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Assessment of Small Wind Turbine Installations at Dhanmondi, Dhaka, Bangladesh

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ABSTRACT

In this study, a six storied commercial building located at the Dhanmondi area in Dhaka city is used as the wind energy harvesting site. A small wind data logger is installed at the rooftop of the building to record daily wind speed and directions. From April 2017 to March 2018, the recorded data for one year is analyzed using Weibull Distribution Functions. Three statistical methods are used to determine and compare Weibull parameters. The analysis shows that the Shape factor of the site is 1.42 and the scale factor of the site is 1.96 m/s. The highest values of these parameters are found in June which is 2.53 m/s and 3.38 m/s. The Mean wind speed of the site is 1.77 m/s and the highest speed is also observed in June which is 2.99 m/s. To estimate yearly energy production three different wind turbine models 'Aventa AV-7', 'DB-400' and 'Archimedes AWM-1500D' are used to do the estimations in a mathematical approach. The possible wind power production capacity of the site would be around 109498.3 Wh to 149750 Wh per year by using 'DB-400' and 'Archimedes AWM-1500D' respectively. The projected energy density of the site is 10.26 KWhm^{-2}. Aventa AV-7 is not suitable for small building but future high rises like The City Centre, Dhaka may include such turbine applications in the design. The findings would be helpful for prior decision-making sessions to install small wind turbines in Dhanmondi and its neighboring areas of Dhaka city.

Keywords: *Weibull, shape factor, scale factor, Wind turbines, Rooftop, Energy Harvesting, etc.*

1. Introduction

Although several studies have been conducted to assess the potential of wind turbine installation in Bangladesh, most of them were in the coastal areas and remote islands [1] [2][3]. The potential of harnessing wind energy from the urban areas of Bangladesh, especially from the rooftops of the high-rise commercial and residential buildings are yet to be explored.

Here, an assessment has been conducted to analyze the wind power potential at building rooftops in Dhaka city. For this research, a six storied commercial building in Dhanmondi Thana located at 23°44'20.47" North and 90°22'59.37" East has been selected to install a wind data logger at its rooftop. The building is used as a shopping complex and within its 1 km periphery, there are no taller buildings on the South and East sides of the building. Wind speed data have been recorded from April 2017 to March 2018 which have been taken from a height of approximately 23 meters above the ground.

(a) (b)

Fig. 1. Selected Site: (a) South facing (b) East Facing

Statistical methods are applied to predict and characterize the site. Weibull Shape and scale parameters are determined using three different methods. Based on the obtained parameters power and energy production analysis are done. A probable wind power production capacity is calculated to forecast the site performance.

2. Methodology

According to the International Standard IEC 61400-12 and other international recommendations, the two-parameter Weibull Distribution Function (probability density function) is the most appropriate tool for wind data [4] analysis. Weibull parameters are used to estimate energy and power density[5]. Most probable wind speed and maximum energy carrying speed can also be calculated using these parameters. Moreover, almost every commercial software that offers estimations of Annual Power Production and Capacity Factor is based on the two-parameter Weibull Function[6]. The two- parameter Weibull Function for Wind speed analysis can be expressed as,

$$f(v) = \frac{dF(v)}{dv} = \left(\frac{k}{A}\right)\left(\left(\frac{v}{A}\right)^{k-1}\right)\exp\left(-\left(\frac{v}{A}\right)^{k}\right) \quad (1)$$

Here, v denotes the wind speed; A is the scale parameter which is the characteristic wind speed of the site. And, k is the shape factor, which determines the shape of the distribution. The shape factor k has no unit. The higher value of k represents relatively stable wind speed, while lower value indicates variation in speeds.

The cumulative distribution function of Weibull distribution is an additional part of the probability density function (PDF), and it is stated as,

$$F(v) = 1 - \exp\left[-\left(\frac{v}{A}\right)^k\right] \quad (2)$$

2.1 Determinations of Weibull Parameters

There are several methods to determine the scale factor A and shape factor k, of them, the Graphical Method, Method of Moments and Empirical Method; these three are used in this experiment.

