Reducing the wind loads

Large rooftop PV systems have to withstand large wind forces acting upon them. Wind tunnel tests can be a valid instrument to both improve the aerodynamics of the system and reduce the amount of ballast needed – and thus the costs.

Large roof areas of industrial buildings are being used more and more for the generation of solar energy and impressive amounts of photovoltaic panels are being placed on such roofs for the sustainable production of electricity. Often you are not allowed to fix these solar energy systems directly to the roof, since this will increase the risk of leakage, and mounting or glueing them to the roof covering isn't desirable either because the solar systems stand a chance of large wind forces acting upon them. That's why the solar energy systems must be provided with sufficient ballast in order to keep them in their place during a storm. But, in order to save costs and to minimise the dead weight loads on the roof, the amount of ballast must be kept as low as possible.

To that end, the Dutch companies Oskomera Solar Power Solutions Ltd., Flamco Group (Flamco Falx system) and Sunbeam (on behalf of Ubbink Ltd.), among others, have designed solar energy systems that reduce the amount of ballast needed. These systems have all been studied in the atmospheric boundary layer wind tunnel at Peutz Ltd. in Mook, The Netherlands. The aim was to reduce the amount of ballast by optimising the aerodynamics of the systems.

Solar energy system by Sunbeam, designed with the help of wind tunnel tests to reduce the amount of ballast needed
Photo: Sunbeam

Wind tunnel study approach

The Dutch draft standard NVN 7250:2007 [1] describes design wind loads and the way to determine the ballast weight needed. But the amount of ballast can be much lower if the aerodynamics of the solar energy systems are improved, for example by making use of mutual shielding, spoilers or plates that prevent the wind from flowing directly under the photovoltaic panels. Besides that, an optimum tilt angle of the panels, as well as smart ventilation slits for pressure equalisation between the top and bottom, are important. Furthermore, mechanical coupling of the solar energy systems is very favourable in order to cancel out the effect of the smallest, but most violent, turbulent eddies in the wind. In this manner, the most local load effects are divided over more neighbouring systems, which can then act together to stay in place.

The wind tunnel happens to be a valid instrument to determine the amount of ballast needed. For the companies mentioned above, their designs for solar energy systems have been studied using scale models.

At Peutz Ltd., both wind pressure and suction are measured in one go with 128 dynamic pressure sensors of the SensorTechnics HCL series. All sensors can be read out simultaneously at a high sampling frequency of 1,000 Hz. They are connected to both the top and bottom surfaces of the panels by means of small tubes mounted flush with the surface. To be able to accurately measure the pressure equalisation between the top and bottom faces of the panels, a

large 1:10 scale has been adopted. In this way, all details can be modelled properly and undesirable scaling effects, particularly in the ventilation slits, can be avoided.

A low-pass filter is used to filter out the smallest scale, short duration pressure peaks, which would only act at a scale that is much smaller than that of the panels. However, a sufficient amount of fluctuations, corresponding to enough larger scale turbulence intensity in the modelled atmospheric boundary layer in the wind tunnel, must remain after filtering. To that end the turbulence-generating "spires" and arrays of small blocks on the floor of the wind tunnel, as seen in the picture on page 16, have been modified in order to augment the amount of larger scale turbulence in the wind tunnel.

An extreme value analysis of the pressure signals has been performed according to the "simplified method" of N.J. Cook [2]. This method has been elaborated in the Dutch CUR Recommendations for wind tunnel testing [3]. The reference period has a length of 25 years, conforming to NVN 7250:2007. The wind speed distribution over the wind directions, i.e. the local "wind rose", has been accounted for in all studies, conforming to [3].

The measurements involve solar energy systems placed near the roof corner, near the edges and at the roof centre. The systems placed at the roof centre benefit from shielding by the others and from the fact that far from the roof edge the wind suction is much less severe. However, near the roof edge the so-called delta-wing vortex acts to lift, drag or overturn the solar energy systems placed there, which as a result run a greater risk of starting to move.

Drag and lift forces

From the measured dynamic pressures the lift and drag forces, as well as overturning moments, have been determined for 12 wind directions. The definitions are depicted in the diagram below. Conforming to the formula given in NVN 7250:2007, the ballast needed has been derived from these forces, while taking account of the favourable contribution of the self-weight of the mounting system and the photovoltaic panels, as well as the friction coefficient of the roof.

Particularly the drag force is complicated, since its effect is closely coupled to the lift force. If a panel is subject to an overpressure at the top, this

Definition of wind forces and moments acting on solar energy systems
Diagram: Peutz Ltd.
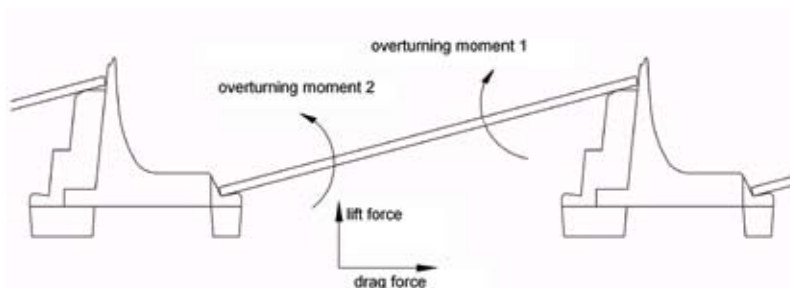
Wind tunnel studies using scale models can help to design an optimal rooftop PV system.

