Study of Wind Action Effects on the Solar Panels Placed on Parking Areas

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Abstract: Studies have been developed all over the world regarding the evaluation of the wind action on solarpanels, placed single or in arrays of elements, justified by the lack of comprehensive recommendations in the codes of practice regarding these specific situations. Placing the solar panels in consecutive rows on parking places is an alternative which has never been covered by codes for wind actions on structures.
An original analysis is developed in the present paper considering the distribution of wind pressures on solar panels mounted abovethe large car parking places, where their presence would bring economy in construction while protecting and increasing the comfort of the parking space.Two constructive solutions have been considered and analysed through physical modelling and testing in atmospheric boundary layer tunnel and a numerical simulation in ANSYS 12 CFX program was in parallel run for a visualization of the flow field characteristics.

Key-Words: solar panels, wind pressure coefficients, wind tunnel, numerical simulation

1 Introduction

The concept of using panels for the conversion of the solar energy has proved its efficiency by continuously updating while remaining profitable.

Placing the solar collectors on independent structures as canopies, above the car parking places, is a new urban trend appreciated by architects. Being an economic solution, because there is no need to extend the constructed area, it increases the comfort of the cars and of the drivers and insures the maintenance of the parking itself. A superior valorisation of the constructed area and the application of the holistic concept of a sustainable development are important targets for the future urban planning.

The design of the panel fixings and sustaining systems against the wind fixing and sustaining systems against the wind action needs to satisfy the exigencies imposed by safe exploitation conditions in situations of storms or strong winds when the wind speed and turbulence are increased. Numerous experimental studies published and international scientific events show clearly the importance given to the design and exploitation of the solar collectors and solar energy convertors.

A realistic evaluation of wind forces acting on solar panels is difficult to make and the codes for design to wind loading give insufficient information. The design of such structures based on insufficient knowledge or simplifications often results in unsafe or uneconomic solutions. The latest versions of all standard recommendations specify that, in such cases, modelling in wind tunnel can give more direct and comprehensive information. The experimental methods are more and moreassisted by numerical modelling, because of their role in a better comprehension of the phenomenon, and in the extension of the analytic methods of modelling.
The work presented shows the influence of the chosen constructive solutions upon the flow field that surrounds the solar panels arrays mounted above the parking place and the variation of the mean net pressure coefficients recorded on the solar panels for various wind attack angles.

2 Evaluation of wind pressure on solar panels

Solar panels are commonly installed with an inclination angle (tilt) equal to the latitude of the site. Studies have shown that as wind impinges on an inclined solar panel, it flows around it and induces unequal pressure on its two surfaces.

According to the European code to wind action on structures [1], the wind pressure acting on external surfaces is determined with the expression:

$$w_e = q_{p(z_e)} \cdot c_{pe} \qquad (1)$$

where:

- $q_{p(ze)}$ is the peak dynamic pressure, z_e being the reference height for the external pressure;
- c_{pe} is the external pressure coefficient.

Wind loads on solar energy systems are not covered by current wind loading standards. For the evaluation of the wind action on the solar collectors, the codes [1], [2] take into account the resultant of the wind pressure as the difference between the positive pressure impinging on the surface and the negative pressure or suction, emerging from the surface, these two manifesting both on the in-wind and the rear faces of the panel. Pressure has positive (+) and suction has negative (-) signs. The net pressure resultant coefficient $c_{p,net}$ represents the combined effect of the wind action on the upwards oriented face of the panel with the action from the downwards oriented face of the same panel.

The net pressure coefficient, $c_{p,net}$ is used for the determination of the local maximum pressure from all the wind directions and consequently, in the design of the roofing elements and of all the fixing systems included in the solar collectors [2].

The wind pressure coefficients used in the design of solar panels are assimilated to those related to the mono-pitched canopies, but this would be the case of only one panel. Usually, several solar modules are placed in arrays on the surface of the roof and this situation is not considered by any of the codes mentioned above. The effect of this arrangement may be a factor of reducing of some of the pressure coefficients for the rows situated behind the first one. More than this, the influence of the spatial arrangement of the modules upon the wind local pressure distribution is not considered either.

