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NUMERICAL SIMULATION OF WIND ACTION ON A SOLAR PANELS ARRAY FOR DIFFERENT WIND DIRECTIONS

BY

GEORGETA BĂETU*, CARMEN-ELENA TELEMAN, ELENA AXINTE and VICTORIA-ELENA ROŞCA

“Gheorghe Asachi” Technical University of Iaşi
Faculty of Civil Engineering and Building Services

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Abstract. Wind actions determines the most important load in the design of the support systems of the solar panels, wherever they are located - on flat or pitched roofs or at the ground level. The goal of simulations of the interaction between wind and the solar panels by Computational Fluid Dynamics (CFD) is to estimate the complex wind flow and pressures that act upon their surface. In the study presented herein, the wind pressure acting on 12 solar panels is simulated. The solar panels are placed in a regular array, mounted at ground level and tilted at 30º. Five wind directions (0º, 30º, 45º, 135º, 180º) have been analyzed with the computer code ANSYS 12 CFX.

Key words: wind action; solar panels; wind angle of attack; numerical simulations; pressure distribution.

1. Introduction

Determination of wind forces on the support systems of solar panels is the subject of many research studies. The behaviour of solar arrays immersed in aerodynamic field, has made the subject of several studies in the wind tunnel with atmospheric boundary layer and numerical simulations, using specialized software in computational fluid flow. In the last decade numerous studies were

*Corresponding author: *e-mail*: geta_vasies@yahoo.com

performed in order to determine the pressure distributions and the size of wind forces on solar panels located on flat and pitched roofs, building envelope or at ground level. Design of the anchor systems must be done so that the extreme values of wind will not affect the integrity of the solar panels. The main problem in design of the anchor systems is to determine the correct uplift forces as well as the pressure field, in order to find solutions to reduce them.

For solar panels located at ground level (Fig. 1), the assessment of the wind loads proves to be an easier task than for panels installed on the roof top. Air flow is influenced by the presence of solar panels and the terrain roughness.

a *b*

Fig. 1 – Solar panels placed at ground level: *a* – in a solar array configuration (www.inhabitat.com); *b* – in consecutive rows (http://www.princeton.edu).

In order to determine the average wind speed and the velocity profile, the influence of orography and roughness factors specific for the terrain type, is fundamental. Particularly in urban and suburban areas where the turbulence of the wind is increased because of the increased roughness of the boundary layer it is important to find how it influences the interaction between the air flow field and the structures immersed in it. According to roughness conditions (different types of vegetation and built areas) the Romanian standard SR EN 1991-1-4:2006 divide the terrain in five categories of exposure (Table 1).

At the ground level, the air flow disturbance is not only a consequence of solar panels presence, but it is also influenced by location (open field, bordering area or neighbouring buildings) and terrain topography (SR EN 1991-1-4/2006). The intensity of wind loading depends on the solar panels array (consecutive rows or isolated solar arrays), the incidence of wind and the distance between the rows of panels. It is known that wind speed decrease on the lower part of the atmospheric boundary layer (Fig. 2), but in the same time the turbulence intensity is far increased. In the case of extreme winds, damages may occur to the anchor systems of solar panels.

Table 1
Terrain Categories and the Corresponding Roughness Length
(SR EN 1991-1-4:2006)

Terrain category			z_0 (m)	z_{min} (m)
I		Large expanses of water, large flat areas, mudflats and snow covered farmlands	0.003	1
II		Lakes , flat grassland or bare soil, without hedges and isolated obstructions	0.01	1
III		Gently undulating countryside, fields with grass or crops, fences and few trees, rare and low constructions separated by spaces at least 20 times the height of the obstacle	0.05	2
IV		Dense woodland or domestic housing or areas with isolated obstacles situated no more that 20 times the height of the obstacle (villages, suburbes)	0.3	5
V		City centres, with buildings mostly more that 15 heightwhich cover more that 15% of the terrain surface	1.0	10

