Wind Action on Specific Building Structure Models of Reduced Height

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Abstract: *Wind action on building structures represents a real requirement on their resistance and there is a real concern on design made by the civil engineers building designers, especially when a multi-storey structure with a considerable height is considered for construction. Information provided in the design codes that specify the specific wind action values are used in the design activity. Analysis tools are also used based on the scale model of the structure being tested in the wind tunnel. The numerical analysis of air flow on the three-dimensional structure virtual model of a certain shape and size is a handy tool that can provide useful information in the design activity. This method is highlighted in this paper, which based on building models presents the results obtained from the air flow for different values of the displacement speed in the fluid region. The numerical analysis is carried out with the Ansys CFX program, and the results are presented in terms of velocity and pressure of the working fluid.*

Keywords: *Air flow, 3D modelling, computational fluid dynamics (CFD)*

1. Introduction

The wind action on the construction structures represent a constant concern of structural engineers because it is an important parameter for these structures stability, especially if a high altitude regime is considered.
In the direction of the wind action, the idea of substituting the dynamic action of wind gusts with an action in a static regime that coincides with the positioning of the action field of distributed hydrostatic pressure on the exposed building facade was early adopted.
On the other hand, the wind dynamic effects on the construction must also be considered so that the results obtained to be comprehensive.
The direct action of the wind on the building elements is illustrated in order to identify the efforts that are formed at the level of their frontal plane positioned in the direction of action.
The cases of different constructive forms of the construction are exemplified, namely the classic building model, as well as the semi-cylindrical model in section to see the differences that appear at the level of the front wall.
The theoretical aspects are presented that show the plane potential air movement model, which involves the principles of fluid mechanics, followed by the numerical analysis carried out on virtual models of buildings of different shape, so that the hydrodynamic effort values on each individual model could be identified, depending on the specific results recorded from the air flow analyses on the specific presented cases.

2. Wind action in terms of velocity

The action of the wind on a structure of any shape involves an energy conversion, so that part of the total energy induced within the structure is further dissipated by the subjected structure by the direct wind action.
This energy dissipation is carried out directly through the resistance structure of the building, but special dissipation and isolation devices can also be used precisely to prevent the devastating effects that can follow the destructive actions of the wind at very high speeds in the case of violent storms or tornadoes.
The value of the reference wind speed, acting in a certain area, which has the ability to generate a reference pressure at the level of a building positioned in a direction perpendicular to the main direction of wind action, must be taken into account.
The following relation can be written that considers the air density (approximately 1.25 kg/m3) 0:

$$p_r = \frac{1}{2}\rho_a \cdot v_v^2 \quad (1)$$

If we refer to the wind action on the constructions in the Romania area, we must take into account the specific speed values with which the air masses move at certain altitudes in relation to the sea level.
It should be noted that based on the studies carried out, the recorded wind regime for the Romanian area can be described, based on the data collected over the last 50 years, of the influence that appears due to the oscillations in the North-Atlantic area, using aggregated records from the majority of meteorological stations located in function.
Based on the recorded values, the multiannual average values recorded over time were thus calculated, following the existing correlation between altitude and wind speed (r = 0.87), making it possible to compose a map of average annual speeds with specific values presented in Table 1 0.

Table 1: Specific wind velocity values recorded for specific areas

Wind energy potential on specific Romanian regions	Wind action specific velocity (m/s)	
	Min	Max
Mountain region (Carpathians) – mountain peaks	7	10
Mountain region (Carpathians) depressions and valleys	3	7
Sea side	5	7
Plain areas	3	5

As expected, the highest wind potential is presented in the area of the Carpathian Mountains, as well as for the Black Sea coast area, where also the highest values of wind turbulence are recorded.
Other specific areas are represented by the plains regions, where medium-intensity wind actions with lower turbulence values are recorded, thus being suitable for the installation of wind turbines.
The highest wind speed values are recorded in spring (March), and the lowest in summer in (August).
For buildings of a certain shape, we expect to obtain different wind action depending on the shape of the building façade that the wind meets, and to exemplify these aspects, the cases shown in figure 1 are considered.