Numerous parameters influence the wind loading actingon solar panels: angle of the module to the horizontal plane (tilt), distance of the module rows to each other, distance to the structure walls, position of the module in the array, gaps between the modules and gap to the ground or roof surface respectively, closed or open sides of the module rows, presence of wind deflectors placed in the rear of the modules, supporting system, free zones inside the modules field, height from the ground, arrangement parallel or diagonal to the structure walls, roof with or without a parapet, shape of the roof corner (round or sharp), geometry of the module array, slope of the ground at free field, wind direction.

This complex combination of parameters that model the wind field of pressures around the modules of panels may be described with accuracy by computational methods which are able to visualize the flow of the wind around any kind of obstacle, like *Computational Fluid Dynamics* (CFD) ANSYS CFX; also through experimental studies in wind tunnels with atmospheric turbulent layer which prove their value in the process of observation, analysis, qualification and quantification of the real phenomenon.

Wind action upon the solar panels is not easy to model,although the experience of testing in wind tunnels has become important. But these studies unfold relevant situations that call for testing: for example, we know that the rear of the solar panels is susceptible to vortex shedding and wake buffeting [3], [4], [5]. And usually, it is the physical modelling in wind tunnel that validates the accuracy of numerical simulations.

In the last years the distribution of wind pressures in the field of solar panels array has been intensively studied for the cases and situations met in real life; different constructive solutions for placing the modules on terraces of buildings with variable heights and dimensions have been studied [6], [7], [8], [9] both with experiments in wind tunnel and with numerical simulations.

However, neither of these studies presents the specific situation of the rows of solar panels sustained by their own structure and covering the parking places because, unlike the case of roofs on buildings, the study herein refers to a free wind flow both over and under the solar panels as a result of the open space beneath.

3 Physical and numerical simulations

3.1 Physicalsimulation procedure

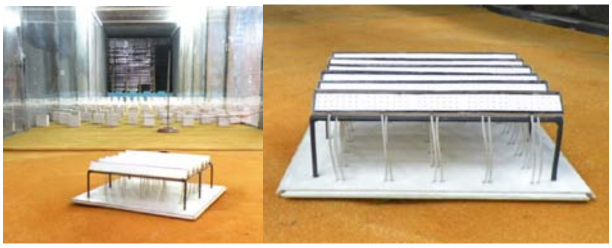
Usually, the parking place is closely situated to other constructions (malls, stadiums, etc.). These urban architectural solutions vary a lot as shape, position, dimensions,so they need particular analyses. We refer here to an isolated parking place, situated at a distance from any other structure equal to its major in plane dimension.

The experiment on physical model is run in the atmospheric boundary wind tunnel SECO2 from the Laboratory of Buildings Aerodynamics from the Faculty of Civil Engineering and Building Services and its main objective is the study the model of wind action upon a structure of a parking place covered by parallel rows of solar collectors. The cross section of the tunnel is 1.40 x 1.40m and the length is 10m. The wind profile is modelled with Counihan's method [10], [11], Fig. 1a.

The dynamic similarity is not an issue for the accuracy of modelling, due to the fact that Reynolds numbers are very high, ($> 2 \times 10^4$), so the pressure coefficient at any location on a bluff body is independent with respect to the criteria [12]; the requirement of minimising the effect of Reynolds number on pressure and forces in the cases of wind tunnel testing is also satisfied[13].Sharp edges and corners on the structure parking and the panel models are important, allowing the flow separation. This way, kinematic and dynamic similarities are insured, even if the Reynolds number of the model is not the same as that for the prototype [8].

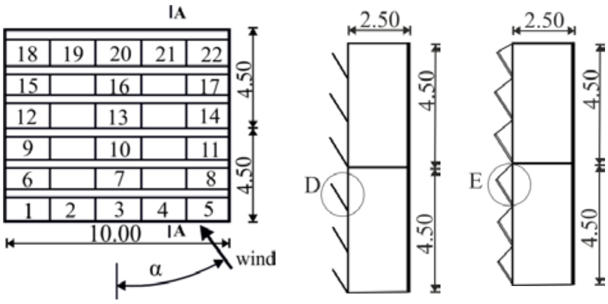
The model is mounted on a turntable in order to simulate all wind directions. The model projection in the cross section covers up to 0.5% from the transversal area of the tunnel (Fig.1a), which respects the condition of being under the blockage level; a full immersion of the model is insured inside the turbulent layer specific to urban texture.

