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CFD AND WIND TUNNEL ANALYSIS FOR MOUNTED-WIND TURBINE IN A TALL BUILDING FOR POWER GENERATION

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Abstract

A mounted wind turbine on the top of a tall building may provide high wind power in regions of high wind speed and low turbulence. The objective of this study is to evaluate wind speed on roof top models to optimize the wind turbine performance for power generation. Comparative analyses from three different roof top models were conducted. Computational Fluid Dynamics (CFD) simulation and wind tunnel testing were performed to evaluate the performance of wind turbine. Wind speed on the building model with a geometric scale of 1:150 was measured in CFD simulation then it was validated in wind tunnel test. Results presented in this paper suggest that an increase of wind speed could be achieved with ¼ circular shapes around the rooftop which can provide additional wind speed of 55.24%, respectively.

Keywords: wind speed, roof shape, CFD, wind tunnel, tall building.

I. INTRODUCTION

In order to cope with global climate changes, it is urgently necessary to further develop new power energy system in which distributed energy is produced based on renewable energy source. Indonesia government created legislatively binding target to reduce fossil fuel consumption by 26% by the year 2020 [1] with the vision of energy mixes originated from four main sources: oil (30%), coal (22%), gas (23%) and new renewable energy (25%) [2]. Hence, tall building may use insulation and low energy devices to reduce energy and electricity consumption. Nowadays architects and designers are starting to seek out an innovative tall building design. They are important players behind the commercial greening movement [3]. In fact, green building is considered one of the most cost-efficient ways of reducing greenhouse gas emissions [4]. Mounted wind turbine on the top of a tall building is one of green buildings which on the rise.

However, installations of a Building Integrated Wind Turbines (BIWT) are still limited because of low mean wind speeds, high

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levels of turbulence and relatively high aerodynamic noise levels generated by the turbine [5]. Abohela *et al.* [6] demonstrated that roof shapes could maximize energy harvesting from acceleration of the wind above the building. Wind turbine power of a wind generator [7] can be expressed as follows:

$$P_{turbine} = \frac{1}{2} \rho C_p A V^3 \quad (1)$$

where $P_{turbine}$ is the wind turbine power, ρ is the air density (1.225 m^3), C_p is the coefficient of performance, A is the swept area of the blades (m^2), and V is free wind speed (6 m/s). From equation (1), it is showed that the power of the wind increases with the cube of the wind speed. It is clear that wind speed has an important part to maximize the power generation. Wind turbine should be located at relatively windy site [8] and best roof shape. A few simulation using Computational Fluid Dynamics (CFD) has been undertaken to study wind flow close to building's roof for applications of roof mounted wind turbine [9]. On the other hand, a wind tunnel can be used to conduct wind turbine performance test [10].

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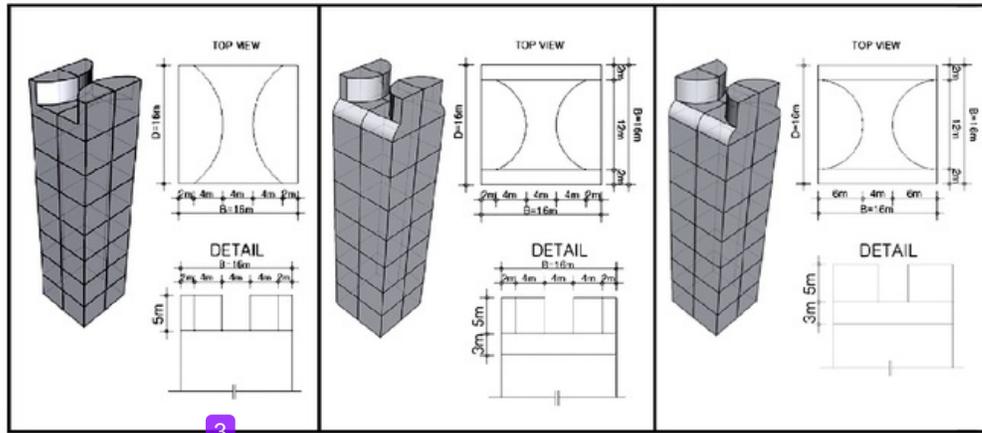


