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Analysis of Wind Speed and Direction as Support for Green Buildings in Urban Areas using the Weibull Method

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Abstrack

Currently, the dominance of electricity in Indonesian providers comes from fossil energy which has the potential to increase the average temperature in various parts of the world or is called global warming. The contribution of the national renewable energy potential mix in 2016 ranging from 6.27%, then reaching 11.28% in 2020. The Government has made a long-term plan for the national renewable energy mix to reach 25% in 2025 and 31% in 2050. One of the renewable energy sources is wind energy, which is usually built on a large scale and is separated from settlements so that a long distribution network is required. Conversely, on a small scale, wind energy can be utilized with a simpler distribution network, this concept is called Small Wind Turbine. For a good wind turbine is designed according to the wind characteristics in real-time, so it is necessary to study wind mapping. This research was conducted as a prelude to observing wind characteristics in the form of mapping wind speed and direction in real-time in the northern part of Balikpapan City Region, using the Automatic Weather Station instrument which was carried out August 6 to September 26, 2022. Data processing in this study using the Weibull distribution method with Microsoft Excel. This study shows an average speed of 1.118 m/s in wind conditions with high wind variability with strong gusts, with a power density value of 1.157 Watts/m^2. The wind direction tends to be east after the wind gusts are blocked by the building profile.

Keywords: renewable energy, wind energy, weibull distribution, density power

1 Introduction

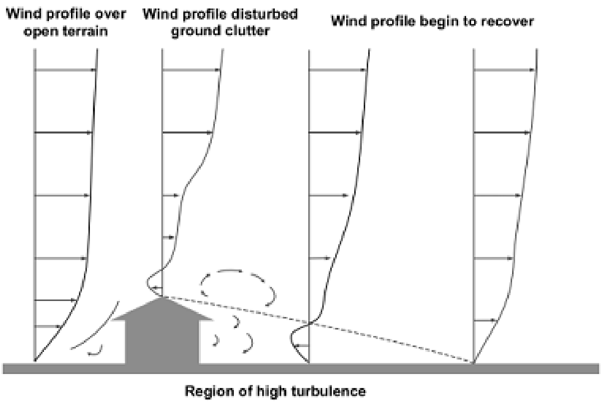
Population growth in Indonesia increases every year with a population of more than 250 million, as a result, the used of electrical energy can reach 7000 MW every year. This encourages the government to increase the supply and use of alternative energy, new and renewable energy, or NRE as a power plant [1][2]. Currently, the dominance of electricity providers is sourced from fossil energy which triggers the greenhouse gas effect, so it has the potential to increase the average temperature in various parts of the world, or is called global warming. [3][4]. From the 1980s to 2016, national energy needs were dominated by energy sourced from fossils, which includes coal, oil, and natural gas, while the use of new and renewable energy has not shown significant growth [5][6]. Meanwhile, the contribution of the renewable energy potential mix nationally in 2016 was around 6.27%, after 2016 there was an increase in the mix of renewable energy utilization which reached 11.28% in 2020 [7-9].

For minimizing air pollution that causes greenhouse gas effects to accelerate global warming, the supply of renewable energy must be balanced with the supply of non-renewable energy sourced from fossils. [10]. Indonesia is geographically located on the equator and has a tropical climate, this affects the potential for power generation from renewable energy which reaches 442 Giga Watt [11]. The government through the ministry of energy and mineral resources (ESDM) makes a long-term plan to contribute to the increasing use of renewable energy in the national energy mix, which is 25% in 2025 and 31% in 2050 [10][8]. Renewable energy sources are energy resources that exist naturally and their availability is always sustainable, these energy sources include water energy, wind energy, geothermal energy, marine energy, biomass energy, and solar energy [12][9].