The parking place and the modules of the solar collectors were reproduced at a 1:50 scale; the full scale dimensions of the parking were 10.0m x 9.0m x 2.5 m and of the panels 1.0m x 2.0m (Fig. 1).

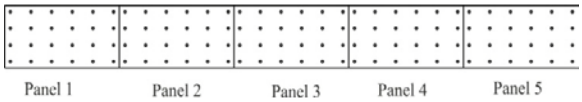


(a) (b)

Fig.1Model of the parking and the solar panels array placed above: a - view in the experimental area of the wind tunnel SECO2, b- model of the parking place



(a) (b) (c)



(d)

Fig.2 Dimensions of full scale parking with the solar panels: a – in-plan array with the number of panels equipped with pressure taps; b - longitudinal section A-A, parking place with panels without deflectors, c - longitudinal section A-A, parking place with panels with deflectors; d - view of one row with the distribution of pressure taps

The characteristics of the boundary layer reproduced in the tunnel were typical for urban turbulence (turbulence intensity of about 22% at the reference height based on the model of the exponential power law of longitudinal wind speed profile).

Solar panels are placed in parallel transversal rows, five modules per row (Fig.1b, Fig.2a), and tilted at a 30° angle. Wind directions considered with respect to the model are between 0° and 180° because of the in-plane symmetry of the model. The model is placed on the turntable, in the middle of the experimental area of the tunnel (Fig. 1a).

The modules array was analysed in two distinct constructive solutions, one for which the panels are not screened (Fig. 2b) and the other for which the panels are screened with deflectors (Fig. 2c).

The acquisition of the wind pressures on both faces of the panels is obtained by pneumatic averaging method of the sequential values measured, previously validated in the published literature [14], and [15]. Via this method the net resultant of the mean pressure values is obtained on both faces, from upward and downward the panel by recording the signal from 24 pressure taps evenly distributed on every of these faces (Fig. 1b, 2a and 3) and averaging the signal in two corresponding chambers, isolated by a tightened wall.

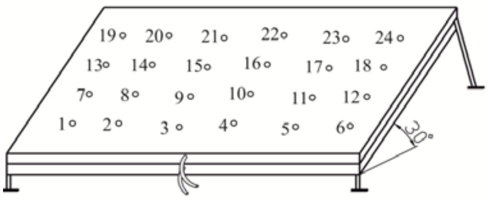


Fig.3 Position of the 24 pressure taps scattered on both faces of the solar panels and the two tubes that collect the averaged pressure values

The application simplifies the acquisition procedure of an important number of data and at the same time, the space under the rows is rather free and exposed to wind stream, situation that corresponds to reality. The simultaneous measurement of the pressure on the 30 solar panels allows the evidencing of the screening effect that the collectors induce upon themselves and on the whole structure.

The acquisition of the experimental data was developed with the help of pressure transducers compatible with the flow characteristics in the wind tunnel.

The final result of the local pressure measurements in the taps (i) placed on the panel surface, the value of the local pressure coefficient normal to this surface is obtained:

$$c_{pi} = \frac{p_i - p_s}{p_t - p_s} \qquad (2)$$

where:

- p_i is the dynamic pressure in the current point i on the model of the panel;
- p_s is the static pressure;
- p_t is the total reference pressure measured in the flow field at the reference height (at the solar panels level).

The mean pressure coefficient on the surface of the panel from upper face, $c_{p,us}$ will be then:

$$c_{p,us} = \frac{\sum_{i=1}^{24} c_{p,i} \cdot a_i}{\sum_{i=1}^{24} a_i} \qquad (3)$$

where:

- c_{pi} is the pressure coefficient for the normal component of the wind pressure corresponding to the pressure tap $i=1,\ldots 24$;
- a_i is the afferent area to the pressure tap i.

