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# NUMERICAL SIMULATION OF WIND ACTION ON SOLAR PANEL PLACED ON FLAT ROOFS WITH AND WITHOUT PARAPET

BY

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Abstract. Used to convert solar energy into thermal energy (solar collectors) or electricity (photovoltaic panels), solar panels has become very popular in the last decade. Increasing the number of solar panels used in the world, determines behavior research on these systems in the aerodynamic field. Wherever they are located, on flat roofs, pitched roofs or at ground level, the wind represents the main action that determine the design of support systems for solar panels.

In this paper the aim is to determine the distribution of pressure on solar panels installed in a compact field on a flat roof. Numerical simulations are used for analysis of wind action on solar panels, located on flat roofs with and without parapets. In the specialty literature is recommended orientation of solar panels to South, South-East, respectively South-West, for benefit of a better sunlight. In Romania the dominant wind direction is from North, North-East or North-West, in which case the wind blows behind the field of panels. It is aimed the highlight of shielding effect produced by the building, respectively by building and parapet on the pressure distribution on the solar panels surface. Numerical simulations are performed in ANSYS 12 CFX, for an incidence wind angle of 45°.

Key words: wind direction; solar panels; CFD simulation; flat roof; shielding effects.

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### 1. Introduction

The techniques for capture and conversion of solar energy are in continuous development. Determination of wind forces on the support systems of solar panels represents the subject of many research studies. The behavior of solar arrays immersed in aerodynamic field makes the subject of several studies in wind tunnel with atmospheric boundary layer and numerical simulations using specialized software in fluid flow. In the last decade numerous studies was performed for determining the pressure distributions and the size of wind forces on solar panels located on flat roofs, pitched roofs, building facades or at ground level.

Wood, Denoom and Kwok (2001) investigated the behavior of solar collectors located on the flat roof, parallel with the roof line. In their studies the distance between roof and collectors and the distance between rows of collectors was varied, proving that none of these parameters have a considerable influence on the pressure distribution. The experiments showed that the distance between solar modules and roof edges, the orientation of panels toward the wind direction and the shape and size of the building, can influence or even change the wind loads on solar collectors placed on flat roofs. Geurts, Ravenhorst and Donkervoort (2005) have measured the pressure developed on solar panels placed on the flat roof of a rectangular building without parapet. In the experimental studies was considered two situation: solar panels mounted on open system and closed system. Blackmore (2004), using his studies, has published a design code for solar panels placed on flat roofs, but he did not consider the maximum pressure that occur for different wind angles. In Romania, Radu, Axinte and Theohari (1986) have performed studies cocerning solar collectors located on flat roofs, using a wind tunnel with open circuit. The collectors were arranged in compact group and two distinct groups and the pressure distribution was analysed for the main wind directions. The net pressure was determined for each collector and for each row of panels was calculated the average pressure. Also was showed the shelter effect produced by the first row of collectors. Radu and Axinte (1989) have investigate the effect of the parapet on collectors modules placed on roof top, showing that it's presence reduces both the pressure and suction in the corner areas of the flat roof. The collectors have been placed on the flat roof of a five story building, reduced to the scale of the model. The height and the permeability of the parapet were varied. The experiments demonstrated that the presence of parapet reduces the pressure up to 45% and the uplift forces up to 25%, for the first row of collectors. Making comparison between various situations, the authors

concluded that the reduction of pressure and wind forces depend on the building height; if the height increases, this reduction become insignificant. Chung (2008) have made wind tunnel studies to determine the average pressure and uplift forces that act on solar collectors and theirs support systems for different wind speed. They find posibility for reducing uplift forces by mounting a small plate, perpendicular to the wind direction, behind the solar collectors.

Solar panels exposed to wind action involve issues such as determining the influence of air flow on energy efficiency and designing the support systems for satisfying the requirements in service with minimal use of materials (Axinte, 1988). Since the wind tunnel experiments and full-scale measurements require time and significant financial resource, in wind engineering has been developed the numerical simulation of wind action, based on computational fluid dynamics. Increased processing speed of computers has led the development of specialized computers programs in fluid flow and numerical simulation results are often comparable with data collected in the wind tunnel experiments.