One of the renewable energy sources, wind energy is usually built with the concept of a wind farm or on a large scale that is separated from settlements so that a long distribution[13]. Conversely, on small scale, wind energy can be utilized with a simple distribution network, this concept is called Small Wind Turbine (SWT) which can meet household energy needs, street lighting energy, to meet the supply needs of electric vehicles. [14][15]. In urban areas or densely populated areas, it tends to be appropriate to apply *Small Wind Turbine* (SWT) which is integrated into the building or called *Building Integrated*. The application of wind turbines in buildings is one of the criteria for energy conservation to meet the green building concept [17][18]. Globally, the actual Small Wind Turbine (SWT) in urban buildings is still limited to low wind speeds, this is due to the turbulent nature of the wind [19]. Urban areas with unequal building heights, along with uneven land contours will change the shape and nature of the boundary layer as shown in Fig. 1 [14]. While each building illustrated in the form of a box as shown in Fig. 2 causes the direction and shape of the wind to change and tends turbulent profile [10].

Balikpapan City is one of the administrative cities located in East Kalimantan with a topography of 70% evidence and 30% sloping areas or swamps adjacent to river channels and beaches [20]. The population of Balikpapan City shows a growth reaching 1.25% annually and a population of 688,381 people in 2020, or an increase of 25.56 million people in 10 years [21]. The increase in the population of an area tends to increase the cumulative energy demand [22], so it tends to be suitable for implementing a green building concept that is integrated with a small wind turbine. A small wind turbine is designed according to the conditions of wind speed and direction [23], for urban areas that have not been mapped, a character study is carried out in real-time and in real conditions with an independent weather monitoring device or Automatic Weather Station (AWS) [17] as shown in Fig. 3 [10].

This research was conducted as a prefix for observing wind characteristics in the form of mapping wind speed and direction in real time and real conditions in the northern part of Balikpapan City, so that the potential value of wind energy can be known by calculating the value of power density (watt/m^2). The results of this study are useful in contributing to the initial reference for mapping and wind speed in urban areas, especially in the city of Balikpapan to apply the concept of green building with an integrated wind turbine model.



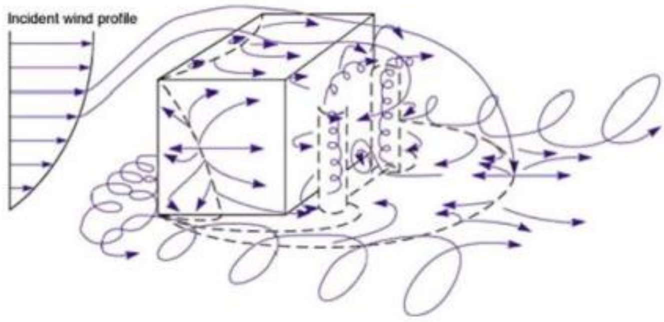


Fig. 1. Boundary layer profile in urban areas [14]

Fig. 2. Illustration of the wind flow profile in the building [10]

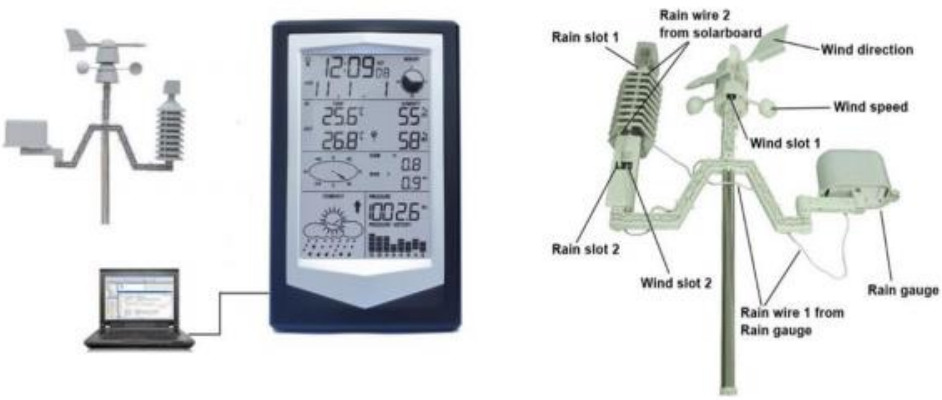


Fig. 3. Automatic Weather Station (AWS) instrumentation [10]

2 Research Methods

This research was conducted at the Politeknik Negeri Balikpapan Integrated Building, Balikpapan City, East Kalimantan by placing the Automatic Weather Station unit on the 4th floor rooftop as shown in Fig. 4 with the installation shown in Fig. 5. The instrument used in this study used an Automatic Weather Station unit which was produced Tiankan Electronic Technology Tiongkok [24] with the specifications of the tools shown in Table 1. The data in this study includes data on wind speed and wind direction in real-time and in real conditions which were carried out from August 06 to September 26, 2022, with forecasts based on estimates from the Meteorology, Climatology and Geophysics Agency (BMKG) is the dry season [25] with data storage intervals every 10 minutes.