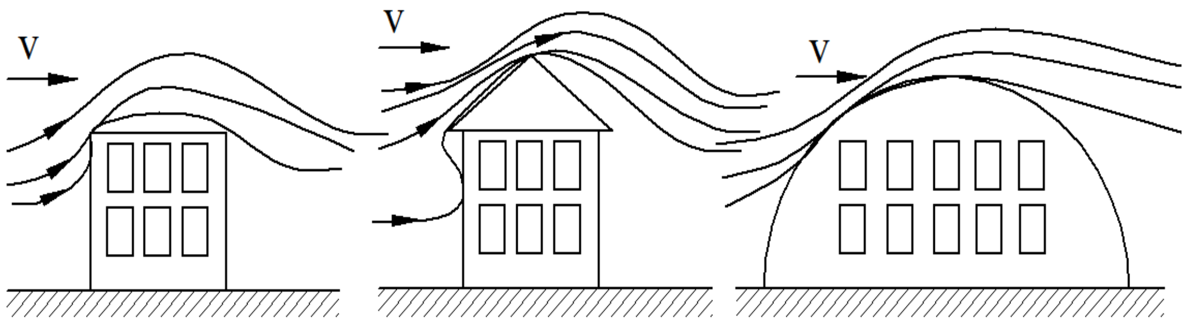


Fig. 1. The main building models considered for analysis

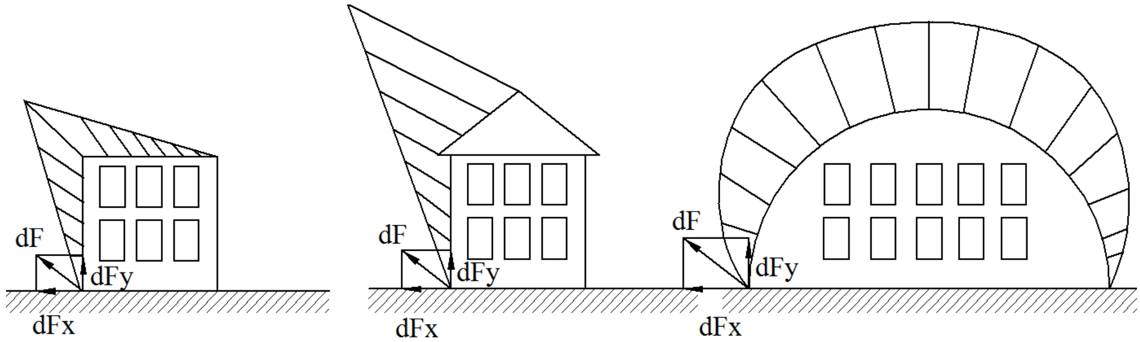


Fig. 2. Efforts considered and formed at the level of building models

The force acting on the front wall of the construction is actually the resultant of all the forces $d\bar{F}$ acting on the elemental surface level dS 0.

$$\bar{F} = \int_A d\bar{F} \tag{2}$$

The distribution of pressure values that form on the wall subjected to the action of the wind must be considered, as well as the velocity values recorded on the exposed contour.
The total velocity can be described by means of the following relations:

$$v = v_x + iv_y \tag{3}$$

$$v = \sqrt{v_x^2 + v_y^2} \tag{4}$$

Stagnation points located on the ground where the velocity is zero are thus considered, as well as the areas where the velocity has a maximum value, being represented by the points of maximum exposure located on the building façade.
The distribution of pressure values on the surface of the building on which the wind acts can be illustrated by writing Bernoulli’s equation between a stagnation point located at the base of the building characterized by values $(p_0, v=0)$ and some point on the surface of the pediment of values (p, v), neglecting mass forces 0, 0:

$$p_o = p + \rho \frac{v^2}{2} \tag{5}$$

$$p_o - p = \rho \frac{v^2}{2} \tag{6}$$

3. The turbulent character of air masses circulation

The action of the wind implies a strongly turbulent movement of the air masses, resulting in a continuous mixture of them, which implies frictional forces between the layers but also with the land that manifests itself from the surface of the land up to approximately 1000 m altitude.
These turbulent movements of the atmospheric masses register changes in the speed values, and by following the action directly on the buildings, it can be considered an intensity of action in the turbulent field on them.
The wind turbulence intensity value is related to the geometric elevation and can be defined as a ratio between the change in the instantaneous speed values and the average wind action values 0, 0:

$$I_{tv}(z) = \frac{\Delta_v}{v_m(z)} \quad (7)$$

Since the action of the wind undergoes substantial changes over time, it is important to establish the maximum pressure value that can be applied to a structural model located on the main direction of action. And this phenomenon is obtained in gusts of wind.
We will also see on the results of the numerical analyzes that are carried out for the air flow on a virtual model how the pressure values are obtained at the level of the exposed facade, while on the opposite facade pressure values that coincide with a depression (low pressure values) are recorded.

4. Interaction between wind and structure

A wind action of a certain magnitude can produce a response close to resonance, especially for structures that benefit from increased flexibility.
It can be considered that for this wind action on a specific building with a certain degree of height, the resultant force, acting on the facade in the static domain at a reference height measured from the ground, receives a structure response quantified by the dynamic response coefficient of the construction being described by the relation 0, 0:

$$F_r = \gamma_{ex} \cdot c_r \cdot c_f \cdot p_d(z) \cdot A_s \quad (8)$$

where:

γ_{ex} - represents the exposure factor;

c_r - the response coefficient of the building in dynamic mode;

c_f - aerodynamic coefficient of the construction;

$p_d(z)$ - dynamic pressure as a function of elevation;

A_s - the area exposed to the action.

5. Mathematical modeling of the air masses movement

Concerns about modeling aspects of fluid flow have existed over time, but in the 18th century flow models for ideal fluids were established by researchers such as Bernoulli and Euler 0, 0:

$$\frac{\partial v}{\partial t} + v \cdot \nabla v = -\frac{\nabla p}{\rho} \quad (9)$$

Later in the 19th century, Navier and Stokes introduced the viscosity factor into the equation of fluid motion 0, 0:

$$\frac{\partial v}{\partial t} + v \cdot \nabla v = -\frac{\nabla p}{\rho} + \nu \nabla^2 v \quad (10)$$

The English physicist Osbourne Reynolds introduces the concept of flow with average and fluctuating fluid velocity values, which led to the RANS (Reynolds Averaged Navier-Stokes) turbulent flow model 0, 0:

$$u(x,t) = \bar{u}(x) + u'(x,t) \quad (11)$$

And based on this consideration, the Reynolds stress is introduced within the fluid flow, which has the possibility to appear at the level of the surface of the particle in motion, being described as follows 0, 0:

$$\tau_{ij} = \rho \cdot \overline{u}_i' \overline{u}_j' \tag{12}$$

Based on these considerations, several mathematical models have been developed that are currently used to analyse fluid dynamics, such as $k-\varepsilon$ turbulence models, which is the most used in numerical fluid flow analysis (CFD), being based on 2 equations of transport for turbulent kinetic energy and dissipation rate of turbulent kinetic energy. The $k-\omega$ and $k-\omega SST$ models are also used for numerical flow analysis [5-11].

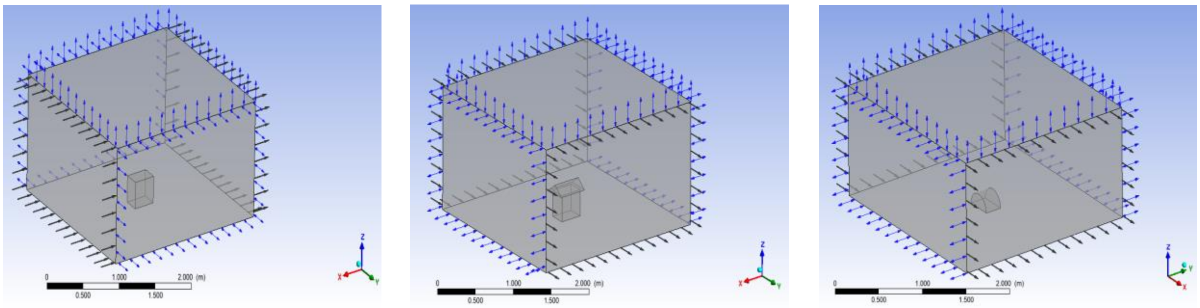
6. Air flow analysis on virtual structure model