2.1.1 Graphical Method

At first, the frequency distribution of recorded data is constructed using Microsoft excel program. For this, wind speed data is stratified and classed into several groups. Sample data of the same class is counted and the number of occurrences is taken as the input data for that class. A graphical interpretation tool is used to obtain the Weibull PDF curve shown in figure 2. Here, the "SWISS Wind Power Data Analyzing Tool" available on the internet is used[7]. The frequency of Classed samples is given as input to this software. This tool first generates a frequency distribution curve for given input then it compares for the best fit between the frequency distribution curve and the PDF from which the Weibull parameters are determined. First, the parameters have been obtained by using the year long data. Later, similarly, the parameters have been determined for each month of the year. Fig-2 shows the Weibull Distribution for the data obtained over the year.

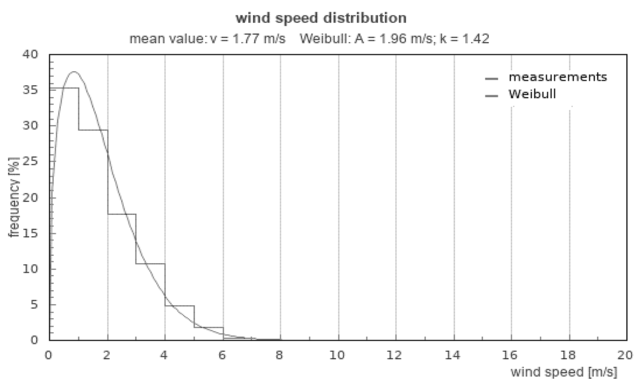

Fig. 2. Frequency distribution and Weibull PDF for yearly obtained data

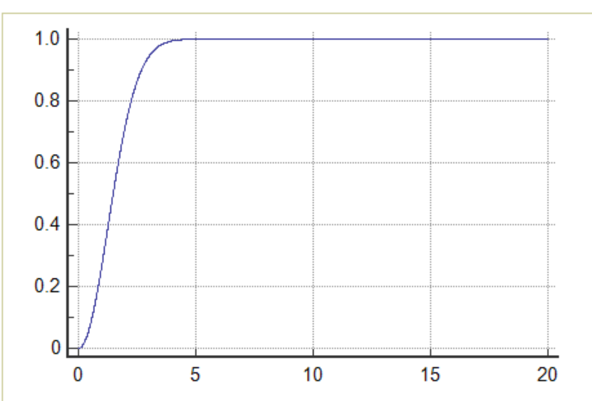

Fig. 3. CDF for yearly obtained data

The cumulative distribution curve is obtained by using the scale and shape factor found from the graphical interpretation of the Probability Density Function (PDF). CDF is shown in figure 3.

2.1.2 Method of Moment

This method requires the values of the sample mean wind speed ($\bar{v}$) and standard deviation (σ)[8][9]. Using the mean wind speed and standard deviation of the obtained data, the value of shape factor k is determined[10]. Scale Factor A is determined by using the following equation:

$$A = \frac{\bar{v}}{\Gamma(1+\frac{1}{k})} \quad (3)$$

$$k = \left(\frac{0.9874}{\frac{\sigma}{\bar{v}}}\right)^{1.0983} \quad (4)$$

2.1.3 Empirical Method

This method requires mean wind speed and standard deviation also which is the same as the method of moment[11][12]. Here, parameter k and A are determined by using the following equation 5.

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \quad (5)$$

$$A = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (6)$$

Then, equation (6) is used to get the value of A.

3. Results and Discussion

The obtained values of A and k by using all three methods are given in Table 1. For MOM and empirical method mean value is taken from the average of measured samples. So the difference between mean values between different methods exists only for the graphical method. MOM and empirical method uses the same mean from measured wind speed.

