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MEASUREMENT TECHNIQUES IN BOUNDARY LAYER WIND TUNNEL FOR DETERMINATION OF THE LOADS ON PLANE SOLAR COLLECTORS

BY

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Abstract. The measurement of fluctuating pressures is an important step in the determination of the wind loads acting on structures or parts of structures. The measurement techniques develop continuously, important improvements being the goal in order to provide solutions to various difficulties encountered in the acquisition or processing of wind data. In the case of experimental studies in boundary layer wind tunnel on scaled models, the pressure taps placed on the model surfaces is the most common method of measuring the normal local wind pressures. The solar panels immersed in aerodynamic field are subjected to the fluctuations of wind loads. The assessment of these wind loads on both faces of the solar collectors is necessary for safety in operation, no matter the support and the arrangement of the solar panels.Punctual measurements of the fluctuating pressure on both sides of a solar panel model are quite difficult to achieve due to the presence of a large numbers of tubes on tributary small areas.The paper presents a methodology of averaging the values of the pressure measurements, and the applicability of this method to studies in wind tunnels.

Key words: pneumatic averaging; fluctuating pressure; solar panels; wind loads.

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1. Introduction

Wind action on buildings manifests through internal/external pressure on buildings surfaces or by wind forces which acts on the buildings and on individual parts of the structures with significant protuberancies exposed to it (CR 1-1-4:2010). The assessment of wind loads consists in considering these effects of wind action by the means of pressure or force coefficients.

For the model of a building immersed in the boundary layer of the wind tunnel, the pressure coefficient in an arbitrary point (*i*) located on its surface is determined with the formula:

$$c_{pi} = \frac{p_i - p_s}{p_t - p_s} \tag{1}$$

where: p_s is the static pressure; p_i – the dynamic pressure measured on the surface of the model, in the *i* point; p_t – the reference total pressure, measured inside of the wind tunnel at the level corresponding to the height of the model.

The pressure on the model surface may be measured with pressure transducers placed on this surface or by using pressure taps connected to the pressure transducers.

The number of pressure transducers that may be placed actually on a surface is limited by the geometrical scale of modeling so for small modeling scales may lead to the impossibility to place the transducer on the surface of the model. The solution consists in placing pressure taps on the surface of the model, thus allowing the measurement of the local pressures. The connection between the pressure taps and the pressure module (transducer) is ensured by the connecting tubes.This method of measurement of wind pressure on surfaces, is successfully used in the civil engineering domain as well as in the aircraft industry and thus, continuously improved. To avoid the errors in the measurements of the surface pressure, a particular attention should be given to the tubing system. Attention is drawn in literature to the situations when the values of the pressure acquired through flexible tubes are affected by the tubing response. The papers of Holmes (1984, 1987 *a*, *b*) and Cook (1985) are presenting the influence that length, diameter and tubing rigidity have on pressure measurements. The length of the tube which provides the connection between the transducer and the pressure taps, may induce distortions in the acquisition data process.

Cook (1985) describes these distortions as a function of the standard frequency response.Depending on the length and characteristics of the tubing, in the middle of the frequency band may occur the so called “organ pipe resonance”. At the upper limit of frequency band, the Helmholtz resonance may manifest itself. It should be pointed out that these distortions affect the fluctuating component of the pressure and by default, its peak values. Bergh and Tijdeman (1965) proposed measures to reduce distortion induced by tubing and also to determine by calculations the response characteristics of the various types of tubing system.

The proposed measures consist in using of a ducting with short length in order that the critical frequencies band of vibrations avoid the organ pipe frequency followed by the correction of the distortions of the signal before its analysis; also, the manifold and the tubing characteristics are modified for eliminating the distortions.