The mean pressure coefficient on the surface of the panel from the lower face, $c_{p,ls}$ is determined in the same way.

In the design of the sustaining elements that carry the solar panels only the resultant force of the wind action is usually the relevant load. For this reason, the data obtained are presented as net mean coefficients $c_{p,net}$, obtained by algebraic summarizing of the normal pressure coefficients on each of the two faces of the analysed panel:

$$c_{p,net} = c_{p,us} - c_{p,ls} \qquad (4)$$

When the net pressure coefficient has negative values, suction occurs and the pressuredirection acts upwards. In order to analyse wind pressures on panels, three parallel rows of solar collectors were considered S_1, S_2, S_3, consisting in six panels each, one by one from the six rows placed on the parking place (Fig. 4).

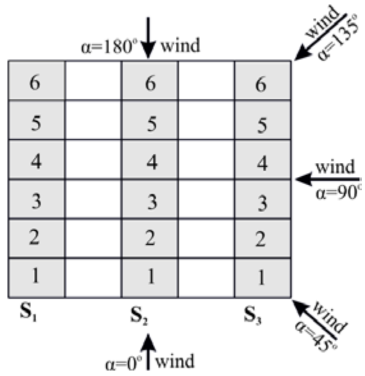


Fig.4 Plane of the parking place with the arrangement of the longitudinal rows S_1, S_2, S_3 and the wind directions considered

3.2 Numerical simulation procedure

The numerical simulation of the wind flow over the parking place was run under the FEM program ANSYS 12 CFX. The model of the parking place with the dimensions from Fig. 2 is immersed in the computational domain which is chosen in accordance with data provided by the literature [16], the 5 wind attack angles being the same as in the physical modelling, from 0^0 to 135°. Wind velocities and dynamic pressures field along the stream lines are visualized through three vertical longitudinal planes cut through the flow domain, one at the edge, the second at one third at the last at half, defined as P_1, P_2 and P_3, (Fig. 5).

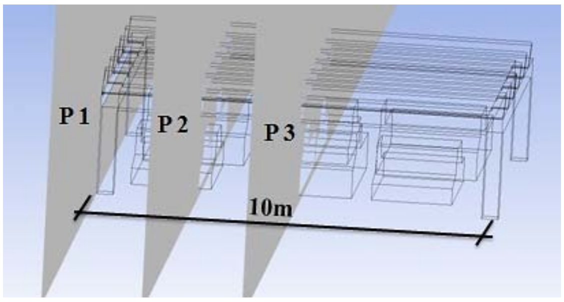


Fig. 5 Planes P_1, P_2 and P_3 cut through the computational domain and the model for visualization of the turbulent flow

4 Results and comments

The pressures measured on the model in the wind tunnel were used for the determination of the mean coefficients on the upper and lower face of the model, ($c_{p,us}$ and $c_{p,ls}$); based on them, the mean net pressure coefficient was determined for every panel, $c_{p,net}$ by algebraic summarizing of the first two with the relationship (5) [17].

