Wind loads on roofs and flush-mounted solar panels

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ABSTRACT

Solar panel arrays are often attached parallel to the roof surface and fixed to rails with a gap of about 100mm. The addition of solar panels on a roof affect the wind flow over the surafce of the roof and influence the loads acting on the roof cladding, its fixings and the immediate roof fixings. This paper presents the wind loads on solar panels and the batten-rafter connections under the the solar panel arrays on typical configurations. Scale model tests were carried out at 1/20 on a 15° gable roof building and a flat roof building with the array of solar panels attached to the central part of the roof. The edge panels on the array experience large net pressures. The addtion of solar panels will increase the loads on the batten to rafter connecttions by more than 20%.

INTRODUCTION

The uptake of solar panel installations on the roof of buildings has increased throughout Australia and future increases are predicted. However, there is a scarcity of data for the structural design of the panels and their support and the underlying roof structure. Previous studies by Stenabaugh et al (2015) and Leitch et al (2016), have generally produced limited data on the uplift loads on the solar panels only. Data currently available including in codes and standards such as AS/NZS1170.2 (2021) do not provide adequate information for a detailed assessment of the change to wind loads on the supporting roof structure due to the presence of solar panels. Predominantly, solar panel arrays are attached parallel to the roof surface and fixed to rails with a gap between the panels and the roof surface of about 100mm.

A pilot study conducted by Parackal et al (2023) indicated that the loads on some elements in the supporting roof structure can be increased to un-conservative levels in areas where solar panels are installed. Analysis of pressures gave the wind loads transferred to different structural elements in the roof by the solar panels and compared the loads in the roof structure with and without solar panels on the same building. These findings show an increase of loads on some roofing fasteners, battens and batten to truss fasteners. These increases could cause premature failure of the roof structure in strong winds as found in TC Seroja and TC Ilsa by Boughton et al (2023), where only the part of the roof under the solar panels failed due to batten loss.

This paper presents the preliminary findings from an extensive study on several typical solar panel configurations parallel to gable and flat roofs found in Australian buildings.

NET LOAD ON PANELS AND LOAD TRANSMISSION TO UNDERLYING ROOF

Solar panel arrays are typically attached to rails with clips and brackets as shown in Figure 1. The rails are screwed through the roof cladding to the underlying batten or purlin, which is supported by the rafters or trusses. Wind load standards such as AS/NZS1170.2 (2021) provide external and internal pressures that are used to obtain the net wind loads for designing cladding, its fixings, the battens/purlins and the rafter /truss on the Baseline building (i.e. building without solar panels) roof.

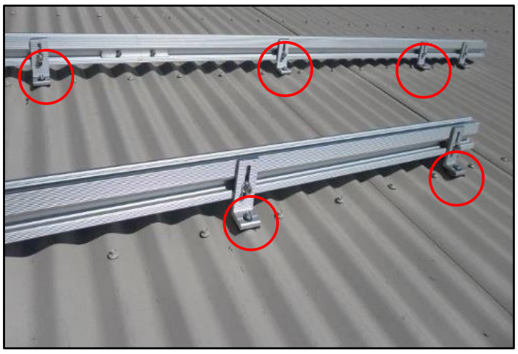


Figure 1. Typical Solar Panel array fixings on roof; rails fixed to supports through roof cladding (left) and clamps securing panels to rails (right)

The addition of a solar panel array will transfer the net load from the panels to the railing to the battens using the screws highlighted in Figure 1. These loads are then transferred to the batten-rafter connection. The loads acting on the batten-rafter connections from the external pressures on the roof surface and the net pressures on the solar panels are shown in Figure 2. The loads experienced by these components can be estimated by analysing the time varying pressures on the top $p_t(t)$ and bottom $p_b(t)$ surfaces of the solar panels, and the pressure on the roof under the panel $p_e(t)$.