Table 1. Weibull Parameters A and k

Month	Goodness of fit (R^2)for Graphical	Graphical Method		Method of Moment		Empirical Method	
		A (ms^{-1})	k	A (ms^{-1})	k	A (ms^{-1})	k
Jan	0.64	1.18	1.76	1.11	1.62	1.11	1.64
Feb	0.57	1.21	1.11	1.2	1.11	1.2	1.12
Mar	0.72	1.95	1.45	1.92	1.41	1.92	1.43
Apr	0.60	3.05	1.93	3.04	1.92	3.04	1.95
May	0.51	2.98	2.09	2.94	2.02	2.94	2.04
Jun	0.28	3.38	2.53	3.37	2.58	3.37	2.6
Jul	0.58	2.41	1.96	2.36	1.93	2.37	1.96
Aug	0.38	2.92	2.32	2.9	2.35	2.9	2.37
Sep	0.69	1.99	1.7	1.9	1.56	1.91	1.58
Oct	0.68	1.23	1.37	1.15	1.29	1.15	1.31
Nov	0.65	0.87	1.39	0.8	1.29	0.8	1.31
Dec	0.65	1	1.68	0.95	1.62	0.95	1.64
Yearly	0.73	1.96	1.42	1.9	1.35	1.91	1.38
Avg.	0.67	2.01	1.77	1.97	1.73	1.97	1.74
Standard Deviation	0.13	0.91	0.42	0.93	0.45	0.93	0.45

Regression analysis is carried out for all months to test the goodness of fit provided by the graphical method. Most of the months it shows a 60% to 70% variance that means the curve obtained from the graphical method is 70% closer to the measured data points. For yearly data, R^2 is found to be 73% where the average is 67%. The standard deviation between all months' scale factor is within 0.9 to 0.93 and for the shape factor it is within 0.42 to 0.45. The standard deviation for R^2 value for the months is about 0.13.

Table 2 presents the month-wise calculated average wind speed from the graphical method and measured values of average wind speed. The average values of wind speed for MOM and Empirical method are taken from measured data hence, these are the same and not presented. Wind Power Density (WPD) is given for both measured and calculated values. The average difference is about 3.47% where the maximum difference is found for November.

Table 2. Average wind speed and WPD

Month	Avg. speed (ms^{-1}) Graphical Method	Avg. speed (ms^{-1}) Measured	WPD (Wm^{-2}) Graphical Method	WPD (Wm^{-2}) Measured	%error
Jan	1.04	1	0.69	0.61	12.49%
Feb	1.19	1.15	1.03	0.93	10.80%
Mar	1.75	1.75	3.28	3.28	0.00%
Apr	2.7	2.7	12.06	12.06	0.00%
May	2.61	2.61	10.89	10.89	0.00%
Jun	2.99	2.99	16.37	16.37	0.00%
Jul	2.11	2.1	5.75	5.67	1.44%
Aug	2.57	2.57	10.40	10.40	0.00%
Sep	1.73	1.71	3.17	3.06	3.55%
Oct	1.12	1.07	0.86	0.75	14.68%
Nov	0.81	0.74	0.33	0.25	31.15%
Dec	0.9	0.85	0.45	0.38	18.71%
Yearly	1.79	1.77	3.51	3.40	3.43%
Avg.	1.77	1.75	3.40	3.28	3.47%

The power and energy production potential of a site can be determined in various ways. Energy and power density is defined as the availability of producible energy in every square meter area. Most probable wind speed is also a key point to summarize a site character. A statistical method is used to measure all these values. Generalized equations are modified as functions of Weibull parameters. k and A determined in the previous section are used here.

Most probable Wind Speed (v_p) and Maximum Energy Carrying Wind Speed (v_m) are determined by using the following equations [13].

$$v_p = A\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \quad (7)$$

$$v_m = A\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \quad (8)$$

Table 3 contains month-wise data for v_p and v_m. The value for A and k is chosen from the graphical method.

Actual measured data shows similarity with data presented in Table 3. Here, mostly recorded speed ranges are shown with maximum speed recorded. For example, In January highest measured speed is found to be 3.97 ms^{-1} and more than 50% speed record are between 0 to 1 ms^{-1}. There are 40% data found for 1 to 2 ms^{-1} for this month. Maximum speed is a single instance for a month or the whole year. This value is nearly 2 times greater than the most energy-carrying speed calculated by the equations.

Table 3. Most Probable Wind Speed (v_p) and Maximum Energy Carrying Wind Speed (v_m).