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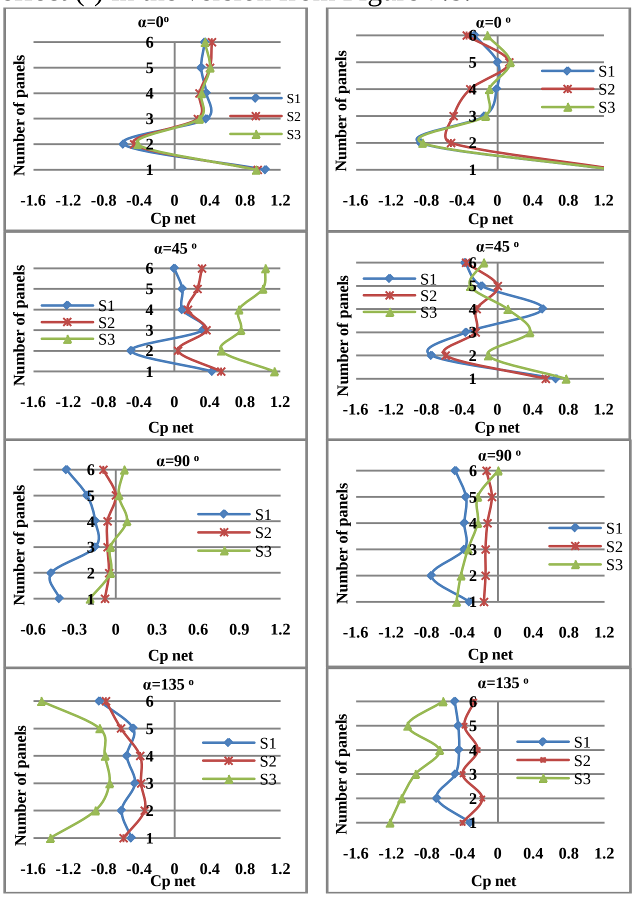
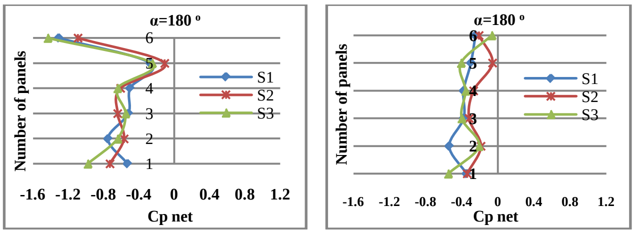
As the parking place is symmetric in plane, only five wind directions of action were considered. In Fig. 6 the graphics present the variation of the mean net pressure coefficients (resultants per module), $c_{p,net}$along the rows of solar collectors, for the five different wind directions considered (0° to180°).

The maximum pressures (+) for the direction of the wind action between 0° and 45° shows similarities for both constructive solutions adopted. Still, the values of $c_{p,net}$for 0° in the case of the sheltered panels with deflectors are the maximum, whether they are pressure or suction, $c_{p,net}$= + 1.4 and $c_{p,net}$= - 0.9; in the case of the panels without deflector they are lower. On the contrary, when the wind incidence reaches the angle of 45°, the positive pressures diminish for the sheltered panels (version b) while suctions increase. A particular situation is met when the angle of wind action is 135°, because in this case the suction is general and rather high, the maximum value of the mean net pressure coefficient being $c_{p,net}$= - 1.6 for panels without deflectors and $c_{p,net}$= -1.2 for panels with deflectors.

The visualization of the flow with the help of numerical simulation shows significant differences of the turbulence comparing the two situations analysed; one may notice the increased suction effect (-) in the version from Figure 7.b.





(a) (b)

Fig.6 Variation of the mean net pressure coefficients along the rows of solar collectors for 5 wind directions (0° … 180°): a - panels without deflectors, b - screened panels with deflectors

In Fig. 8 the important modifications induced by the wind action at 135° may be seen.

Fig. 9 presents the pressures field in the plane of the solar collectors for wind action of 0°. In Fig. 9 a, the first row of collectors is exposed to pressure (+), the second row to suction (-) and the following rows are exposed to increasing positive values of wind pressure (+). In Fig.9 b excepting the first, all the other rows are exposed to suction (-).

In Fig. 10and Fig. 11the stream lines of the wind flow are presented in the longitudinal planes P1, P2 and P3 cut through the model (Fig. 5) for wind acting at 0°. A substantial modification of the wind speed lines is observed in the version of the panels without deflectors in comparison with the others. The free air flow around the panels diminishes the resultant of the pressure when panels are not sheltered compared with those with deflectors, in this last case the panels forming a continuous shed shaped roof over which the shear layers detach more abruptly and spread over the whole panels array determining pronounced suction values.

During the measurements in the wind tunnel increased values of the wind pressures were recorded in the case when wind acts at 135°, (Fig. 4), for both constructive solutions, as one may notice in the graphs in Fig. 6 and in the numerical simulation in Fig. 12.

The wind speed is increased in the case presented in Figure 13 with respect to the one form Figure 14 because of the presence of the deflectors placed in the last row, which divert the stream lines over the parking place.

