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Local and overall wind pressure and force coefficients for solar panels

Ted Stathopoulos [a], Ioannis Zisis [b,*], Eleni Xypnitou [c]

[a] Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Quebec, Canada
[b] Department of Civil and Environmental Engineering, Florida International University, Miami, FL, USA
[c] Formerly at Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Quebec, Canada

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ABSTRACT

This paper reports on an experimental study carried out to better understand the wind pressure distribution on stand-alone panel surfaces and panels attached to flat building roofs. A complex model capable to incorporate solar panels at different locations and various inclinations was constructed at a 1:200 geometric scale. Three model panels equipped with pressure taps on both surfaces (36 in total) for point and area-averaged pressure measurements were used. Pressure and force coefficients were computed for every pressure tap and for all the panels. Different configurations were tested under similar conditions in order to examine the effect of various parameters on the experimental results. A minimal gap occurred between the solar panels and the roof of the model. The study found that the net values of pressure coefficients corresponding to different configurations are affected by the panel inclination for the critical 135° wind direction, for which panels on the back location undergo higher suctions in comparison to those in the front. The effect of building height on the solar collector total load is minimal, whereas corner panels are subjected to higher net loads for critical azimuths. Simplified net pressure coefficients for the design of solar panels are provided.

1. Introduction

The evaluation of wind-induced loads applied on solar panels plays a very important role for design purposes. During the last decades, a strong interest has been developed towards renewable energy resources and to this end the utilization of solar panels has been expanded. However, the effect of a number of factors such as the upstream exposure, the landscape, the panel inclination and location, the building height for panels attached to building roofs and the like have to be carefully considered in all experimental and computational procedures. Experiments can be performed nowadays with more sophisticated and cutting edge technology resulting in more accurate results.

The main scope of this research project is the systematic study of wind-induced pressures applied on the surface of solar panels, placed on the ground or on the roof of buildings. This project followed a detailed literature review, which compared experimental results generated by previous studies (Stathopoulos et al., 2012). Although several ad hoc studies of wind loads on particular solar system configurations have been commissioned and completed, this exercise included only studies reported in the open literature. The review demonstrated clearly the discrepancy among the results of previous studies, even those carried out under nominally similar conditions, which in turn explains the lack of design provisions for solar collectors and PV systems in wind loading standards and codes of practice at present. The literature review concluded that a new comprehensive study would be necessary in order to put together a set of provisions for different configurations including both point and area-averaged loads.

The current study performed in the atmospheric boundary layer wind tunnel of Concordia University, examines the influence of a number of factors such as building height, panel inclination, and location, as well as, the wind direction, which has a direct impact on design decisions for these structures. The collection of the experimental data for a number of different configurations, in addition to their analysis and transformation to pressure, force, and area-averaged pressure coefficients was of major significance in this work.

2. Previous studies

Several studies, that include both small and large scale experiments as well as numerical simulation approaches, examined the wind-induced load on solar panels. The results from these studies, some of which correspond to similar configurations, show significant differences. In an effort to categorize the available literature, the findings were organized separately for solar collectors on

* Corresponding author.
E-mail address: izisis@fiu.edu (I. Zisis).

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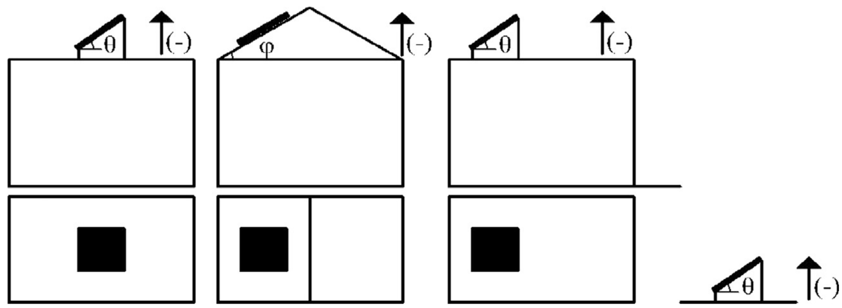

Fig. 1. Configurations of photovoltaic systems considered for comparison to current study.

Table 1
Previous studies on solar panels attached on flat roofs.