# 2. Solar Panels Placed on Flat Roofs

The solar panels benefit of a variety of placement options. Populating the flat roofs with solar panels is a useful and appreciated solution because it doesn't occupies a different space of installation on and the energy created is closer to the users. Design of support systems must be made so that the extreme values of wind will not affect the integrity of solar panels. The main problem in design of support systems is determining the correct uplift forces and pressure field, as well as finding solutions to reduce them. Installation of solar plant involves important financial resources and the economic criteria have an important role in design of supporting systems. In the analysis of wind loads on solar panels, the parameters that influence the air flow depend on the build environment, building dimensions and shape and the wind properties (Ruscheweyh *et al.*, 2011). Therefore in the assessment of wind loads on solar panels located on flat roofs, occur

a) wind speed;

b) wind direction;

c) height of the building and the presence of the parapet;

d) building position in the build environment;

e) parallel or oblique arrangement of the solar panels to the sides of the building;

f) angle inclination of the panels;

g) position of the panels to the roof edges;

h) position of the panel in the panels field.

The solar panels benefit of a variety of mounting possibilities. Solar industries are in continuous development. The new panels, more thinly or as membrane, grow mounting possibilities so that the evaluation of wind action on active roofs is often a particular case. Solar array mounted on building's roofs, regardless of the angle of inclination or their position, modify the velocity field and the pressure distribution to the roof. Unfortunately the pressure coefficients given into design codes for flat roofs, cannot be used to determine the pressure on panel's faces.

#### 2.1. Building Influence on Pressure and Velocity Field

The building has a major influence on changing velocity field. Analysing the roof terrace of a rectangular building (Fig. 1 a), is necessary to notice that the streamlines that meet the building are deflected. In the eaves area of the exposed face forms an aerodynamic jump (SP1) that favours the appearance of separation bubble on the roof and the development of negative pressures (Cook, 1990).



Fig. 1 – Air flow at roof level: a – roof without solar panels; b – roof with solar panels.

If the length of the roof is large enough, the streamlines are reattached (RP) and on the roof surface area appear positive pressure. In the active roof case the air flow is influenced not only by the building but also by the presence of solar panels (Fig. 1 b). Reattaching distance of the streamlines is much larger

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and between the rows of the panels small eddies are formed. In the solar panels field the air flow is complex and is significantly influenced by the geometry and dimension of the building and the incidence of wind by the building (Fig. 2).



Fig. 2 – Conical vortex on the corner of the building and the roof area for wind angle of 45°.

The presence of vortexes detached from the roof edge increases the turbulence in a relatively small area, located on the roof perimeter which avoided these zones of location of the solar panels (Axinte, 1988). From studies prior developed at the Faculty of Construction and Building Services in Iaşi regarding the wind action on the collectors placed on flat roofs (Axinte & Radu) it was observed that the local turbulence lifting forces act on the panels as well as pushing forces, their intensity being influenced directly by the way that these collectors are placed, the speed and the direction of the wind with respect to the building and finally, by the presence of other similar elements placed on the terrace (Radu *et al.*, 1986,1989).

# 3. Numerical Simulation Using ANSYS CFX

The numerical simulation in the study presented here was developed using ANSYS 12 CFX. The building is immersed in the computational domain, its minimal dimensions respecting the specifications from the literature (Franke *et al.*, 2004). Two cases are analysed: solar panels rows arranged in compact group on the flat roof of a building with and without parapets (Fig. 3). Solar panels rows have 27.5 m length, 1.58 m height and 0.008 m thick and are titled by 35° to the roof plan. The distance between two rows of panels is of 1.0 m and the distance from the roof edge to the first row is of 3.0 m. Numerical simulation was done for each of two cases, considering the wind angle equal to 135°. Solar panels are facing to South, while the wind direction is North-East (Fig. 4).

The building equipped with solar panels on the roof is a regular one,  $30 \text{ m} \times 20 \text{ m}$  in plane dimensions and 15 m height; an attic of 1.0 m is placed on the roof perimeter (Fig. 5). The solar panels are lifted at 0.2 m height from the



Fig. 3 – Arrangement of solar panels on flat roof: a – roof without parapet; b – roof with parapet.



Fig. 4 – Solar panels orientation and direction of wind action.



level of the roof and situated in consecutive rows, respecting the recommendations from the literature: the distance between these rows and the edge of the attic is about e/10, with

$$e = \min(b, 2h), \tag{1}$$

where: *b* is the dimension of the face normal to the wind direction, h – height of the building.