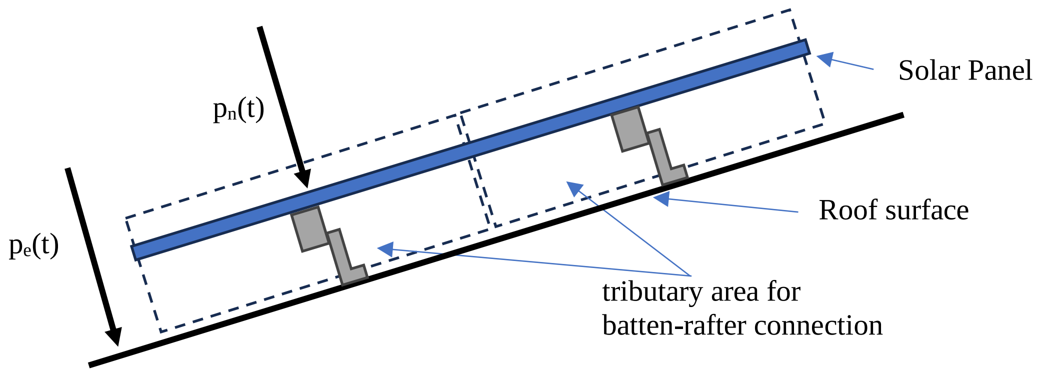


Figure 2. Loads on Batten-Truss Connection on Building with Solar Panels

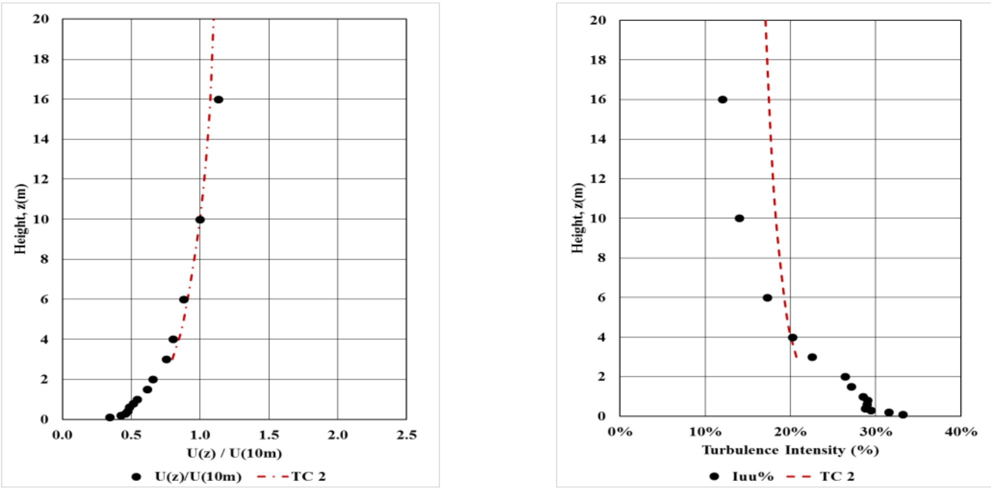
The time varying net pressure on the solar panel; $p_n(t) = p_t(t) - p_b(t)$, where $p_t(t)$ and $p_b(t)$ are the pressures on the top and bottom surfaces of the solar panel respectively.

The external pressure on the roof surface of the building (under the solar panels) will generate a load of $p_e(t) \times A$, on the batten truss connection. The load on the batten truss connection on the building with solar panels attached is $(p_e(t) + p_n(t)) \times A$. Here, A is the tributary area, (i.e. the distance between rafters × distance between battens).

The study shows that the net pressures on the solar panels in addition to the uplift on the underlying roof surface can generate loads on battens and purlins and their fixings which may exceed their design capacity in some configurations.

MODEL SCALE STUDIES

Tests were carried out in the 2.0m high × 2.5m wide × 22m long boundary layer wind tunnel at the Cyclone Testing Station, James Cook University at a length scale L_r = 1/20. The simulated mean velocity and turbulence intensity profiles are shown in Figure 3.

