BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LVI (LX), Fasc. 2, 2010
Secţia
CONSTRUCŢII. ĂRHITECTURĂ

METHODS TO REDUCE THE RISK TO WIND ACTION OF THE FIXING SYSTEMS OF SOLLAR COLLECTORS

BY

ELENA AXINTE, ELENA-CARMEN TELEMAN, VICTORIA-ELENA ROŞCA and GEORGETA VĂSIEŞ

Abstract. The interest in the non-conventional energy resources, a consequence of the severe restrictions imposed towards pollution of any kind, arises again the interest in using solar collectors. Implanting them on the terraces of new or existent home residencies, or any kind of other buildings, means to solve a sum of engineering problems, among them being also the stages of safely designing the plane panels for collectors and the sustaining skeleton, made in steel as well as the fixing systems adopted for the interface with the building itself. The necessity of considering the maximum wind speeds actions along other dynamic effects of its turbulence is the result of a many years experience, specially if one must also think in terms of efficiency and costs both for construction and exploitation.

The pattern of the wind flow field suffers intricate alterations in the proximity of these collectors placed in the vicinity of the building surface and, in these situations, it is common to test the models at a reduced scale in wind tunnels with atmospheric boundary layers. The experimental study presented in this paper was undertaken in the Laboratory of Aerodynamics of the Faculty of Construction and Building Services in Iaşi and it reveals the results and the conclusions drawn from the analysis of the wind flow over a row of collectors differently arranged in order to evaluate the wind pressure coefficients used in design.

Key words: solar collectors; wind tunnel; wind turbulence; wind pressures.

1. Introduction

Scientific research in the early days of the XXI$^{\text{the}}$ century is challenged by the implications of the new concept of a sustainable development. Forecasting the conservatory values in the design to wind dynamic actions had become a main goal for a wide situations occurring during the design process.

Wind engineering is a science based on the evaluation of risk to failure of structures and as now day's storms, hurricanes and other combined effects of wind intensity their actions on the antropic space as a whole, this severe evaluation must determine the realistic limits of the safety exploitation of human environment.

As we already observed through centuries, wind action induces random effects but wind speed may be, in general, very well characterized by two main components: a steady part, with constant intensity in time but variable in space and a fluctuating part, with abrupt and random variation in time and space. Averaging the intensity through a long enough period of time is not relevant any more because of the important effects of the instantaneous values, so in the present, the extreme winds and extreme values of wind speeds and pressures are those that really interest the specialists in wind engineering. This goal is reached by intensive research programs, through observations at full scale, which must be developed during great periods of time (years, decades, etc.) but also, at small scale, in laboratory.

Solar collectors are exposed to wind dynamic action and the following problems must be solved by engineers [1]:

a) Design of the collectors based on the concepts of optimizing the steel consumption and the energetic efficiency and their structural systems in order to satisfy the exigencies of a safety exploitation.

b) Control the influence of the wind flow in the proximity of the solar collectors, in order to obtain a high energetic efficiency.

In both cases complex phenomena may appear namely

a) The pattern of laminar or turbulent flow is imposed by wind speed, internal structure of vortices, the presence of various obstacles and their shape, the nature and shape of the collectors, different convective movements, etc.

b) Thermal convective transfer coupled with the convection–radiation alternative changes.

c) Static and dynamic response of the steel structure (the skeleton of the solar collectors).

The study of the mechanical interaction between the wind action and solar collectors will take into account that

a) A wide variety of solar collectors is present on the market now.

b) Every type has its own constructive solutions, hence specific systems for supports and fixing to the structure.

c) The design of the supports is in particular affected by the effects of wind dynamic action.

2. Wind Actions on the Plane Solar Collectors

Solar plane collectors placed under a specific angle may be mounted in parallel rows on the plane roofs of the buildings (terraces) by means of metallic supports, in steel or aluminium. These systems may be directly anchored or using mounting chairs or reinforced concrete prisms or even steel plates. Any of these systems might very well alter locally the continuity of the hydro-thermal insulating layers and nobody will think to the consequences.

The panels that contain the solar collectors transfer to the main structures forces from their weight and the wind pressure.

