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ANALYSYS OF THE PERFORMANCE OF SMALL WIND TURBINES DARRIEUS AND OPTIONS FOR THEIR INTEGRATION IN BUILDINGS

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Abstract: Given the environmental and energy saving effect of the use of small wind turbines in urban environments, scientists, architects, manufacturers, investors and government institutions have joined forces for more extensive studies. The paper deals with research work of the optimized design of Darrieus turbine with 1 kW rated power in a particular climate. For purposes of the study a universal algorithm implemented with code in C++ has been developed. Thus it is possible to determine the turbine power developed and its efficiency in climate change factors air temperature, speed and intensity of the wind. The monitoring data cover a period of six months (a total of 18 533 measurements) for specific climatic region.

Keywords: Darrieus small wind turbine, urban wind turbine, wind energy in the urban environment.

1. INTRODUCTION

As a result of the greenhouse effect and global energy crisis as a source of clean, alternative energy and improvement of its work for the daily lives have become urgent tasks. The world is forced to face a contradiction between the energy-efficient passive sustainable design of buildings and the energy active one with the need of comfort. In this respect, a very challenging issue becomes how to use architectural design to maintain the autonomy of energy and resources. Wind turbine and a vertical axis combined in hybrid systems with other renewable sources show promising results in an urban environment. This type of turbines is considered to be less effective, but the fact is that there is still insufficient data for their improvement until today. Despite the convenience that the small hybrid plants offer, including small wind turbines, the following problems appear during their implementation:

1. Price. Prices of small wind turbines are still high (for capacities ranging of 10 kW−250 kW from $50000 to $200000). The payback period should be 4−6 years to be commercially viable.
2. There is no proper infrastructure for sale, servicing and maintenance teams. In emergency situations downtimes are long.
3. There are still few manufacturers in the market for the most sought power 1 kW - 20 kW and 50 kW - 500 kW, which limits choice and often wind turbine is resized. The studies represent the recommended capacities for small wind turbines: households - up to 10 kW; farms and villas – up to 50 kW; small agricultural businesses - 100 kW − 250 kW; for big agricultural businesses − 500 kW − 1 MW.
4. Spare parts from different manufacturers with a short expiry date.
5. Building of micro-grids for grid-connection of those wind turbines / hybrid plants.

2. STUDY APPROACH

Essential to the effective operation of small wind turbines alone or as part of a hybrid plant is choosing the right location for it. It is known that they are suitable for remote infrastructure of towns, where there is wind potential of 3-4 m/s, average speed of the wind and the possibility for mounting at 10 m to 35 m in height. The location is close to the road fed and topography is an important factor. Recommendations for placement are generally presented in Figure 2.

In cases where there are nearby buildings with a height H, increasing wind speed can be seen, as well as turbulence and energy generated at different locations. The most appropriate location is from 15H to 20H. There is an extremely wide variety of wind

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turbines structures for integration in buildings developed by producers and investors together with the architects. But most unfortunately they have not been tested in real conditions for an extended period of time. Integration into buildings was an issue at the beginning because of the noise, vibration and security of the people.

