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Field investigation of pressure loadings on rooftop photovoltaic panel array

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SUMMARY:
During 2021, multiple time series data sets were recorded for a rooftop pedestal style photovoltaic (PV) array. These time series data were comprised of wind speeds using 2 ultrasonic anemometers, *netCp* values using 10 pressure sensors, accelerations of the panels using 5 accelerometers, and strains using 17 strain gauges. Wind speeds greater than 4.46 m/s (10 mph) were the threshold for recording data. The pedestal-style PV array is located on the Hogue Technology Center low-rise building on the Central Washington University campus in Ellensburg, Washington, USA. Results of the pressure loading analysis will be the primary focus of this paper.

Keywords: pressure loadings, field investigation, PV panel arrays

1. INTRODUCTION

A field investigation into full-scale pressure loadings on rooftop photovoltaic (PV) panel arrays was undertaken as part of the development of a hybrid approach to partial turbulence simulation in wind tunnels. The major goal of the project was to create a new physics-based methodology for predicting peak wind loads on low-rise buildings and their appurtenances. To achieve this goal, the results of measurements on a full-scale PV array in situ were compared with full scale measurements in the Wall of Wind at Florida International University (FIU). The in-situ PV array is located on the low-rise building Hogue Technology Center (HTC) in Ellensburg, WA on the campus of Central Washington University (CWU). The highest steady wind speeds typically occur in Ellensburg during late spring and early summer (Mass, 2008). The end panels experiencing the highest wind pressures were instrumented for analysis. The estimated Reynolds number for these measurements ranged from 10^6 to 10^7. Preliminary results of the investigation, with a focus on the net pressure loadings, will be provided in this paper.

2. DATA COLLECTION

The instrumented low-rise building Hogue Technology Center (HTC) is rectangular with nominal dimensions of 12 m [40 ft] height, 42 m [138 ft] width, and 56 m [184 ft] length with a rooftop parapet wall height of 825 mm [2.7 ft] (Bender, Waytuck, Wang, & Reed, 2018). The campus surroundings are low-rise buildings, tennis courts, and parking lots. The terrain is assumed to be sparse suburban. An aerial view of Hogue is provided in Figure 1. The panel array faces South, and the primary wind direction shown in the lower corner of the figure is out of the NW quadrant between approximately 335-340 degrees. Five modular pressure sensors were placed directly on the roof as shown.

