CFD on Wind Energy Potential Assessment in Ubonratchathani University

T. Unchai, A. Janyalertadun and A.E. Holdo

Abstract *— A finite volume method numerical study of wind effect on cluster building of Faculty of Engineering at Ubonratchathani University is presented in this paper. The techniques of Computational Fluid Dynamics (CFD) with turbulent k-ε model were adopted in this study to evaluated a suitable wind site for power generation. The steady state of wind velocity in two directions are applied, North-East (in winter) and South-West (in rainy). The simulation results show the relative of wind direction and amplitude of wind velocity position. Results illuminate more output of energy in winter than rainy. Moreover, a suitable site for wind power plants can be appropriated on the top of the supreme building or the building passage. Finally, meteorological wind data and statistically analyzed are utilized for determine the potential of wind power generation.*

Keywords— Computational Fluid Dynamics, Cluster building, Wind power, Statistical analysis

1. INTRODUCTION

Nowadays, environmental concerns on the causes of global warming have led many countries to introduce renewable energy technologies such as wind power. Wind power is proportional to the cube of velocity as shown in Eq. 1 [1]:

$$P = \frac{1}{2}\rho A u^3 \qquad (1)$$

where P is an output power, A is a wind cross section area and u is a wind velocity.

In Thailand, wind potential assessment are not available [2]. However, a local velocity in the meteorology data for each district area has been observed by the Department of Alternative Energy Development and Efficiency (DEDE) and the Thai Meteorological Department [2]. All of the local velocity data are measured on a plain area. In urban area, there are many wind obstructions such as buildings, trees and advertisement boards. Consequently, if we want to install a small wind turbine in urban area, these obstruction factors need to be investigated.

In order to overview a wind profile for this situation, a Computational Fluid Dynamic (CFD) can be applied. The CFD has been developed rapidly over the last decade [3]-[4]. For the application of a wind profile, a CFD technique can reduce time and asset to assessment wind potential in the interest location especially in urban area.

2. THEORY AND NUMERICAL SETUP

Domain analysis

This research takes an interest in a cluster building of faculty of engineering at Ubonratchathani University. There, which has 10 building and the highest is about two times tall from others. The area of cluster building is shown in Figure 1 covers about 500 m × 500 m × 30 m, while numerical domain of an approximate region of 1,500 m × 1500 m × 150 m is used. Computational domain, coordinate definition and boundary conditions are giving in Figures 2.

Fig.1. Faculty of Engineering at Ubonratchathani University

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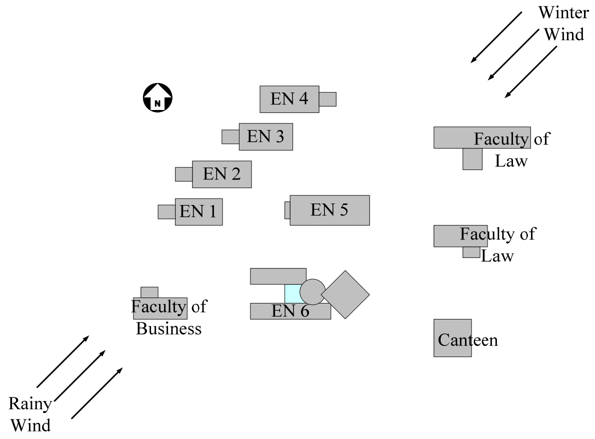

Fig.2. Computational Domain

Turbulence model

Turbulence of flow is difficult to define precisely, and is most often described by its properties. The first property of turbulence described by Panofsky and Dutton [5], states that the fluid velocity is a chaotic and apparently random function of both space and time. This means that the turbulent information is contained in the velocity fluctuations. The only expression containing the velocity fluctuations is the Renolds stresses, which therefore represent the turbulence of the flow. Another property of the turbulence is non-linearity. The Renolds stresses are also non-linear terms, in accordance with its property are in the Renolds Averaged Navier-Stokes equations:

$$P\frac{\partial U_i}{\partial t} + U_j\frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} - \frac{\partial \overline{U_i U_j}}{\partial x_j}, \qquad \frac{\partial U_i}{\partial x_i} = 0 \tag{2}$$

where U_j are the Reynolds averaged components of the mean flow, P is the pressure and ρ is the density and $u_i u_j$ with an overbar are turbulent stresses. This formulation includes both vertical and horizontal turbulent flux divergence. Equations for each of the six Reynolds stresses and dissipation are solved at each time step to close the mean equations. The model equations are solved using a fractional step method in which the equation for pressure is derived in such a way that it ensures a divergence-free momentum field.

The standard k-ε model are the industrial standards turbulence model in engineering practice. In this case, the transport equations of momentum, potential temperature, mixing ratio of water vapour and turbulence energy are adopt, while near-wall treatment are enhanced [6]. Because of their computational robustness and efficiency, the two-equation k-ε turbulence model and its variants are most commonly used in wind energy researches [7]-[8]. In particular, they have been extensively validated and calibrated for engineering application flows around bluff bodies and structures [9].

Outline of k-ε turbulence model

The standard k-ε model is computed from the turbulent kinetic energy, which is provided from the solution of its transport equation. The turbulent length scale is estimated from two properties of the turbulence field, usually the turbulent kinetic energy and its dissipation rate. The dissipation rate of the turbulent kinetic energy is provided from the solution of its transport equation via the relation:

$$\mu_{eff} = \mu + \mu_t \tag{3}$$

where μ_t is the turbulence viscosity. The k-ε model assumes that the turbulence viscosity is linked to the turbulence kinetic energy and dissipation via the relation

$$\mu t = C_\mu \rho \frac{k^2}{\varepsilon} \tag{4}$$

where C_μ is a constant. The values of k and ε come directly from the differential transport equations for the turbulence kinetic energy and turbulence dissipation rate:

$$\frac{\partial(\rho k)}{\partial t} + \nabla \bullet (\rho U k) = \nabla \bullet \left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\nabla k\right] + P_k - \rho\varepsilon \tag{5}$$

$$\frac{\partial(\rho\varepsilon)}{\partial t} + \nabla \bullet (\rho U \varepsilon) = \nabla \bullet \left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\nabla \varepsilon\right] + P_k \frac{\varepsilon}{k}(C_{\varepsilon 1}P_k - C_{\varepsilon 2}\rho\varepsilon) \tag{6}$$

Standard values of the constants in these equations are $C_{\varepsilon 1}$ = 1.44, $C_{\varepsilon 2}$ = 1.92, σ_k = 1.00 and σ_e = 1.30 are constants [10]. P_k is the turbulence production due to viscous and buoyancy forces.

3. SIMULATION RESULTS

Analysis of wind speed profiles

The simulation results are given and discussed for each of wind speed. All these results are based on meteorology data which are lowest and highest are 3.0 and 11.0 m/s, respectively. Figures 3-6 showed that velocity profile are likewise, but velocity value are difference. On winter, N-E direction, the results show that the minimum and maximum velocity increase to 3.11 m/s and 11.42 m/s, respectively. Which increase 3.56 % and 3.82 % compare to the inlet velocity. While in rainy, where wind flow from S-W direction, the results show that the minimum and maximum velocity increase to 3.19 m/s and 11.719 m/s, respectively, which increase 6.33 % and 6.54 % compare to the inlet velocity.