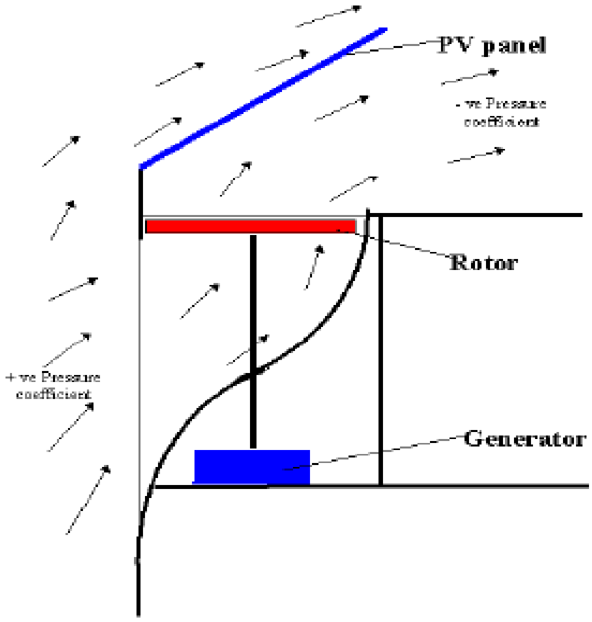


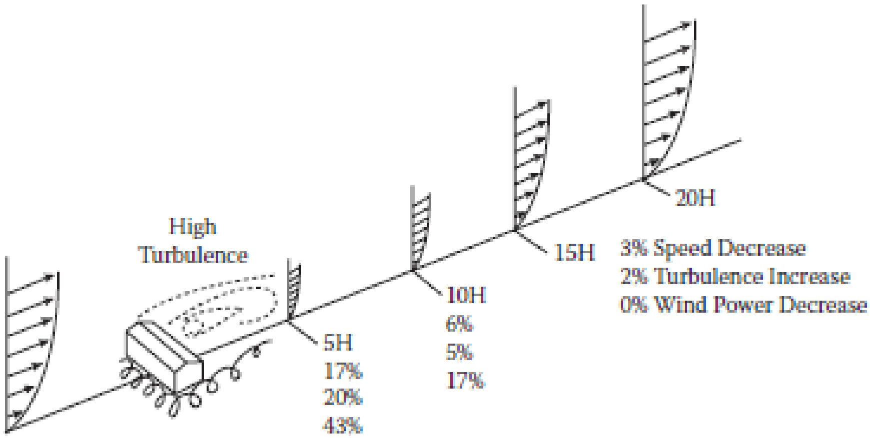
Figure 1. Concept for hybrid plant Wind turbine-Photovoltaic System

According to [1,2,7] 1.7 ÷ 5 TWh is energy extracted from wind turbines in urban environments. Nowadays there are already widely available designs and advice for the integration of small wind turbines in buildings and urban environments as part of hybrid plants: European Urban Wind Turbine Catalogue; Urban Wind Turbine: Technology Review; Urban Wind Turbine Guidelines for Small Wind Turbine in the Built Environment; Wind Energy for the Urban Environment.

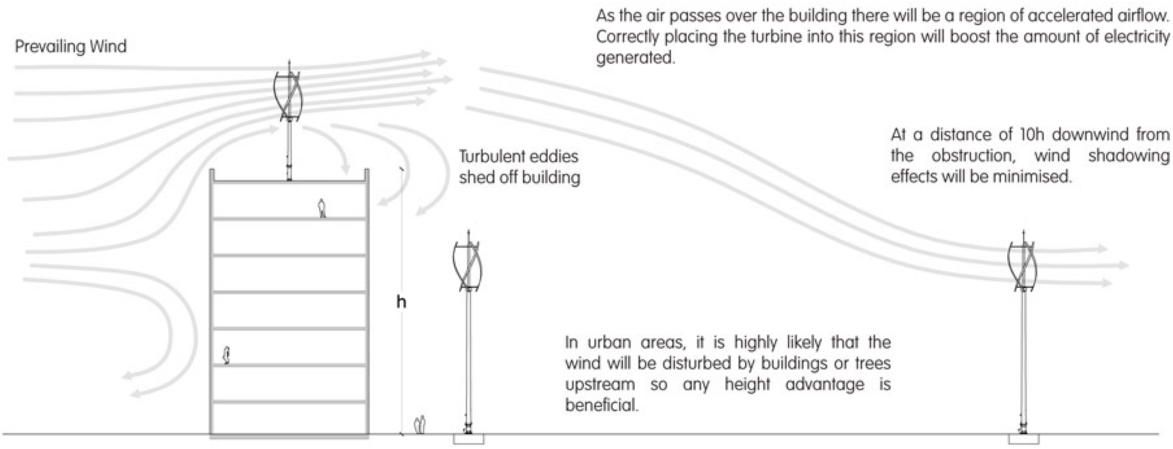
In technology development and improvement of structures noise levels are not a problem for integrated wind turbines. The levels are similar to noise in offices and our homes. According to researches for wind turbine, 10 kW levels measured with wind speed 9−11 m/s are 49 dB at work next to it and 46 dB − a distance of 15 m from the wind turbine [2]. The highest measured levels mentioned in the literature are 60dB.

