Wind Tunnel Experiment for Pedestrian Wind Comfort in Sun Valley Campus

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Abstract. Various urban spaces around the world, were designed and built in respect with the design theories in order to satisfy different requests of users and inhabitants and to provide a quality urban spaces. The use of these spaces by the city citizen depends on many factors that influence their decision while choosing the urban space where to spend time. Among these factors, the comfort provided in any area is a crucial determinant that depend mainly on a wide range of climatic parameters such as air temperature, wind velocity, relative humidity, solar radiation etc. However, the impact of the micro-climates parameters on the user’s comfort in these open spaces has often been ignored and architects tend to pay more attention and consider the indoor comfort, but they may not consider the effect of their buildings on the outdoor environment, and pedestrian comfort. The article concerns an experimental study on the effects of the wind velocity on the pedestrian comfort and safety in a campus inside a bigger project called Laser Valley Land of Lights. With the purpose to provide a project with a complete harmony with the physical elements of the environment. Due to the fact that the interaction between the wind and the city buildings, create aerodynamic phenomena around building that impact directly the outdoor environment and make the study of the human outdoor comfort more complex. The study was carried out at the Aerodynamics and Wind Engineering Laboratory “Constantin Iamandi” (LAIV) from the Technical University of Civil Engineering Bucharest (UTCB). The project Laser Valley Land of Lights aims to implement the world’s most powerful laser, Extreme Light Infrastructure Nuclear Physics ELI NP Project. The campus under study won an international competition by providing an open research ecosystem taking into consideration that is based on green building and sustainable development. In this paper we describe the result obtained from the experiment performed in the TASL1-M Boundary Layer Wind Tunnel on the effects of the wind on the pedestrian comfort and the mitigation solution proposed for the critical and uncomfortable areas detected.

1. Introduction
The degree of comfort depends on numerous factors such as the individuals, their surroundings, the place where they are also the micro-climates parameters. In order to assess and investigate the pedestrian comfort, many methods are practiced, among them, mapping, interviews, wind tunnel investigation. The mapping and interviews consist of asking the public space users about what are the comfort factors that they may influence them to use this public space or no and to map this comfort factors. In this article wind tunnel investigation was tacking, the primary research goal of the study is to investigate the pedestrian wind environment in the campus of the Laser valley. The investigated parameters are the velocity and turbulent characteristics mainly at the high of the pedestrian. The results will help to prevent the wind problems that may occur due to the building presence and that may cause comfort problems to
the pedestrian. Furthermore, a sets of measures will be proposed in the case were wind problem are detected in the area in order to maintain velocity and turbulence levels in the comfort range.

The investigations were carried out on the project Laser valley campus, this project is the winning project of an international competition that was developed by a group of architectural student with the main objective to develop and create a mixed use area that allow professor, students and staff to work and live on the site. The fundamental concept in the design was to achieve a sustainable project. Significant importance was to be given to the wind comfort as an integral part of a wider environmental strategy.

2. Experimental setup of wind tunnel and instrumentation

In order to investigate the wind environment and to provide comfortable area for pedestrian, we carried out wind tunnel measurement on the pedestrian wind level in the outdoor space of the campus inside a project Laser Valley Land of in Bucharest, Romania.

The research infrastructure used for this study is the new Boundary Layer Wind Tunnel (BLWT) at the Aerodynamics and Wind Engineering Laboratory “Constantin Iamandi” (LAIV) of the Hydraulics and Environmental Protection Department from the Technical University of Civil Engineering Bucharest. The wind tunnel was renovated in order to get improved capacities based on the old TASL1 BLWT.

The wind tunnel of the technical university of Bucharest is the largest research infrastructure for wind engineering in Romania where it is possible to generate a velocity field and turbulent structure which is adapted to new demands of wind engineering phenomena with the high and modern precision measurements [1].

The wind tunnel is characterized by a length of 27 m, the active section has a length of 18.9 m moreover, the cross-section of the experimental vein is square with a characteristic length of 1.75 m [1]. LDA system was used in this experiment.

3. Design and manufacturing of the sun valley area model

It is based on the architectural design (figure 1) that the model of the sun valley area was manufactured, the material used for the building models is the extruded polystyrene mainly the polystyrene boards were overlapped, glued then cute in order to have the desired high according to the high of the houses.

