BULETINUL INSTITUTULUI POLITEHNIC DIN IAȘI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iași
Tomul LXI (LXV), Fasc. 2, 2015
Secția
CONSTRUCȚII. ARHITECTURĂ

STUDIES FOR PREVENTING THE IMPACT OF CLIMATE CHANGES UPON BUILT ENVIRONMENT

BY

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Received: May 29, 2015
Accepted for publication: June 12, 2015

Abstract. Current climate changes correlated with development of urban areas on large scales, often exposing the communities to unanticipated consequences caused by extreme manifestations of natural phenomena produced by intensification of wind action. These climate challenges have prompted an increase of studies regarding the effects of random wind action on construction and the built environment. The paper summarizes some of the experiments performed in turbulent boundary layer wind tunnel, in parallel with numerical simulation techniques, developed lately with the purpose of refining the process of modelling at reduced scale in laboratory and also of advancing on the analytical directions of study of the wind flow in boundary atmospheric layer. These studies helped to enrich the information from standards, regarding the fluctuating pressure distributions on the surface of tall buildings or other important structures with atypical geometry, the movement of the air flow at the ground level with notable consequences for outdoor activities, the uneven snowdrift on rooftops and also on the traffic infrastructure during the winter deposits resulting in more accurate and realistic design loads from snow.

Key words: wind action; boundary layer wind tunnel; numerical simulations; snow action; pedestrian comfort.

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1. Introduction

High-rise structures are sensitive to wind action and recent scientific advances contribute to improvement of the design process. Two relative new directions of engineering emerged from the combination of mathematics, statistics, meteorology, physics and building engineering: building aerodynamics, domain of studying the modifications of the wind flow field by the presence of the built environment that induce consequences upon the human comfort and wind structural engineering, domain related with the safety design to wind dynamic action. Lately massive preoccupations were directed towards integration of the wind action in producing the green energy; the design of the individual solar collectors or of solar farms obtained by grouping these individual elements revealed new directions of study.

The aerodynamics of environment is one of the most active fields of study at international level; the framework of different governmental programs comprise exhaustive analyses underlying the entire policy of regional development and the policy in the field of buildings and spatial planning.

One of the most significant cases of studies on the impact of wind action that fundamentally changed the traditional concepts was developed in U.S.A. and Canada (Boundary Layer Wind Tunnel Laboratory, South Ontario University, Canada). After disastrous collapses of important bridges in USA and UK early in the years of 1900 due to wind extreme action, highlighting the impact of wind forces induced on tall buildings is quite a relevant case of the XX century studies. In Europe, large urban areas have master plans validated and developed based on aerodynamic testing environment (*e.g.* the environmental wind tunnel C.S.T.B. in France).

A relevant example in the field is the involvement von Karman Institute from Brussels to city development, in accordance with the requirements of the criteria of urban comfort. Accordingly, the whole European Community subsequently adhered to the principles and recommendations developed, so far a standard analysis of the impact of wind is required as an important condition for granting certificates of construction and environmental permits. Insufficient knowledge of all aspects that define the action of wind on buildings led to the production of numerous accidents (Fig.1), requiring the need to develop and deepen the aerodynamics and the wind engineering.

At the Faculty of Civil Engineering from Iasi, is working the Laboratory of Building Aerodynamics that has over 40 years research activity, dedicated to the vast effects wind action on the built environment. Settled in 1969 from the initiative of prof.univ.dr.eng. h.c. Adrian Radu, the laboratory is intended for experimentation on physical models and is equipped with a turbulent boundary layer wind tunnel used to simulate the mechanical effects of wind loads on buildings and building elements, the moving of air flow to ground level with important consequences on outdoor activities, the dispersion of pollutants under wind action, optimization of the urban architectural details for reducing heat loss from buildings and natural ventilation of buildings, snow loads uneven deposits on rooftops and on roads and high ways, etc. The laboratory is equipped

a *b*

Fig. 1 – Damages produce by wind: *a* – Takoma Narrows bridge (http://en.wikipedia.org/wiki/Tacoma_Narrows_Bridge); *b* – Roof from Colentina, Bucureşti (http://www.gandul.info/stiri).

with a wind tunnel for very small scales of modelling (SECO 1) (Fig. 2 *a*) and an atmospheric boundary layer wind tunnel for larger scales (SECO-2) having a 1.40m x1.40 m cross-section (Fig. 2 *b*), and a 10 m length, satisfying a wide range of tests (Axinte, 1988; Pescaru, 2000; Axinte & Pescaru., 2000).

a *b*

Fig. 2 – Laboratory of buildings aerodynamics: *a* – SECO1 tunnel, *b* – SECO 2 tunnel.