Various situations will describe the intensity and direction of these forces, also the dynamic manifestations, as vibrations and fluctuation of intensity and sign (changing pressure to suction or *vice-versa*) of these wind forces, such as

a) The slope of the roof and also the slope of the panels.

b) The place of the panels in respect to the edge of the roof.

c) The space between the panel and the edge of the roof.

d) The space exposed in the rear of panels.

e) The position of each panel with respect to the other-individual or in rows.

f) The presence or absence of other obstacles in their immediate neighbourhood (skylights, chimneys, etc.).

Total force from wind action normal to the surface of the solar collector is decomposed into several forces of compression, tension and shear which are transferred to the sustaining and fixing systems.

Thus, the resultant, F_n, is transformed into three components (Fig. 1 *c*) namely

a) A vertical component, in a plane normal to the wind direction, along *Oz*–axis, named also *lifting force*, F_v.

b) A horizontal component in the wind direction along the *Ox*–axis, which is named *drag force*, F_l.

c) A horizontal component normal to the wind action in the direction of *Oy*–axis, named *drift force*, F_t.

Reducing the resultant force, F_n, with respect to a specific point of the plane of the collector, a resultant force (no matter the reducing point) will be accompanied by a moment (Fig. 1 *b*). This moment is decomposed into two vectorial components, one in a vertical plane and the other in a horizontal one, the effects being of twist and overturning of the skeleton of the solar collector and in certain situations, the direction of the resultant force may be different to the wind direction.

The Romanian code SR EN 1991-1-4 [2] regarding the evaluation of the forces due to wind action on the structural elements is determined with the relationship

$$F_w = q_{\text{ref}} c_e\left(z\right) c_f c_d A_{\text{ref}}. \tag{1}$$

Both in the case of plane solar collectors and in the case of solar collectors mounted on independent structures on the roof terrace, the force coefficients, c_f, may be global coefficients describing the resultant force and local coefficients describing the local maximum force for different directions of wind attack.