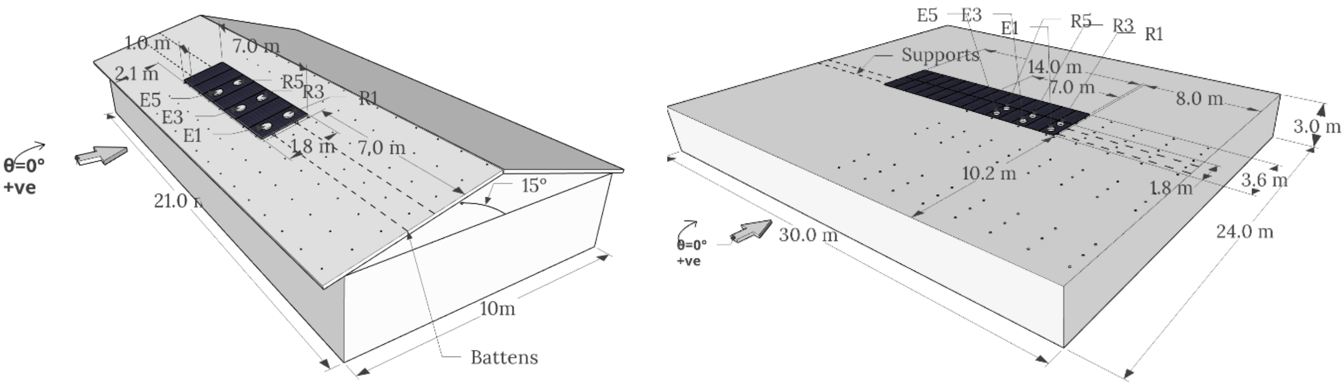


(a). Mean Velocity Ratio

(b). Turbulence Intensity

Figure 3. Simulated approach Atmospheric Boundary Layer flow at a Length Scale of 1/20

This paper presents results obtained on a 21m × 10m × 3m building with a gable roof pitch of 15°, and a 30m × 24m × 3m flat roof building shown in Figures 4a and 4b respectively. External roof pressures were obtained for the Baseline case (i.e. Roof without solar panels) and for the roof with the illustrated Solar Panel Array Configurations respectively. A panel array consists of seven 1m × 1.7m panels, each panel having 8 pressure taps (4 top and 4 bottom) to measure pressures on the top and bottom surfaces of each panel. The net pressures on the Solar Panel arrays and the loads on Batten to Rafter connections with and without solar panels are presented.



a) **b)**

Figure 4. a) 21 m × 10 m × 3 m house with a gable roof pitch of 15°, and Solar Panel Configuration 6 & b) 30 m × 24 m × 3 m Flat Roof and Solar Panel Configuration 1

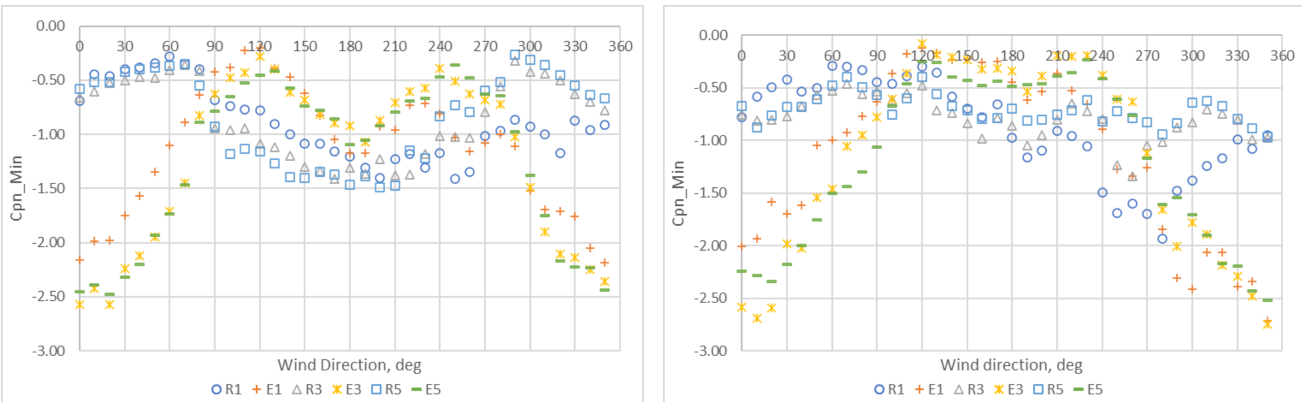
The 1/20 length scale building and solar panel array models were fixed to a turntable and the external pressures on the roof and pressures on the top and bottom surfaces of the panels varying with time $p(t)$ were measured simultaneously at 250 Hz for 60 sec. Tests were conducted for 5 consecutive runs, for wind approach direction θ of 0° to 360° at 10° intervals. The external and net pressures on the panels were analysed, and the mean and minimum pressure coefficients in an observation period of 60 sec (equivalent to about 10 min in full-scale) are given as: $C_{\bar{p}} = \frac{\bar{p}}{\frac{1}{2}\rho \bar{U}_h{}^2}$ and $C_{\breve{p}} = \frac{\breve{p}}{\frac{1}{2}\rho \bar{U}_h{}^2}$, where ρ is the density of air and $\overline{U}_h$ is the mean wind speed at mid roof height, h.