The development of methods used for the investigation the wind effect in B.L.W.T. by reproducing at small scale the built area and the possibility of obtaining the specific turbulent boundary layer conditions from a specific environment was important because of the most advantageous ability to put in evidence by wind tunnel experiments the sensitivity to wind action of the prototypes. Because both wind tunnel and experiments at natural scale require significant time and financial resources, a new direction emerged from aerodynamics and wind engineering that allows the numerical simulation of the wind effects, based on computational fluid dynamics (CFD). The numerical simulation is an ambivalent method of supplying the physical modelling if the simulation conditions are clear and verification and visualization of the general aspects of air flow surrounding the structures situated on the ground and immersed in the boundary layer.

2. Experimentations Concerning the Wind Effects on the Built Environment

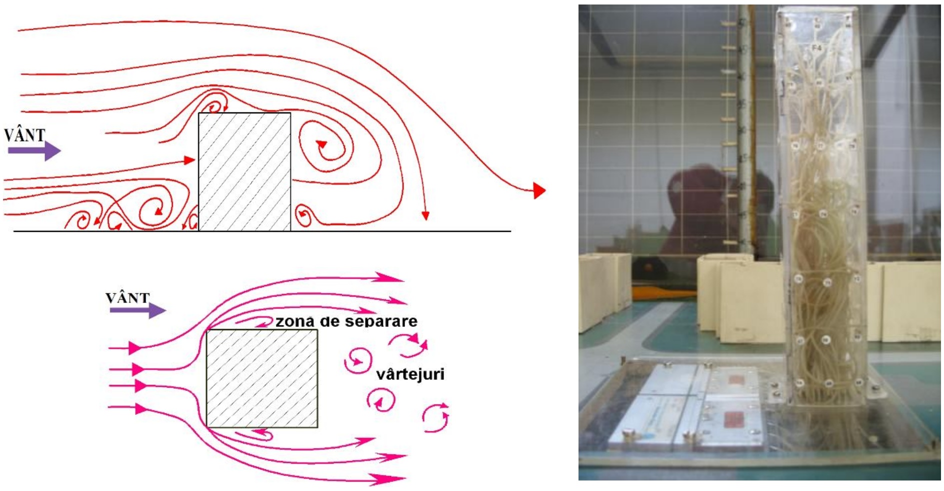
Full scale observations and measurements, correlated with the physical modelling technique of turbulent air flow in the building area, revealed different manifestations of wind action, sometimes with unexpected unfavourable effects.

The assessment of wind loads required for the strength structure design of buildings and their light envelopes (walls and roofs), are based on the pressure coefficients that reproduce the wind pressure field. The pressures values obtained as a result of the measurements on rigid models in wind tunnel allow the evaluation of wind loads for both long term, mean effect, used for the structural design and the short term gust effects, important in the design of the non-structural elements sensitive to wind action.

2.1. Assessment of the Pressure Field on the Surface of the Buildings

In urban areas, sharp edged buildings, so called bluff bodies, from aerodynamic point of view, have the capacity to model the air flow due to shape and size (Fig. 3 *a*); the wind speed increased generates turbulence occurring in strong eddies on the in wind building face and at the corners. Behind the buildings the wind flow in wake produces strong vortices whose dimensions are scaled by the speed of the flow and the in plane shape of buildings; regardless of these dimensions, it is a common fact that on encountering a bluff body the air flow diverges, the deflected streamlines being shaped by the speed of the flow, the dimensions of the building and the turbulence of the site. The pattern of the air flow, in plane or in space, is directly related to the configuration of the buildings and theirs neighbouring areas.