Month	v_p(ms^{-1})	v_m(ms^{-1})	Most Recorded speed range (ms^{-1})	Max Speed recorded (ms^{-1})
Jan	0.73	1.82	0-1|1-2	3.97
Feb	0.15	3.06	0-1|1-2	6.57
Mar	0.87	3.55	0-1	6.67
April	2.09	4.41	1-2|2-3	7.68
May	2.18	4.1	1-2|2-3|3-4	7.35
June	2.77	4.26	2-3|3-4	7.12
July	1.67	3.45	1-2|2-3	9.49
Aug	2.29	3.82	1-2|2-3	7.27
Sep	1.18	3.14	0-1|1-2	6.29
Oct	0.47	2.37	0-1|1-2	7.08
Nov	0.35	1.65	0-1	4.13
Dec	0.58	1.59	0-1	2.89
Yearly	0.83	3.64	0-1	9.49

Energy Density and Wind Power density (WPD) are calculated by using the following equations. [13] [14]In equation 11, wind speed is denoted by v.

$$E_d = \frac{1}{2}\rho A^3 \Gamma(1 + \frac{3}{k})T \quad (9)$$

$$P_d = \frac{1}{2}\rho A^3 \Gamma\left(1 + \frac{3}{k}\right) \quad (10)$$

$$WPD = \frac{1}{2}\rho v^3 \quad (11)$$

Here, ρ denotes the air density of the site, which, in this case, is assumed fixed at 1.225 kgm^{-3}. Table 4, contains month wise calculated Wind Power density of this site.

Table 4. Energy Density and Power Density

Month	Graphical		MOM		Empirical		Hour
	E_d $kWhm^{-2}$	P_d (Wm^{-2})	E_d $kWhm^{-2}$	P_d (Wm^{-2})	E_d $kWhm^{-2}$	P_d (Wm^{-2})	
Jan	1.16	1.56	1.09	1.47	1.07	1.44	744
Feb	3.05	4.54	2.98	4.43	2.89	4.31	672
Mar	7.21	9.69	7.28	9.79	7.07	9.51	744
April	17.29	24.02	17.23	23.93	16.93	23.51	720
May	15.34	20.61	15.24	20.48	15.08	20.27	744
June	18.62	25.86	18.23	25.32	18.15	25.20	720
July	8.67	11.65	8.28	11.13	8.24	11.08	744
Aug	13.18	17.72	12.79	17.19	12.71	17.08	744
Sep	5.66	7.86	5.64	7.84	5.61	7.79	720
Oct	2.03	2.73	1.91	2.57	1.84	2.47	744
Nov	0.68	0.94	0.62	0.86	0.60	0.83	720
Dec	0.75	1.01	0.68	0.92	0.67	0.90	744
Yearly	89.87	10.26	91.22	10.41	88.30	10.08	8760
Avg.	67.03	7.65	65.13	7.43	64.60	7.37	8760

Table 5. Differences between Energy Density and Power Density by different methods

Month	% error for Energy Density (E_d kWhm^{-2})			% error for Power Density P_d (Wm^{-2}) Error in %		
	Graphical-MOM	**Graphical-Empirical**	**MOM-Empirical**	**Graphical-MOM**	**Graphical-Empirical**	**MOM-Empirical**
Jan	6.03	7.76	1.83	5.77	7.69	2.04
Feb	2.30	5.25	3.02	2.42	2.71	2.71
Mar	0.97	1.94	2.88	1.03	2.86	2.86
April	0.35	2.08	1.74	0.37	1.76	1.76
May	0.65	1.69	1.05	0.63	1.03	1.03
June	2.09	2.52	0.44	2.09	0.47	0.47
July	4.50	4.96	0.48	4.46	0.45	0.45
Aug	2.96	3.57	0.63	2.99	0.64	0.64
Sep	0.35	0.88	0.53	0.25	0.64	0.64
Oct	5.91	9.36	3.66	5.86	3.89	3.89
Nov	8.82	11.76	3.23	8.51	3.49	3.49
Dec	9.33	10.67	1.47	8.91	2.17	2.17
Yearly	1.50	1.75	3.20	1.46	3.17	3.17
Avg.	2.83	3.63	0.81	2.88	0.81	0.81

The difference between measured WPD (shown in Table 2) and calculated WPD by equation 10 would nearly be 50% shown in table V. The source of this difference is for the multiplication of $\Gamma(1+\frac{3}{k})$. This factor implies the use of Weibull parameters. However, the general equation which is equation 11 uses average wind speed for a given sample. The variation of results from different methods while calculating Energy Density and Power Density is shown in Table 5.