During the numerical simulation season, the considered wind speed is of 14 m/s and the turbulence intensity is 10%. As a result of the numerical simulation for the two analysed cases, the pressures coefficients on both faces of the exposed solar panels were registered.

#### 4. Discussions and Results

According to the standard SR EN 1991:1-4, the evaluation of the global wind forces on the whole structures is determined with the following relationship:

$$F_{w} = q_{\text{ref}} c_{f}(z) c_{s} c_{d} A_{\text{ref}}, \qquad (2)$$

where:  $F_w$  is the wind cumulated force acting on the whole structure or a part of it, particularly on a structural element;  $q_{ref}$  – reference wind pressure at the reference height above the ground level, z;  $c_f$  – force coefficient;  $c_s c_d$  – structural coefficient;  $A_{ref}$  – reference area for structure or, for a structural element or part of the whole structure.

In the case of the plane solar panels the coefficients  $c_f$ , normal to the surface of the building, may be globally evaluated, in this case being used to determine the resultant force that acts on the whole surface of the panel, or local pressure coefficients with which the resultant from a small surface may be obtained. The vectorial characteristics of the normal pressure coefficients (sign and spatial direction) depend mainly on the wind angle of action with respect to the surface of the building (Axinte, 1988). In the case of the plane solar panels mounted on supports the local pressure coefficients will act on both faces of the panel and the resultant of the normal component will be obtained with the relation

$$c_{LR} = \pm c_{ns} \pm c_{ni}, \tag{3}$$

where:  $c_{ni}$  is the pressure coefficient on the in wind surface of the panel and  $c_{ns}$  – the pressure coefficient from the leeward face (Fig. 6 *b*).



Fig. 6 – The air flow around the plane surface of the solar panel and the computation of the coefficient  $c_{LR}$ .

Romanian wind standard not give information available for design of solar panels systems, also don't specified how important is the location for pressure distribution registered on the plane solar panels.

### 4.1. Analysis of the Results Obtained During the Numerical Simulation

Pressure produced by wind action was registered on every row of panels in 45 points, placed in 5 lines respective 9 columns, according to Fig. 7.



Fig. 7 – Distribution of the points on the surface of the solar panels where the local wind pressure was measured.

Distance between the points placed on a line is of 3.45 cm and between the points on a row is of 0.32 cm, at the model scale. For each point was measured the pressure values on both sides of the solar panels and calculated the resulting pressure. After gathering the values obtained in every point graphics were traced for the observation of the variation between the lines and the columns for every row and between the rows. In the both cases the resultant pressures in all analysed points is negative.

### a) Building with parapet

The average pressure values obtained on the 45 points located on each side of panels rows are entirely negative. The lower suction appears in the points of first row of solar panels, increasing gradually until the penultimate row.



(active) face; b – underside (exposed) face.

The negative pressures measured in the first column of rows number 1, 2 and 3 (right extreme) are double compared with negative pressure values measured on the panels located in the left extreme of this rows (column 9) (Fig. 9). Starting with row number 4, the pressure measured on left extreme grows compared with values measured on right extreme. The difference gets up to 60% higher in case of the sixth row and 110% higher in case of the last row of solar panels (Fig. 10).



Fig. 9 – Pressure variation on the first (*a*) and last (*b*) rows of solar panels.

Positive pressure, lower in value, appear in the central area of the solar panels group (Fig. 8). These positive values appear in points 7 and 16 on the third row, in points 6 and 15 on the fourth and fifth row, respectively in points 5 and 14 on the last row of solar panels. The positive values appear only on active face of solar panels, while the resultant pressure is negative (Figs. 11 and 12).



Fig. 10 – Mean pressures variation on the rows of solar panels.



Fig. 11 – Mean pressure variation on the first (*a*) and last (*b*) column of solar panels rows.



### b) Building without parapet

Panels displaced in the first row have the lowest values of negative pressure, while the panels located on the second row have the biggest values of mean pressure.