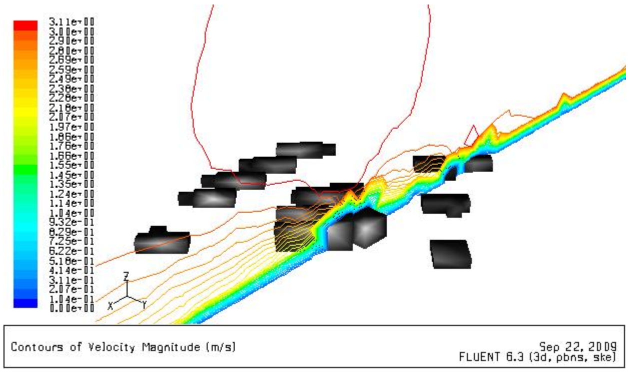

Fig.3. Wind Speed Profiles of 3.0 m/s in Winter

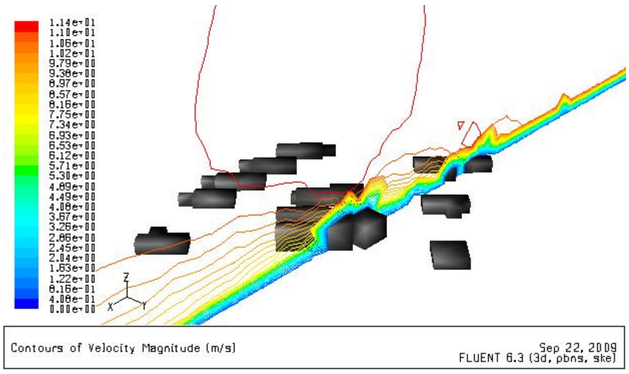

Fig.4. Wind Speed Profiles of 11.0 m/s in Winter

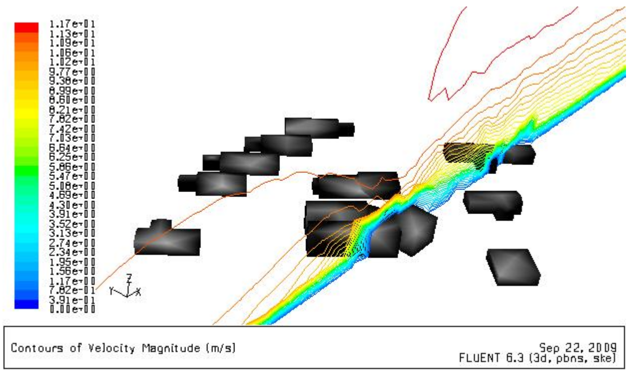

Fig.5. Wind Speed Profiles of 11.0 m/s in Rainy

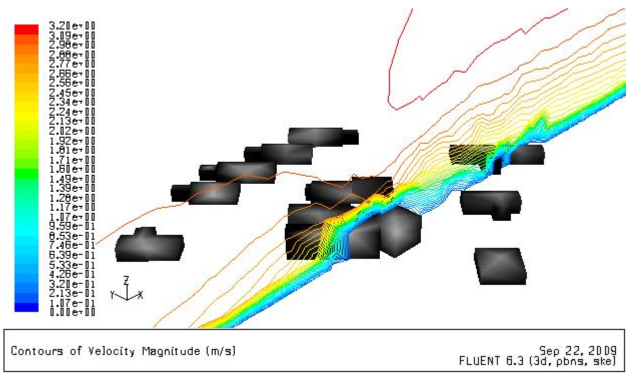

Fig.6. Wind Speed Profiles of 11.0 m/s in Rainy

Explanation of various velocity and wind direction will show in afterwards.

Analysis of wind direction profiles

The simulation results of wind direction aspects are given and discussed. All these results are based on meteorology data which wind direction in Ubonratchathani are North-East (in winter) and South-West (in rainy). Therefore, the simulations results in each directions are not similarly, such as turbulent kinetic energy, maximum velocity, position and region of its. Figures 7-8 showed comparison of 3.0 m/s and 11.0 m/s flow between winter and rainy season.

