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Study on High-Rise Building Using Wind Energy at Humid Tropical Climate

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In Low Carbon City it is important to reduce the emission of greenhouse gases (GHG). It means buildings have to reduce the energy consumption of fossil fuel and take action to use clean energy such as wind energy. The higher altitude, the higher wind speed. Wind speed as a function of altitude has a chance to be used in high-rise buildings. Indonesia is a humid tropical country, which generally has the character of relatively low wind speeds. In another hand, high-rise buildings have considerable potential value to utilize height as a factor to obtain sufficient wind speed.
This study aims to identify the potential for wind energy in high-rise buildings in humid tropical climate. Problems focused on the design arrangement of wind turbine type on the building and the potential energy can be harnessed. This research was conducted in suburban areas where the roughness level is lower than the city centre. This study focused on assessing the potential of the wind on tall buildings in a built environment in suburban areas.
The research method is quantitative research which the variable is observed from wind speed data. Research developed by the experimental research method with CFD simulation to meet the built environment wind profile for further analysis. The variable data is observed from field measurement and local wind speed data. Case study takes on campus Bina Nusantara Alam Sutera as a case of the building which represents a type of high-rise buildings in suburban Jakarta area.
This study shows at least five types of possible arrangements which can be applied to buildings. This study presents the alternative use of wind energy utilization at Bina Nusantara University as a cross-subsidy scheme. Wind energy can replace 3.27 % of main building energy consumption equal with CO_2 emission reductions as 127,650 kgCO_2.

1. Introduction

Today, the building sector is contributing significantly to global warming and climate change. It contributes as much as one-third of total greenhouse gas emissions. In Low Carbon City it is important to reduce the emission of greenhouse gases (GHG). It means buildings have to reduce the energy consumption of fossil fuel and take action to use clean energy.
Increasing the altitude, the wind speed will higher. To gain enough wind speed, the wind turbine is generally built using a high tower or above the building. Wind speed as a function of altitude has a chance to be used in high-rise buildings. High-rise building has considerable potential value if can utilize height as a factor to obtain sufficient wind speed. Associated with wind speeds as a critical factor in the utilization of the wind as energy, urban areas have the character of the surface which are considered to have friction, however, this area has a high rise building as potential. Our study based on two stages. The first stage is evaluating the wind velocity on a rooftop in a proposed wind turbine hub height, based on CFD (computational fluid dynamics) simulation. The CFD simulation carried out with the Win Air and modeling in Ecotec. The second is evaluating the arrangement possibility of wind turbines on roof top area and the energy can be harnessed. This study will focus on identifying the potential of the wind on tall buildings in a built environment in suburban areas. Based on the suburban environment with few tall buildings have a surface roughness value of α = 0.25 to 0.50. Thus the wind speed conditions in urban areas will be smaller than the area of the open area. However, on the other hand, the air at the top an urban area is not much affected by surface roughness. (Jeongsu Park, 2015)

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1.1 Case Study

Bina Nusantara Alam Sutera Campus with total land area of 25,000 m^2, consists of two buildings. The first is main campus, a building stands as tall as 21 floors in +97.500 meters elevation. This tower building has 796.25 m^2 rooftop area. Basically, this building is designed to save energy through building envelope and efficient building service system. The building uses natural ventilation in the corridor and service area.
Another building is a 5 floors student dormitory next to the tower building. Using feature design based on green building such as water saving, and energy saving. (Figure 1)

1.2. Wind Turbine

The wind turbine is a device that converts kinetic energy from the wind into electrical power. Basically, there are two types of wind turbines: Horizontal Axis Wind Turbine (HAWT), and Vertical Axis Wind Turbine (VAWT). This study presents 5 reference models wind turbine as roof mounted Built-environment Wind Turbine (BWTs) by (Smith, 2012) as shown in Table 1.