The geometric scale of the model was chosen with taking in consideration the properties of the wind tunnel, its rotating plate in order to respect the geometrical similarity.

![Figure 1. lazer Valley campus 3D](image-url)
The model has geometric scale of 1:65. The diameter of the model tower is 16 cm; the total height of the experimental model is 38 cm for the tower and 8.2 cm for adjacent houses, respectively. The model was subjected to a process of punching, drilling and painting (figure 2), the black color was chosen in order to increase the quality of the photo capture.

Figure 2. Laser Valley model preparation painting and drying

The models are mounted on the turntable placed on the floor of the wind tunnel (figure 3), in the experimental vein, every time the turntable was rotated in order to investigate the eight different wind directions. On the \( \frac{1}{4} \) of the tower lateral surface 78 holes with a diameter of 3 mm were designed in order to install the pressure taps inlet tubes; among that, 15 pressure taps are placed on the top of the model.

4. Investigation of the wind effect on pedestrian comfort in sun valley area

4.1. The pawns method

The pawns method consists of detecting the area where the wind may cause uncomfortable situation for pedestrians mainly by dispersing the pawns in the study area. The pawns were made from extruded polystyrene which they were cute in homogenous shape and then distributed equally on the zone under investigation. Figure 3 shows the pawns distributed on the area. When starting the fan of the wind tunnel it was noticed that the pawns stagnate in some areas, however some other area stayed free of pawns.

Figure 3. Distribution of the pawn in the model
Mainly the area with stagnant pawns represent the areas with the lowest velocities which doesn’t represent a danger for the pedestrian however the no pawn zone represents a source of discomfort. Figure 4 a, b: shows the pawns before and after starting the fan of the wind tunnel. The area with the stagnation pawns mainly represent the areas with the lowest velocities.

However, this method provides only qualitative results which may not be accurate and need to be investigated and verified with more accurate method due to that we carried velocity measurement tests by the LDA in order to get quantitative results and to investigate in an accurate way the no pawns zone that represent the area with higher velocities and mainly a source of discomfort for pedestrian.

4.2. Velocity measurement in horizontal plane

After the pawn method, LDA measurement was done on the laser valley campus model already installed in the wind tunnel in order to investigate in accurate way the no pawn area because the pawn method provided only qualitative results.

The wind profile (Figure 5), is generated by the roughness system situated between the inlet of the tunnel and the experimental veins. The roughness on the bottom of tunnel can be modified automatically by adjusting the height of 560 bricks between 0 and 200 mm in order to obtain a simulation closer to the reality. The wind flow inside the aerodynamic tunnel is correlated with the mean wind speed profile of Bucharest according to the Romanian code CR 1-1-4/2012 [2]. Thus, the roughness height was setted-up to 10 cm.

In the present case, where the project Sun Valley being on a category III field, the factor kr (z0) is 0.214.

Given the characteristics described above, and considering the logarithmic law across the entire thickness of the atmospheric boundary layer, the following average velocity profile emerged:

Performing experimental tests in the aerodynamic tunnel requires that the wind action be modeled in respect to:

• the average wind speed profile
• turbulence characteristics in the construction site

The average velocity profile used in the experimental tunnel tunnel test performed in the present work was determined according to wind code CR-1-1-4 / 2012.
Figure 5. Wind profile Magurele created according (CR-1-I-4/2012 – Design Code Assessment of Wind Action on Buildings)

We opted for the LDA system, because it doesn’t interfere with flow in the opposite of other technique that doesn’t allow the measurement of the very low velocities and introduce thermal convection in the flow. Furthermore, the LDA system is characterized by its high spatial resolution and the directional sensitivity. Moreover, the measurement is independent of the thermos-physical properties of the fluid (Figure 6).

The LDA system is an optical instrument used for more than three decades in order to measure the instantaneous speeds and to provide information about turbulences or average speed of the flow or gases in different environments (closed or open, high temperature or combustion, etc.) [3].

From the desire to determine the velocity distributions in a free-flow or under-pressure flow, over the years several techniques were developed to investigate and study local velocities in fluid flow. Among these techniques, there are intrusive methods such as pressure probes, hot wire anemometers, on the other hand non-intrusive methods for example the Particle Image Velocimetry (PIV) or Laser Doppler Anemometry (LDA) [3].