According to the report of WINEUR project supported by the program Intelligent Energy Europe „Wind Energy Integration in the Urban Environment“, February 2007, wind turbines integrated into buildings constantly improve and have significantly improved their structures. Capital costs for urban wind turbine range from €2400 to €9100 per 1 kW, while the costs for large wind turbines were about €1000/1kW on-shore and about €2500/1kW into the sea, for photovoltaic systems - €6200/1 kWp. It is not without significance and the fact that wind turbines integrated in buildings reduce emissions of harmful substances as follows for 1 kW: CO_2 – 0.566 kg/kWh; NO_* − 0.15 kg/kWh; SO_2 – 0.42 kg/kWh, according to the Annual Report of the Danish government on energy saving possibilities („Cijers en Tabellen”, 2006).

Time and technology have changed today. Interest and experimentation in new Darrieus technologies is high and can be clearly seen in dozens of websites and literature, various patents on various vertical axial optimized structures. The structures are mechanically and dynamically optimized, the operation starts at low wind speeds (at some 1.5 m/s). In the context of combining several renewable energy sources for partial supply of buildings asking whether vertical axis wind turbines (VAWT) offer constantly usable energy without having the disadvantages of conventional wind turbines. To contrast their technology with that of conventional wind turbines present arguments used by supporters of the new VAWT: they are simpler, more reliable, cheaper, more efficient, do not kill so many birds, and quieter.



a)



b)

Figure 2. a) Variation of wind speed, turbulence and power when installing wind turbine around building with height H; b) Recommendations for use of Darrieus wind turbine in urban environment

2.1. Modern small VAWT

In support of the claim for placing small wind turbines in urban conditions, including Darius turbines is the report of the working project WINEUR (Wind Energy Integration in the Urban Environment), supported by the program Intelligent energy Europe. The project started in February 2007 and aims to assess the current status of the constructions and technologies, new researches and materials, as well as to provide guidelines and recommendations for successful and larger use of small wind turbines in urban conditions. Early in the project five organizations were involved: Axenne and ADEME from France, IT Power from England, HORISUN and ARC from the Netherlands. As of today the participants are already 60 organizations from Europe. The most suitable for urban conditions are small turbines with capacities 1 kW ÷ 20 kW.

In all studies, the lowest input value, i.e. most economical structure maximum energy output was a key factor for the evaluation . Aerodynamic combinations of blades and different structures offered by researchers are limited to choosing between 2 and 3 blades. Preferred turbines are with three blades (despite the higher cost) since their torque pulsations are significantly smaller, and are more resistant dynamically and structurally. Nowadays, when increasingly modern materials are successfully used, and speed control of used generators applied, it is still difficult to summarize the results and draw definitive conclusions. There are no investments in long-term research projects with subsequent production and not enough data for small capacities. Innovative developments include university teams, design firms, often only for scientific purposes and rarely on behalf of small or medium business.

However, the routes along which the designers work can be summarized as follows:

− There is a tendency to increase the height / diameter of the rotor to reduce unit costs.

− Special materials and improved constructions of the blades to reduce the mechanical fatigue and stress, as referred to herein and the currently investigated blades with a hinge at the base, are further developed and tested.

− Mass and cost of wind turbines can be reduced by using high-speed generators.

− Simplification/optimal design of the gear is possible according to the specific application of Darrieus turbine - to the foundation on the ground or integrated into the building.

− Managing a wide range of variation of the rotor speed, consistent with the dynamics of change in the wind.

Very often conclusions are made about how effective and how expensive Darrieus turbines are made as compared with conventional horizontal axis wind turbines. This assessment is very unfair and leads to more disadvantages of Darrieus turbines. Upgrading of small wind turbines of Darrieus type and their increased effectiveness when integrated into buildings is necessary to solve the following problems [1,2,7]:

− Reducing the pulse of the torque during wind gusts.

− Variable speed control.

− Lightweight construction of the rotor.

− Through the use of new materials and structures for the blades to optimize their aerodynamics, mechanical and their dynamic sustainability.

− Reducing the mass of wind turbines.