Table 1: Study on 4 types of wind turbine on roof mounted

	Type	Reference Model	Rotor Diameter	
1	HAWT Up Wind	AirForce 10	8 m	
2	HAWT Down Wind	Power works 100	18 m	
3	HAWT Down Wind	The Sky stream 3.7	3.72 m	(XZERES Wind Corp, 2010
4	VAWT H-Rotor	Aeolos v 3kw	2 m, h. 5 m	(Aelos Wind Energy Ltd, n.d.)
5	VAWT Helical	UGE-9M	4.2 m	(UGE, 2016)

2. Method

2.1. Simulation

The CFD modeling in this study involved the followings: developing a 3D model for the main building and add the surrounding high-rise buildings. Determine dimension of the simulation field by minimum 5H upstream of the building, 5H on each building side, 5H above it and 15 H downstream of the building (Hall, 1997). The analysis grid dimensions developed as 2,000 m x 2,000 m and 500 m (Figure 2).

Figure 1: Bina Nusantara University

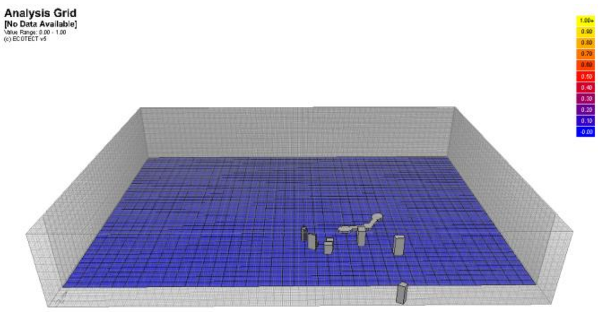


Figure 2: Determine the dimension of simulation field

Developing mixed meshed cells (tetrahedral, hexahedral and pyramids) for the computational domain. Integrating the local weather data with the developed CFD model and defining the upwind free boundary inlet. Applying “constant pressure” boundary conditions at the downwind and upper free boundaries; Calculating turbulence quantities (kinetic energy and dissipation rate) required for the upwind free boundary from empirical relationships. Predicting air velocity in terms of three directions, pressure profile, and turbulence parameters.
This study is based on two types data: wind data and wind turbine data. Wind data is observed from field measurement and local wind speed data. Wind turbine data is obtained based on the company publication and others references. Field measurement using a digital anemometer, placed on the rooftop of the building at height of 1 m (+98.5 m). The annual wind data obtained from the nearest weather station, as a baseline to observe the trend of the wind that occurs in the environment. Weather station data showed that average wind speed per month at 10 m height is around 2-2.5 m/ s, with the wind direction mostly coming from 90 (east) in the period from July to October and 250-270 (West) in December to April.

Wind speed extrapolation is a formula that calculates wind speed from wind data, by using *Power Law* based on the comparison of shear exponent of the wind speed (Newman, 2013).

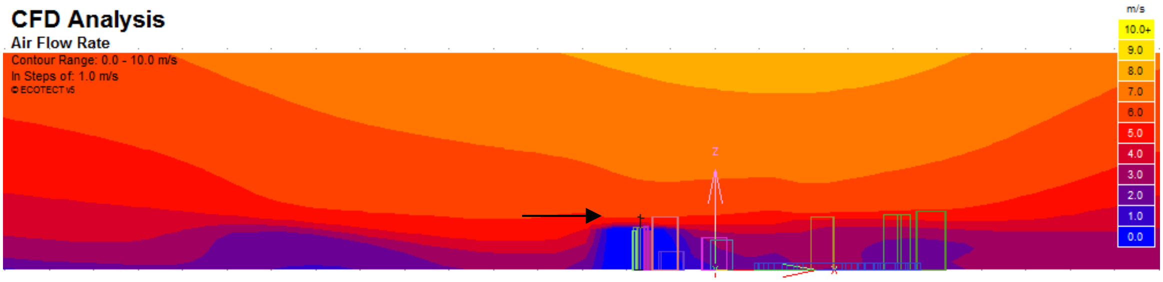
$$V = V1\ (Z/Z1)^{1/n} \qquad (1)$$

$1/n$ city 0,25 - 0,50.
V = wind speed at a certain height (m/s)
V1 = Wind speed reference (m/s)
n = *shear exponent*
Z = Measured height (m)
Z1 = Referenced height (m)