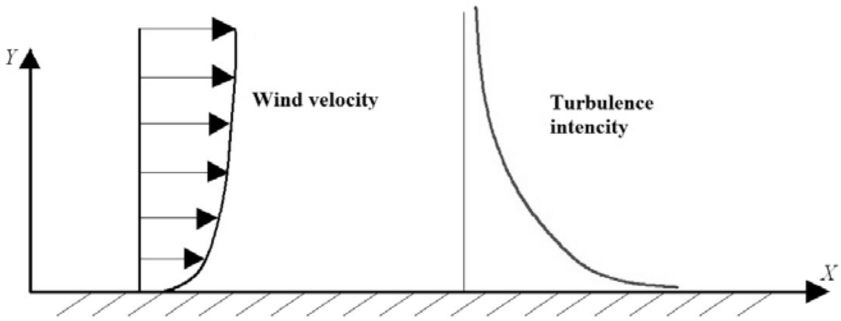


Fig. 2 – Profile of wind velocity and turbulance in atmospheric boundary layer.

The Romanian code for the design of buildings to wind actions scarcely gives information for the evaluation of the wind loads on the solar panels. The method of evaluation of the wind pressures in this code that may be extended and applied for the solar panels is that which offer guidance for wind loads on on mono-pitched canopies. According to SR EN 1991-1-4 wind force acting on a structure is determined based on either global force coefficients, c_f, or local pressure coefficients, c_p. Global force coefficients c_f and local pressure coefficients c_p, take into account the combined effects of wind acting on the upper and lower surfaces of the canopies for all the wind directions (Fig. 3).

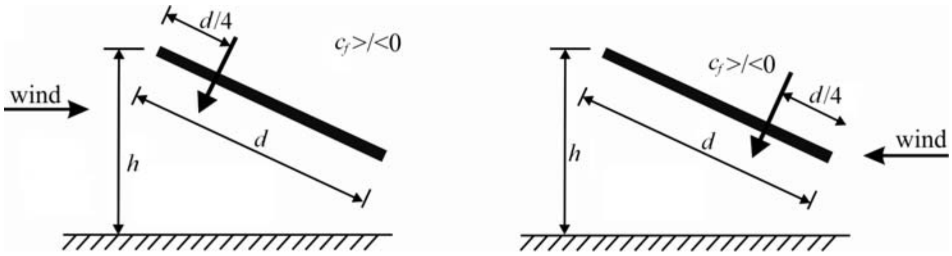
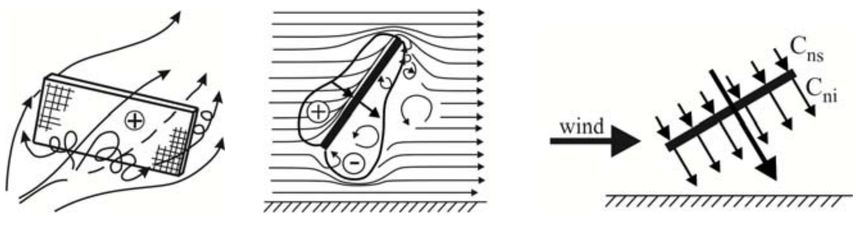


Fig. 3 – Location of the application point of the global wind force acting on monopitch canopies (SR EN 1991-1-4/2006).

Both of the faces of the solar panel are subjected to wind pressures, the final force being obtained from a vectorial sum, the local pressure coefficients for the normal component of wind force having the same significance as of the resultant of wind action on these faces:

$$c_p = \pm c_{ns} \pm c_{ni}\,, \tag{1}$$

where: c_{ns} is the pressure coefficient on the in-wind surface of the panel and c_{ni} – the pressure coefficient on the rear of the panel (Fig. 4).



a *b* *c*

Fig. 4 – Scheme of a free standing panel in the air flow (*a*, *c* – Radu *et al*., 1986); *b* – and the resulting movement due to flow separation (Bitsuamlak *et al*. 2010).