The value of $\Gamma(1+\frac{3}{k})$ is greater than 1 which increases the calculated power density by equation 10. In these equations, the scale factor is considered as the wind speed which is also a bit larger from actual measured speed. The error between energy densities and Power densities found from different methods for different months ranges between 0.3% and 9.5%. Yearly error value ranges from 1.5% to 3.5% where averages are between 0.5% and 3%. Errors between different methods are less than 10% as shown in table 5. The values presented here are the percentage of the difference between the two methods stated in column names. The Absolute value of the difference is taken here.

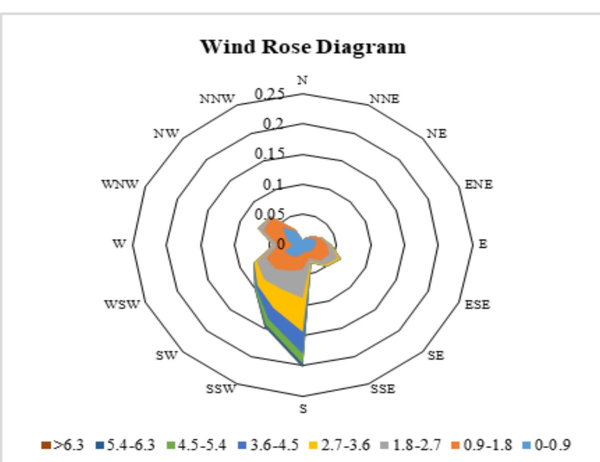

Fig. 4. Wind Rose Diagram

Fig. 4 shows the Wind Rose diagram of the site. The diagram indicates that higher speed wind flows from the south, south-west and south-eastern directions of the site, while lower speed flows from the northern direction. Figure 5 shows a bar diagram. It shows that the most productive wind is available straight to the south of this site. However, Strong, medium and weak flows are also available in all other directions. Most significant incidents can be found in S, SSW, SW, WSW, WNW and NW corners.

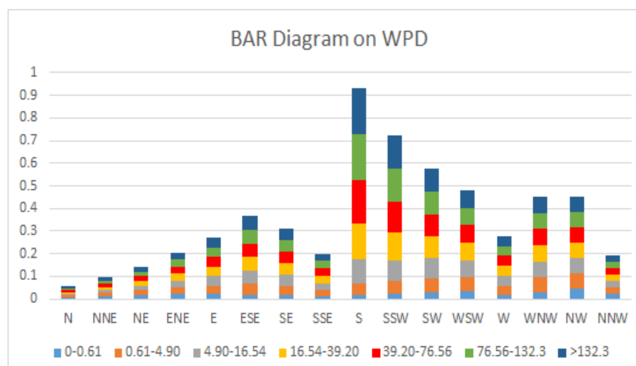

Fig. 5. Bar Diagram for WPD

As the daily wind data are recorded with 10 minutes' interval throughout the year, four segments of timeframes with six hours' interval i. e. 00:00- 06:00, 06:01- 12:00, 12:01-18:00, and 18:01- 23:59 are taken for the simplicity of data analysis. Table 6 shows in detail the Time segmented Wind speed characteristics of the site.

Table 6 shows that higher speed wind flows from midday to late afternoon or early evening. It is also evident that in April, May, June, July, and August, exhibits higher and stable wind speed. The shape factor for these months is also found higher than 2. On the other hand, other months show lower wind speed.

Table 6. Time Segmented Wind Speed Characteristics

Month	00:00-06:00	06:01-12:00	12:01-18:00	18:01-24:00
January	0.77	1.07	1.35	0.79
February	0.84	1.1	1.74	0.94
March	1.42	1.65	2.01	1.92
April	2.32	2.52	3.14	2.71
May	2.10	2.50	2.1	2.83
June	2.69	2.98	3.26	3.03
July	1.99	2.05	2.38	1.97
August	2.19	2.55	3.02	2.53
September	1.34	1.69	2.12	1.7
October	0.61	1.17	1.51	0.98
November	0.42	0.86	1.09	0.56
December	0.66	0.84	1.16	0.68

The data are presented in Fig. 6.