In order to illustrate the characteristics of air movement at the buildings front area, a numerical analysis was carried out on virtual structure models, with the $k-\varepsilon$ turbulence model, considering three constructive types of structure.
Two of these models have a planar frontal plane and the third model has a semi-circular structure in section.
For the numerical analysis, air is considered as the working fluid, at atmospheric pressure, and the wind speed values are declared in three variant values, namely 3, 5 and 7 m/s.
Three distinct cases are analysed with three sets of values of the atmospheric air circulation speed resulted, being shown in Table 2.

Table 2: Specific information on main analysed cases and air velocity

Structure model	**Frontal area (m2)**	**Flow velocity (m/s)**		
		Case number		
		I	II	III
Rectangular frontal plane	0.09	3	5	7
Rectangular frontal plane with roof	0.15			
Semicircular	0.09			

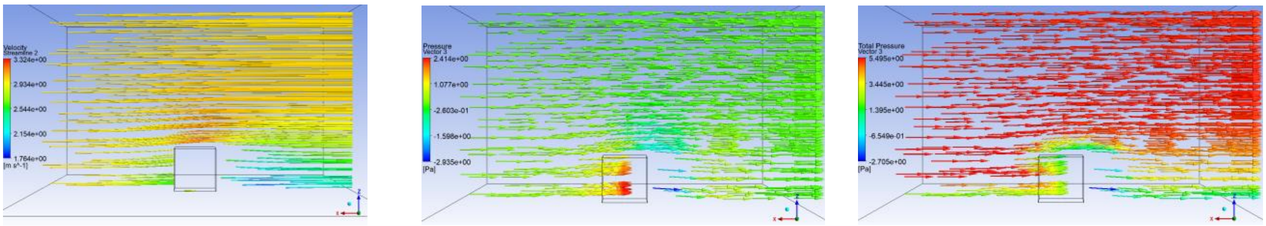
It is expected that at the modification of air flow velocity at each structure model will result in specific pressure values registered at the structure interface at each analysed region.
The building models considered for analysis were launched into flow numerical analysis using ANSYS CFX software to highlight the air flow parameters when the air is circulated for each structure model in part.
The results are presented in terms of air velocity and pressure, specific values being recorded at the building model interface within analysed fluid regions.



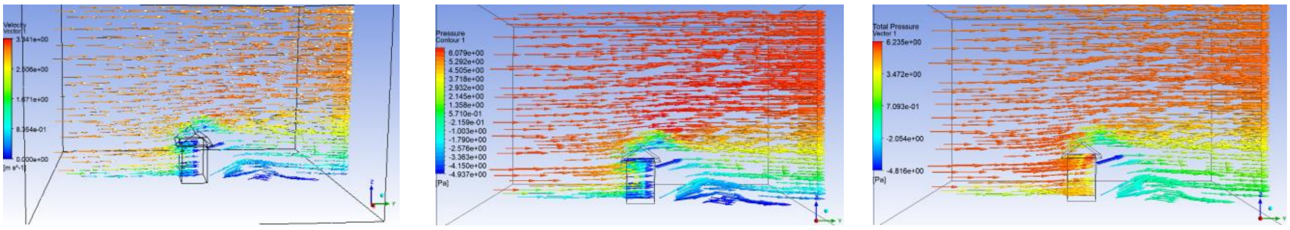
Rectangular frontal plane | Rectangular frontal plane with roof | Semicircular