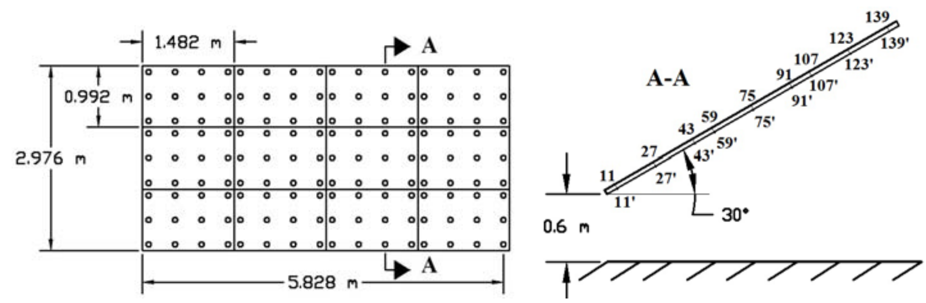
According with the sunlight conditions in Romania, solar panels should be placed at angles situated between 30º and 40º from the ground level. Scientific literature recommends that solar panels should be facing the south direction with small deviations to south-east and south-west. This study aims to determine the loads produced by wind action on a solar panels array, for different angles of attack and the simulation consisted in wind acting upon a group of 12 solar panels placed in perpendicular rows of 4x3 array, placed at the ground level.

2. CFD Simulation Cases

The numerical simulation was developed using ANSYS 12 CFX code. The solar array is immersed in the computational domain (Fig. 6, where it may be observed the minimum dimensions respecting the specifications from the literature). Five different incident angles were considered, listed in Table 2. The solar array has 17.641 sq.m and it consists in 12 solar panels (Fig. 5 *a*). The array is lifted at 0.6m height from the ground level. The dimensions of the solar panels are: 1.482 m length, 0.992 m width and 0.045 m thick.

Table 2.
CFD Simulation Cases

Case	Panel type	Panel inclination	Angle of attack
1	Arrayed	30º	0º
2	Arrayed	30º	30º
3	Arrayed	30º	45º
4	Arrayed	30º	135º
5	Arrayed	30º	180º



a *b*

Fig. 5 – Pressure points distribution on the surface of the solar array.

The pressure distribution was evaluated for the entire array and also for every individual solar panel. On the surface of the array, the pressure is measured in 144 points for each face, aligned in 9 rows (Fig. 5 *b*), and the resultant pressure has also been calculated.

During the numerical simulation session, the wind speed considered was 18 m/s and the turbulence intensity 10% for the all five analyzed cases. The pressures values on both faces of the exposed solar panels array were registered.

