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Utilize computational fluid dynamics to simulate potential wind power of urban high-rise building platform

Zhen-Yuan Luo[1], Ting-Yu Wei [1], Yu-Hsuan Juan[1*]

[1]*Department of Mechanical Engineering, National Taipei University of Technology*

SUMMARY:
Renewable energy development has become a global trend in recent years, with a significant focus on wind energy. Urban wind farms are also receiving recognition as a sustainable environmental strategy. Previous studies have explored the installation of wind turbines in high-rise buildings from the perspective of building planning and urban design, but this study takes a different approach. It investigates how building design can enhance urban wind power generation by examining the commonly used façade designs in buildings and their effect on wind speed changes caused by airflow through geometric configurations. The study aims to identify the optimal location for installing wind turbines with the highest wind energy density based on different geometric design schemes of the platform. By doing so, it can improve the power efficiency of wind turbines while meeting the specifications for low turbulence intensity of small wind turbines. This research has the potential to promote sustainable urban development by integrating wind power generation into urban planning and building design. In conclusion, this study is a promising step towards exploring the potential of urban wind power generation. It demonstrates the importance of building design in enhancing wind power generation and could pave the way for further research in this area.

Keywords: CFD; urban wind energy; high-rise building; urban physics; corner platform

1. ABSTRACT

In recent years, renewable energy development becomes a global trend, mainly with a focus on wind energy. In addition to the construction of offshore wind farms, the application of urban wind farms has also begun to receive attention to promote sustainable environmental strategies. Previous studies [1-4] have considered the installation of wind turbines in high-rise buildings from the perspective of building planning and urban design. The presence of the building corner can produce flow expansions, also accelerating the airflow while it passes through the gaps between high-rise buildings. This study starts from the perspective of urban potential wind energy and takes the façade designs commonly used in buildings as the research topic. It explores how building design can enhance urban environmental wind power generation from the effect of wind speed change caused by the airflow throughout the geometric configuration. The aim of this study is to discover the optimal location of installing wind turbines with the highest wind energy density based on different geometric design scheme of the platform to improves power efficiency of the wind turbines. Simultaneously, it needs to meet the specifications for low turbulence intensity of small wind turbines to provide the possibility of sustainable urban development for integrating wind power generation into urban planning and building design.

Figure 1. Example of common building façade design and schematic diagram of wind turbine placement.

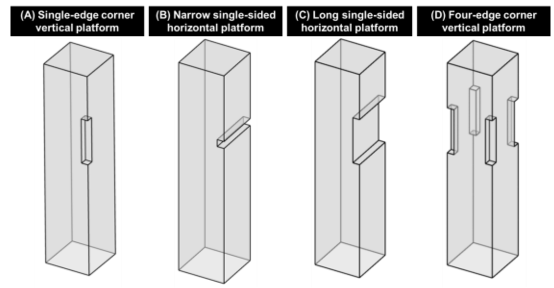

Figure 2. Four geometric design schemes of façade platforms

2. RESEARCH METHODS

To investigate the wind environment of high-rise buildings, the computational fluid dynamics (CFD) simulation is employed in this research. A three-dimensional numerical model is established on the basis of regular façade platform designs for building construction. Numerical calculations are utilized to solve for the wind field velocity, pressure, and wind energy density in the flow field. Hence, the simulation results can be integrated to provide references for the design of high-rise buildings as well as sustainable urban planning and development. During the analysis process, the numerical simulation was assumed as steady, three-dimensional, and incompressible turbulent flow. As the entire flow domain is under the same atmospheric conditions, it can be considered as nearly isothermal. The velocity and pressure of the flow field are solved by continuity, momentum, and turbulence equations. The standard k-ε model and the semi-implicit method for pressure linked equations (SIMPLE) algorithm are used to achieve velocity coupling and modify the pressure values. Furthermore, the velocity field is solved with revised pressure values. The iteration requires that the normalized residuals converge to 10-5 to calculate the velocity distribution over in the whole domain

This study examines four geometric design schemes of façade platforms with 20-meter-long and 90-meter-high edifice, as shown in Fig. 2:
A. Single-edge corner vertical platform (length × width × height = 3m × 3m × 20m)
B. Narrow single-sided horizontal platform (length × width × height = 20m × 3m × 3m)
C. Long single-sided horizontal platform (length × width × height = 20m × 3m × 20m)
D. Four-edge corner vertical platform (length × width × height = 3m × 3m × 20m)

3. RESULTS AND DISCUSSIONS

The results indicate that the acceleration effect is obtained from the design of building facade platforms for applying as a judgment of the potential for developing wind power generation by analyzing wind speeds of four different platform geometric configurations.