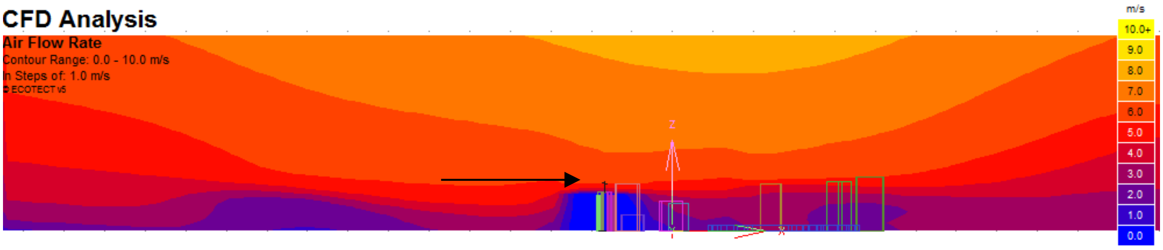
3. Result and Discussion

3.1 Wind profile

Relate to Safety Zone Flight Operations of Soekarno Hatta Airport, Building height at Alam Sutera limited to a maximum of 130 m. The wind velocity is reviewed based on wind turbine hub at height of 120 m.
In the period of December-April which wind conditions are influenced by the west monsoon, the wind comes from 250 - 270º. This area is a residential and industrial low rise building about 3 floors. From windward, Bina Nusantara main campus building face wind flows directly without any obstruction. The simulation shows wind velocity on this period is 5.80 – 6 m/s (Figure 3).



a. Wind velocity on April (270º)

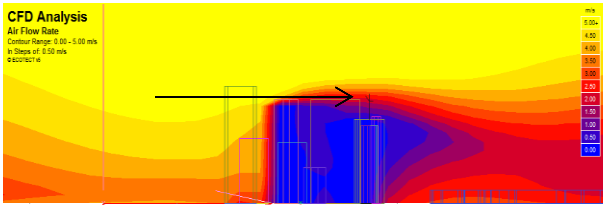


b. Wind velocity on December (270º)

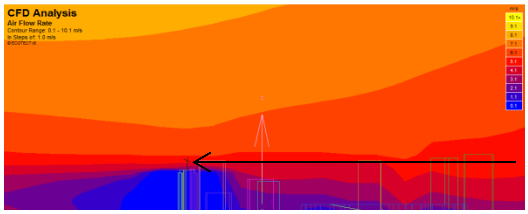
Figure 3: Wind contour and velocity on April and December. Wind direction from 270º

On May, the wind comes from the direction of 160º. Wind velocity drop to 2.5 m/s influenced by wind shadow from 120 m and 80 m building stands previously. Figure 4(b) shows the study building has a distance of 120 m from the nearest building. The Wind flows over the buildings and creates a wind shadow as far as <600 m behind the building with a height of 100 m. In this case should be more than 720 m distance to have wind shadow free. As building as a barrier, wind pass through the barrier will require high 6x distance barrier (building) in order to return to its original direction (Koenigsberger, 1973).
In the period of July to October, wind conditions are influenced by east monsoon wind, the wind blows from 90º. Wind velocities vary from 5.3 m/s to 5.5 m/s. This speed reduction is influenced by the effects of the turbulence of the building in front of it (direction 90). There is certain turbulence zone area due to the high-rise buildings in the direction of the windward region. Mention the barriers with high '*H*' will create high turbulence 2 H in front of the barrier and 20 H behind. At this area, there will be changes in the flow and the speed of the wind (Ariaga, 2009). For Building height of 80 m, will create turbulence zone along 1,600 m behind the building. Figure 4(d) shows the distance is 400 m. Wind turbine requests 800 m as a distance from the barrier, but in this case, the turbine is located on the high-rise rooftop above the shadow. A minimum distance of wind turbines is 10 H in front of the barrier and in a position above it, thus the influence of wind shadow and turbulent flow has been reduced (Solacitiy Inc., 2006).
On November the wind comes from 180º (south). In south direction, it is a residential area and low rise (2 floors) township. It is also open areas such as fields and rivers. For November, the wind is not experiencing any obstruction. On this calmest period, the wind velocity average at hub height is 1.5 m/s (Figure *5*)