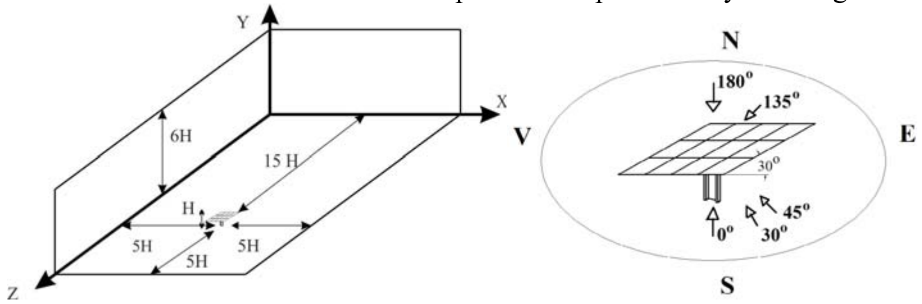


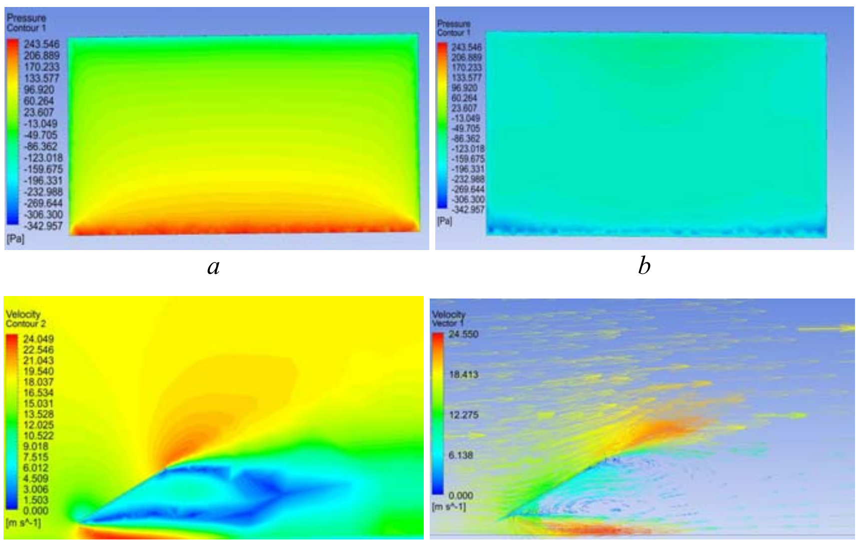
Fig. 6 – Computational domain (Franke *et al*., 2004) and the angles of the wind action.

3. Results and discussions

For all the analyzed cases a global analysis was run in order to determine the averaged pressure on the solar array and a local analysis to identify the critical panels (subjected to the greatest wind pressures) of solar array. The angle of wind action producing the largest loads was singled out by comparing the results.

3.1. Case 1: Angle of wind action at 0º

The highest pressures occur on surface of panels 9, 10, 11 and 12, placed on the top of the solar array (Fig. 7). Panel number 2 is subjected to the smallest



c *d*

Fig. 7 – Pressure distribution on inwind face (*a*) and on rear face (*b*) of the solar panels, velocity contour (*c*) and velocity vectors (*d*) for the angle of action of 0^0.

negative mean pressure value, –23.7 Pa and the panel number 12 is subjected to the greatest negative mean pressure value, –177.858 Pa (Fig. 8). The mean pressure on the total surface of solar array is –103.254 Pa.

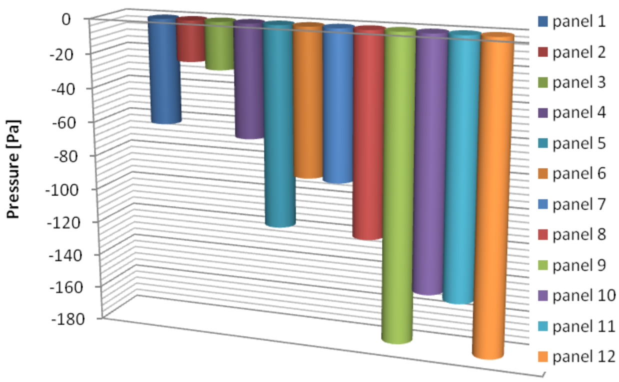
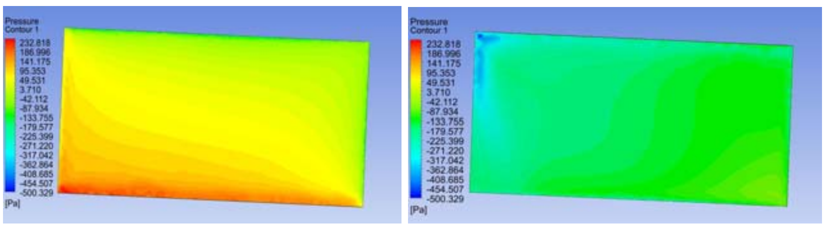


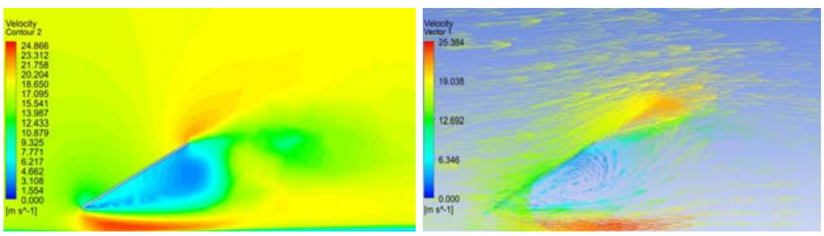
Fig. 8 – Mean pressure on the solar panels in array.