2. Pneumatic Averaging of Pressure

In particular situations, a higher accuracy of the results impose placing as large as possible a number of pressure taps, distributed on the surfaces of the scaled model which is rather reduced in dimensions. A large number of tubes, in addition to any signal distortion, may disturb the flow of the air in the vicinity of the analysed model, and the accuracy of the acquired fluctuating pressures is debatable. The pneumatic averaging of pressure is a viable solution, which eliminates or reduces signal distortion, decreases significantly the time for data acquisitions and, by default, the time spent for processing it. The literature dedicated to these studies present several methods of acquiring pressure, aimed to obtain average values of wind pressure by internal averaging.

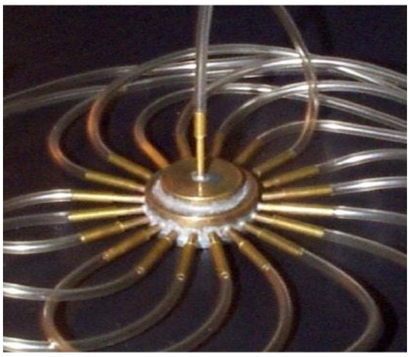


Fig. 1 – Pneumatic manifold proposed by Surry and Stathopoulos (1977).

In 1977, Surry and Stathopoulos proposed a method for the improvement of the pressure measurements. According to this method, the signal acquired through the tubs, which are fixed in the pressure taps, would not go directly to the pressure module, but in an enclosure called *manifold*, where a pneumatic average (internal) of the pressure occurs.The connection between manifold and transducer is provided by a single tube as shown in Fig. 1, and the recorded pressure represents the average value of pressures collected from the considered pressure taps.

Radu and Axinte (1986, 1989) used the method of the pneumatic averaging in order to obtain the mean values of the wind pressure on the surfaces of the solar collectors.The solar collector was modeled at 1:50 scale, so that the size of the model was 40 × 20 mm. The experiment was run on eight rows of solar collectors, with five collectors on each row. A number of 24 holes were made on the exposed and sheltered surfaces of each solar collector where pressure taps were placed for the acquisition of the normal wind pressure.

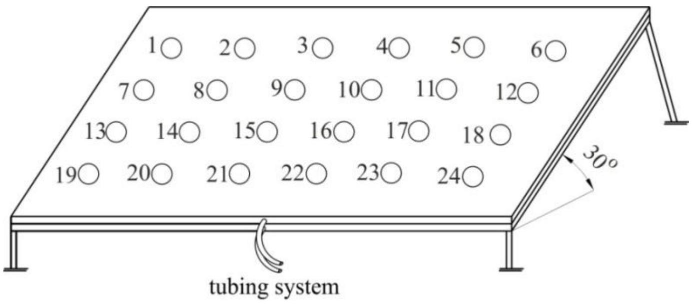


Fig. 2 – The sketch of the solar collector which has been used for the pneumatic pressure averaging method (Radu, Axinte).

The pressure inside of each compartment was acquired by a single connecting tube and sent to the differential manometer. This pressure represents the average value of the pressures that occurs on each surface of the solar collector.

3. Experiments for Validation the Pneumatic Averaging Method for Mean Wind Pressure Data on the Surface of the Solar Collectors

The Romanian code for buildings design to wind actions, does not give the required information for the evaluation of the wind loads on the solar panels. The evaluation method of the wind pressures on mono-pitched canopies presented in this code may be extended and applied for the solar panels. Both 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 play the role of the global force coefficients applied to the resultant of wind action on both faces of the panel.

Therefore, both the experimental studies made in boundary layer wind tunnel and numerical simulations should reproduce the real distribution of wind pressure/suction on the inwind face of the panel, as well as on the rear face, the resultant local pressure values being thus determined (Fig. 3).