RESULTS AND DISCUSSION

This section presents the peak (i.e. minimum) net pressure coefficients in the solar panels, the minimum external pressure coefficients on the Baseline building batten-rafter connections and the minimum combined pressure coefficient on the batten-rafter connections under the solar panels.

Loads on Solar Panels

Figure 5a and 5b show the minimum Cp_n on Solar panels 1, 3 and 5 on the 15° gable roof and the flat roof for all wind directions, θ.



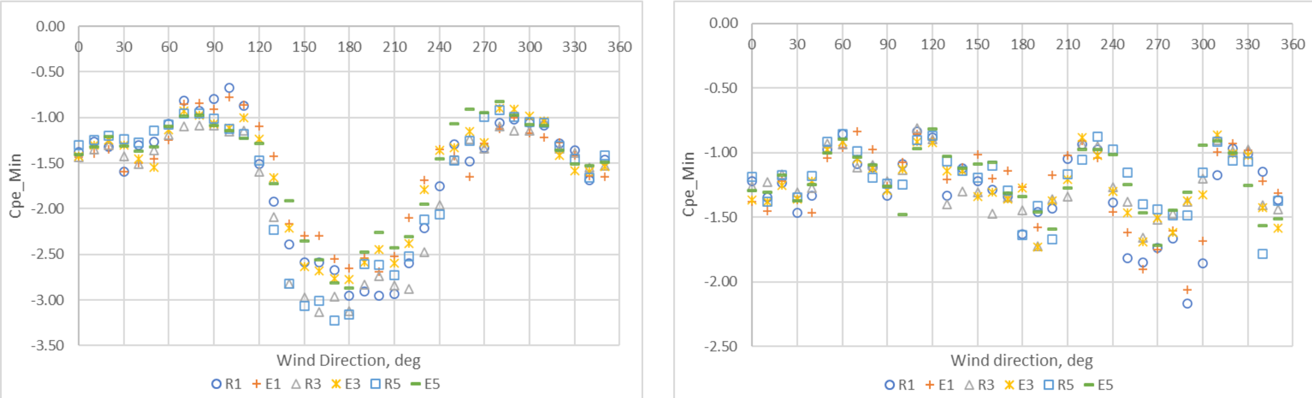
(a) Cp_n on solar panels mounted on the 15° gable roof (b) Cp_n on solar panels mounted on the flat roof

Figure 5. Minimum Cp_n on Solar panels 1, 3 and 5 on the 15° gable roof and flat roof for all wind directions, θ

Figures 5a and 5b show that the edge solar panels on the 15 deg gable roof and the flat roof experience peak_C_{pn} of about -2.5 and -2.75 respectively for winds approaching from 0° ± 30°. These are equivalent to $C_{shp,n}$ = peak_C_{pn}/G_u^2 of -0.83 and -0.88 respectively. These values are about 20% lower than the values given in AS/NZS1170.2 (2021) for the centre of the roof panels.

Loads on batten to truss connections in the Baseline Case

Figures 6a and 6b show the Minimum Cp_e on the Batten-Truss connections on the Baseline building under the solar panel area on the 15° gable roof and flat roof for all wind directions, θ. These values were obtained from the time series analysis of roof pressure taps to get pressures leading to loads on the batten to truss connections.