In the case of multi-storey buildings with 16 to 30 levels (Teleman, 2000), the unfavourable effects manifest regardless the position of the building in a particular site. Wake is present in the rear flow and the sharp edges model the divergence of the wind lines of flow, which generate corner shear and delta wing vortices caused by the interface between the in wind positive pressures and the shear layers generated on the surfaces parallel to wind flow, resulting in negative pressures. Local increased speeds and turbulence are always expected in these particular areas on the surface of the buildings.



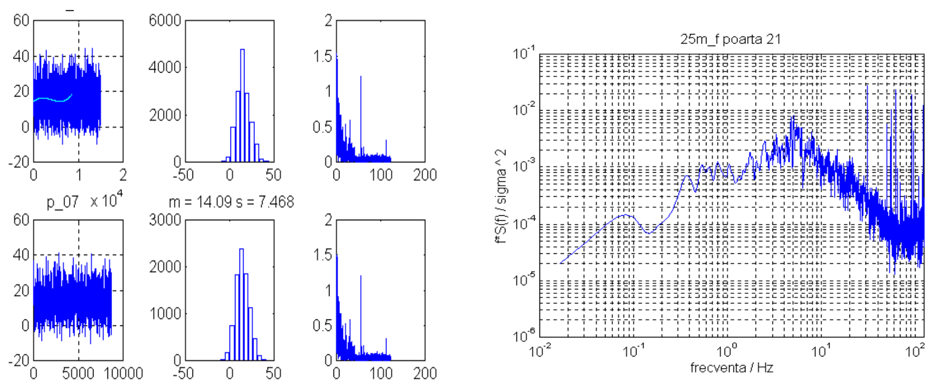
a *b*

Fig. 3 – The complexity of fluctuating air flow around tall buildings: *a* – Changing the direction of air flow due to the building geometry, *b* – The model of the building equipped for wind tunnel measurements.

Some studies carried out in the Laboratory of Building Aerodynamics aimed to assess wind pressures required for the design of multi-storied buildings and their façades and their goal consisted in obtaining the values of fluctuating pressure coefficients that customize the intensity of pressure field. The classic and most reliable measurement equipment and data processing of the laboratory, allowed the acquisition of instantaneous velocities and pressures and the possibility of determining the dynamic characteristics of the turbulent flow in the wind tunnel (Fig. 4).

According to the results obtained, the internal pressure depends on the action of external pressure on the whole building, as well as the importance and the location of the openings (windows and doors) provided on the envelope. For these situations, studies were performed in order to put in evidence the particular effects that occur in the case of light facades of multi-storey buildings, sensitive to wind fluctuations.

An example of evaluation of the wind effects upon the roof of a particular structure sensible to wind action refers to the study of a construction placed on Catalina hill (about 400 feet) situated closely to Iasi, in the Cucuteni area, the habitat of the well-known Neolithic culture. Having a shape of parabolic hyperboloid shape, sustained by tensioned gables this structure is most particularly sensitive to wind dynamic actions. Due to strong galloping with large amplitudes and periodic phenomenon of vortex detachment, the roof cover membrane, made of heavy panels began to deteriorate gradually, finally reaching the collapse (Fig. 5).



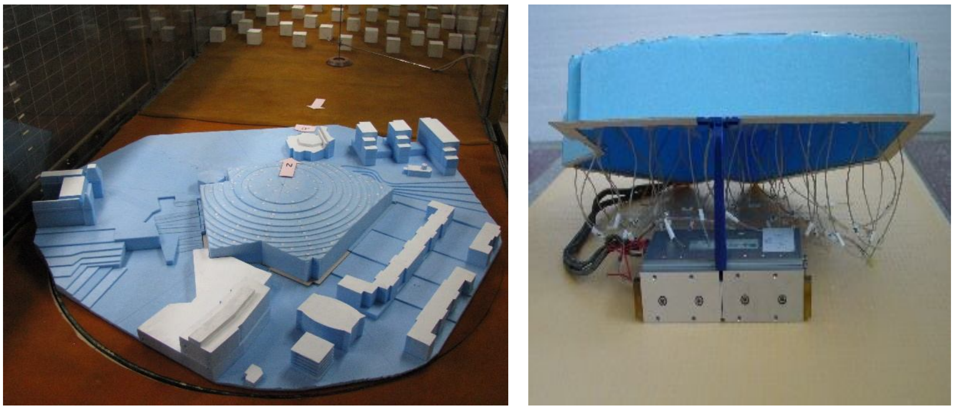
a *b*

Fig. 4 – *a* – Signals recorded/processed based on data acquisition in wind tunnel, *b* – Energy spectrum of fluctuating pressure.