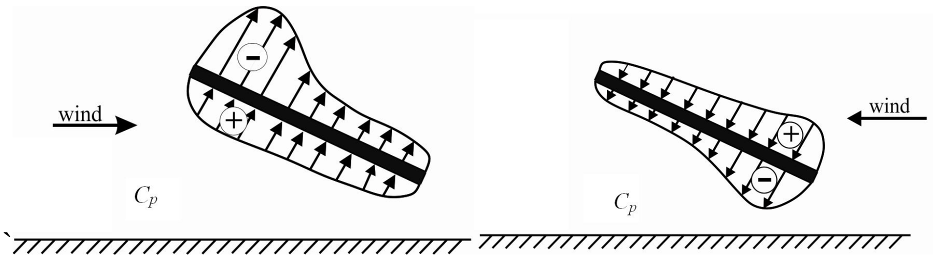


Fig. 3 – Pressure distribution on the surface of the solar panel for from north and south wind directions (Ruscheweyh *et al*., 2011).

The experimental study presented here was run in the Laboratory of Building Aerodynamics of the Faculty of Civil Engineering from Iaşi, in the boundary layer wind tunnel SECO 2 and aimed to determine the wind pressures on the surfaces of small-scaled solar panel. The two rigid scaled models of the plate measuring 20 × 10 × 4 cm have been provided with a mid-wall (Fig. 4), which separates internal space in two compartments that do not communicate with each other.

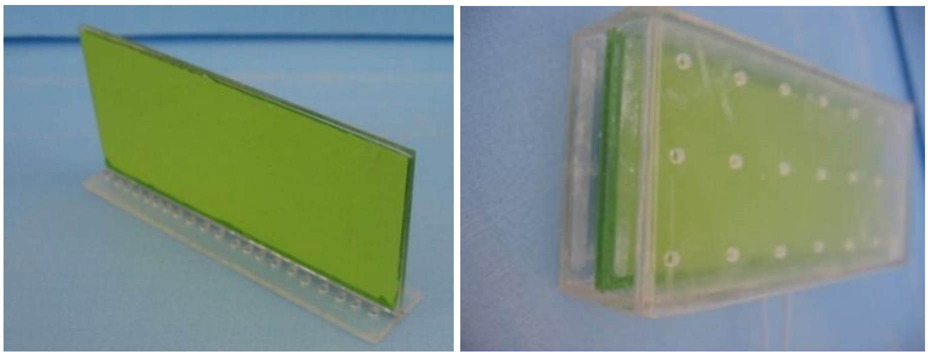


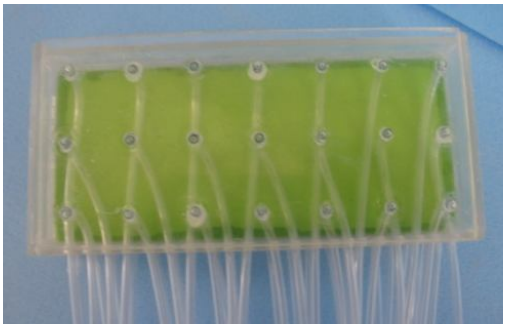
Fig. 4 – Mid-wall as partition inside the models.

On each side of the rigid plate a number of 21 holes with a diameter of 1 mm were evenly distributed, holes which represent pressure taps as shown in Fig. 5.

One of these models has each hole (pressure tap) linked to the pressure module ZOC 17, through flexible tubes with a length of 20 cm (Fig. 5 *a*), while the other has open holes. It is equipped with only two tubes, one for each compartment.(Fig. 5 *b*).

The models were positioned in the center of the turntable, in the experimental area of the wind tunnel, at a height of 10 cm above the tunnel floor.