5 Conclusions

The exploitation of renewable resources like solar energy is a top priority due to its major advantages. Including the systems of conversion of this energy in the urban space is a great challenge both for the architects and engineers and for all the

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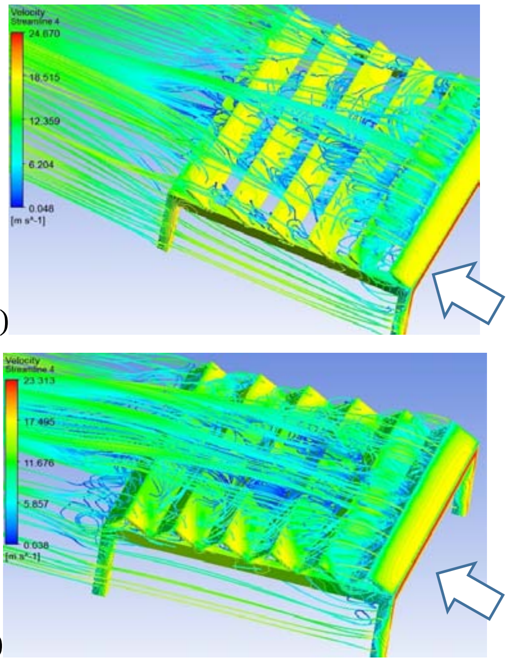
specialists involved. Urban planning is involved inthe development of the concept of a sustainable economy and the projects of refurbishing, renewal and re-use of old built spaces are important issues. The solution of covering the parking places with structures that sustain the solar or photovoltaic panels increases the comfort in exploitation.

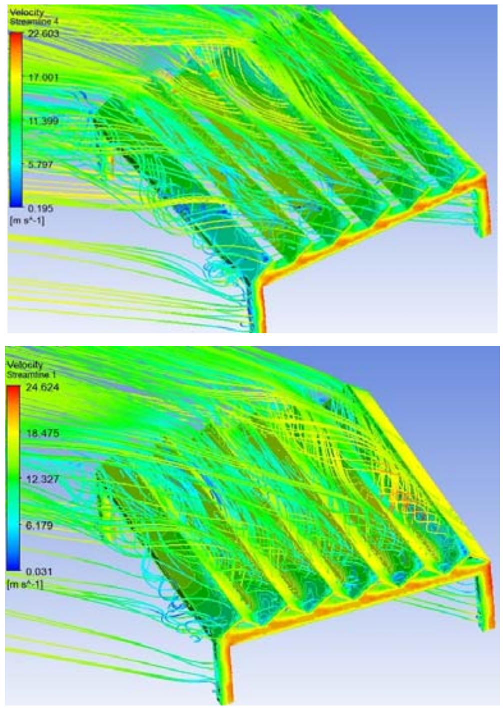
Among other studies in wind tunnels the study presented herein is quite new as a concept because the effect of wind action on solar panel arrays on large surfaces covering the parking places has not been studied yet in particular. The free exposure of the panels to wind from all sides, even from beneath, the degree of obstruction of the flow in the presence of the cars and the individualization of the flow for each variation of the wind angle, makes this research theme interesting. Another purpose is to observe the influence of the presence of deflectors on the solar array, a benefit being an important argument during the design stage. In both the study on the physical models and on the numerical simulations the maximum suction effects are evidentfor the wind action at 135° angle of incidence, situation which is not presented in any codes for design to wind action, nor may it be assimilated. At the same time, grouping the solar collectors has the effect of sheltering against wind action, lower values of wind loading resulting; but this case is neither to be foreseen nor quantified through the means of the codes for design.