Fig. 3. The main fluid regions considered for analysis

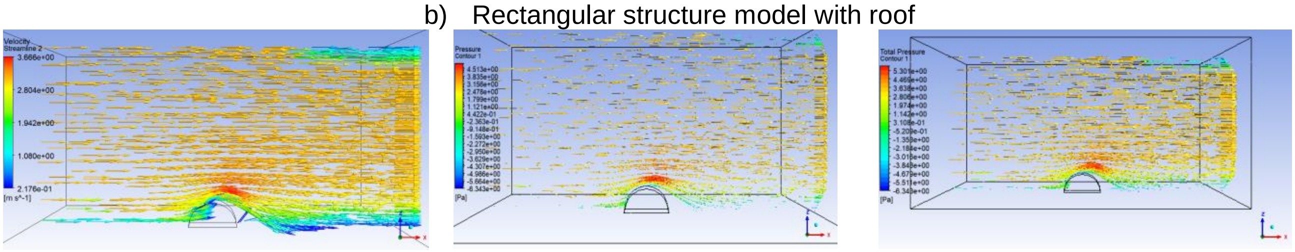
The flow analysis was made for air circulation at 25 degrees Celsius, with the declared velocity values (Table 1), while the reference pressure was 1 atm. Three sets of result values were obtained for the parameters that describe fluid flow through the model enclosures, being represented by pressure and velocity specific values on each analysed fluid region. The obtained numerical results are presented for the three cases in the following figures 4-6.



a) Rectangular structure model

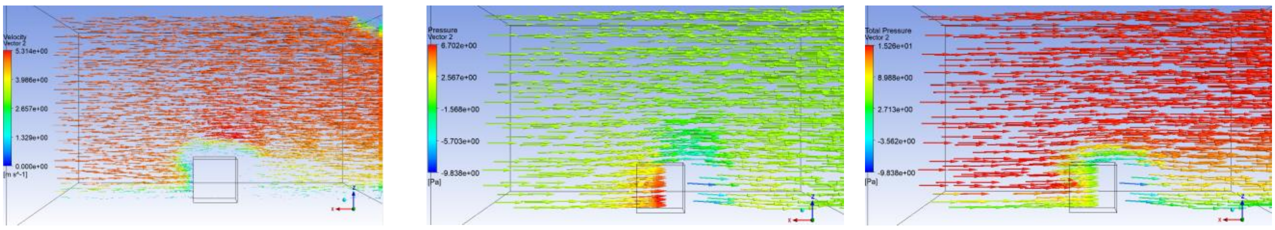


b) Rectangular structure model with roof

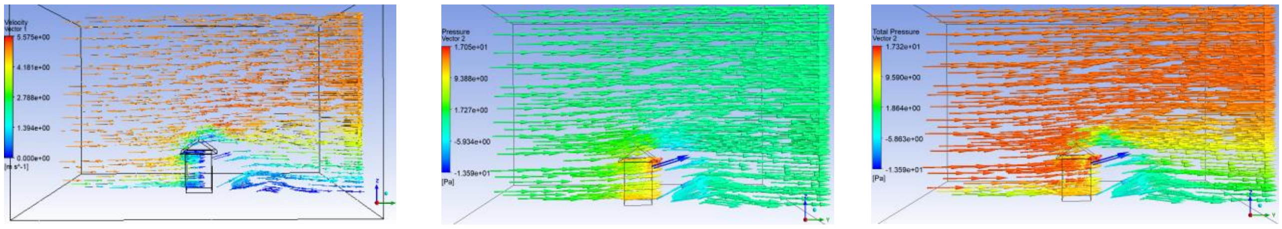


c) Semicircular structure model

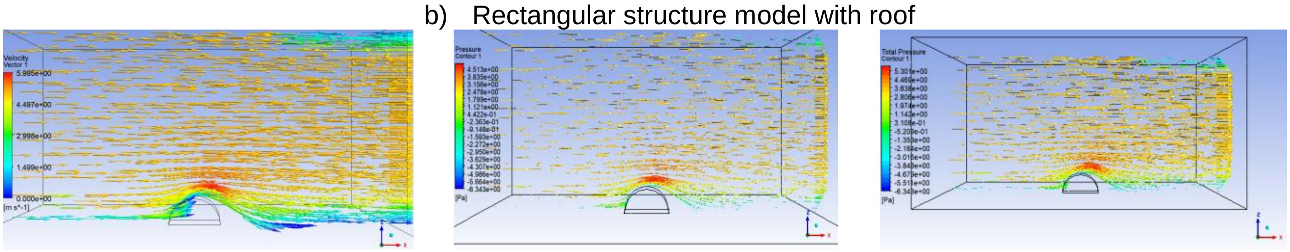
Fig. 4. Case I (air velocity of 3 m/s)