Fig. 5 – The damaged construction and rigid model reduced to a 1/100 scale.

As a result of the measurements made on rigid model scaled 1/100 as well as the model of the construction and the Catalina hill, on the 1/400 scale, the mean and peak pressure (suction) were determined by algebraic summarizing the external and internal effect of wind action on the envelope.

An important experimental program of study in the Laboratory of Building Aerodynamics aimed to assess the behaviour of a large roof to the action of wind and snow (Fig. 6 and 11) (Teleman *et al.*, 2012; Teleman *et al.*, 2011).



a *b*

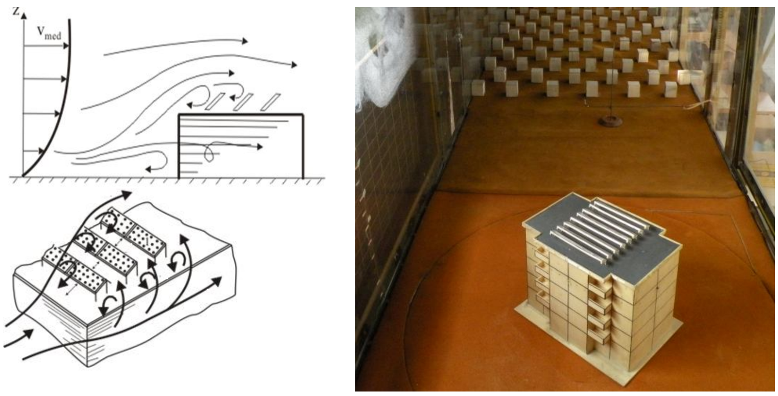
Fig. 6 – *a* – The model of the building with large-span roof and the neighbouring area; *b* – the model of the building equipped for pressure measurements and pressure tubes connected to the scanner.

The irregular shape and wide dimensions of the structure and of the cupola that covers it, as well as the particular at site position of the building in the surroundings, made impossible the classification of the building in the standard situations given by design codes specific to climate actions. The experimental study was conducted in two stages, the goals being to determine the drag coefficient of average and peak pressure on roof surface and the evaluation of snow drifted deposits in blizzard conditions and erosion of the deposited snow layer, respectively (Teleman *et al.*, 2011). Considering several directions of wind action, small-scale reproduction of the building and the adjacent built area, the accurate reproduction of details that alter the airflow at full scale, as well as the large number of taps where pressure measurements were made, have led to a large amount of information needed to assess the effect of wind and snow on dome roof.

2.2. Evaluation of Wind Pressures on Solar Panels Placed on the Roofs of the Building

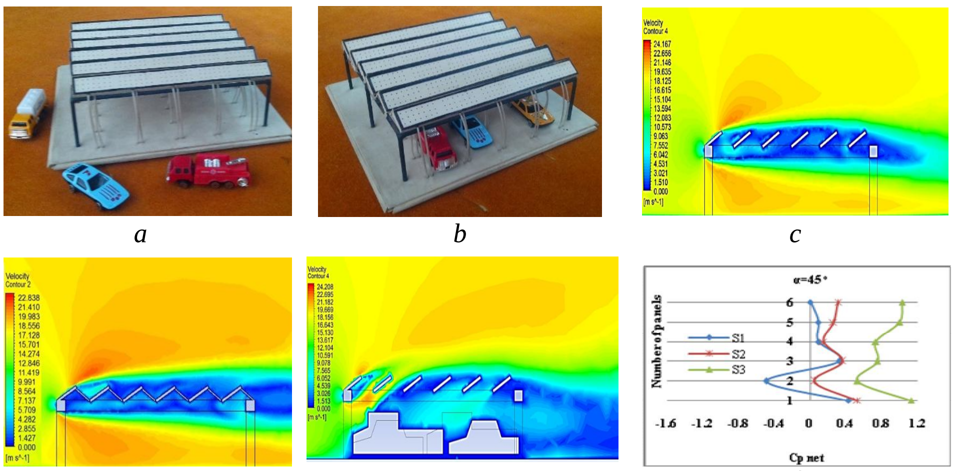
Many experimental and numerical studies were carried out all over the world with purpose to assess the effect of wind action on solar panels, single or displayed in consecutive rows, particularly motivated by the lack of adequate recommendation that the design codes would give for such cases of design to wind action.