3.2. Case 2: Angle of Wind Action 30º

When the wind angle is at 30º, the left part of the solar array is more loaded than right one (Fig. 9). Like in the previous case, pressure values are negative on entire solar panels array with a mean value of –112.338 Pa.



a *b*



c *d*

Fig. 9 – Pressure distribution on the upper face (*a*) and the underside face (*b*) of the solar array, velocity contour (*c*) and velocity vectors (*d*) for wind angle action of 30^0.

The panel number 9 is subjected to the smallest mean negative pressure value, –161.994 Pa, followed by panel 10 with a mean suction of –154.155 Pa. On the panel number 3 the smallest value of mean suction, –49.68 Pa (Fig. 10).

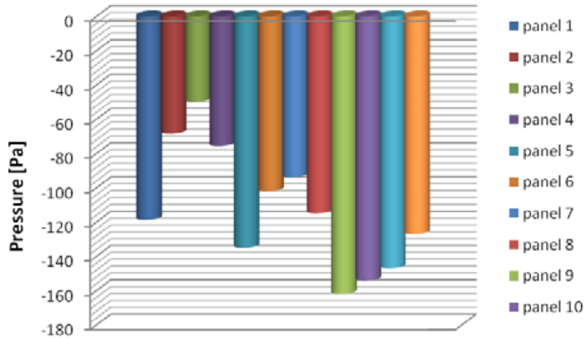
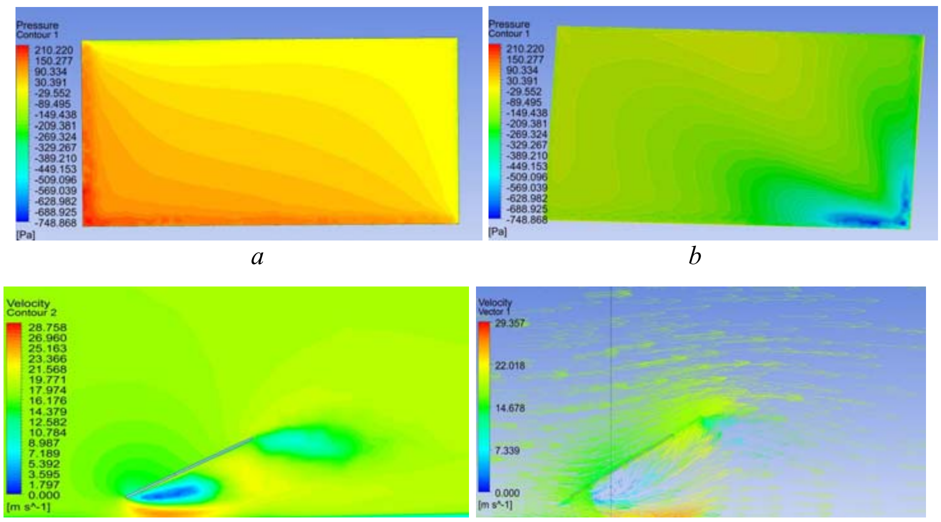


Fig. 10 – Mean pressure on the solar panels in array.

3.3. Case 3: Wind Angle of Action 45º

As in the previously analyzed cases, over the entire surface of the solar array negative pressure have been found (Fig. 11). The mean pressure obtained for the solar panels array is –118.883 Pa. The suction values in the left side are



a *b*

c *d*

Fig. 11 – Pressure distribution on the upper face (*a*) and the underside face (*b*) of solar array, velocity contour (*c*) and velocity vectors (*d*) for an angle of wind action 45º.

up to 45% higher that the values of the right one. Panel number 1 is the most strongly affected by the mean negative pressure values, –291.354 Pa. The smalles values are registered on panel number 4, the mean negative pressure being –69.1 Pa (Fig. 12).