The results of taking every 10 minutes show real-time data of wind speed and wind direction at random, so it is necessary to analyze the probability weibull distribution statistical method with the final result obtained wind power density data (Watt/m^2) [26]. The probability weibull distribution consists of two main parameters, namely the value of *k* (distribution form factor) and the value of *c* (distribution scale factor) which can be calculated by the graphical method as shown in the Eq. (*1*).

$$1 - F(V) = e^{-(V/c)^k} \quad (1)$$

F(V) = Cummulative Frequency

which:

$$\ln\{-\ln[1\text{-}F(V)]\} = k\ln(V_I)\text{-}k\ln c \quad (2)$$

Plotting in Eq. (*2*) is the relationship of ln (*Vi*) along the *X* axis with *ln{-ln(1-F(V))}* along the *Y* axis which forms a straight line. Based on Eq. (2), the value of k is the slope of a straight line, while *–k ln c* represents the constraint.

From these equations, the regression equation obtained through a spreadsheet is known for the Weibull k and c values. Furthermore, the Weibull distribution statistical method is used to analyze random wind speeds using two functions, namely the probability density function and the cumulative distribution function. The probability density function *(f(V))* shows the time grouping against a certain wind speed indicated by the Eq. (*3*)

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} e^{-\left(\frac{V}{c}\right)^k} \quad (3)$$

Where k is weibull shape factor, c is scale factor

While the cumulative distribution function is used to calculate the probability value of the wind speed equal to or lower than *V*, so that the cumulative distribution or *F(V)* is the integral of the probability density function, as in the Eq. (*4*).

$$F(V) = \int_0^{\alpha} f(V)\,dV = 1\text{-}e^{-\left(\frac{V}{c}\right)^k} \quad (4)$$

So the value of wind power density, based on the weibull distribution method, is

$$P_w = \frac{1}{2}\rho\, c^3\Gamma\left(1 + \frac{3}{k}\right) \quad (5)$$

Random analysis of the wind speed and direction data in this study was processed using Microsoft Excel software in the form of a distribution displayed in tables and a wind rose with wind direction and wind speed in several color contours representing the percentage of wind speed [26].

Fig. 4. Rooftop 4th floor of the Politeknik Negeri Balikpapan integrated building

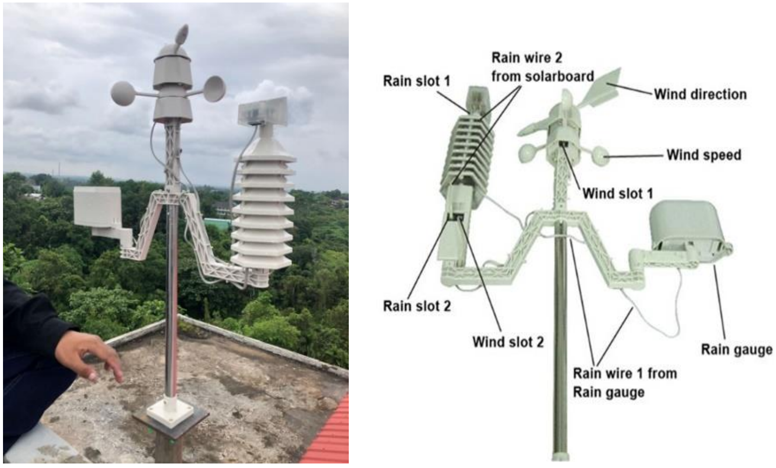


Fig. 5. Installation of the automatic weather station

Table 1. Specification of automatic weather station Unit [24]

