	18.5	141	15.4	24.8	266
Feb.	11.7	18.8	147	10.9	17.5	121	10.6	17.1	112	15.5	24.9	270
Mar.	12.2	19.6	163	11.5	18.5	141	10.6	17.1	112	14.2	22.9	228
Apr.	13.3	21.4	205	13.3	21.4	199	11.7	18.8	147	14.5	23.3	237
May	13.1	21.1	192	13.6	21.9	208	12.6	20.3	176	13.4	21.6	202
June	11.5	18.5	141	12.0	19.3	157	11.3	18.2	134	12.6	20.3	176
July	10.1	16.2	96	10.6	17.1	112	10.3	16.6	102	13.3	21.4	199
Aug.	10.6	17.1	112	10.7	17.2	115	10.0	16.1	92	15.7	25.3	276
Sept.	11.7	18.8	147	11.9	19.1	154	11.6	18.7	144	16.1	25.9	289
Oct.	12.6	20.3	176	12.4	19.9	170	11.9	19.2	154	16.5	26.5	302
Nov.	12.6	20.3	176	12.1	19.5	160	11.6	18.7	144	14.5	23.3	237
Dec.	12.1	19.5	160	11.4	18.3	137	10.9	17.5	121	14.7	23.7	244

Conclusions

This paper describes a method for estimating monthly average values of total cumulative energy associated with monthly mean windspeed. It is very simple and relies on evidence that a satisfactory linear relationship exists between average windspeed and cumulative energy. A boundary condition is that the average annual windspeed should be greater than 10 mph (16 km/h) at any location to which it is applied. Also, estimates of wind energy obtained by this method pertain only to averages of cumulative totals associated with windspeeds at the station in the range 7 - 35 mph (11-56 km/h).

It should be noted that only theoretical energy values are being considered. In CDS-76 the Betz Theorem is mentioned as showing that the recoverable portion of this energy is restricted to 60 percent of the values given. In practice, a further restriction is presented by the efficiency of wind machines which is mentioned in CDS-76 as varying from 80 percent to 50 percent.

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It should also be noted that the windspeed at a given location is greatly dependent on local topography and on height above ground. Thus, a wind energy machine site must be chosen with great care to maximize the average windspeed in relation to costs associated with installation and servicing. A study of the distribution of available wind energy in terms of gradient wind patterns would probably be worthwhile on the assumption that suitable local sites could be found.