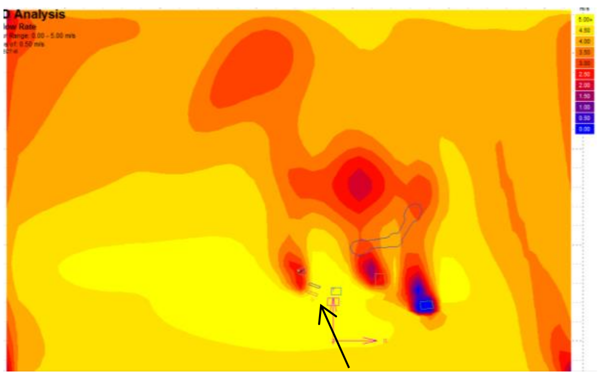
Wind speed as a result of the simulation of Bina Nusantara University building at built environment reviewed at hub height during the year is shown in Figure 6. It also shows the extrapolation of wind speed at 10 m, 98 m and 120 m (hub height) as a comparative study.



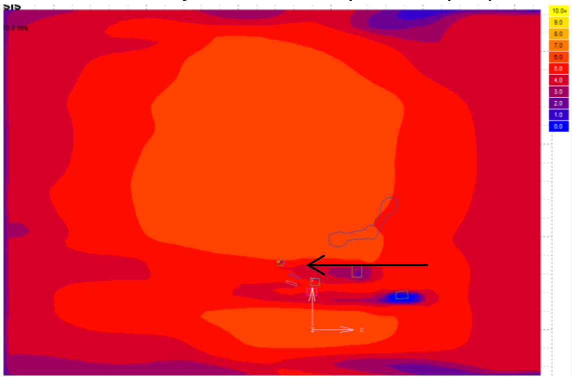
a. Wind velocity contour on May,(160º)



c. Wind velocity contour on *September* (90º)



b. May 160º



d. September 90º

Figure 4: Wind flow from 160º and 180º, experienced wind barrier.

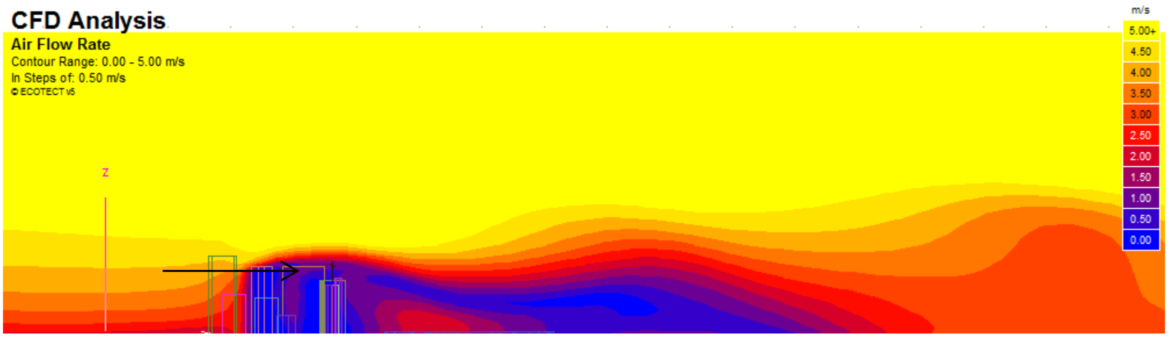


Figure 5: November, *wind direction 180*.