Parameter	Unit Indoor/ Receiver	Unit Outdoor/ Transmitter
Temperature range	0℃～50℃(32℉～122℉);	-40℃～60℃(-104℉～140℉)
Temperature accuracy	±1℃	±1℃
Temperature resolution	0,1℃	0,1℃
Humidity range	20%~99%	20%~99%
Humidity accuracy	±5%	±5%
Humidity resolution	1% (condition: temp 25℃, humidity 50%)	1%
Pressure range	920~1080hPa	
Pressure accuracy	±5hPa	
Pressure resolution	0,1 hPa	
Update data	Transmission 48s	48s
Alarm	2 minutes	
Power	3*1,5V AA battery	2*1,5V AA battery
Battery life	about 12 months	about 24 months
Low battery check	power-on check; 00:00 check everyday	power-on check; 00:00 check evey day
Work temperature	0℃ to 50℃	-40℃～60℃(-104℉～140℉)
Wind speed range		0~50m/s
Wind speed resolution		0,1 m/s
Rain range		0~9999mm
Rain resolution		0,1mm(rainfall<1000 mm) 1 mm(rainfall>1000 mm)

3 Result and Discussion

Real-time data from August 06 to September 26, 2022, or for 52 days with data collection intervals every 10 minutes from the Automatic Weather Station unit, obtained 5702 wind speed data loggers with wind directions divided into 13 categories of wind speeds ranging from 0.0 m /s to 5.2 m/s, as shown in Table 2. Based on the data logger, the wind speed that was read around the location was dominated by 0.9 to 2.2 m/s with the wind direction that was read tending to be dominated by the east direction.

Table 2 shows the wind speed that was read in this study ranging from 0.4 – 5.3 m/s, so in analyzing this data logger using 1646 data as shown in Table 3. Before calculating the power density value of the research area, first find the value of k (distribution form factor) and the value of c (distribution scale factor) for the weibull distribution using the graphical method according to Eq. (*1*) and Eq. (*2*). In calculating Eq. (*1*) and Eq. (*2*) using Microsoft Excel software, and the output results are shown in Table 3.

Based on Table 3, the value of the parameters k and c for the weibull distribution is calculated by the graphical method by converting the cumulative frequency function into a linear regression graph by adopting a logarithmic scale, the calculated value of "*Ln (Vi)*" as a function of x and "*Ln{-Ln(1- F(V))}*" as a function of *y* is represented in the form of a graph shown in Fig. 6 with a linear Eq. $y = 0.8336x - 0.0933$, so that the parameter values for k and c are based on the formula in reference [27], namely *k=0, 8336* and *c=1.118*. Table 4 shows the output of the calculation of the probability density function based on Eq. (*3*) and the cumulative frequency distribution function based on Eq. (*4*), this is represented by graphs in Fig. 7a and Fig. 7b. Fig. 7a shows that based on the statistics of the Weibull method, the most frequent wind speed during the study period was 0.4 m/s with a probability density value of 0.656. The *k* value indicates the stability of variability and gust level [28]. In this study, the *k* value = 0.8336 in the wind classification with high wind variability with strong gusts ($k \leq 1.5$). The value of parameter c shows the average speed value based on the weibull distribution [29], so that in this study the average speed is 1.118 m/s. Based on Eq. (*5*) the value of density power with an air density value 1.24 kg/m2 [30] 1.157 Watt/m^2, this shows that every m2 in the research area has a wind energy potential 1.157 Watt.

Table 2. Real-time data mapping wind speed and wind direction

Wind Speed (m/s)	**Wind Direction**								**Total**
	East	**North**	**North-East**	**North-West**	**South**	**South-East**	**South-West**	**West**	
0.0	951	475	1210	532	177	428	67	210	4050
0.4	50	44	52	62	4	30	5	11	258
0.9	68	49	85	73	1	67	2	21	366
1.3	100	60	91	62	5	37	3	5	363
1.8	53	61	62	45	5	25	3	9	263
2.2	23	48	34	22	1	15	8	3	154
2.6	11	27	18	27	3	4	4	2	96
3.1	11	25	15	8	1	2	2	2	66
3.5	11	10	13	7	1		2	1	45
4.0	2	2	4	3		1	2	2	16
4.4	1	3	3	1		1	1		10
4.8	2	1	2			3			8
5.3							1		1
Total	**1283**	**805**	**1589**	**842**	**198**	**613**	**100**	**266**	**5696**