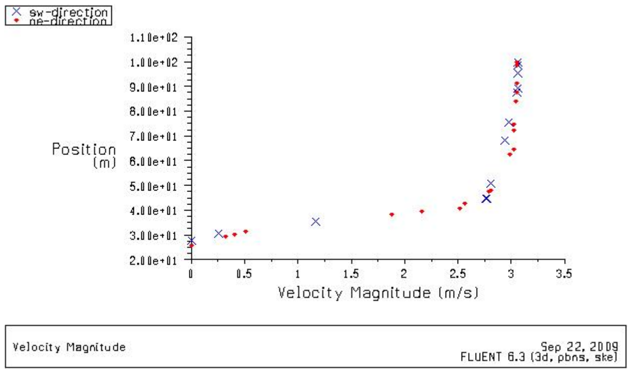

Fig.7. Comparison of 3.0 m/s Wind Direction

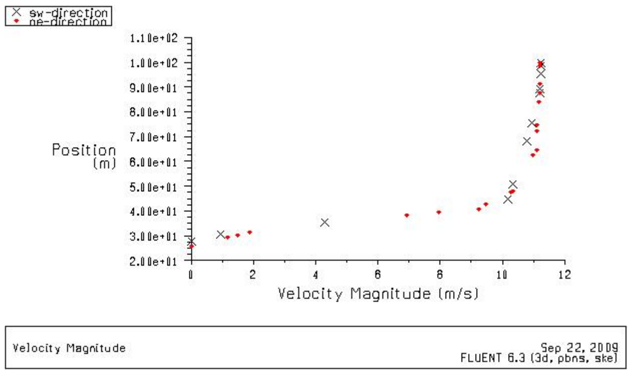

Fig.8. Comparison of 11.0 m/s Wind Direction

4. WIND ENERGY ASSESMENT AND STATISTICAL ANALYSIS

Data source

Within this piece of work, wind speed data specific to Ubonratchathani downtown district, assumed to be fairly representative of the cluster building of faculty of engineer in Ubonratchathani University, have been considered. The data is obtained from Thai Meteorological Department at Ubonratchathani branch. This data is also relatively recent in year 2008, take at a high of 40 m and recorded hourly all the year. The Figures 9 showed the monthly averaged wind speed given by the source.

Into the data obtained from above source are the available raw data. The frequency classify are separate to showed wind potential for turbine generator are showed in Figures 10.

The above-mentioned at the meteorology data without obstacle, but aim of this work is to assessment potential wind energy using CFD technique. Thus, results from simulations obtained with meteorology data above in next session.

Simulation analyze

Table 1 showed simulation results for each various velocity and wind direction. The data obtained using for assessment wind energy potential. The simulation showed obtains velocity increase for all section compare with inlet velocity.

Table 1. Simulation Analyze

Background Velocity (m/s)	Obtained Velocity (m/s)	
	Winter	Rainy
3.0	3.110	3.190
3.5	3.628	3.722
4.0	4.147	4.254
4.5	4.666	4.787
5.0	5.185	5.319
5.5	5.704	5.852
6.0	6.223	6.385
6.5	6.742	6.917
7.0	7.261	7.451
7.5	7.781	7.984
8.0	8.300	8.517
8.5	8.820	9.051
9.0	9.340	9.584
9.5	9.860	10.118
10.0	10.380	10.652
10.5	10.900	11.186
11.0	11.420	11.719

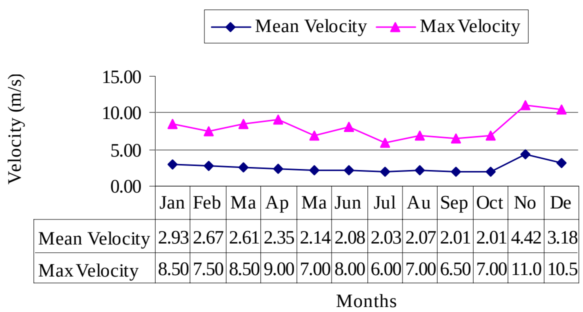

Fig.9. Monthly Wind Data.

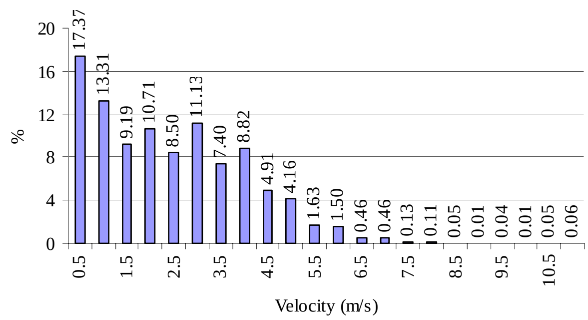

Fig.10. Wind Frequency Classify

Statistical analyze

To assessment wind energy potential, wind velocity distributions were investigated. Tables 2 showed explanation all the year of wind speed frequency and wind energy obtained from 1 kW wind turbine.