3.1. Single-edge corner vertical platform

In Figure 3, the wind speed of vertical-axis platform can reach up to 8.43 m/s, with a peak wind speed of 8.39 m/s at the roof level. Therefore, the vertical-axis platform demonstrates significant potential for wind power generation.

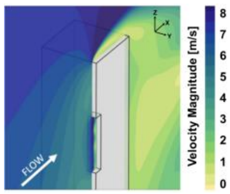

Figure 3. Single-edge corner vertical platform

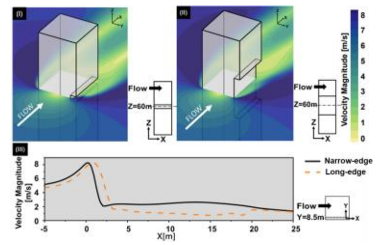

Figure 4. (I) Horizontal section of the narrow single-sided horizontal platform (II) the long single-sided horizontal platform

3.2. Narrow vs. long single-sided horizontal platform

The comparison of the narrow with long single-sided horizontal platform are shown in Figure 4I and Figure 4II, respectively. The velocity magnitude plot reveals an acceleration effect at the front end of the platform where the wind flows in. Through a comparison of wind speeds along a horizontal line at an altitude of Z=60m, the maximum wind speed is observed to occur at the inlet opening (approximately at X=1m). Moreover, the average wind speed on the narrow single-sided horizontal platform is 14% higher than that on the long single-sided platform. Thus, using a narrow single-sided horizontal platform is more efficient for wind power generation, takes up less space, and increases floor area.

3.3. Single-edge vs. four-edge corner vertical platform

As comparing the velocity magnitude of single-edge and four-edge corner vertical platforms, as exhibited in Figures 3 and 5, the average upstream wind speed discrepancies between the two is only 1.3%. Also, the overall trend indicates that the wind speed on the windward side is significantly higher than that on the leeward side. Figure 6 compares the wind speed and altitude variation at the central point of the platform by taking a vertical line from the platform. The result demonstrates that the average wind speed of vertical platform in the windward side is 82.2% higher than that of the leeward side. Therefore, wind power potential of the vertical platform on the windward side may be considered exclusively during building design stage.

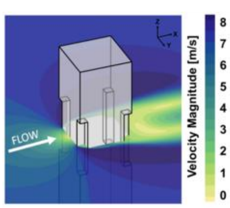

Figure 5. Four-edge corner vertical platform.

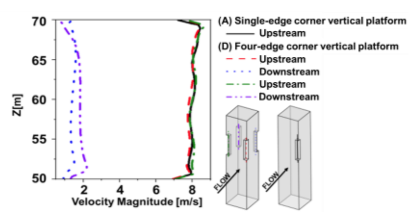

Figure 6. The comparison speed chart of single-edge and four-edge corner vertical platform.

4. FUTURES RESEARCH

Future research will aim to conduct an optimization parameter analysis of the geometric configuration design for vertical platform by employing computational fluid dynamics simulations. The design parameters, as displayed in Figure 7, include:

A. The length (L) of the vertical platform,
B. The width (W) of the vertical platform,
C. The height (H) of the vertical platform,
D. The edge shape configuration of the vertical platform (Sharp corners, rounded corners, chamfered corners),
E. The additional flow-guiding plates on the exterior façade

Through the different design of vertical platform schemes, wind is directed into the platform and accelerates. By analyzing the results, the optimal location of installing wind turbines with the highest wind power density is identified to improve efficiency of wind turbine power generation, while also meeting the specifications for small wind turbines with low turbulence intensity. The integration of wind power generation into urban planning and building design can offer possibility for sustainable city development. To achieve the target of 20% renewable energy by 2025, not only the existing innovation promotion plan for green energy technology industry but also the potential wind energy development in urban architecture should be paid attention to. Moreover, via combining with the United Nations Sustainable Development Goal 7 (SDG 7), which is about ensuring access to clean and affordable energy, the promotion of urban wind power generation can be facilitated.

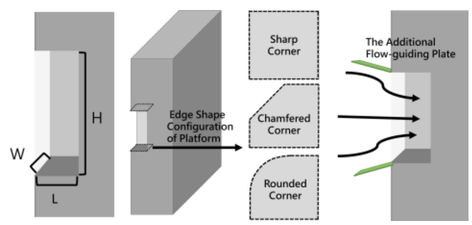

Figure 7. (I) Platform dimensions (II) the edge shape configuration of platform (III) platform with additional flow-guide plates

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