Figure 1. Modelled roof shapes, from left to right: Building A, Building B, Building C

To maximize the wind turbine performance, three different roof shapes covering a tall building were simulated using CFD. In this study wind tunnel tests were carried out to validate the wind speed distribution and to determine turbulence flow. This model was tested in Seoul, South Korea. It rises about 64m from the ground. Each model was simulated and tested with scale of 1:150. The objective of this study is to find the best design of rooftop on a tall building which can maximize wind turbine performance.

II. MODELLED PARAMETERS

A mounted-wind turbine in a tall building is usually located in urban areas. This case study took place at Seoul, the capital city of South Korea. From the Korean Building Code (KBC) 2009 [11], Seoul is classified as terrain B which means urban and suburban areas with closely spaced residential or other buildings with height of 3.5m or so or scattered medium-rise buildings.

A unique characteristic of wind is the variation of speed with height. The movement of the wind is controlled by the deviating force due to the earth's rotation and the effects of friction of the surface of earth [12]. The wind velocity profile at certain area in atmospheric boundary layer could be calculated using Power Law formula [12]. The urban terrain type specifies a mean wind speed profile with a power law exponent of $\alpha = 0.22$. Exposure constant of $Z_b = 15$ m and nominal height of the atmospheric boundary layer of $Z_g = 400$ m.

For specifying the optimum roof shape, the CFD commercial code Fluent 6.2.16 was used to simulate wind flow and to calculate wind speed above three different roof shapes above rectangular building shape whose edge height is 64m (high rise building ratio depth : width :

height = 1:1:4). Wind turbine mounted building models are single tall building which were adopted and redesigned from mounted-wind turbine which currently exist (Fig. 1). This building tower was designed to increase wind speed to maximize wind turbine power.

Using the wind turbine mounted building model in Figure 1, experimental results are shown as velocity coefficient. It is obtained from the velocity in a certain point (at horizontal coordinate x) divided by velocity approach from boundary layer in terrain B.

$$C_v = \frac{V(x)}{V_\alpha} \quad (2)$$

Wind turbine locations on Building A, Building B and Building C are in the top of the building in the height range between 50m to 70m from the ground. The average wind velocity is 10m/s so that the wind velocity approach V_α for each model is normalized to 10m/s.

III. CFD SIMULATION

First of all, each building is analyzed using CFD. CFD is used for simulating wind flow between twin towers and to develop the models to find the best aerodynamic shape and the point for wind turbine to get maximum wind velocity.

Building A, Building B and Building C are drawn using Gambit 2.3. (scale 1:150). This scale is used for similarity in wind tunnel test to validate the CFD analysis result. Each model uses boundary layer in terrain B with viscous K-epsilon and all of the models were successfully iterated.

The $k-\epsilon$ turbulence model solves the flow based on the assumption that the rate of production and dissipation of turbulent flows are near-balance in energy transfer. The $k-\epsilon$ model is one of the most common turbulence models [13].

Figure 2 shows simulation results using CDF. The left hand side figure indicates vertical position (y), the right hand side figure demonstrates wind speed contour and horizontal position (x) from top view, and the middle figure plots velocity coefficient. In the middle figure, horizontal axis denotes horizontal position (x), vertical axis indicates velocity coefficient and each curve has certain vertical position (y) as its parameter. The wind velocity in Building A increases in the center between the rounded towers. Wind velocity coefficient increases to 1.4 (Fig. 2(a)) or 40% more than wind velocity approach.

Figure 2(a) shows the best horizontal position for turbine, with height 2m up to 5m above the roof between the rounded towers. Building B and Building C are analyzed using the same method as Building A. As to Building B and Building C, wind velocity was calculated at vertical location from 1m up to 5m above the roof surface (Fig. 2(b)(c)). Figure 2(d) compares velocity coefficient among Building A, Building B and

Building C. It can be seen that Building B has the highest wind velocity coefficient in the value of 1.49.