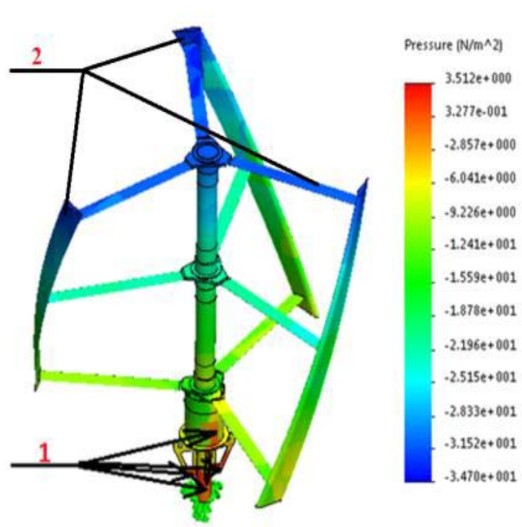
− More research on the work of these wind turbines at a height of mounting (60-80-100 m).

2.2. Subject of study

Object of research and analysis included the models of small wind turbine of type Darrieus, suitable for urban conditions with specific geometric data: rotor diameter – 2.4 m, height of the rotor 2 m. Mechanically and dynamically optimized structure, seen in [4− 6] was used for the purpose of the work. This gives a better picture of wind flow around the rotor, and the way the components of the rotor respond to the resulting pressure. The turbine is first modeled in 3D CAD system and simulation is made in the flow simulator in a virtual wind tunnel. Tested for typical fluctuations in the dynamic pressure, vulnerable areas of the blades and the structure of wind turbine have been established. The advanced design of the wind turbine type Darrieus is with spiral rotor with lift drive, contrary to other VAWT designs that are drag driven.

Leaf blades have a spiral design, twisted around their flagship lines, Figure 3. While the turbine rotates, its blades periodically pass through the airflow and develop constant driving torque and create intermittent gusts. The aerodynamic profile of the blades corresponds to the type NASA 1082. The blades are fixed in the middle and at both ends of the supporting structure by elastic bodies, allowing changing the angle of attack, though to a lesser degree.

This optimized configuration of VAWT type Darrieus was tested to produce maximum energy in a particular climate. Such analysis significantly reduces costs for prototype and allows structural optimization of production resources, and last but not least the duration of the process of product development.



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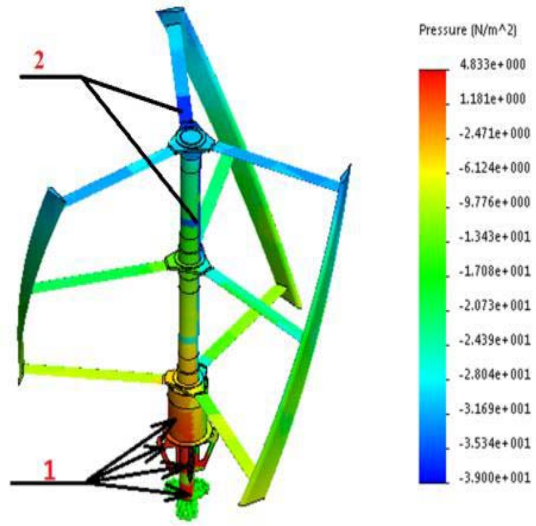


b)

Figure 3. Wind loads on VAWT, [Pa], in two successive positions of the rotor

3. STUDY RESULTS

For purposes of the study multivariant calculations with specialized software NREL (National Renewable Energy Laboratory, USA), System Advisor Model (SAM) have been carried out to select the appropriate drive power for this design with optimal energy and financial indicators. Based on these criteria multiple comparisons were done at the specified input: rotor diameter of 2.4 m and a height of 2 m, Figure 4.