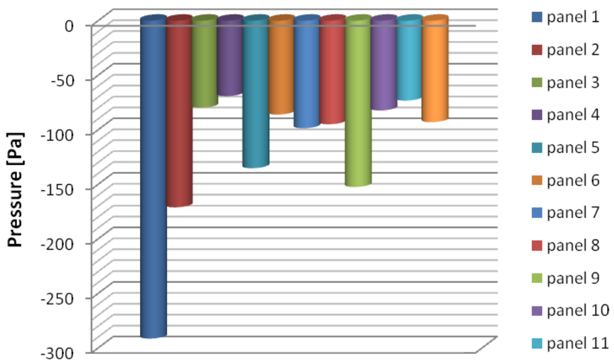
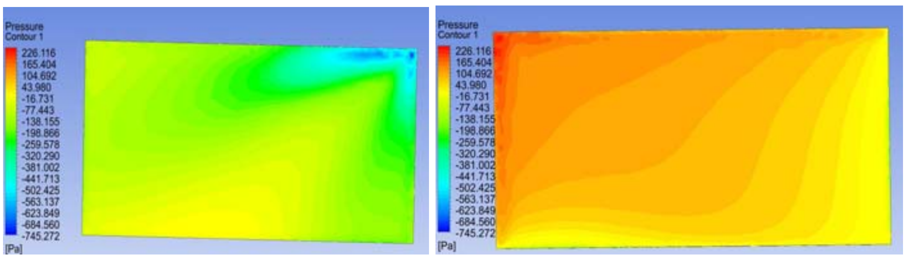


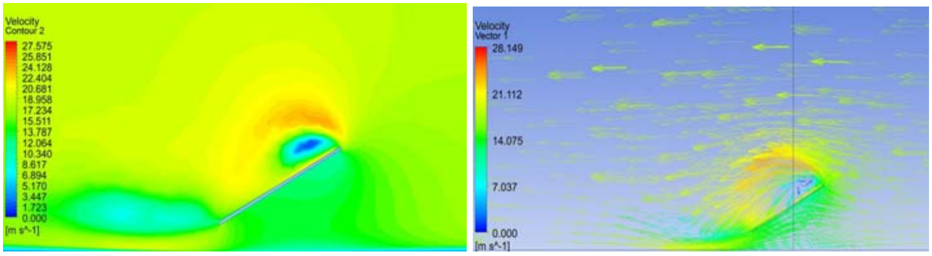
Fig. 12 – Mean pressure on panels of solar array.

3.4. Case 4: Wind Angle of Action 135º

For an attack angle of 135º, the mean pressure on solar panels have both positive and negative values. The negative values are registered on the panels placed at the extremities of the array, while the pressures on central panels are



a *b*



c *d*

Fig. 13 – Pressure distribution on the upper face (*a*) and the underside face (*b*) of solar array, velocity contour (*c*) and velocity vectors (*d*) for an angle of wind action 135°.

positive (Figs.13 and 14). The mean pressure on solar array surface is –62.8 Pa. Panel number 12 has the highest mean negative pressure (–257.898), and panel number 7 has the lowest positive pressure (16.253Pa).

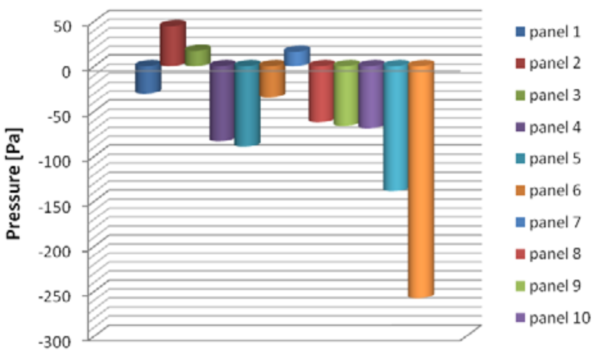
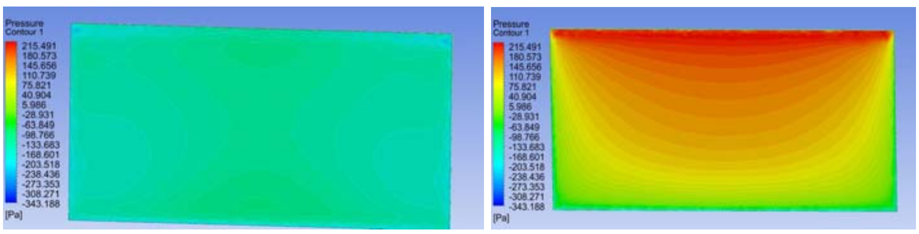