References

1. Atmospheric Environment Service, Environment Canada: Climatic Data Sheet, CDS 3-76

2. Atmospheric Environment Service, Environment Canada: Canadian Normals, Vol. 3, Wind, 1955-1972

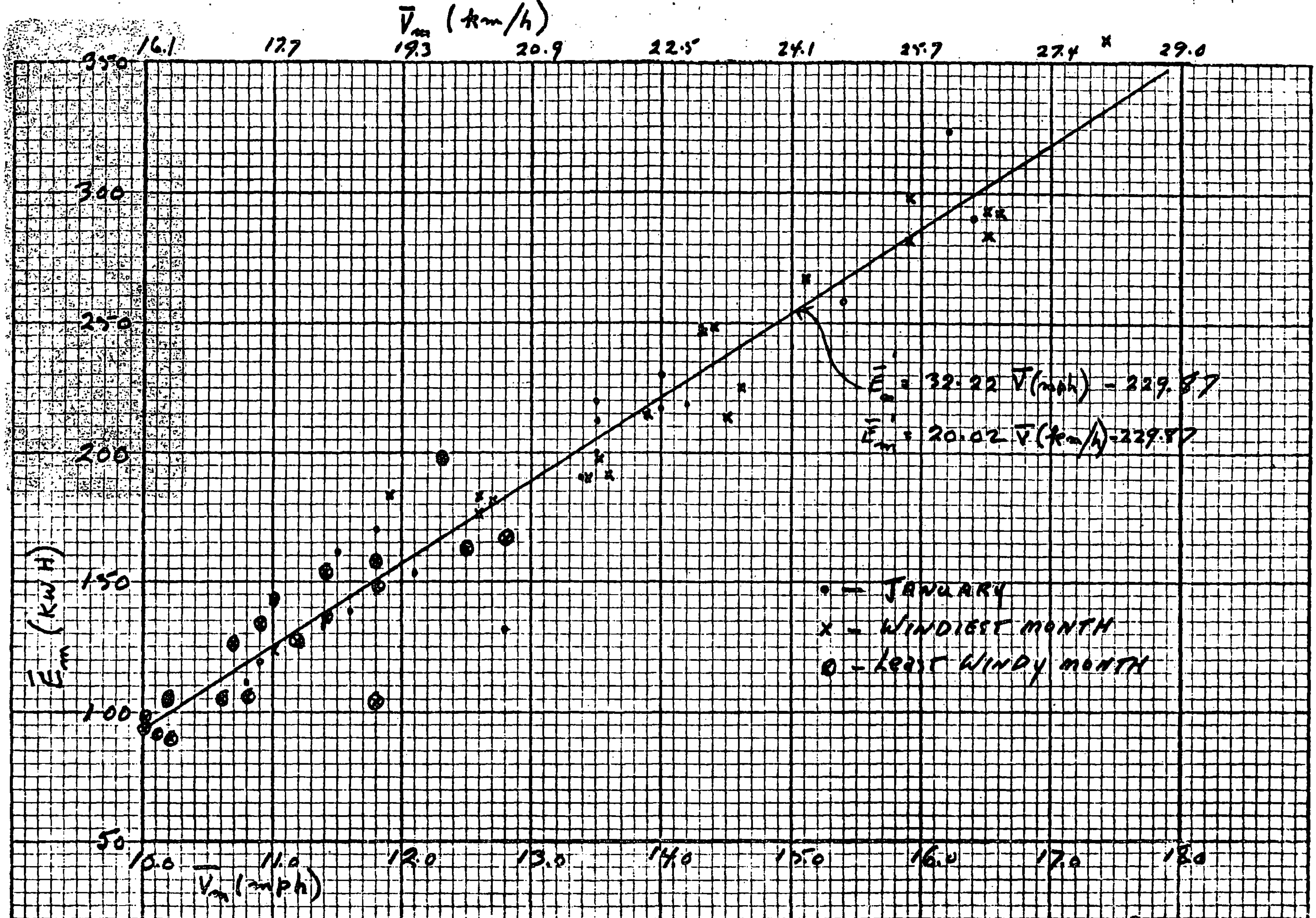

Figure 1 – Monthly Average Total Energy, $\bar{E}_m$ versus Monthly Average Wind Speed, $\bar{V}_m$

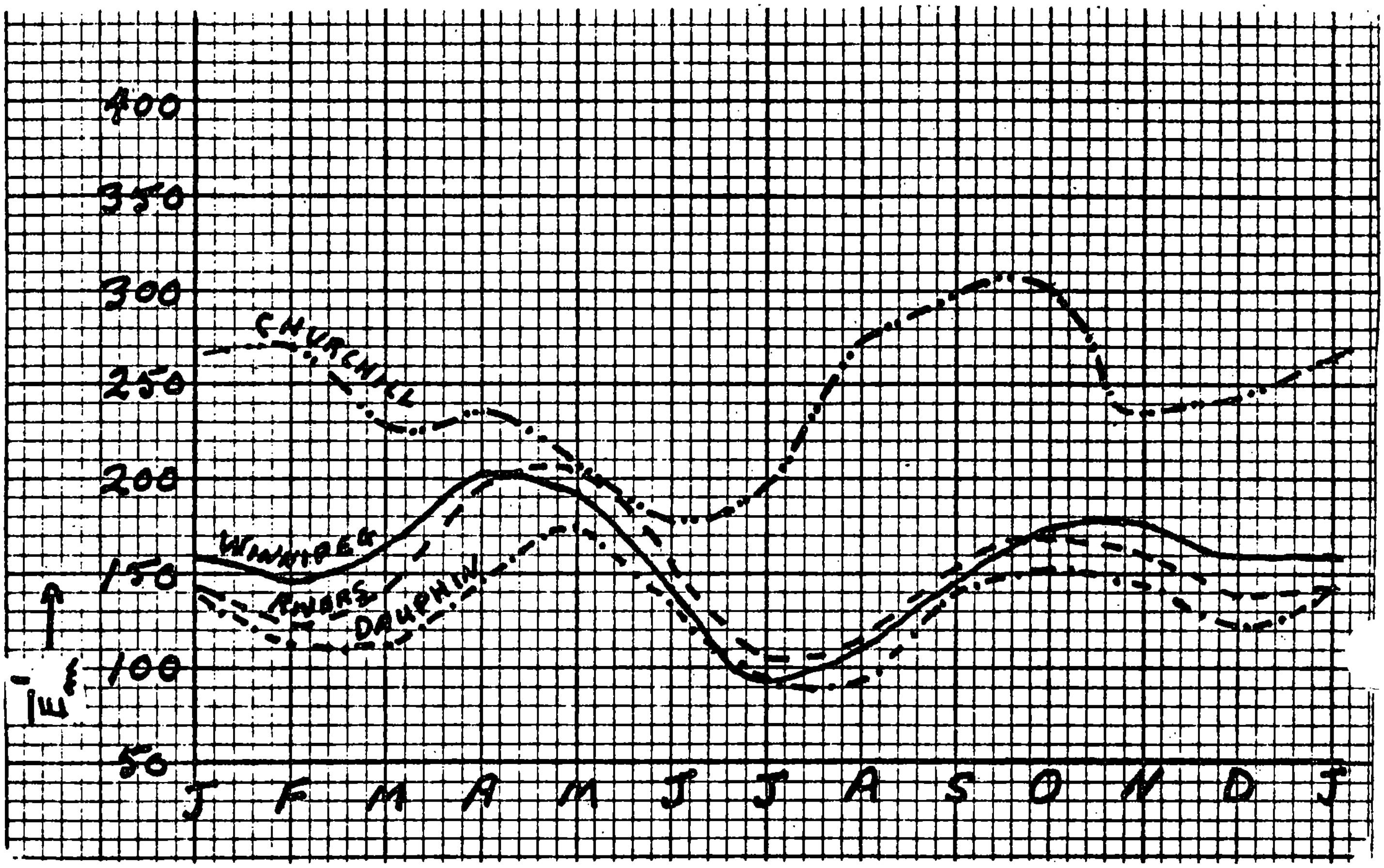

Figure 2 - Computed Values of Monthly Average Cumulative Energy, $\bar{E}_m$ (from Table 3).