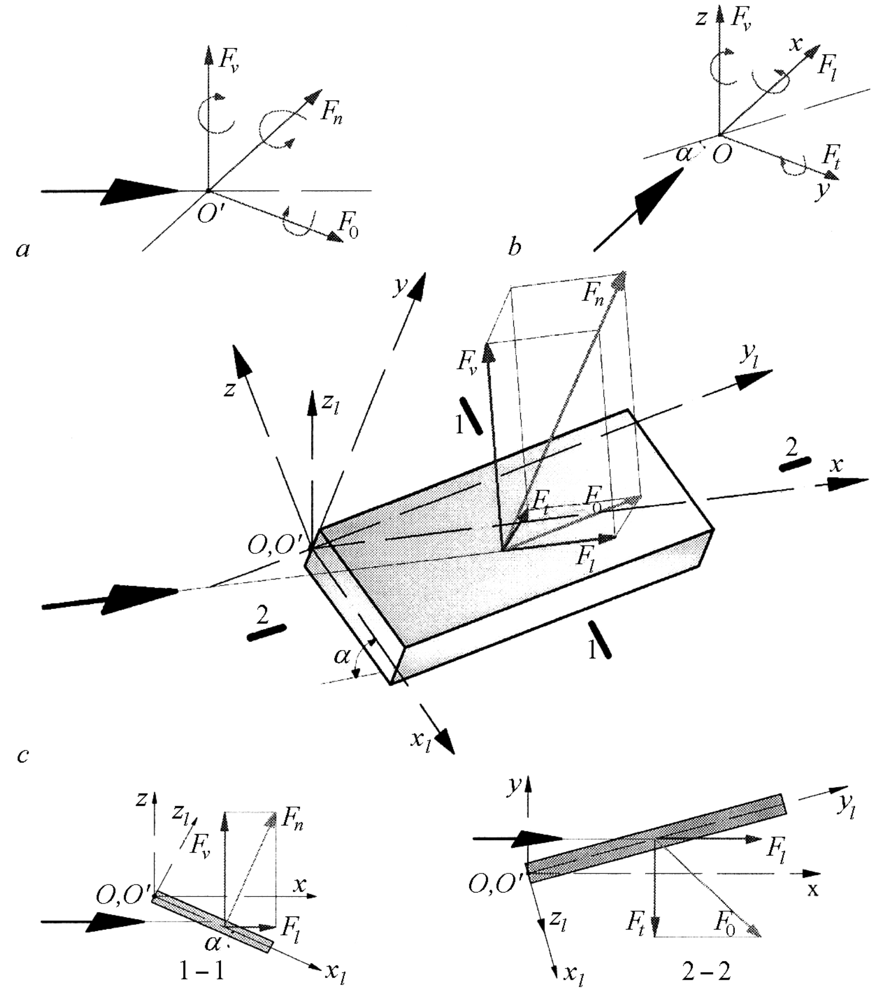


Fig. 1 –Resultant forces and moments on the surface of the sloped solar collector due to wind action (observed in the tests in atmospheric boundary layer wind tunnel): *a* – with respect to the axis of the tunnel, *b* – with respect to the axis of the model of the plane of the collector, *c* – with respect to the solar collector.

Wind action is described by distributed pressure forces on both faces of the plane of the collector, the resultant being a vectorial sum; the significance of the normal pressure coefficients being the resultant of forces on both faces

$$c_{LR} = \pm c_{ns} \pm c_{ni}, \tag{2}$$

where c_{ns} is the pressure coefficient on the external surface of the plane of the collector and represents the pressure coefficient on its rear surface (Fig. 2).

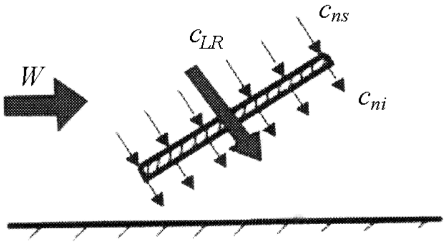


Fig. 2 –The computation of the resultant coefficient.

The Romanian code gives values of local pressure/suction coefficients on one pitch canopies, the situations specific for solar collectors never being studied. In the same time the coefficients for canopies are not considered in the context of the position of solar collector, depassing the ground level.

The flow of the air in the field described by the group of the solar collectors is complex being strongly influenced by the geometry and the dimensions of the building along with the wind attack angle in the contact with the building itself.

Eddies detached from the shear layers in the edge areas of the terraces and in the corners of the building intensify the local turbulence, placing the solar collectors there being in general forbidden.

3. Experimental Studies in Atmospheric Boundary Layer Tunnel

An experimental program has been developed in ABL wind tunnel (SECO 2) in the Laboratory of Aerodynamics from the Faculty of Civil Engineering and Building Services in Iaşi, with the goal to evaluate the wind loading on the terraces of standard existent buildings.

The model of the building P + 4E (Fig. 3) was scaled 1 : 50, the details being reproduced in order to obtain a realistic turbulent flow. The scale was chosen in order to meet all the criteria for obtaining a typical urban wind speed profile the corresponding turbulence and also to avoid blockage in the test area [3].

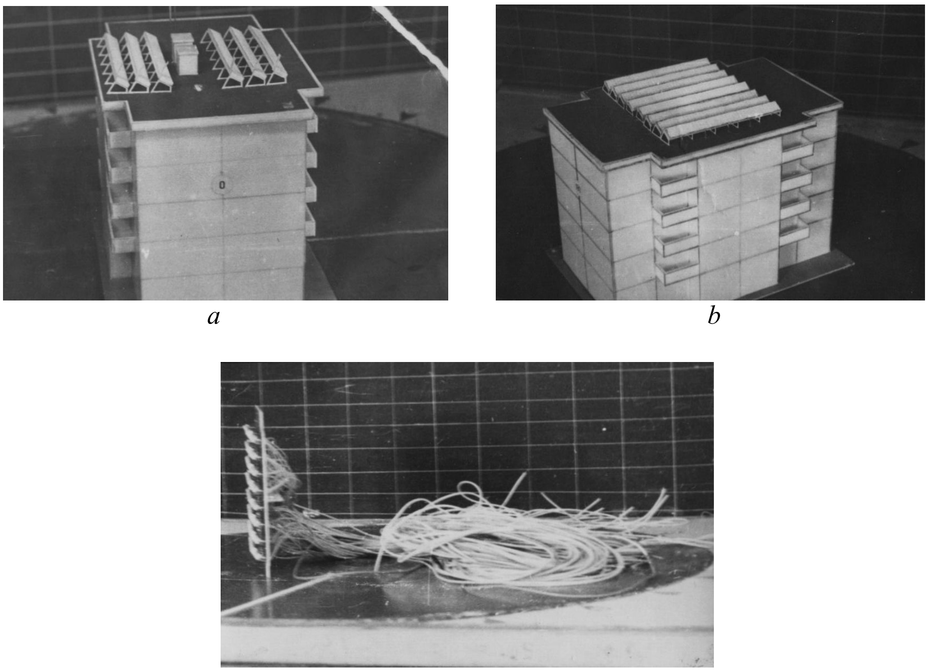
Solar collectors are placed in parallel rows with respect to the long dimension in the cross section of the building, in two situations:

a) groups of three parallel rows, separated by chimneys or ventilations (Fig. 3 *a*);

b) compact group formed by eight parallel consecutive rows, covering all the surface of the terrace (Fig. 3 *b*).

The inclination angle of the solar collectors with respect to the horizontal was 30°, and the distance between these and the terrace was 30 cm.

Being placed on the turning table, in the longitudinal axis of the tunnel, the model was sequentially rotated with 15º, and different wind attacking angles were obtained in order to observe the alterations of the pressure coefficients with the variation of this angle.


a *b*

c

Fig. 3 – Model of the building and the solar collectors: *a* – collectors placed in two groups of rows, *b* – collectors placed in groups of consecutive rows, *c* – model of the terrace with the collectors and the connecting pressure tubes.

The values of local pressure coefficients were determined considering the reference pressure at the height of the building.

Local pressure coefficients determined with the relationship (2) were thus studied for the two situations, a) and b), in the form of one averaged value, c_{LR}, on the row of collectors, for different angles of wind attack.

In order to put into evidence the effects of the wind upon solar collectors placed in the two versions presented herein, the variations of the averaged coefficient, c_{GR}, were studied and the results are presented in Fig. 4.

Scientific research in the early days of the XXI$^{\text{the}}$ century is challenged by the implications of the new concept of a sustainable development. Forecasting the conservatory values in the design to wind dynamic actions had become a main goal for a wide situations occurring during the design process.

From the presented study a general conclusion was drawn: the compact and uniform groups of collectors reduce the averaged wind pressure and thus, the consumption of metallic elements. Further more, a compact group is more advantageous from energetic point of view, comparing to the version of using separate groups of collectors.