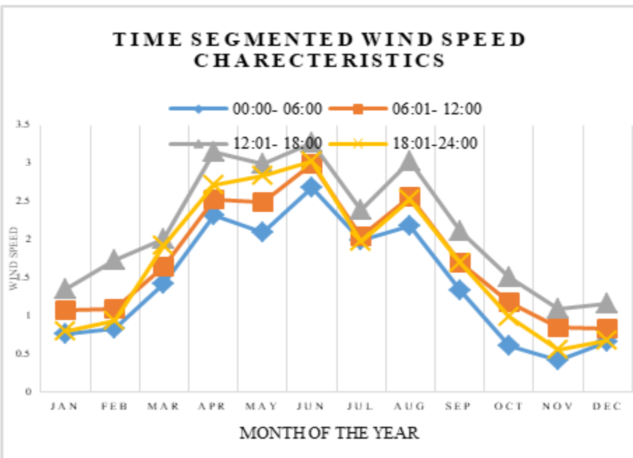

Fig. 6. Time Segmented Wind Speed Characteristics

Some important features that denote the prospect of wind energy in a site are Average power output and capacity factors. Nowadays, it is a common practice to use the obtained data to simulate and estimate the possible output of any site. Here, the recorded data are used to simulate the power output and capacity factor for different models of wind turbines

Average power output for a particular site can be expressed as Weibull Scale Factor A and shape factor k by using following equation:[15]

$$P_{e,\,avg} = P_{rated}\left(\frac{e^{-(\frac{v_c}{A})^k} - e^{(-\frac{v_{rated}}{A})^k}}{(\frac{v_{rated}}{A})^k - (\frac{v_c}{A})^k} - e^{-(\frac{v_c}{A})^k}\right) \quad (12)$$

$$E_{e,\,avg} = P_{rated}\left(\frac{e^{-(\frac{v_c}{A})^k} - e^{(-\frac{v_{rated}}{A})^k}}{(\frac{v_{rated}}{A})^k - (\frac{v_c}{A})^k} - e^{-(\frac{v_c}{A})^k}\right)_T \quad (13)$$

In equation 12, $P_{e,\,avg}$ stands for average output power by a wind tubine, P_{rated} denotes the rated power of that turbine, V_{rated} is for voltage rating and V_c denotes the cut in speed. Multiplying equation 12 by the total time of a year yields the average energy production per year. Capacity factor can be obtained by following equation:

$$C_f = \frac{P_{e,avg}}{P_{rated}} \quad (14)$$

Here, a simulation is done to estimate the yearly power production potential and capacity factor by using three different wind turbines of three different manufacturers having different rated output power. These are Aventa AV-7, DB-400, and Archimedes AWM-1500D[16][17][18]. As the site exhibits low-speed, small wind turbines are chosen for the analysis[19]. The Highest capacity of examined turbines is 6.5 kW. The lowest is 400 watts and another 1000-watt turbine is considered. The estimated results are shown in Table 7.

Table 7. Turbine Detail with simulation result

Turbine Model	Aventa AV-7	DB-400	AWM 1500D
Rated Output	6.5 kW	400W	1000W
Rotor Diameter/Size	12.9 m	1.2 m	0.91 m
Cut In Speed	2 ms^{-1}	3 ms^{-1}	3 ms^{-1}
Cut Off Speed	15 ms^{-1}	30 ms^{-1}	30 ms^{-1}
Energy Output (kWh/year)	3307	101	147
Capacity factor	5.80%	2.9%	1.7%
Full load hours(h/year)	508	251	147
Operating hours(h/year)	4420	2133	7587

The simulation result shows that the capacity factor and energy output of Aventa AV-7 is highest among all three. But due to the size of this turbine, it is not suitable for a 23 m high building rooftop. So, the other two turbines, DB-400 and AWM-1500D are chosen for further calculations. DB-400 exhibits better capacity factor than AWM-1500D but lower in power generation. These turbines are very small and light in weight and suitable for installation on small and large buildings' rooftop. Multiple installations of these turbines on the same rooftop would increase the generation capacity. The power curve for DB-400 and AWM-1500D are given in Figure 8 and Figure 10, respectively. The physical appearance of these turbines is given in figures 7 and 9. Month wise power generation profile at 23-meter height for DB-400 and AWM-1500D is given in Table 8.

