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Aerodynamic loading of solar trackers on flat-roofed buildings

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ABSTRACT

This study uses wind tunnel experiments to investigate the aerodynamic loading of the solar tracker installed on a flat-roofed building. The pressure distributions of a rectangular plate are measured under different wind directions, azimuth angles, inclination angles and pedestal heights. The experimental results reveal that the attack angle of the wind to the tracker is the essential parameter for the wind load of the tracker, and the net pressure of the tracker increased as the pedestal height and inclination angle increased, regardless of the wind direction and azimuth angle. Due to the separation shear layer on the building roof, the maximum wind load occurs when the inclination angle $\beta = 45^\circ$, and the attack angles are 0° and 180°. In addition, the shelter effect of the adjacent building reduces the windward pressure of the tracker and leads to a larger net pressure for the solar tracker on the downwind building, when the spacing between two buildings is less than five times of the building's height.

1. Introduction

Photovoltaic solar panels installed on building roofs have become more and more popular around the world due to the advantages of acquiring the solar energy close to the energy user and no additional land being required for the solar panels. However, the high wind speed on building roofs may damage the solar panels. Therefore, the wind loads of the solar panels are of great interest to engineers. The wind load of solar panels installed on the building roofs is dependent on the building configuration, roof slope, parapet height, inclination angle of the panels, row spacing and the offset from the leading edge of the building roof (Kopp and Banks, 2013).

Most previous studies on this problem used wind tunnel experiments to determine the force coefficients of the solar collectors. Peterka et al. (1989) measured the mean and peak wind loads on rectangular and circular heliostats on the ground in a boundary layer wind tunnel. Their results showed that the wind forces about the horizontal and vertical axes of the heliostat in a turbulent boundary layer flow is higher than that in a uniform, low-turbulence flow. Pfahl and Uhlemann (2011) studied the drag, lift and pitching moment coefficients of a heliostat model for two inclination angles (0° and 4°) in a high-pressure wind tunnel. Their results confirmed that the force coefficients of the heliostat were independent of the Reynolds number Re when $2.2 \times 10^5 < Re < 1.7 \times 10^6$. Pfahl et al. (2011) used a high-frequency force balance and pressure sensors to measure the wind load of stand-alone heliostats of different aspect ratios. Their results demonstrated that the mean force coefficients were insensitive to the aspect ratio of the heliostat, however the peak pressure and moment coefficients were dependent on the aspect ratio.

For the solar panels on flat-roofed buildings, Radu et al. (1986) experimentally demonstrated that the steady wind pressure on the solar array is significantly reduced by the sheltering effects of building itself. Meroney and Neff (2010) used wind tunnel experiments and Computational Fluid Dynamics (CFD) models to explore the wind load on the photovoltaic (PV) modules on a tilted roof for two wind directions: 0° and 180°. They found that the numerical models of RNG κ-ε and k-omega turbulence models provided reasonable agreement with the measured wind loads, whereas the standard k-ε model failed to replicate the experimental results.

Kopp et al. (2012) compared the wind load of the solar arrays mounted on the ground and on the building roof measured in a boundary layer wind tunnel. Their results indicated that, due to the complex interaction between the building generated vortices and the turbulent flow induced by the array, the presence of the building substantially changed the wind loads compared to ground-mounted solar panels. Also, the solar array generated turbulence increased the net wind loads for higher tilt angles. Banks (2013) also examined the wind load of the solar arrays on the roof of a low-rise flat-roof building and found that, owing to the corner vortices on the building roof, the uplift wind load was dependent on the direction of the solar panel relative to the building edge and the proximity of the panel to the vortex-originating corner. Stathopoulos et al. (2014) experimentally investigated the influences of various parameters on the peak pressure coefficients of the solar panels on

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Fig. 1. Photograph of solar trackers on a flat-roofed building in the campus of National Central University, Taiwan.