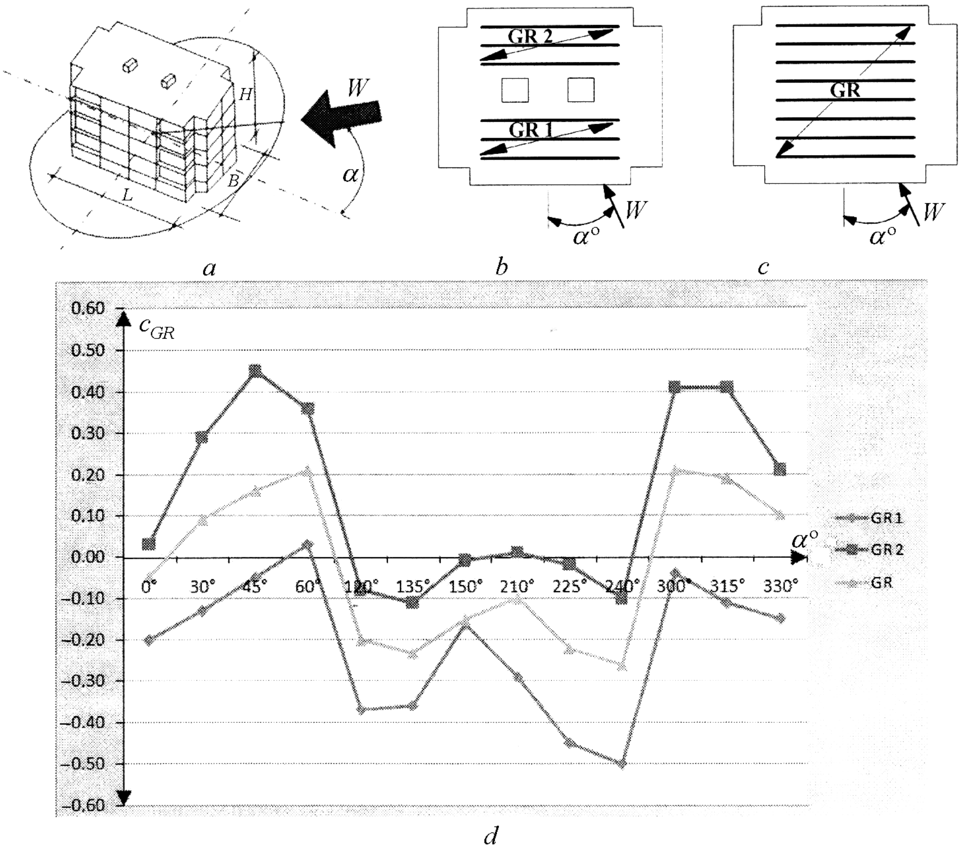


Fig. 4 – Variation of the wind pressure in the group of solar collectors placed on the building with a total height of P + 4E with $B/H = 0.7$; $H/L = 0.7$ (*a*), placed in separate groups (*b*), or in a compact group (*c*).

Existent elements place on terraces, like chimneys influence by number, size and height the distribution of wind pressure.

Solar collectors placed on the roof terrace of residential buildings are in general surrounded by a suction area with high turbulence, placed under the flow over the ridge of the terrace. This screening effect, generated by the building itself (Fig. 5), has an important consequence: the horizontal flow lines are deviated, spiral vortices surrounding the building.

Based on the local pressure values measured on the surface of the solar collectors wind local effects are obtained with a high precision, these values being used directly in the design of the metallic fixing elements and the sustaining structures.

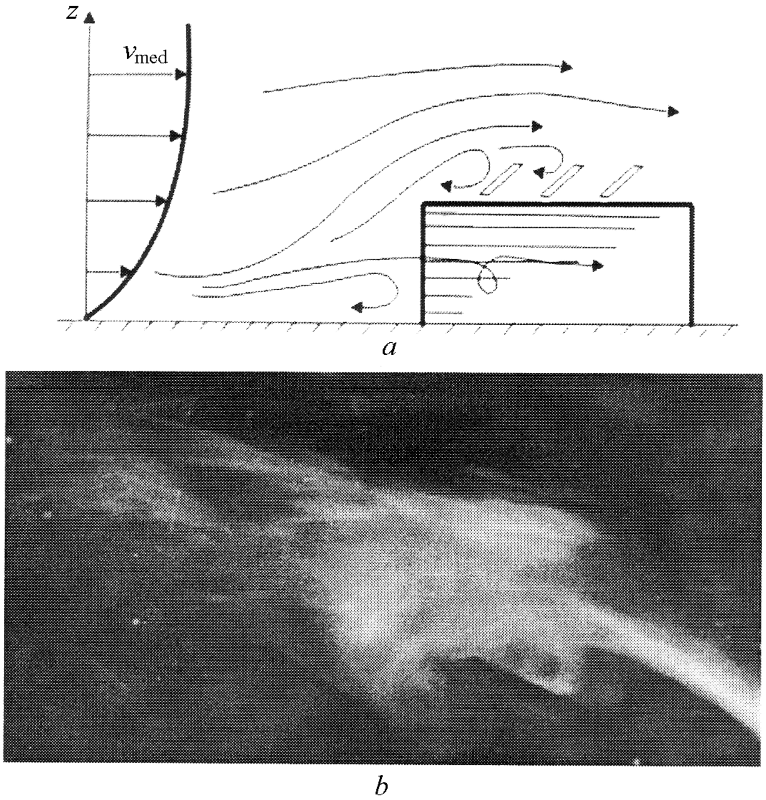


Fig. 5 – Air flow upon solar collectors placed on flat roofs: *a* – general flow, *b* – visualization of the turbulent flow between the rows of solar collectors.