Table 3. Calculation of the graph method

Wind Speed (*Vi*)	**Number of Data (*fi*)**	**Presentase (*%*)**	**Frequency**	**Komulatif Frekuensy (*F(V)*)**	***Ln (Vi)***	***Ln{-Ln[1-F(V)]}***
0,00	4050	15,67	0,157	0,157	-0,999	-1,769
0,40	258	22,24	0,222	0,379	-0,916	-0,741
0,90	366	22,05	0,221	0,600	-0,105	-0,088
1,30	363	15,98	0,160	0,759	0,262	0,354
1,80	263	9,36	0,094	0,853	0,588	0,651
2,20	154	5,83	0,058	0,911	0,788	0,885
2,60	96	4,01	0,040	0,951	0,956	1,107
3,10	66	2,73	0,027	0,979	1,131	1,348
3,50	45	0,97	0,010	0,988	1,253	1,496
4,00	16	0,61	0,006	0,995	1,386	1,650
4,40	10	0,49	0,005	0,999	1,482	2,002
4,80	8	0,06	0,001	1,000	1,569	2,002
5,30	1	0,00	0,000	1,000	1,668	2,002

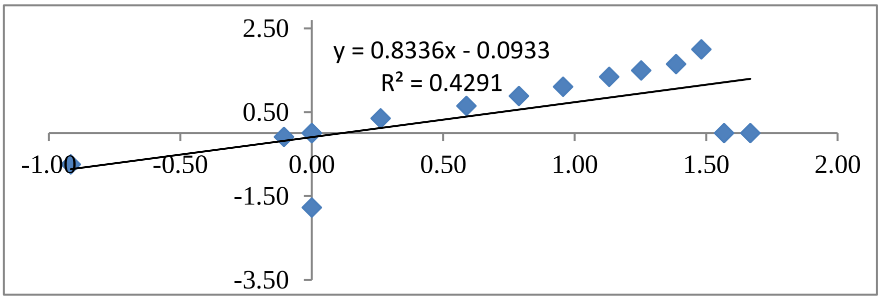
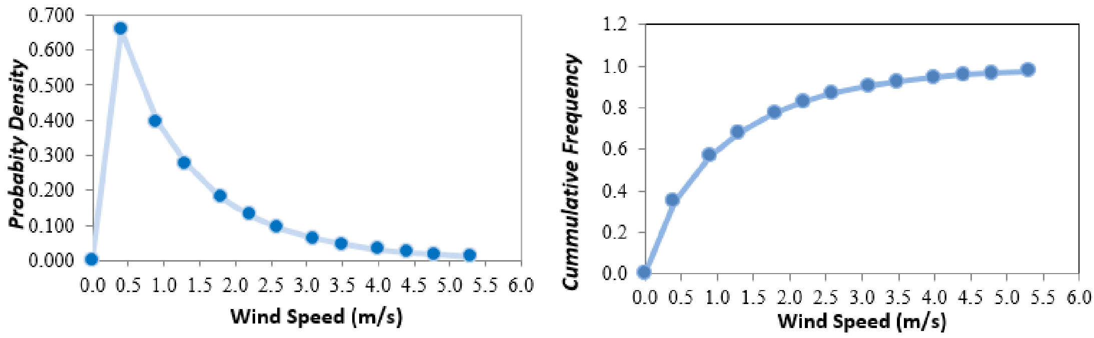


Fig. 6. Graph of estimated values of parameters *k* and *c*

Table 4. Output weibull distribution

Wind Speed (*Vi*)	Weibull Distribution		Wind Speed (*Vi*)	Weibull Distribution	
	Probability Density	Cummulative Distribution		Probability Density	Cummulative Distribution
0,40	0,656	0,346	3,10	0,062	0,904
0,90	0,395	0,566	3,50	0,045	0,925
1,30	0,276	0,678	4,00	0,031	0,945
1,80	0,180	0,774	4,40	0,022	0,956
2,20	0,129	0,828	4,80	0,016	0,966
2,60	0,093	0,867	5,30	0,011	0,974