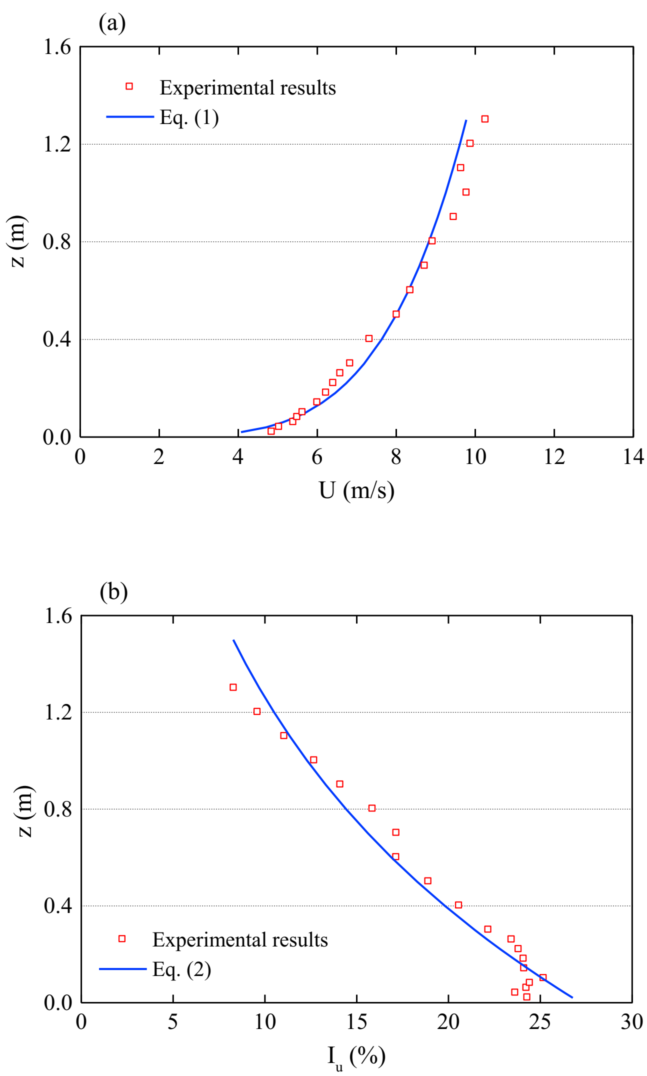

Fig. 2. Vertical profiles of time-averaged velocity and turbulence intensity of the approaching flow. (a) Time-averaged velocity U(z); (b) Turbulence intensity Iu(z).

building roofs. Their results revealed that the critical wind direction was 135°, and the corner panels were subjected to higher wind loads, due to the conical vortices on the roof edges. Besides the above wind tunnel experiments, several studies (Shademan and Hangan, 2009; Bitsuamlak et al., 2010; Bronkhorst et al., 2010) used CFD models to simulate the wind loads of stand-alone or arrayed solar panels.

In view of the above studies, most studies considered the wind loads of fixed solar panels on the ground or on building roofs. Their results may not be applicable to the photovoltaic solar trackers on building roofs. The vertical pedestals of the solar trackers usually leave a clearance between the solar trackers and the roof surface (see Fig. 1), while the solar arrays are much closer to the roofs. In addition, the inclination angle and the azimuth angle between the solar tracker and the roof edge will change with time, whereas the solar arrays are usually fixed and parallel to the roof edges (Cao et al., 2013). Therefore, the interaction between the building generated turbulence and the solar tracker are more complicated. In addition, the inclination angle and the azimuth angle could be adjusted to minimize the wind load during cyclones and/or strong wind events, therefore it is essential to understand the influences of the pedestal height and the azimuth angle on the wind loads of solar trackers on rooftops. Furthermore, the previous studies did not provide enough information on the bending moment on the load-bearing pedestal of the tracker. The objective of this study is to use wind tunnel experiments to examine the influences of wind direction, azimuth angle, pedestal height, parapet and an adjacent building on the wind load of the solar trackers on flat-roofed buildings.

Fig. 3. Photograph of the model tracker in wind tunnel experiment.