6. Conclusions

The use of solar collectors is now considered as a necessity meeting the criteria emerged from the new concepts of a sustainable development and also having in view the increased human comfort imposed by a modern society. The solar radiation is a perpetual renewing source of unconventional energy and an economic solution fit for the climatic conditions in our country.

Placing the solar collectors on the top of the flat roofs raises specific engineering problems viewing the design of the collector itself but also the computation and design of the structural framework that sustain the collector and fix it on the roof. The main loading values for these structures are determined by the wind local fluctuations and in order to optimize the consumption of materials, the constructive solutions must meet several important criteria of strength, stability and also energetic efficiency.

The interaction between wind and the solar collectors is influenced by the wind characteristics (flow direction, spectral frequency of fluctuations, turbulence scales), by the building itself and the solar panels (dimensions, grouping, position, and inclination, fixing details and sustaining elements).

Wind action integers numerous effects caused by the existent obstacles between the collector and the incident pressure. In almost all the codes for practice these situations are presented with very general aspects, any particular case being the object of tunnel scale test recommendations.

The results from special studies in wind tunnel are relevant for the design for the solar collectors systems to wind action and also they give solutions for optimization in the design in order to satisfy both economic and safety criteria.

Received, February 14, 2010

"Gheorghe Asachi" Technical University of Iaşi,
Department of Civil and Industrial Engineering
e-mail: eaxinte@ce.tuiasi.ro
carmen_teleman@yahoo.com
roscave@yahoo.com
geta_vasies@yahoo.com

REFERENCES

1. Axinte E., *Modelarea fizică a interacţiunii vânt-structură pentru proiectarea captatoarelor solare*. Ph.D.Diss., Polyt. Inst., Iaşi, 1988.
2. * * * *Acţiuni asupra structurilor*. Partea 1-4: *Acţiuni generale - Acţiuni ale vântului.* SR EN 1991-1-4/2006, Eurocod 1
3. Axinte E., Pescaru R.-A., *Studiul acţiunii vântului în tunel aerodynamic*. Ed. Cermi, Iaşi, 2000.
4. Radu A., Axinte E., *Wind Forces on Structures Supporting Solar Collectors.* J. of Wind Engng. a. Industr. Aerodyn., **32**, *1-2*, 93-100 (1989).
5. Naeeni N., Yaghoubi M., *Analysis of Wind Flow Around a Parabolic Collector* (1) *Fluid Flow*. Renewable Energy, **32**, *11*, 1898-1916 (2007).
6. Wood G.S., Denoon R.O., Kwok K.C.S., *Wind Loads on Industrial Solar Panel Arrays and Supporting Roof Structure – All 2 Versions*. Wind and Structures, an Internat. J., **4**, *6*, 481-494 (2001).
7. Chung K., Chang K., Liu Y., *Reduction of Wind Uplift of a Solar Collector Model.* J. of Wind Engng. a. Industr.Aerodyn., **96**, *8-9*, 1294-1306 (2008).

REDUCEREA RISCULUI LA VÂNT A SISTEMELOR METALICE DE FIXARE ALE PANOURILOR SOLARE

(Rezumat)

Interesul pentru utilizarea surselor de energie neconvenţionale, determinat de restrângerea severă a surselor de poluare, aduce în actualitate panourile solare. Amplasarea acestora pe acoperişurile terasă ale blocurile de locuinţe, noi sau existente,

ridică unele probleme inginereşti, printre care dimensionarea panourilor plane şi a sistemelor metalice de susţinere şi fixare astfel încât să fie satisfăcute exigenţele de siguranţă în exploatare la viteze mari ale vântului, cu consumuri minime de material şi pe baza unor soluţii structural-constructive convenabile.

Întrucât interacţiunea vânt–captatoare–clădire este complexă, se recurge la încercări pe machete în tunel cu strat limită turbulent pentru determinarea acţiunii vântului. Studiul experimental efectuat s-a derulat în Laboratorul de Aerodinamică a Construcţiilor de la Facultatea de Construcţii şi Instalaţii din Iaşi şi a relevat structura curgerii în zona de amplasare a şirurilor de captatoare dispuse în grupuri separate sau în grup compact precum şi intensitatea presiunilor (pozitive şi negative) necesare calculului de rezistenţă.