(a) Cp_e (batten-truss) on 15° gable roof baseline building

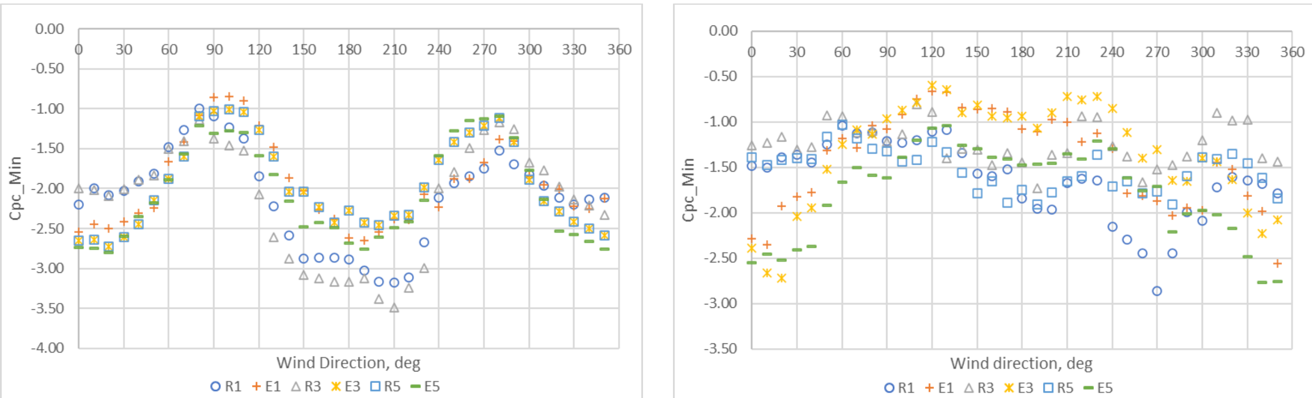
(b) Cp_e (batten-truss) on baseline the flat roof building

Figure 6. Minimum Cp_e on the Batten-Truss connections on the Baseline building under the solar panel area on the 15° gable roof and flat roof for all wind directions, θ.

Figures 6a and 6b show that the peak_C_{pe} batten-truss connections on the 15° gable baseline roof is about -3.1 for θ =180°, and the peak_C_{pe} on the baseline flat roof is about -2.0 respectively for winds approaching from 280°. These are equivalent to $C_{shp,e}$ = peak_C_{pe}/G_u^2 of -1.04 and -0.63 respectively.

Loads on batten to truss connections in the buildings with Solar panel arrays

Figures 7a and 7b show the Minimum Cp_c combined pressure coefficient on the Batten-Truss connections on the building under the solar panel area on the 15° gable roof and flat roof for all wind directions, θ. Again, these values were obtained from the time series analysis of roof and solar panel pressure taps to get pressures leading to loads on the batten to truss connections.



a) Cp_c combined pressure coefficients on building with the 15° gable roof

b) Cp_c combined pressure coefficients on building with the flat roof

Figure 7. Minimum Cp_c combined pressure coefficient on the Batten-Truss connections on the building under the solar panel area on the 15° gable roof and flat roof for all wind directions, θ.

Figures 7a and 7b show that the peak_C_{pc} on batten-truss connections for the 15^o gable roof under the leading edge solar panel is about -3.4 for θ =180^o ± 30^o, and the peak_C_{pc} on the batten-truss connections under the leading edge solar panels on the flat roof is about -2.75 for winds approaching from 0^o ± 30^o. These are equivalent to $C_{shp,c}$ = peak_C_{pc}/G_u^2 of -1.14 and -0.88 respectively.

Figures 6 and 7 show that the addition of solar panels will increase the critical loads on the batten truss connections under the leading edge panels on a 15^o gable roof by 10% and on a flat roof by 40%.

CONCLUSIONS

A series of wind tunnel model tests were carried out at 1/20 on a 15^o gable roof building and a flat roof building defined as the baseline case. The external pressures were measured on these baseline buildings. Arrays of solar panels were attached to the central part of the roof of these buildings, and the external pressures on the roofs and the net pressures on the panels were measured simultaneously.

The edge panels on the array experience large net pressures which are transferred to the building structure. The addition of solar panels increases the peak loads on the batten to rafter connections under the leading edge panels by about 10% on the 15^o gable roof and by more than 40^o on the flat roof.

ACKNOWLEGEMENT

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