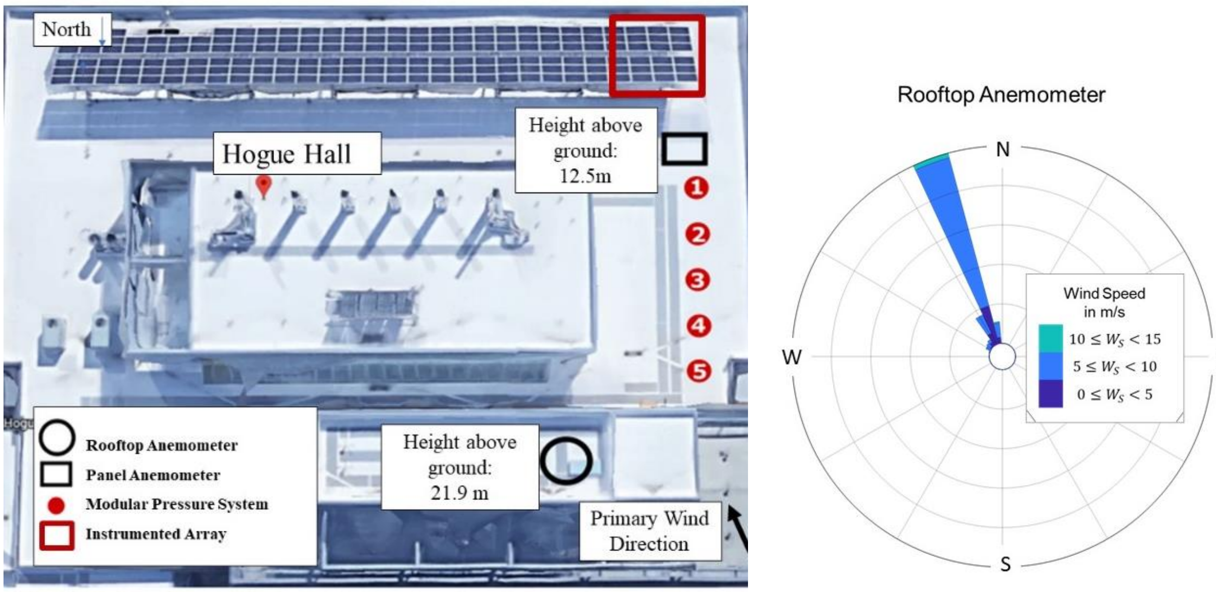

Figure 1. Aerial view of the HTC with array, pressure sensors, and anemometers identified along with the wind rose of the rooftop wind speed data [Source: Google Earth].

Figure 2. Close-up of the PV panel instrumentation.

Figure 2 contains a close-up of the edge portion of the array designated as the red box in Figure 1. Locations of the 10 pressure, 5 accelerometer and 17 strain gauge sensors are identified in Fig. 2. The sensors used were Setra 267 pressure transducers; Triax Accelerometers; and NI-9235 strain gauges. Modular pressure sensors were constructed to measure roof pressures as shown in Figure 1.

3. RESULTS

Figure 3 shows an example of one 15-minute time series data for the $netC_p$ values, with the associated spectra in Figure 4. The data were sampled at 500 Hz. The sensor plots correspond to the location in the array with sensors 1 and 10 being on the cantilevered edge of the array.

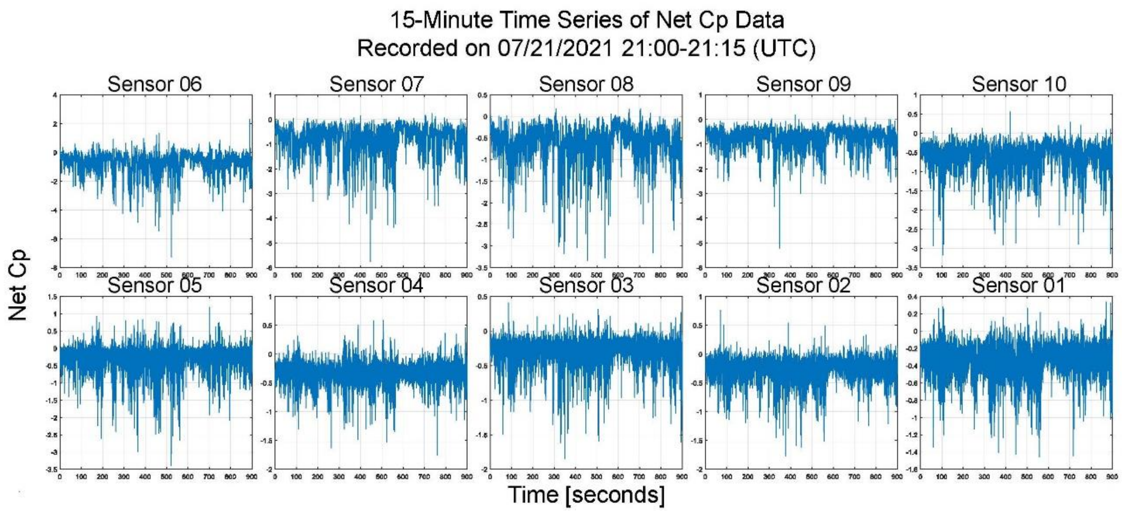

Figure 3. 15-minute time series of data for the 10 sensors.