Car parking spaces are potential sites for solar panels as well as building roofs. A complex program has been developed in the laboratory (Axinte, 1988), based on physical modelling and numerical simulation (Văsieş, 2012), having as object the solar panels placed on the flat roofs of buildings (Fig. 7) or open car parking (Fig. 8). The measurement of local pressure values on the solar panels surfaces without perturbing the air flow around them, was possible by using a new method for averaging the pressure pneumatically (Radu *et al*., 1986; Radu & Axinte, 1989).



a *b*

Fig. 7 – *a* – Altered pattern of the air flow on the roof terrace of the building due to the presence of solar panels rows; *b* – The physical model used in experiments.



a *b* *c*

d *e* *f*

Fig. 8 – Study of the air flow in the field of the solar panels array placed on the top of a parking place: *a* – Model of the parking place free of any occupancy; *b* – Model of the parking place occupied by cars; *c*, *d*, *e* – Pressure contours on the panels in the situated analysed obtained by simulation in ANSYS CFX; *f* – Variation of the pressure coefficients resulted from variation of the wind direction and the position of the panel in the array.

2.3. Analysis on Small Scale Models in Wind Tunnel of the Pedestrian Comfort in Urban Areas

Our city centres with important monumental historical buildings have always represented our cultures and civilization, true centres of touristic attraction. A sustainable development must have several goals in attention; accordingly, besides rehabilitation of these built environments that worth being preserved, the human comfort in urban context must also be considered. The interaction between the urban texture and the wind flow confined in narrow spaces proves to become critical in specific situations; the wind bursts at the ground level increasing in turbulence with the spatial dimensions of the obstacles and the density of the built environment, human activities are affected sometimes in the acutest level. The following two methods are conceived for the investigation of the pedestrian comfort in laboratory.

a) *The powder method*

This is known as a classic method of visualization of the movement of air currents at the ground level. It consists in placing the models that form the built area on a smooth plate in glass or plastic board and covering it with a thin uniform layer of a mixture of white powder and a volatile substance; the air flow drives the mixture forming the stream lines, the areas of stagnation and the shape of the eddies that wipe out the white fluid solution from the floor (Fig. 9). When drying, the image gives qualitative, eloquent information about the exposed or sheltered areas, the areas of formation of the stationary vortex, the flow lines and in particular, the snow agglomerations (Pescaru, 2000; Axinte & Pescaru, 2000;), being similar to the radiography of the air flow between the obstacles implanted in the urban texture.

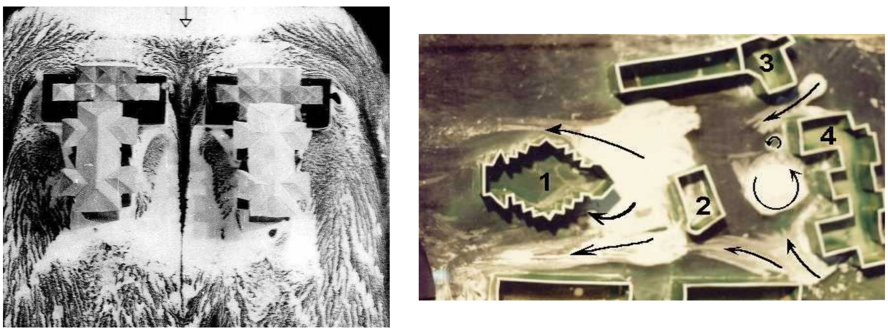


Fig. 9 – Visualization of air currents using powder method.

b) *The pawns method*

An original method was developed in the Laboratory of Building Aerodynamics of the Civil Engineering Faculty in Iasi that allows determining the wind discomfort in the built environment by using aluminium pawns, arrayed at gauged distances throughout the area of interest around the built obstacle (Pescaru *et al*., 2000). The method consists in a slow growth of air speed, in the wind tunnel, until the first pawns are falling (Fig. 10).