Fig. 7. DB 400 wind turbine

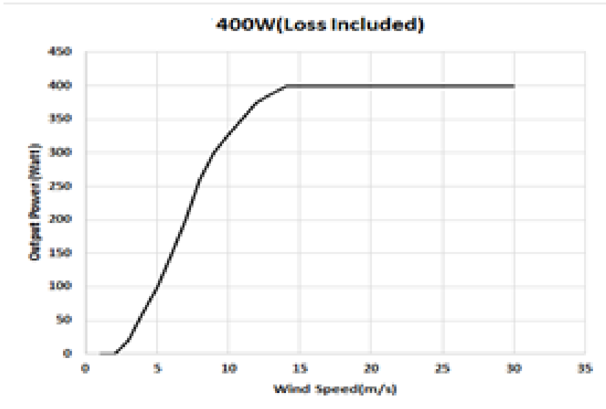

Fig. 8. DB 400 wind turbine

Physical properties and features of DB-400 and AWM-1500D are given in table 7. These turbines can withstand high-speed winds like 40 to 50 $ms^{-1.}$ The weight of DB-400 is very low whereas AWM weighs about 120 kg. AWM-1500D can directly be installed on the rooftop but DB-400 requires an extra stand.

Fig. 9. AWM wind turbine

In table 9 month-wise energy production profile and capacity factor are shown. The yearly yield of energy production by DB-400 would be 109498.3 Wh and 149750 Wh by AWM-1500D.

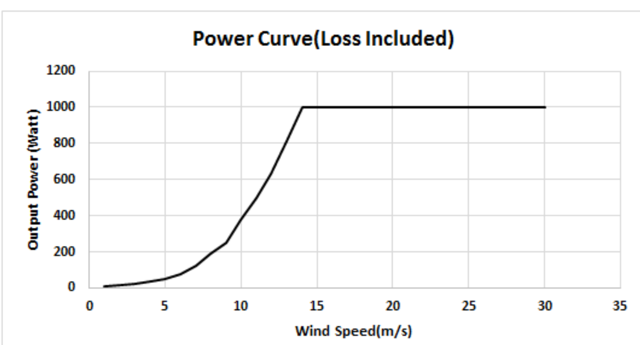

Fig. 10. Power curve of AWM wind turbine

From the above analysis, it can be said that in the testing height which is in this case approximately 23 m above the ground, there are prospects of harnessing wind energy in this site and its adjacent areas in April, May, June, July, and August. Five months of a year shows the potential of power production from wind at this height but the yearly energy yield is low by capacity factor. However, capacity factor can be improved by increasing the height of turbine and using light weight small turbines. In the following sections a performance analysis of small turbines at different heights has been given.

Table 8. Physical Properties and Features of AWM-1500D and DB-400

Physical Properties	AWM-1500D	DB 400
Maximum Power	1000W	400W
Rated Power	700W	400W
Operating Wind Speed	0.9 ms^{-1}	2.5
Cut In wind speed	3 ms^{-1}	3 ms^{-1}
Rated Power Speed	12 ms^{-1}	12ms^{-1}
Max Power Speed	14 ms^{-1}	14 ms^{-1}
Cut Out	15 ms^{-1}	15 ms^{-1}
Survival Speed	50 ms^{-1}	40 ms^{-1}
Rated RPM	330	950
Cut Out RPM	400	-
Size/Rotor Diameter	0.75m (Width), 1.9m (Length), 1.75m (Height)	1300mm
Weight	120 kg	6.5 kg
Control System	MPPT Control, Auto and Manual Braking System	-

Table 9. Month-wise Generation Profile by DB-400 and AWM-1500D at 23-meter height

Month	DB-400		AWM1500D	
	Wh per month	**Capacity factor**	**Wh per month**	**Capacity factor**
January	416.6	0.10%	7916.7	1.10%
February	3333.3	1.10%	8250.0	1.10%
March	7916	2.70%	12166.7	1.70%
April	21083	7.20%	19083.3	2.60%
May	18500	6.30%	17916.7	2.50%
June	24083	8.20%	20333.3	2.80%
July	9916.6	3.40%	14083.3	1.90%
August	16083.3	5.50%	17000.0	2.30%
September	6166.6	2.10%	11916.7	1.60%
October	1583.33	0.50%	8000.0	1.10%
November	250	0.10%	6083.3	0.80%
December	166.6	0.10%	7000.0	1.00%

There are several ways to improve the performance characteristics of a site. By increasing the wind tower height and by using multiple wind turbines at the same site may increase the wind power potential of the site significantly. Tower height can be increased up to a notable extent for lightweight small turbines. Increasing tower height on a small building rooftop would not be a good choice for heavy turbines due to mechanical load considerations. However, structures that are on the design phase might consider the scope of having wind turbines in the future and account the load into the designs. It would increase the cost also. In Dhaka city more than 100-meter-high building is common in commercial areas. Some residential area has also high rises. The highest building in Dhaka city is The City Centre having a height of 171 meters. These high rises can be tested for the actual generation capacity.