(a)

(b)

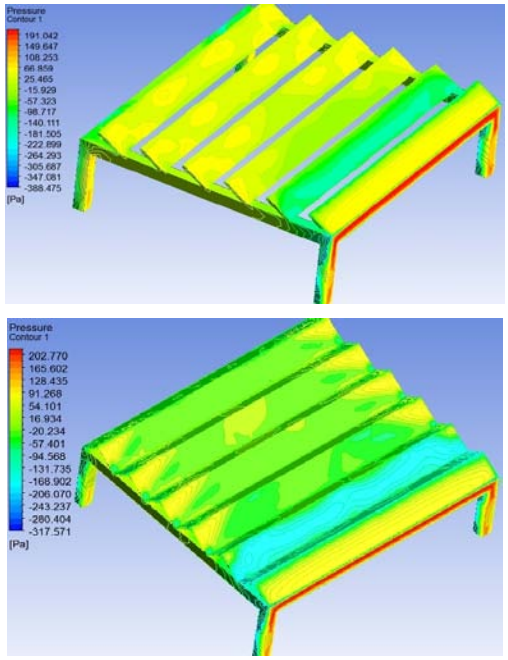
Fig.7 Stream lines in the flow field for wind angle action at 0°; a - panels without deflectors, b - panels with deflectors



(a)

(b)

Fig.8 Stream lines in the flow field for wind action of 135°, a- panels without deflectors, b - panels with deflectors



(a)

(b)

Fig.9 Contour of wind pressures for the wind action direction at an angle = 0° with respect to the parking place: a - panels without deflectors, b - panels with deflectors

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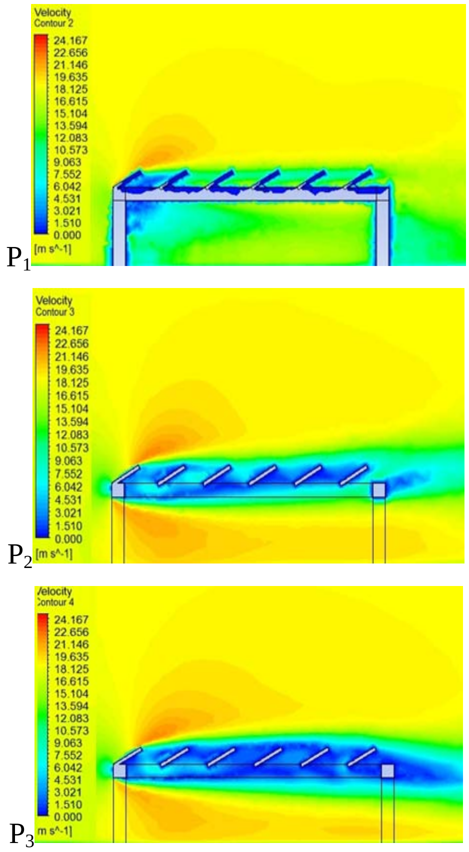

Fig. 10Contour of the wind velocities in the vertical planes P1, P2 and P3 for wind action direction of 0° with respect to the panels array:

a. - panels without deflectors

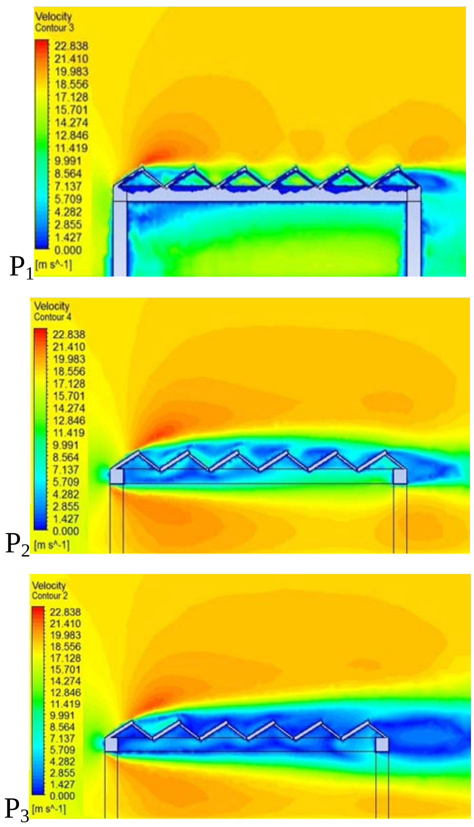

Fig. 11 Contour of the wind velocities in the vertical planes P1, P2 and P3 for wind action direction of 0° with respect to the panels array: b. - panels with deflectors