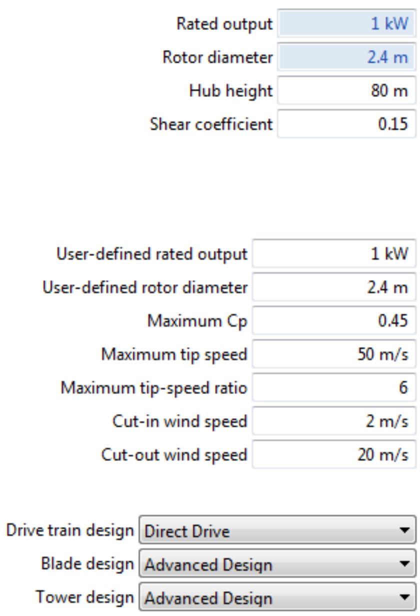


Figure 4. Model 1 – wind turbine type Darrieus with rated power 1kW and relevant input data

When analyzing the dependence of the energy produced by the wind speed, it is important that the curves of the two variables should be as close to one another - in this case we maximize the wind resource. This is a way to evaluate the accuracy of positioning according to geographical location and height, Figure 5.

Apart from the above models of specialized software for preliminary assessment, site specific analysis included the measured data for a period of six months in 2012, total of 18366 values. SAM software is used to obtain adequate power for the modified structure, and the following analysis was made for a specific geographical area - to assess the behavior of the selected wind turbine for specific location: urban environment (integrated in the building or roof). Dependence, Figure 6 on energy produced and the wind speed in hours for each month of 2014; (wind speed (m/s) − orange: energy produced − blue (kWh).

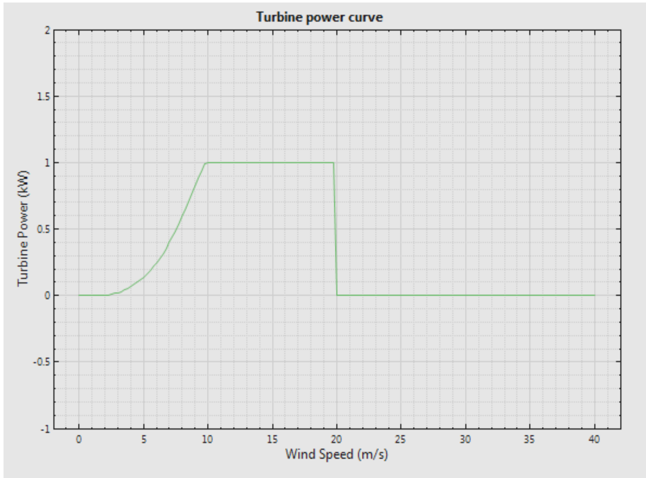


Figure 5. Power curve of the wind turbine of Model 1

After processing the data in C++ environment and making algorithm in Matlab environment the results have been displayed. This allows to analyze how much and under what conditions the study design of Darrieus wind turbine with 1 kW rated power will be useful.

The following variables were included in the algorithm [3]:

− Effective (energy-significant) wind speed Ve. This is prevalent in a given interval, i.e. this speed, which is the largest weighting corresponding to the longest period of time:

$$Ve = \sqrt[3]{V(1+5I^2)}\,, \qquad (1)$$

where: V – the horizontal component of the wind speed measured at a height pivot point, m/s; I – turbulent intensity; $I = \sigma_x / V$; σ_x – indicator of turbulence along the axis X.

− Density of wind energy flow

$$P = 0{,}5\rho V_e^{\,3}\,, \qquad (2)$$

where: P – density of wind energy flow, W/m^2; ρ – air density, $\rho = const = 1.225 kg/m^3$; Ve – effective wind speed, m/s.

− The power generated from wind generator, P_{WG}:

$$P_{WG} = \frac{\rho \pi D^2 C_P V^3}{8}\,, \qquad (3)$$

where: P_{WG} - power output of the generator, W; ρ – air density, kg/m^3; D – diameter of rotor blades, m; C_P – efficiency of the wind turbine; V – horizontal wind component, *m/s*.

Since the density of the air changes with temperature change using the expression:

$$\rho_i = \frac{P_0}{RT_i} e^{-\frac{gz}{RTi}}, \quad (4)$$

where: P_0 − normal atmospheric pressure, $P_0 = 101325 Pa$; g − acceleration of gravity; $g = 9.81 m/s^2$; z − altitude of a particular place, m; R − specific gas constant, $R = 287 Jkg^{-1}K^{-1}$; T − air temperature in Kelvin.