a) Rectangular structure model

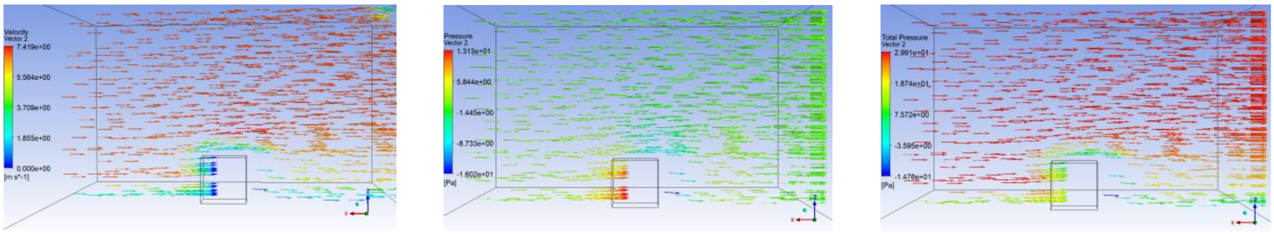


b) Rectangular structure model with roof

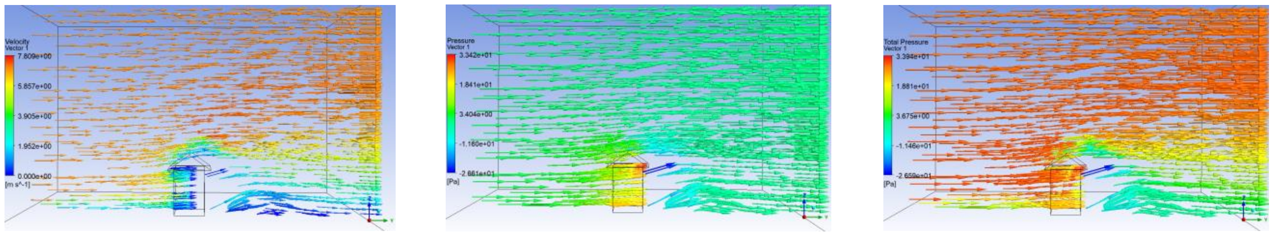


c) Semicircular structure model

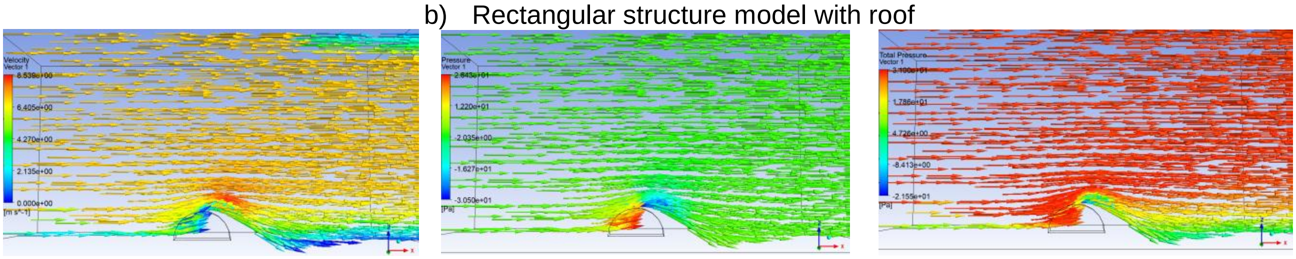
Fig. 5. Case II (air velocity of 5 m/s)



a) Rectangular structure model



b) Rectangular structure model with roof



Velocity values Static pressure Total pressure

c) Semicircular structure model

Fig. 6. Case III (air velocity of 7 m/s)

The obtained results show the specific recorded values for the static and total pressure formed as well as for air flow velocity being noted the differences that appear between the models of the analysed structure but also between the modified values of higher velocity declared on the inlet area.
Also highlighted are the specific current lines that are formed once the air current meets the structure model analysed in part.
All these results provide results regarding the level of wind action on the respective structure model depending on the specific wind speed, thus making it possible to determine the specific efforts that can demand the structure during the direct action of the wind.