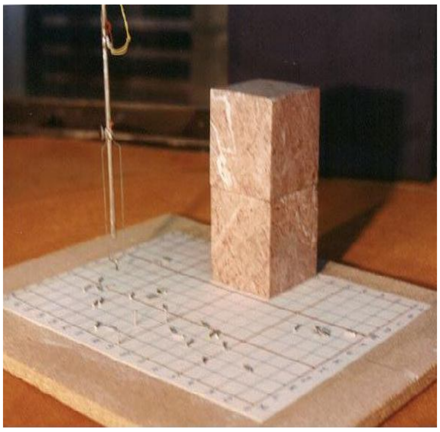
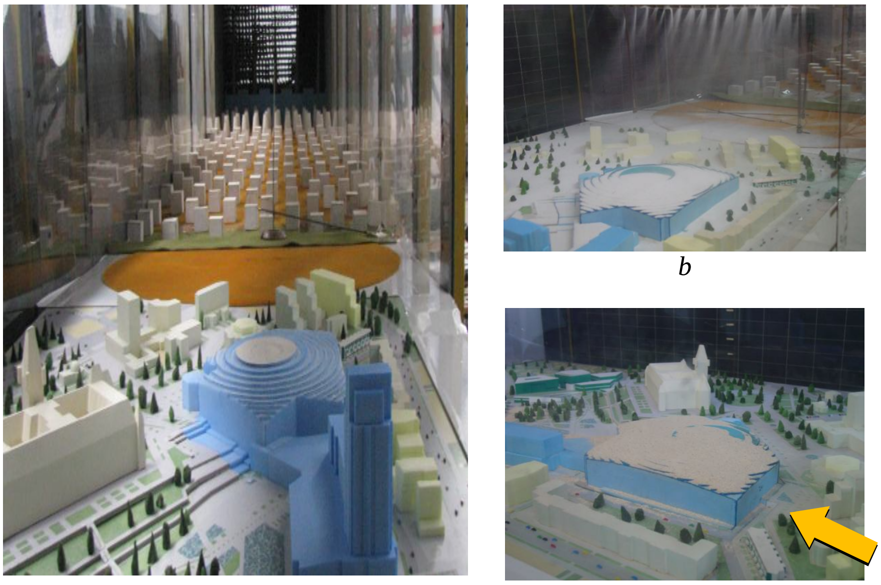


Fig. 10 – The model at scale representing a tower building and the iso-comfort map of wind speeds drawn by using the pawns method.

The air speed is marked and the entire procedure is repeat, increasing gradually the air velocity. Comparing the speed of falling the pawns on the ground level without obstacles (V), in the absence of the building with the speed of falling of the pawns placed in the array containing the building (V_1 ... V_n) a k_i coefficient is obtained, representing the degree of discomfort to wind speed, at pedestrian level, for different points of location of pawns. The data are used for drawing maps marking the pedestrian areas of similar degree of pedestrian discomfort caused by wind. The method is useful for optimizing the details of the systematic circulation in the proximity areas of large buildings.

2.4. Agglomeration of Snow Due to Wind Action

Simulation of deposits snow in the conditions of generating blizzards involves understanding the phenomena that occur during snowfall accompanied by an increase of wind speed and also the choice of an optimal material that simulates the snow fall in order to reproduce the real trajectory of snowflakes carried by wind. The amount of deposited snow, as well as the snow agglomerations or the sheltered areas, depend on the wind speed and turbulence.



b

a *c*

Fig. 11 – Snow agglomerations on a wide span roof having a geometry that favours the snow deposits: *a* – model of the building and the surroundings placed in the SECO2 wind tunnel, *b* – snow drift formation during snow storms, *c* – eroded areas of the snow deposit under wind action.

According to Iversen (Iversen, 1979), the physical scale model of wind transportation has to reproduce the saltation phenomenon, which is predominant in the first few centimetres above the snow layer. Modelling the snow-scale in wind tunnel is quite difficult due to the complexity of snow fall phenomenon extremely sensitive to several factors among which the air temperature, ground temperature, duration of the event, wind flow field and other characteristics of the studied areas.

To evaluate the snow deposits and highlighting the drifting phenomenon, two methods have been used in laboratory during multiple simulations that are based on the erosion and deposition of a material that simulates the snow particles. Two granular materials were used to simulate the snow, wood sawdust and glass micro beads. Using both methods, quantitative measurements of deposited respectively eroded snow layer have been made for a roof with large dimensions (Teleman *et al.*, 2011), (Fig. 11).