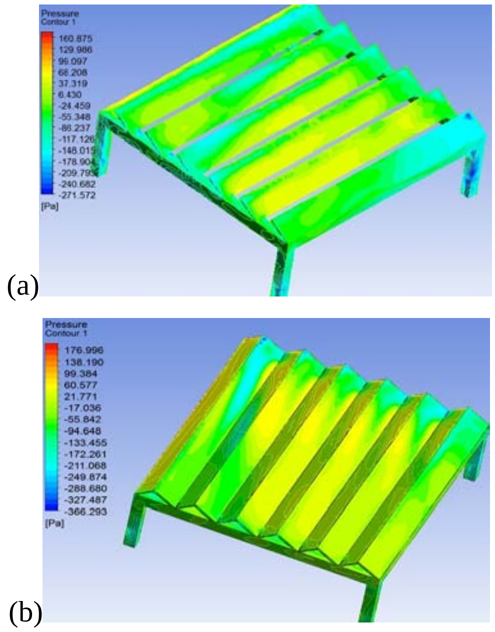

Fig. 12 Contour of the wind pressures for the incidence of wind action angle of 135° with respect to the parking place: (a) panels without deflectors, (b) panels with deflectors

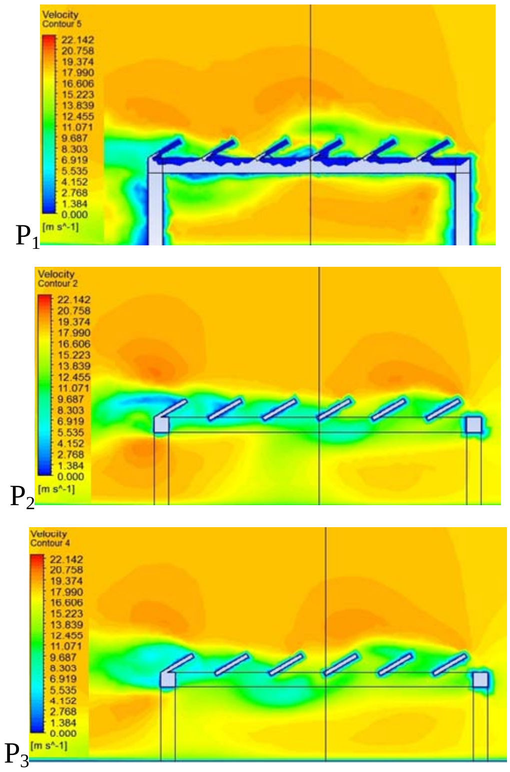

Fig.13Contour of constant speed in the planes P_1, P_2 and P_3, for wind incident angle of 135° with respect to the panels array: a - panels without deflectors

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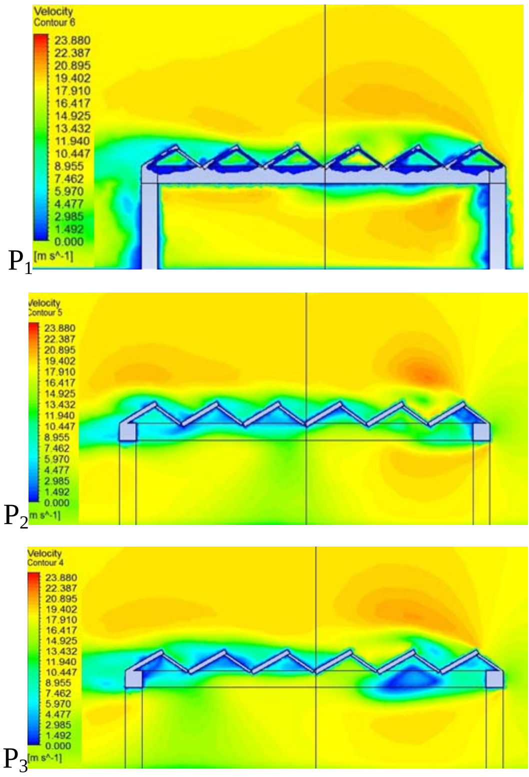

Fig.14Contour of constant speed in the planes P_1, P_2 and P_3, for wind incident angle of 135° with respect to the panels array: b - panels with deflectors

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