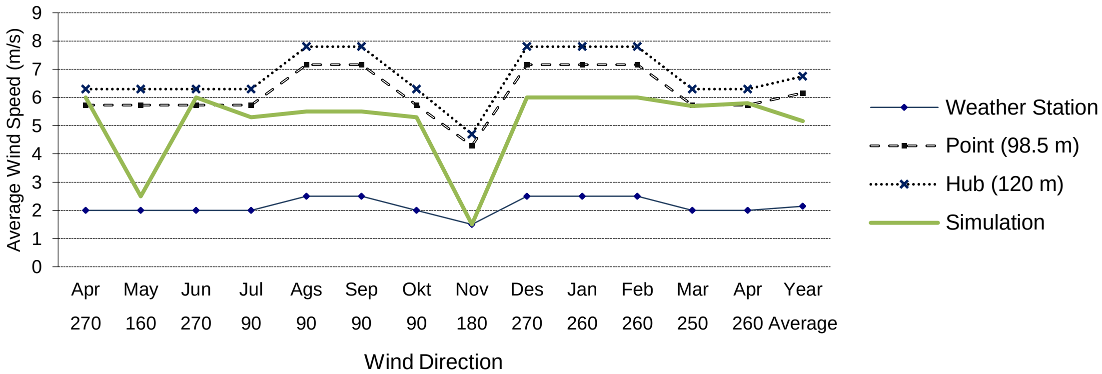


Figure 6: Wind direction and wind speed during the year.

3.2 Lay out and arrangement

Based on some certain condition, this study presents 4 layouts applied on the roof top area. Each type has specific requirement relate to the distance of wind turbine. It forms a certain arrangement. The basic requirement as follows: for HWAT, it needs 5 diameters rotor for the distance between wind turbines. For VAWT, it needs minimum 2 diameter rotor. In general, the distance between wind turbines is determined by rotor diameter and local wind conditions. If the wind comes generally in the same direction, the distance is 3-4 rotor diameters. In another hand, if it comes in any direction suggested 5-7 rotor diameters. The minimum distance is strictly 3 D (Global Energy Concepts and AWS Truewind, n.d.). Maximum building height in this area reaches up 130 m. For HAWT type, it gives 20 m for the wind turbine to be mounted and needs minimum 10 meters away from any barrier on the roof top to have free turbulence.
In this study, the arrangement named by the nature of its layout for identification purposes. Refer to wind turbine type on Table 1, the arrangement of the wind turbines as follows:
Type 1: This type needs 35 m distance. Only 1 wind turbine can be used (Figure 7a)
Type 2: 100 kW wind turbine has 18 m rotor diameter, therefore the hub located at +120 m. Only 1 wind turbine mounted (Figure 7a)
Type 3: With a rotor diameter of 3.72 m, this type needs distance as 20 m. Turbine placed at 4 corners of the roof and the height of the rotor should be placed at 10 m from the floor LMR +97.5 m (Figure 7b)
Type 4: Number and configuration are determined by the area of the roof and arrangement of the turbine. This type needs 2D or 4 m distance between wind turbines, which is the larger size would be better than several small ones. If not, utilize the lay out alternate as staggered as shown in Figure 7(c).
Type 5: This type needs 13 m distance. It is possible to install 3 10 kW VAWT with the staggered lay out, shown in Figure 7(d).
From above study, the arrangements present as a single mounted, a few turbines placed at a separate location as detached arrangement, and a few turbines placed furthest at the staggered location.