(active) face; b – underside (exposed) face

The pressures developed on the first row of panels are up to 50% lower that the pressure measured on the second row and up to 42% lower that pressures measured on the last row of solar panels (Figs. 14,...,17). Like in the previous case, in the central area of solar array appears positive pressure but only on the active face of panels (Fig. 13). In case of rows 4 and 5 can find positive values in points 6 and 15 (column 6) and in point number 14 (column 5) for rows 6 and 7. The resultant pressure is negative for these points too.



Fig. 14 – Pressure variation on the first (*a*) and last (*b*) row of solar panels.







solar panels.

#### 4.2. Discussions

Wind direction has a major influence on the pressure distribution on flat roof surface and also on faces of solar panels arrays. Local suctions are more intense for wind direction of  $\pm 45^{\circ}$  and that wind acts from N-E direction, behind the solar arrays, leads to negative pressure on both sides of panels. Considering the incidence angle of  $45^{\circ}$ , would create conical vortices (deltawing vortex) at the roof level. These vortices are usually in pairs, one on each roof edge, and the center of each vortex is an area where high suctions occurring (Fig. 18).



Fig. 18 – Development of conical vortexes for angles of incidence wind between 30° and 60° (Cook, 1985) and their action area.

Conical vortexes action leads to development of high uplift forces, which means a biggest load on support systems of solar arrays (Fig. 19). Solar panels mounted on flat roofs increase the local turbulence that affect entire group of panels.



Fig. 19 – Streamline on roof level for building with parapet (*a*) and without parapet (*b*).

The shape and size of the building have a big influence in pressure distribution on solar panels mounted on building roof. Placement of solar panels on the roof surface favours the appearance of local turbulence with change of pressure distribution and reduces uplift force by down force. Though, wind incidence would create wake vortexes and suction effects are more obvious. By their position, solar panels can shield each other, phenomenon more evident for the building with parapet (Figs. 20 and 21).













Fig. 21 – Velocity contour in: a – right extremity; b – central zone; c – left extremity of solar panels rows, for building without parapet.

In the left extremity of solar panels arrays the sheltering produced by the parapet and the first row of panels for the roof with parapet, and by the first row of panels for roof without parapet, favours the occurrence of high suctions on both sides of solar panels.

#### **5.** Conclusions

Oblique direction of wind action is an unfavourable case, generating high intensity of uplift forces in the corner areas of the flat roof, forces which bring an additional load on support systems of solar panels. Placement of solar panels to a height of 20 cm above the roof level allows infiltration of streamlines under rows of solar panels. In the middle of the roof, where conical vortexes influence is lower; on active face of solar panels appear positive values of pressure. Building height has an important role in the pressure distribution on the roof and panels arrays. Presence of the parapet help mitigate the wind loads, and average pressure is up to 18.6% lower that for solar panels placed on flat roof without parapet.

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### SIMULAREA NUMERICĂ A ACȚIUNII VÂNTULUI ASUPRA PANOURILOR SOLARE AMPLASATE PE ACOPERIȘURI TERASĂ CU ȘI FĂRĂ ATIC

#### (Rezumat)

Folosite pentru a converti energia solară în energie termică sau în energie electrică, panourile solare se bucură de o mare popularitate în ultima decadă. Creșterea numărului de panouri solare folosite la nivel mondial determină aprofundarea cercetării privind comportarea acestor instalații în câmpul aerodinamic. Indiferent de locul în care sunt amplasate, pe acoperișuri terasă, pe acoperișuri inclinate, la nivelul solului sau pe fațadele clădirilor, vântul reprezintă principala acțiune care determină dimensionarea sistemelor de susținere a panourilor solare.

Se urmărește determinarea distribuției de presiuni asupra panourilor solare plane amplasate în grup compact pe suprafața unui acoperiș terasă. Utilizând simulările numerice, sunt analizate două cazuri și anume: panouri dispuse la nivelul acoperișului terasă cu și fără atic. În literatura de specialitate este recomadată orientarea panourilor solare spre S, S-E, respectiv S-V, pentru a beneficia de o cât mai bună însorire. În România, însă, direcția dominantă a văntului este dinspre N, N-E, N-V, caz în care acțiunea eoliană se manifestă din spatele câmpului de panouri. Se urmărește evidențierea efectului de ecranare produs de clădire, respectiv de clădire și atic, asupra distribuției de presiuni pe suprafețele panourilor solare. Simulările numerice sunt realizate în programul ANSYS 12, pentru un unghi de incidență al vântului de 45°.