IV. WIND TUNNEL EXPERIMENT

CFD simulations result has shown that maximum wind speed could be reached in Building B and Building C. Hence, only Building B and Building C was tested using wind tunnel. Wind tunnel experiment is use to validate the CFD analysis result. Wind tunnel experiment was held in CKP Wind Solutions, Gimje, South Korea. Detail of the wind tunnel size and component is shown in Figure 3.

Wind tunnel test is also possible to calculate turbulence intensity which cannot be detected in CFD. The results are more accurate than CFD analysis and include the information for structural engineer. Turbulence intensity is important to detect the turbulent flow around the wind turbine. This information is important to prevent the blade flicker and the user's safety.

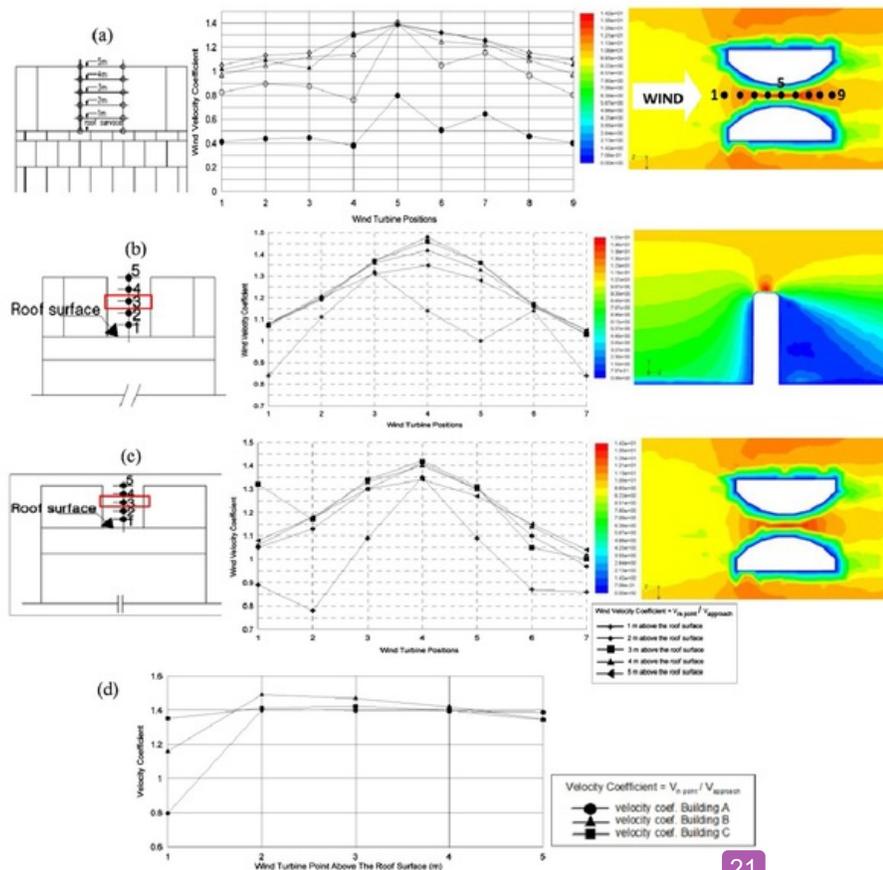


Figure 2. Location of measurement point, wind speed coefficient results and wind speed contour: (a) Building A, (b) Building B, (c) Building C, (d) Wind velocity coefficient comparison between Building A, Building B and Building C. The highest wind velocity coefficient is in Building B

Table 1.
Turbulence Intensity Data from Cobra Probes in Building B and Building C