7. Conclusions

Theoretical aspects related to the wind action on building structures are presented in this paper and their importance in the structure design activity is highlighted, especially for buildings involving a high height regime.
Also, a numerical analysis presenting three distinct cases of building models is carried out to identify the specific parameters of the wind action at the level of the building plan when it acts with specific speed values that have been recorded over time for the wind action.
The results are presented in terms of static and dynamic pressure at the wall of the analysed building model, as well as circulation speed around the contour of the analysed building model, according to the three analysed cases with the same declared values of air input velocity.
It is thus possible to identify the differences recorded for the analysed structure models, depending on the specific values of air circulation speed declared and recorded for each individual case.
Based on the two components of static and dynamic pressure, the direct action of the wind on the respective structure model can be highlighted, and it is also possible to determine the main demands that may appear on the main action direction of the air stream on the respective model.

References

[1] Vasilescu, Al. A. *Fluid Mechanics* / *Mecanica fluidelor*. Galati, Ministry of Education, University of Galati, 1979.

[2] Vespremeanu-Stroe, Alfred, Sorin Cheval, and Florin Tatui. "The Wind Regime of Romania – Characteristics, Trends and North Atlantic Oscillation Influences." *Geographic forum. Geography and environmental protection studies and research* / *Forum geografic. Studii și cercetări de geografie și protecția mediului* 11, no. 2 (December 2012): 118-126.

[3] Blaga, F. G. *The dynamic action of wind on multi-storey metal structures* / *Acțiunea dinamică a vântului asupra structurilor metalice multietajate*. Doctoral thesis. Technical University of Cluj-Napoca, Faculty of Civil Engineering, 2022.

[4] Vita, G., A. Šarkić-Glumac, H. Hemida, S. Salvadori, and C. Baniotopoulos. "On the wind energy resource above high-rise buildings." *Energies* 13, no. 14 (2020): 3641.

[5] Micallef, D., and G. Van Bussel. "A review of urban wind energy research: aerodynamics and other challenges." *Energies* 11, no. 9 (2018): 2204.

[6] Olabi, A. G., T. Wilberforce, K. Elsaid, T. Salameh, E. T. Sayed, K. S. Husain, and M. A. Abdelkareem. "Selection guidelines for wind energy technologies." *Energies* 14, no. 11 (2021): 3244.

[7] Žegarac Leskovar, V., and M. Premrov. "A review of architectural and structural design typologies of multi-storey timber buildings in Europe." *Forests* 12, no. 6 (2021): 757.

[8] Toja-Silva, F., C. Peralta, O. Lopez-Garcia, J. Navarro, and I. Cruz. "On roof geometry for urban wind energy exploitation in high-rise buildings." *Computation* 3, no. 2 (2015): 299-325.

[9] Hemida, H., A. Šarkić Glumac, G. Vita, K. Kostadinović Vranešević,s and R. Höffer. "On the flow over high-rise building for wind energy harvesting: An experimental investigation of wind speed and surface pressure." *Applied Sciences* 10, no. 15 (2020): 5283.

[10] Ying, X., Y. Wang, W. Li, Z. Liu, and G. Ding. "Group layout pattern and outdoor wind environment of enclosed office buildings in Hangzhou." *Energies* 13, no. 2 (2020): 406.

[11] Kuo, C. Y., C. T. Tzeng, M. C. Ho, and C. M. Lai. "Wind tunnel studies of a pedestrian-level wind environment in a street canyon between a high-rise building with a podium and low-level attached houses." *Energies* 8, no. 10 (2015): 10942-10957.