	Country	Scale	Building model dimensions (m)	PV model dimensions (m)	Inclination angle (deg)
Radu et al. (1986)	Romania	1:50	0.3 × 0.43 × 0.3	0.04 × 0.02	30
Radu and Axinte (1989)	Romania	1:50	N/A	0.08 × 0.04	N/A
Wood et al. (2001)	Australia	1:100	0.41 × 0.27 × 0.12	0.41 × 0.027	0
Ruscheweyh and Windhövel (2011)	Germany	1:50	N/A	N/A	30
Saha et al. (2011)	Japan	1:50	0.45 × 0.45 × 0.4	0.02 × 0.04	0, 15, 30 and 45

Table 2
Previous studies on solar panels attached near roof corners and edges.

	Country	Scale	Building model dimensions (m)	PV model dimensions (m)	Inclination angle (deg)
Hosoya et al. (2001)	CO, USA	1:50	0.182 × 0.274 × 0.08	0.0244 × 0.0244 × 0.0244	N/A
Bronkhorst et al. (2010)	Netherlands/Germany	1:50	0.6 × 0.8 × 0.2	0.024 × 0.6	35
Bienkiewicz and Endo (2009)	CO, USA	Variable			
Erwin et al. (2011)	FL, USA	Full-scale	4.3 × 4.3 × 3.2	1.57 × 0.95 × 0.041	−45, −15, 0, 15, 45
Saha et al. (2011)	Japan	1:50	0.45 × 0.45 × 0.4	0.02 × 0.04	0, 15, 30, 45

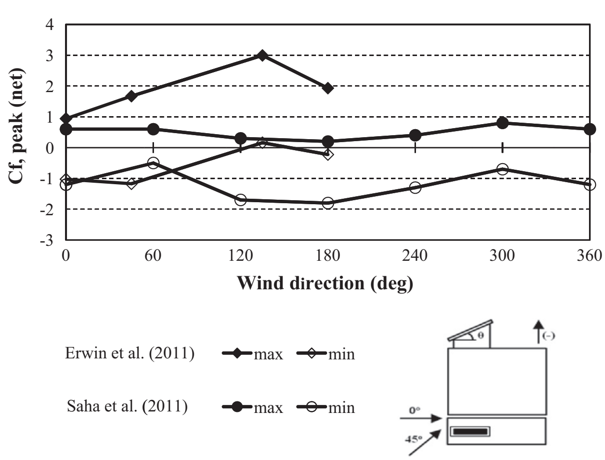

Fig. 2. Comparison of peak force coefficients for 15° panel inclination for the Erwin et al. (2011) and Saha et al. (2011) studies.

flat or pitched roofs and stand-alone panels – see Fig. 1. Also, the inclination of the collector, as well as its location on the roof, has been taken into account. A summary of the studies considered is presented in Table 1 (solar panels attached on flat roofs) and Table 2 (solar panels attached near roof corners and edges). A detailed critical discussion can be found in Xypnitou (2012). In addition to the experimental study of wind-induced pressures on solar panels, recently published studies are focusing on identifying important parameters for both experimentation and data analysis in wind tunnel testing Stenabaugh et al. 2011 (Kopp and Banks, 2013), as well as, details related to the use of experimental data in the structural design of such systems (Maffei et al., in press).

A representative comparison of peak net force coefficients obtained from two different studies (Erwin et al., 2011 and Saha et al., 2011) on solar panels inclined at 15° is presented in Fig. 2. The absolute minimum and maximum net force coefficients in both studies compare well only for 0° azimuth. It should also be noted that for certain wind directions the force coefficient values follow a similar pattern (e.g. 0–75° for minimum net force coefficients) whereas significant differences are noticed for other wind directions. While this can be partially attributed to the different geometries considered for the building and solar panel models, the need for additional experimental efforts on the subject is apparent.

3. Experimental study description

The main scope of this study was a systematic examination of wind-induced pressures applied on the surface of solar panels, placed on the ground or on the roof of buildings. The size and the configurations of solar panel systems vary greatly, with some typical solar panel systems presented in Fig. 3a (mounted on the ground) and Fig. 3b (mounted on roofs). For the present study the solar panel model was selected to have a relatively larger size which served a dual purpose. First, it allowed the accommodation of the tubing system for the pressure taps on both the top and bottom surfaces of the panels. The second objective was related to wind load criteria that should ultimately provide adequate information for design of the racking systems that panels are mounted on. These racking systems accommodate arrays of panels rather

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