Building B					Building C				
Position	I ^a overall (%)	Iu ^b (%)	Iv ^c (%)	Iw ^d (%)	Position	I ^a overall (%)	Iu ^a (%)	Iv ^b (%)	Iw ^c (%)
V inlet	12,488	14,005	11,920	11,256	V inlet	12,773	14,574	12,394	11,161
Point 01	21,872	21,872	21,683	21,967	Point 01	25,759	23,010	30,593	22,631
Point 02	23,673	24,811	24,052	22,157	Point 02	19,218	23,389	17,702	15,616
Point 03	12,299	15,427	11,446	9,360	Point 03	9,266	11,730	9,019	6,251
Point 04	10,024	13,342	8,555	7,086	Point 04	9,550	12,488	8,640	6,754
Point 05	9,550	12,394	8,697	6,896	Point 05	9,218	11,730	8,555	6,650

I^a is The value of turbulence intensity; Iu^b is The value of turbulence intensity from the longitudinal (horizontal) direction; Iv^c is The value of turbulence intensity from the vertical direction; Iw^d is The value of turbulence intensity from the lateral directions.

Wind Tunnel Experiment also uses roughness block for terrain B to create boundary layer as the same as in the CFD analysis (Fig. 3). Wind velocities in wind tunnel experiment are calculated using cobra probes and pitot tube. Figure 4 shows measurement set up and experimental result. Wind velocity increases in the center of rounded towers along horizontal direction (x axis). In Building B, the highest wind velocity is at point 3 in vertical direction between rounded towers. This point corresponds to the

height of 3m above the roof surface. The maximum wind velocity coefficient is 1.33 or increase of 30% from approach wind velocity. In Building C the maximum velocity coefficient increases 43% from wind velocity approach after passing rounded tower. Wind velocity is higher and more stable compared to that in building B. The highest wind velocity is located in point 2 and 3. Maximum wind coefficient is 1.43. Turbulence intensity is shown in table 1. In Building B it increases at point 1 and 2, and

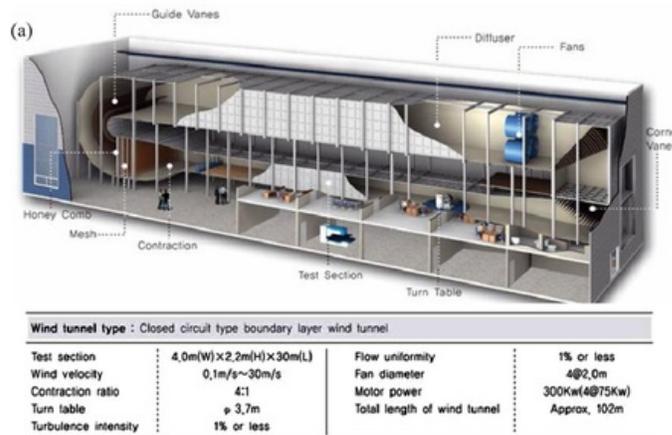


Figure 3. (a) Wind tunnel at CKP wind solutions, South Korea; (b) Roughness block of terrain B in wind tunnel experiment