Table 1. Simulation Analyze

Inlet Velocity (m/s)	Period (hours)		Wind Energy (kWh)	
	Winter	Rainy	Winter	Rainy
3.0	627	313	66160.68	35656.30
3.5	450	175	75424.25	31665.98
4.0	555	190	138897.03	51348.68
4.5	335	80	119406.52	30792.55
5.0	285	66	139388.26	34857.37
5.5	115	23	74882.94	16177.13
6.0	101	26	85407.84	23748.44
6.5	32	7	34414.25	8131.46
7.0	33	6	44338.59	8710.05
7.5	11	0	18183.43	0.00
8.0	9	0	18060.82	0.00
8.5	4	0	9630.91	0.00
9.0	1	0	2859.76	0.00
9.5	3	0	10092.98	0.00
10.0	1	0	3925.12	0.00
10.5	4	0	18180.51	0.00
11.0	5	0	26136.77	0.00
Total	5,513	2,934	885390.66	241087.96

To assessment wind power potential with wind turbine, the simulation results and statistical analyzed showed in rainy obtained more capability than winter. And throughout the year 1 kW wind turbine can generate 1,126,478.626 kWh electricity (electricity lost do not consider included).

5. CONCLUSION

The simulation results has been propose for assessment wind energy potential in cluster building of faculty of engineer in Ubonratchathani University. The simulation may be helpful to guideline for assessment wind energy potential cooperate with data.

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REFERENCES

[1] J. F. Manwell, J. G. McGowan, and A. L. Rogers. Wind Energy Explanted. John Wiley & Sons Ltd, Chiehester. England.

[2] Thai Meteorological Department (2008). Daily Wind Data at Ubonratchathani. From the World Wide Web http://www.tmd.go.th/daily_forecast.php.

[3] Y. Tominaga, A. Mochida,S. Murakami and S. Sawaki. Comparison of various revised k–ε models andLES applied to flow around a high-rise buildingmodel with 1:1:2 shape placed within thesurface boundary layer. Journal of Wind Engineering and Industrial Aerodynamics 96 (2008) 389–411

[4] Y. F. Lun, A. Mochida, S. Murakami,H. Yoshino and T. Shirasawa. Numerical simulation of flow over topographic features by revised k–ε models. Journal of Wind Engineeringand Industrial Aerodynamics 91 (2003) 231–245

[5] Panofsky, H. A. and Dutton, J. A. (1984). Atmospheric turbulence Models and Methods for Engineering Applications. John Wiley & Sons Ltd, USA.

[6] S. Murakami, A. Mochida and S. Kato. (2003). Development of Local Area Wind Prediction System for Selecting Suitable Site for Windmill. Journal of Wind Engineering and Industrial Aerodynamics 91 (2003) 1759–1776

[7] D.M. Hargreaves and N.G. Wright. On the use of the k–ε model in commercial CFD software to model the neutral atmospheric boundary layer. Journal of Wind Engineering and Industrial Aerodynamics 95 (2007) 355–369

[8] S. Murakami. Overview of turbulence models applied in CWE–1997. Journal of Wind Engineering and Industrial Aerodynamics 74-76 (1998) 1-24

[9] M. Tsuchiya, S. Murakami, A. Mochida, K. Kondo, Y. Ishida. Development of a new k-ε, model for flow and pressure fields around bluff body. Journal of Wind Engineering and Industrial Aerodynamics 67&68 (1997) 169 182.

[10] Ove Undheim. The non linear microscale flow solver 3Dwind. Doctoral Theses at NTNU. Department of Energy and Process Engineering. 2005:90