By reproducing the phenomenon of snow falls during wind storms on the roof terrace equipped with solar panels, the snow drifted areas were analysed (Axinte *et al.*, 2012) (Figs. 12 and 13); systematic studies were also developed for modelling at small scale the efficiency of the snow fences that protect the roads from snow drifting (Florescu, 2001) (Fig. 13).

a *b*

Fig. 12 – Simulation of the snow agglomeration during storming weather on a terrace provided with solar collectors placed in parallel rows: *a* – formation of the snow drift; *b* – increased amounts of the snow deposit due to the presence of the solar panels.

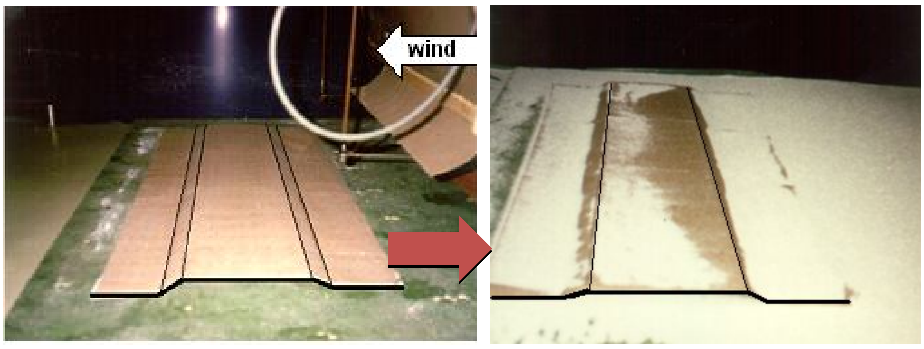


Fig. 13 – Physical model of the snow drift on roads using glass beads.

3. Conclusions

The experimental studies developed in wind tunnel provide us relevant information upon the effects of wind flow around the buildings placed in urban areas. They help by enlarging the necessary data for the design of a wide range of buildings and other structures, draw the attention upon unexpected effects of wind turbulence in built environment and increase the accuracy of the analytical modelling via numerical methods. They are now a powerful instrument of simulation of the complex impact of the field of speeds and pressures on the volumetric shape generated by the presence of the built structures in the atmospheric boundary layer.

The advantages of studying on scaled models in wind tunnel are important: optimizing the structural design, reducing the excesses in the design due to uncertainties, a quasi-exhaustive assessment of the wind effects upon the environment and the possibility of modelling a wide range of other connected phenomena (pollution, thermal effects of increasing the urban density, etc).

The future research directions in the boundary layer wind tunnel have in view important fundamental aspects, like: accuracy of the physical in order to match a larger number of similarity, validation of the results obtained, calibration of the methods adopted for measurements through statistical analyses of the sets of data, application of several types of numerical simulations in order to obtain accuracy and control the complex mechanisms of modelling the wind flow.

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PREOCUPĂRI ÎN PREVENIREA CONSECINȚELOR IMPACTULUI SCHIMBĂRILOR CLIMATICE ASUPRA MEDIULUI CONSTRUIT

(Rezumat)

Modificările climatice actuale corelate cu dezvoltarea rapidă a zonelor urbane, expun comunitățile la consecințe adesea neanticipate, cauzate de manifestările extreme ale fenomenelor naturale produse de intensificarea acțiunii vântului. Aceste provocări climatice au determinat intensificarea studiilor privind efectele acțiunii aleatoare a vântului asupra construcțiilor şi a mediului construit. În lucrare se prezintă sintetic unele dintre experimentele realízate în tunel aerodinamic cu strat limită turbulent, completate in ultimii ani cu simularea numerică. Aceste studii au contribuit la completarea informațiilor din normative referitoare la distribuții de presiuni fluctuante pe suprafața clădirilor înalte sau cu forme atipice, deplasarea curenților de aer la nivelul terenului cu consecințe importante asupra activităților în aer liber, aglomerarea zăpezii cu consecințe asupra încărcărilor pe acoperişuri şi a circulației pe căile de comunicație pe timp de iarnă etc.