7.1 Increasing the Height of the Wind Tower

In this experiment, the data are acquired at 23-meter height, however, wind speed can be estimated at different heights from the following equation: [20]

$$V_n = V_m \left(\frac{H_n}{H_m}\right)^{\alpha} \tag{14}$$

Where V_n, the new speed at a new height, V_m is the measured speed at measuring height and α is the Hellmann exponent, the value of which, in this case, is 0.34. This value is considered because of the site characteristics. The location is a human-inhabited are. There are no other taller buildings within its 1 km periphery. Thus neutral airflow can be found. Calculated wind speed at different heights for each month is given in Table 10.

Table 10. Projected Wind Speed at Different Heights

Month	Speed at different heights(ms^{-1})				
	23 m	50 m	100 m	150 m	200 m
Jan	0.99	1.3	1.64	1.88	2.08
Feb	1.15	1.5	1.9	2.18	2.41
Mar	1.75	2.28	2.88	3.31	3.65
Apr	2.7	3.51	4.44	5.1	5.63
May	2.61	3.39	4.3	4.93	5.44
Jun	2.99	3.9	4.93	5.66	6.24
Jul	2.1	2.73	3.46	3.97	4.38
Aug	2.57	3.35	4.24	4.87	5.37
Sep	1.71	2.23	2.82	3.24	3.57
Oct	1.07	1.39	1.76	2.02	2.23
Nov	0.74	0.96	1.22	1.4	1.54
Dec	0.85	1.11	1.41	1.62	1.78
Yearly	1.75	2.28	2.88	3.31	3.65

Table 11. Capacity factor at different heights by sample turbines

Turbine Model	Height	Power Production (kWh/year)	Capacity factor	Full load hours (h/year)	Operating hours (h/year)
DB-400	50 m	145	4.10%	363	3407
	100m	294	8.40%	736	4847
	150m	423	12.10%	1057	5597
	200m	534	15.20%	1333	6060
AWM-1500D	50 m	181	2.10%	181	8435
	100m	249	2.80%	248	8555
	150m	316	3.60%	316	8604
	200m	385	4.40%	384	8632
Aventa 7	50 m	4681	8.20%	720	6236
	100m	9293	16.30%	1429	7079
	150m	13182	23.10%	2027	7455
	200m	16333	28.70%	2511	7672

By using table 10 the power production and capacity factor with other information for DB-400, AWM-1500D and Aventa 7 turbines are estimated by using the SWISS Energy Tool. The results are given in Table 11. Aventa cannot be considered for small buildings. But for future high rises like The City Center might consider turbines like Aventa. From table 11 it can be seen that capacity factor increase for DB-400 and Aventa but not for AWM. It is because of the difference in its full capacity and rated capacity (Table VIII). Another issue lies in this turbine that to produce the same amount of energy as like DB-400 it takes higher wind speed because of its mechanical friction loss. For Aventa 7 and DB-400 capacity factor can be improved up to 15% to 29% if a 200m building rooftop is considered.

4. Conclusion

The Shape factor of the site is found to be 1.42 and the yearly scale factor is 1.96 ms^{-1}. The shape factor is below 1.5 and represents a broader wind speed distribution. The site is found to have low wind speed; however, five months of the year might show better performance than other months. The probable energy production capacity of this site would be around 109498.3 Wh to 149750 Wh per year using small lightweight turbines described in this paper. The yearly capacity factor is found 1.7% to 2.9% which is low but still could return some economic benefits. Usually, the rooftops of markets, offices and in many cases, apartments remain unused. If an additional load is supported by the existing infrastructures similar wind turbines examined here can be installed directly on these rooftops using small stands and thus can save the construction cost of a big tower for each turbine. Multiple installations of such small turbines on the same rooftop could increase the overall power generation capacity of the site.

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