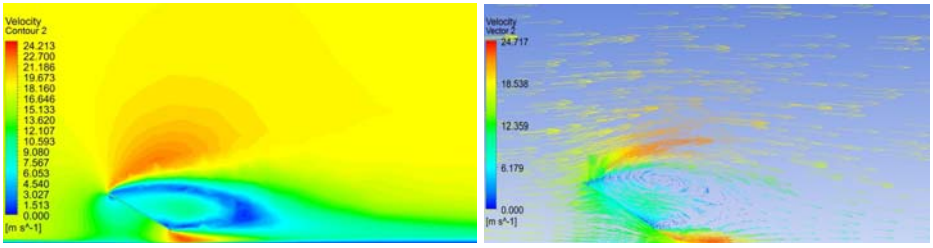
Fig. 14 – Averaged pressure on: *a* – panels in array; *b* – solar array surface.

3.5. Case 5: Wind Angle of Action 180°

The mean pressure measured on solar array surface has a negative value (–39.7 Pa). The panel number 1 is subjected to the smallest value of mean negative pressure of –140.95 Pa. The panel number 6 is subjected to the



a *b*



c *d*

Fig. 15 – Pressure distribution on the upper face (*a*) and the underside face (*b*) of solar array, velocity contour (*c*) and velocity vectors (*d*) for an angle of wind action 180°.

smallest values, the mean positive pressure being 1.77 Pa. The resultant pressures on bottom and lateral sides of solar array are negative, while in the central zone positive pressures were registered (Figs. 15 and 16).

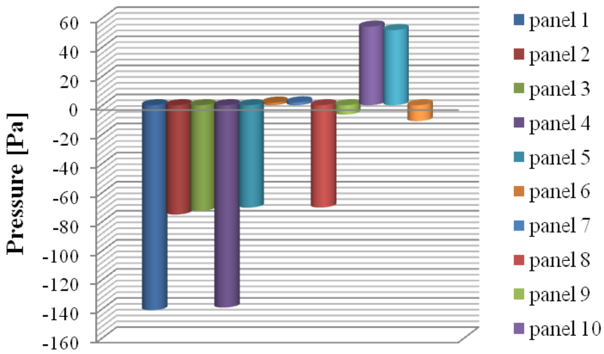


Fig. 16 – Mean pressure values on the panels of solar array surface.

5. Conclusions

From all the analyzed cases it has been pointed out that wind direction has a major influence on the pressure distribution on solar array. Suction values are greater for wind directions of 30º, 45º, 60º and 135º, due to the the incident flow which creates conical vortices on surface of solar array. These vortices manifest symmetrically in pairs, one on each edge of solar array, and in the center of each vortex an area of high suctions occurrs. The obtained results for each analyzed case where used to make a comparison between mean pressures developed on each panel of the solar array. A global analysis was performed; the mean pressure was compared for each considered attack angle. The biggest suctions appear for attack angle of 45º respectively 30º.

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SIMULAREA NUMERICĂ A ACŢIUNII VÂNTULUI ASUPRA UNEI MATRICE SOLARE

(Rezumat)

Acţiunea vântului reprezintă principala acţiune care determină proiectarea sistemelor de susţinere, indiferent de amplasament – pe clădiri cu acoperişuri terasă sau în pantă sau la nivelul solului. Pentru determinarea presiunii vântului pe panourile solare se folosesc programe de simulare numerică a curgerii fluidelor (CFD). În cadrul lucrării, modelarea numerică s-a relizat cu programul ANSYS 12 CFX şi a implicat studiul presiunii vântului, pentru cinci unghiuri de atac (0º, 30º, 45º, 135º, 180º), pe o reţea formată din 12 panouri solare amplasate la nivelul solului, unghiul de înclinare a acesteia fiind de 30º.