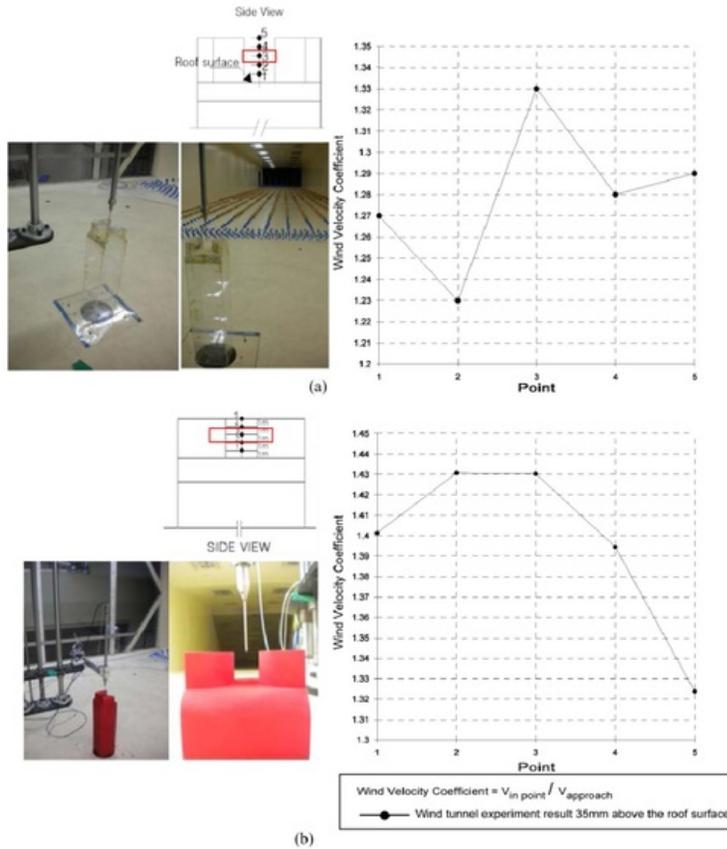


Figure 4. Cobra probes test in wind tunnel windward surfaces in the middle of rounded towers and wind velocity coefficient results: (a) Building B, (b) Building C

being normal at point 3. In Building C it increases at point 1 and 2 and normal at point 3.

V. VALIDATION

Figure 5 shows validation result between CFD analysis result and wind tunnel testing result. Figure 5 (a) shows the result of Building B while figure 5 (b) shows the result of Building C. Wind velocity increases in the center of rounded towers. As to Building B, wind velocity increases 30% in wind tunnel experiment and 50% in CFD

analysis. One reason of wind velocity decrease in wind tunnel test is because of the roughness surface of the rounded tower in the model. Even though wind tunnel result has been proven to be representative of real world situation, it requires a correct model which accounts for the features of the atmosphere and exact scaling as well as model shape.

Building C is a modified twin tower from Building B. Wind velocity increases at the center of rounded towers. The highest wind velocity is

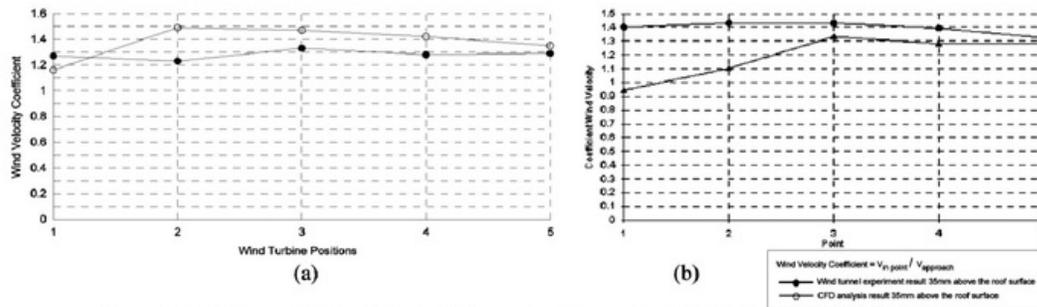


Figure 5. Validation result from CFD simulation and wind tunnel test: (a) Building B and (b) Building C

in point 3 between rounded towers. In wind tunnel experiment, wind velocity increase 32 to 42% from wind velocity approach. Wind velocity increase 42% in CFD. Blockage effect in wind tunnel test because of swept area (A) is covered by cobra probes (blockage effect in Building C is 7.49%). Normally, blockage effect is not more than 5% [12]. This model shape is less performance than Building B. On the other hand, Building C's turbulence intensity is more stable than Building B, which is safer and less vibration.

VI. CONCLUSIONS

Based on CFD simulation and wind tunnel test result on three roof shapes, this study evaluated wind speed, wind flow and turbulence intensity on the roof top of tall building. The most important results of this study can be summarized as follows:

1. Wind speed plays an important role to maximize performance of mounted-wind turbine in a tall building. Modifying the building roof top could increase wind speed ranging from 27 to 55%.
2. CFD simulation and wind tunnel test on roof top designs show that wind speed increases at the center of rounded towers.
3. The CFD simulation results show that the minimum performance is in Building A and the maximum performance is in Building B.
4. The wind tunnel test results in Building B and Building C indicate a good agreement with the CFD simulation results.
5. The wind tunnel test data also shows that Building C is the safer and less vibration building design, based on turbulence intensity result.

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