For each of the two models, wind pressures were acquired, considering two positions of the plate: vertical and tilted at 30° in relation to the floor of the tunnel (Fig. 6).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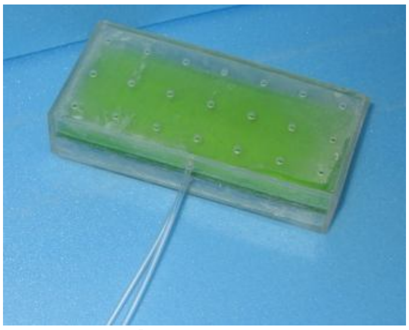
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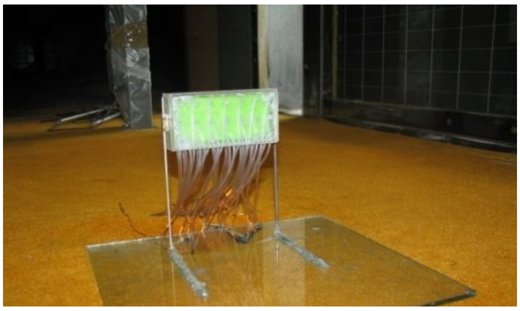
Fig. 5 – The solar panel model: *a* – model used for the local pressure values, *b* – model used for the aquisition of the mean pressure values.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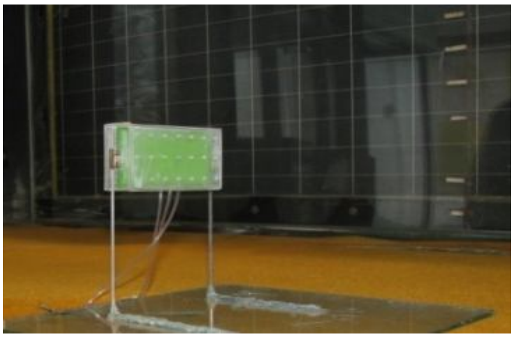
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Fig. 6 – Model of the solar collector vertically placed in the experimental area: *a* – model equipped with 2 × 21 flexible tubes corresponding to the pressure taps; *b* – model equipped with 2 flexible tubes corresponding to the two separate compartments of the model.

Wind pressures from the inwind and rear faces were acquired. The pressure measurements were made for experimental mean wind speed of 1.4 m/s, measured upstream from the testing area, with a probe located in the middle of the tunnel, at the reference height corresponding to the maximum height of each model.

For each pressure measurement, the time of the signal acquisition has been 1 minute and the frequency of acquisition of 1,000 Hz. A number of 60,000 values were obtained for each pressure measuring stage been processed statistically afterwards. The normal pressure from wind action on the solar panel surfaces, was determined by two methods:

a) acquisition of local pressure fluctuating values followed by determination of the mean values and integration (by summarizing) of the whole surface of the panel;

b) pneumatic averaging the local pressure values followed by mediation.

Table 1
Mean Local Pressure Values Recorded on Model Number 1 and Averaged Values of Pressure on Both Surfaces of the Model

Tap number	30°		90°	
	Pressure, [Pa]			
	Inwind face	Rear face	Inwind face	Rear face
1	0.132	–0.096	0.506	–0.130
2	0.145	–0.089	0.780	–0.157
3	0.14	–0.084	0.578	–0.169
4	0.126	–0.096	0.560	–0.177
5	0.153	–0.09	0.880	–0.188
6	0.134	–0.085	0.609	–0.248
7	0.126	–0.1	0.383	–0.175
8	0.144	–0.094	0.911	–0.165
9	0.146	–0.087	0.582	–0.205
10	0.121	–0.096	0.638	–0.131
11	0.131	–0.094	1.035	–0.156
12	0.14	–0.087	0.451	–0.184
13	0.134	–0.098	0.471	–0.168
14	0.143	–0.09	0.965	–0.210
15	0.132	–0.083	0.512	–0.194
16	0.126	–0.094	0.485	–0.119
17	0.135	–0.09	0.853	–0.158
18	0.14	–0.083	0.548	–0.144
19	0.133	–0.095	0.492	–0.142
20	0.143	–0.092	0.783	–0.149
21	0.131	–0.086	0.577	–0.160
Averaged pressure	0.135524	–0.0909	0.647714	–0.16805

It may be easily observed that between the mean wind local pressures obtained by processing the data acquired during the experiment and the values obtained by pneumatic averaging the difference is under 10%, depending on the case studied.