(a) (b)

Fig. 7. (a) Weibull distribution graph. (b) Cummulative frequency weibull distribution graph

In analyzing the real-time wind speed with its direction as shown in Table 2, it is shown in the classification of wind speed, in this study the wind speed is classified in a class, then shown in Table 6 and can be displayed in the form of a wind rose diagram as shown in Fig. 8, based on the diagram, the wind direction in the study period was dominated by the east direction at wind speeds of 0-1 m/s. This research was conducted during the dry season, but the wind direction obtained was not dominated by the southeast direction by the wind direction conditions in the dry season [25]. The difference in the readable wind direction is due to the wind passing through the building profile as shown in Fig. 1 and Fig. 2 which causes resistance to the building profile and tends to occur in the phenomenon of wind vortex or turbulent flow so that the wind direction will change [5][8].

Table 6. Real-time data on wind direction

Wind Speed	North	North-East	East	South-East	South	South-West	West	North-West	Total
0-1 m/s	9,97%	23,65%	18,77%	9,22%	3,20%	1,30%	4,25%	11,71%	82,06%
1-2 m/s	2,12%	2,69%	2,69%	1,09%	0,18%	0,11%	0,25%	1,88%	10,99%
2-3 m/s	1,32%	0,91%	0,60%	0,33%	0,07%	0,21%	0,09%	0,86%	4,39%
3-4 m/s	0,61%	0,49%	0,39%	0,04%	0,04%	0,07%	0,05%	0,26%	1,95%
4-5 m/s	0,11%	0,16%	0,09%	0,09%	0,00%	0,05%	0,04%	0,07%	0,60%
5-6 m/s	0,00%	0,00%	0,00%	0,00%	0,00%	0,02%	0,00%	0,00%	0,02%
Total	14,13%	27,89%	22,52%	10,76%	3,47%	1,75%	4,67%	14,78%	100,0%

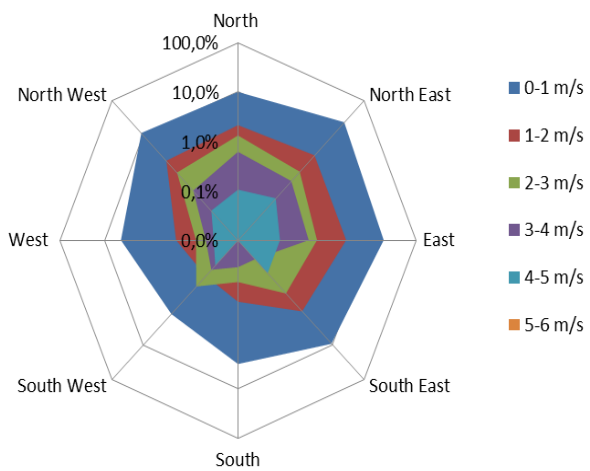


Fig. 8. The wind rose wind direction diagram by wind speed category

4 Conclusion

Research on the initial mapping of wind speed and wind direction in industrial areas has been carried out from August 6 to September 26, 2022 or for 52 days in the dry season period. The data from wind mapping and wind direction have been obtained after real-time data is processed using the weibull distribution method with a parameter value of k = 0.8336 which includes wind classification with high wind variability with strong gusts, and parameter c = 1.118 indicating the average velocity value, so that the average speed is 1.118 m/s. Based on the parameter values of k and c, the value of density power in the research area is 1.157 Watt/m^2, which shows that in the research period the value of available wind power is 1.157 Watt for each meter area. While the wind direction that is read tends not to be the same as the normal wind direction in the dry season, in this study the wind tends to go east after the wind gusts are blocked by the profile of the building. Basically, this research is used as a preliminary analysis for 52 days in the dry season, so this research cannot be used as a reference for designing wind turbines. To get data as a reference for designing wind turbines, mapping wind data in real-time for at least one full year through the dry season and the rainy season.

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