In every time, two components of the wind velocity were registered at the heigh of the pedestrian, in the horizontal plane at the high of 1.5 m full scale and 15.38 mm height at model scale. The velocity in the free stream, measured in the centroid of the cross-section placed upwind the model, after the wind tunnel honeycomb was equal to 9 m/s. The velocity was normalized in respect with the velocity in the free stream.

In this study, the south area was investigated with the LDA system among the other direction due to the fact that the measurements area was limited by the 3D traverse system that couldn’t move further in the area because of the the height of the central building.

The results of the velocity measurement tests by the LDA system are shown in Figure 7, it was registered that a zone of low velocity was registered in the wake of the tower in the south zone and represented with the blue color, this effect extends for a considerable distance upstream the tower indicating that the buildings provide shelter to these locations from the wind for a certain distance.
However, high velocity was registered on the two sides of the tower mainly the South East and south west zone of the tower represented with the red color, mainly the velocity magnitude attended the value of 0.6 and 0.65 which make this zone as a source of discomfort for the pedestrians who traverse that area.

**Figure 6.** Experimental model with the LDA system at the Aerodynamics and Wind Engineering Laboratory ‘Constantin Iamandi’ (LAIV)

**Figure 7.** Velocity measurement results

4.3. Results of the pressure measurement

In the cylindrical building, was installed the 78 holes for the pressure taps inlet tubes, that was linked to the pressure scanner of the wind tunnel at the Aerodynamics and Wind Engineering Laboratory ‘Constantin Iamandi’ (LAIV) (figure 8).
In the above we present the results for the pressure measurement on the cylindrical building. The measurements made in the aerodynamic tunnel with an atmospheric start limit led to the determination of the local pressure distribution on the surface of the cylindrical building.

Based on these pressure values as well as the static pressure values in the tunnel and the air velocity measured at the reference height, the values of the local pressure coefficients for the eight wind directions considered were determined. The distribution of local coefficients was shown below.

The results of the pressure measurement tests along the tower for the north direction are illustrated in Figure 9. The values of the pressure coefficient recorded on the front side of the tower model are in the interval of (-8.5, 0) and is by far the most representative of the exposed ones and the maximum value found.

Whereas in the case of the latter, the interval changes significantly and it decreases the becoming (-7.5, 0) in the case of the rearward face the pressure remains low and approximately constant between (-3.5, -4.5). However; the lowest pressure values were measured on the two sides.

For all sides investigated here, the pressure coefficient on the front side was the higher value registered due to the fact that is exposed to the wind. Due to that it will be important to provide a specific treatment in the case where the will window glasses or balconies.

Figure 8. The pressure taps linked to the pressure scanner of the wind tunnel at the Aerodynamics and Wind Engineering Laboratory ‘Constantin Iamandi’ (LAIV)

5. Conclusions

The comfort and the well-being of a city and its inhabitants can be affected by many conditions, we believe that the users are not arbitrarily distributed in space, but partly according to its morphological characteristics and its layout. These offer possibilities of protection against the negative aspects of the climate or to expose to its positive aspects.

The use of the outdoor space could be modified or oriented by microclimatic conditions, among that, wind environment is one of the urban physical environmental factors that affect the pedestrian comfort, an uncomfortable outdoor space may make inhabitants avoid using the spaces designed mainly in the purpose to foster the society integration. A wind tunnel experiment was conducted on the campus Laser Valley in order to investigate the pedestrian wind comfort.
Figure 9. Pressure measurement results

A preliminary study made using the pawn method gave inconclusive results. In order to gain more data, LDA measurements were performed on the model at a height corresponding to 1.5 m in the real environment. The first measurements gave high wind velocity, which was registered especially in the two side of the cylindrical building, which will cause discomfort for the pedestrians. Numerical simulation will be done in the further work in order to visualize the velocity in the entire area and to be able to compare it with wind tunnel result.

After the detection of the zone that cause discomfort it is essential to propose solution and the investigate their impact in further work.

- Comparison studies would be necessary in order to reveal similarities and differences in the result with a similar case studies.
- Comparison of the wind velocity with wind comfort criteria would be provided

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