Table 2
Global Pressure Values, Obtained by the Method of Pneumatic Averaging on the Model Number 2

30°		90°	
Pressure mediated, [Pa]			
Inwind face	Rear face	Inwind face	Rear face
0.149	–0.101	0.716	–0.141

4. Conclusions

The analysis of the values of mean local pressures on the inwind face, both for the vertical and the tilted models, reveals that they are smaller than the averaged pressure value.These differences are tributary to the large number of pressure taps (21 taps spread over an area of 50 cm^2) and associated with the tubing sistem.

In the case of the model equipped with 42 tubes, their presence disrupts the air flow and the space between layout and floor tunnel is partially blocked. Pressure taps arranged at the bottom of the model (taps number 1 to 7) are located from 0.50 cm above the lower edge. Pressure values measured in the pressure taps which are located on the inwind surface, are affected by the presence of the tubes (Fig. 7) because the tubing system prevents partially the air from moving and generates a state of turbulence, accompanied by a decrease in wind speed and a reduction in the pressure value. The pressure values measured on the rear surface of the model are also affected by the presence of tubing.The partial obstruction of the space between the model and the floor tunnel is the general reason of decelaration of the air movement and modifications of the flow field in the vicinity of the model so the model of the flow in the rear region is different from the real one.

Application of this method in achieving the future experimental studies contributes to reducing the physical and material allocated resources and allows the determination of the average pressure of the experimental studies where a large number of pressure taps are needed. Using this method, both the duration of acquiring data and processing time are considerably reduced. Another advantage of the pneumatic average method, is to eliminate the large number of connecting tubes which may lead to errors of acquiring the data.

The method of pneumatic averaging is extremely useful in wind tunnel experiments for the determination of the wind loading of the solar panels.

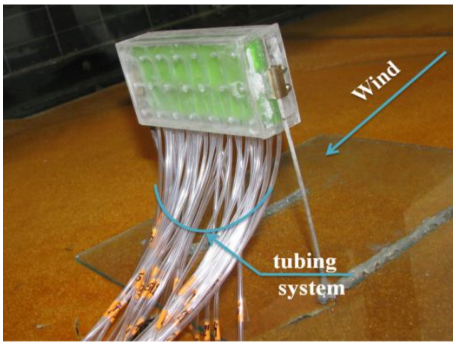

Fig. 7 – Partial obstruction of the space between the model and the floor of the tunnel.

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TEHNICI DE EXPERIMENTARE ÎN TUNEL AERODINAMIC PENTRU DETERMINAREA ÎNCĂRCĂRII DIN VÂNT ASUPRA CAPTATOARELOR SOLARE PLANE

(Rezumat)

Măsurarea presiunii fluctuante reprezintă o etapă esenţială în deterinarea încărcărilor induse de vânt structurilor sau elementelor structurale. Tehnicile de măsură sunt într-o continuă dezvoltare şi perfecţionare astfel încât să ofere soluţii pentru diferitele probleme întâlnite în achiziţia, respectiv procesarea datelor. În cazul studiilor experimentale realizate în tunel aerodinamic pe modele la scară redusă, cea mai uzuală metodă de măsurare o reprezintă utilizarea traductorilor de presiune dispuşi pe suprafeţe reprezentative studiului. Panourile solare, imersate în câmpul aerodinamic sunt sensibile la fluctuaţiile încărcărilor din vânt. Indiferent de sistemul de susţinere ales şi de modul de dispunere a panourilor evaluarea încărcărilor din vânt pe ambele feţe ale plăcilor de captare este necesară pentru asigurarea siguranţei în exploatare. Imposibilitatea realizării măsurătorilor punctuale de presiune pe modelul unui panou solar redus la scară, reflectate prin prezenţa unui număr mare de tuburi de legătură care deservesc o suprafaţă redusă, a condus la adoptarea unui procedeu de mediere pneumatică a presiunilor. În conţinutul lucrării este prezentată metodologia de realizare a măsuratorilor de presiune medie, precum şi aplicabilitatea acestei metode în studiile experimentale realizate în tunelul de vânt.