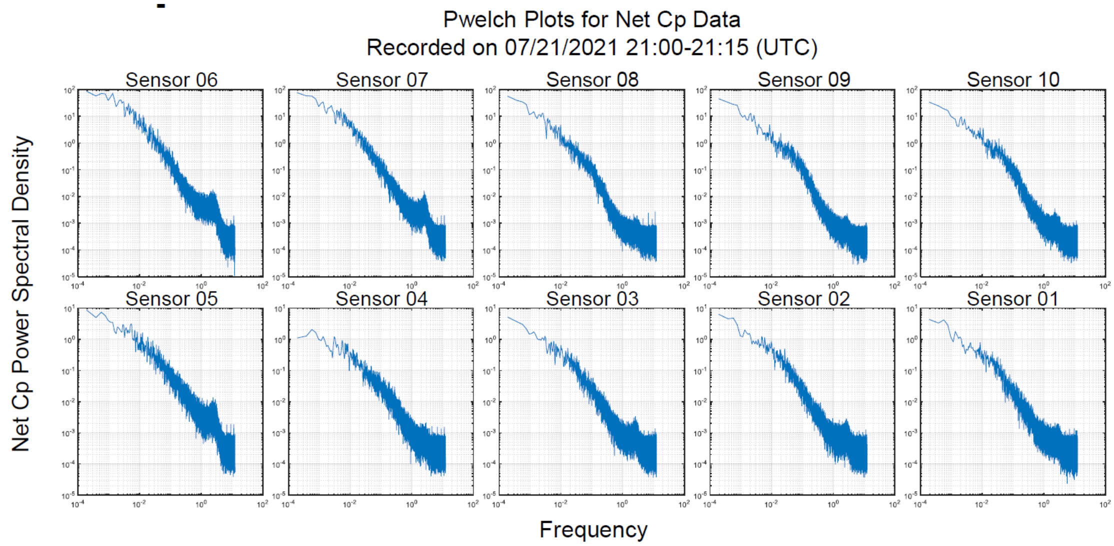

Figure 4. Spectral plots derived using PWelch app of Matlab ("MATLAB programming language," 2020) for the sensor time series in Figure 3.

Probability plots of the $netC_{p,min}$ for the 488 recorded 15-minute time series data sets are shown in Figure 5. From these data, the area-averaged coefficient of -1.7 was obtained which is comparable with the ASCE7-22 standard (ASCE, 2022).

Acceleration *a* time histories for 15-min mean wind speeds greater than 7 m/s and a mean wind direction of 330^0 yielded the results in Table 1 for the 5 accelerometers. The natural frequency f_n (Hz) is in the range of 10.5 to 11.2 Hz, which corresponds to those from a finite element analysis (Estephan, 2022). The results reflect the dynamic nature of the panels under wind conditions, where the motion of the individual panels is visible.

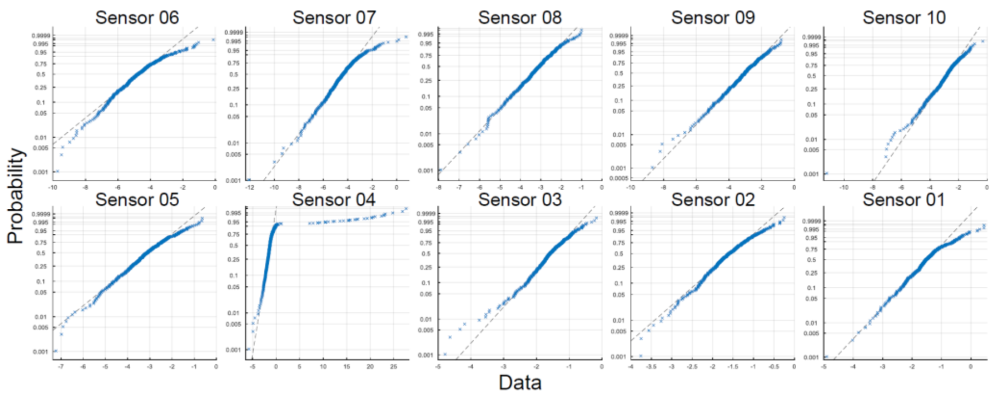

Figure 5. Type I extreme value probability plots for the *netC*$_{p,min}$ for the 15-minute data sets.

Parameter	Accelerometer				
	1	2	3	4	5
a_{min} (m/s^2)	-6.7	-8.3	-13.7	-14.7	-9.9
a_{max} (m/s^2)	5.6	14.5	9.9	12.2	7.9
σ_{a_z} (m/s^2)	0.56	1.67	0.97	1.03	0.63
f_n (Hz)	10.5	13.1	11.5	13.2	11.2
ζ (%)	4.2	3.8	4.4	4.1	3.9

Table 1. Acceleration statistics and dynamic properties.

4. CONCLUSIONS

Preliminary results of a full-scale field investigation into pressure loadings on PV panels in a rooftop pedestal style array have been presented. Analysis of the data has confirmed the higher peak pressure values on the upper tier of the edge array section, and illustrated the dynamic behaviour of the individual panels. The resulting strains of the panels are under investigation. Details of the ongoing analysis of the data sets will be available for the final paper.

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