3.3 Energy Production

The power production of wind turbine can be calculated by Eq(2) (Gitano-Briggs, 2012)

$$P\ turbine\ = ½ .CP. \rho. A.V3 \qquad (2)$$

P turbine = turbine mechanical power (Watts)
Cp = coefficient of performance = 0:25 to 0:45
ρ = air density (kg / m3) = 1:21 at 120 m
A = rotor swept area (m) = 3:14 x (4) 2
V = wind speed (m / s) = 6.75

The average energy production of wind turbine shows in Figure 8. It indicates the relationship between the wind, rotor diameter, and energy production. At wind velocity 5.2 m/s, 100 kW curve indicates 100,000 kWh/y energy productions with rotor diameter 18 m (swept area 229 m^2). 10 kW indicates 42,000 kWh/y, VAWT 3kW indicates 4,485 kWh/y, and VAWT 10 kW indicates 34.158 kW/y. The energy potential possibility of five arrangements indicates the largest potential energy come from the type of HWAT Single Mounted 100 kW. (Table *2*)
Energy consumptions for main building are 3,058,104 kWh/y and dormitory are 318,000 kWh/y. With energy yield as 100,000 kWh/y, wind energy can replace 3.27 % of main building energy consumption or 31.8 % of dormitory energy consumption.

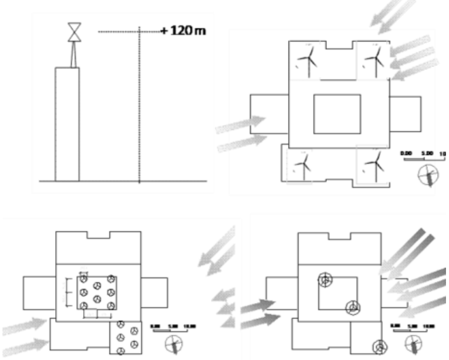


Figure 7: Roof mounted wind turbine arrangement

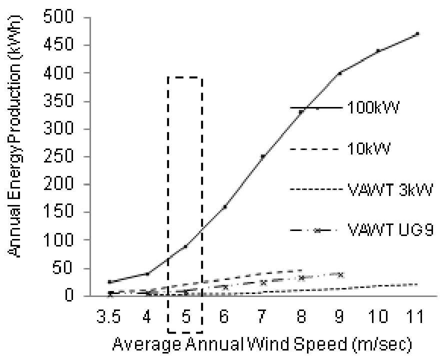


Figure 8: Annual energy production every single wind

3.4 CO_2 Emission

The amount of CO_2 emissions is calculated from the amount of fuel used and converted into CO_2 emissions (in tons of CO_2) by using a multiplier factor (emission factor) that published by the IPCC (Intergovernmental Panel on Climate Change). The energy productions of wind turbine denote the amount of energy that can be reduced from the grid. Average grid emission factor for Indonesia in 2016 was 0.851 kgCO_2/ kWh (PLN, 2016). This study shows The Roof mounted Built-environment Wind Turbine (BWTs) can reduce carbon emissions by 127,650 kgCO_2. CO_2 emissions reduction potential for each type of arrangement shown in Table 2.

Table 2: Energy production

Type	Type of Arrangement	Single wind turbine (kWh/y)	Arrangement wind turbine (kWh/y)	CO_2 emission reduction (kgCO2)
HAWT	Single Mounted 10 kW	42,000	42,000	35,742
	Single Mounted 100 kW	100,000-150.000	100,000	85,100
	Detached	5,400	21,600	18,381.6
VAWT	Staggered 3 kW	4,485	58,305	49,617.56
	Staggered 10 kW	11,386	34,158	29,068.46

4. Conclusions

In this study presents at least 3 arrangements for roof mounted built environment wind turbine (BWTs) application on tower building. The highest energy yield is obtained from a single HAWT 100 kWh type by 100,000 kWh/y at 5.2 m/s average wind speed. For moderate planning, type of VAWT 3 kW staggered arrangement give the promising result with energy production as 58,305 kWh/y on 796.25 m^2 rooftop area.

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