Photo: Peutz Ltd.
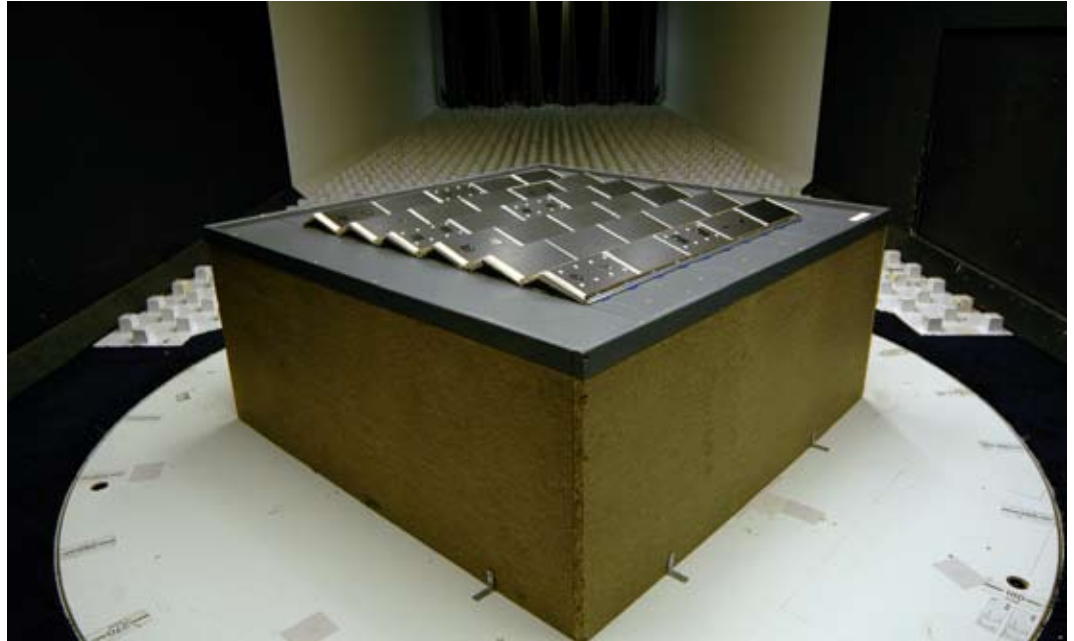
overpressure will tend to horizontally drag the panel forwards but will at the same time push the system more firmly to the roof surface, thus augmenting the favourable friction force. The opposite can be the case as well, however. Therefore, the drag and lift forces have been elaborated in a coupled way at individual pressure sample levels.

The drag force has been measured for five solar energy systems placed near the south-western roof corner as a function of wind direction, for a roof height of 12 m. This consisted of a system with wind shielding plates to the rear of each panel and side plates at the ends of the rows of panels. The panel closest to the roof corner undergoes a peak drag force that amounts to almost 450 N for wind from the south-west. The ballast weight needed for this panel amounts to approximately 90 kg, less than half the value determined with NVN 7250:2007. For panels in the centre of the roof the ballast weight needed is approximately 40 kg per panel.

Besides this, the net forces and moments acting upon sets of mechanically coupled solar energy systems have been measured. This is possible since all pressures have been measured simultaneously. In this way, the peak forces and moments averaged over sets of five panels have been determined as well as the resulting effect at the ballast weight needed for the sets. This revealed that coupling of the solar energy systems cancels out about 50 % of the effect of the wind, since most local load effects are spread over more neighbouring systems. Because the self-weight of the systems on its own remains the same, the ballast needed decreases more than proportionally, yielding zero ballast in the shielded centre area for some systems.

Optimal pressure equalisation

The first conclusion from the tests is that ventilation slits near the bottom of the solar energy systems, along the bottom of the photovoltaic panels and along the bottom of the side plates, yield very favourable results. Then the pressure equalisation is optimal, without the system being impaired by wind that is directly forced to the bottom face of the panels. The combination of ventilation slits and wind deflection plates can yield a reduction of 50 % in the ballast needed as compared to the draft Standard NVN 7250:2007. In the centre region of the roof, on the other hand, the effect is small.

Half of this reduction can be attributed to the wind plate at the rear side of the panels. Side panels have less effect, but still can reduce the ballast needed by approximately 15 % by reducing the drag force particularly on the corner panels. It should, however, be noted that such panels can impair the thermal ventilation of the bottom face of the solar energy panel, which might reduce the efficiency of the panels.

But the effect of the mechanical coupling of solar energy systems is at least as large as the other measures, mostly near the roof corner and roof edges. In the centre region the effect is still large enough to reduce the ballast needed to zero even at a building height as high as 12 m. Furthermore, varying the tilt angle of the panels has a small impact at tilt angles from 10 to 20°. Larger tilt angles do show an impact, with, for example, a 30 % increase in the drag force at a tilt angle of 40°, resulting in additional ballast being needed.

Helped by the wind tunnel tests, several clients could reduce the ballast needed considerably. In this manner, such tests can contribute to a reduction in the costs of solar energy and make the production of solar energy possible on many more large roofs.

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[1] NVN 7250:2007 "Solar energy systems – Integration in roofs and façades – Building aspects"
[2] N.J. Cook, The designer's guide to wind loading of building structures, 1990
[3] CUR Recommendations 103 "Wind tunnel research for the wind load upon (high) buildings and building parts" 2005