− Efficiency of the turbine. An induction generator for driving of turbine tested has been used, which is approaching with a certain relationship.

$$C_P = C_{P1} = -0{,}0046\lambda^2 + 0{,}1071\lambda - 0{,}1996, \quad (5)$$

where: $\lambda = \frac{\pi Dn}{60} V$; n - rotational frequency of the rotor, $\min^{-1}$.

For the period characteristic curves have been plotted P_{WT} = f(V_e), Figure 7, $C_p = f(\lambda)$, Figure 8 and the operation of the wind turbine has been assessed.

For purposes of the study density of wind energy flow, its maximum and average value, can be traced Figure 9 and Figure 10.

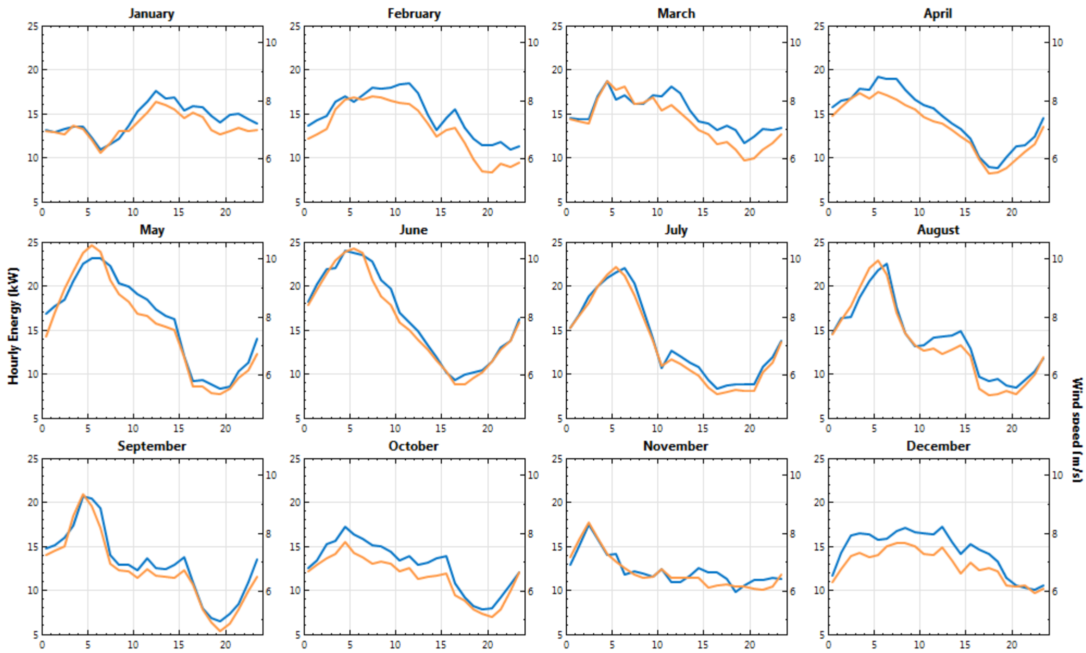


Figure 6. Dependence on energy produced and the wind speed in hours for each month of 2014; (wind speed (m/s) - orange: energy produced - blue (kWh)

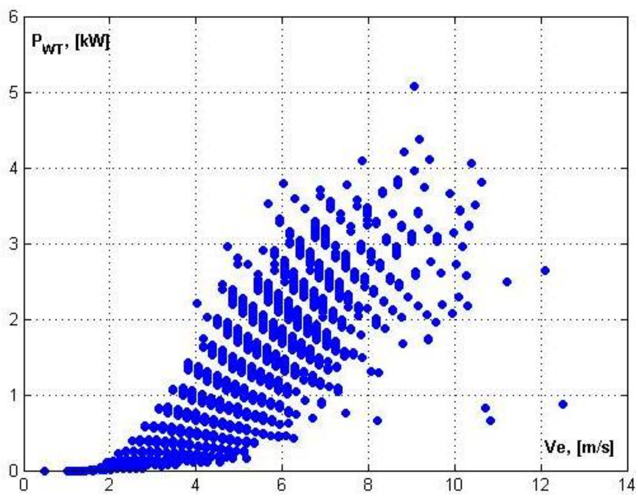


Figure 7. Dependence P_{WT}=f(V_e)

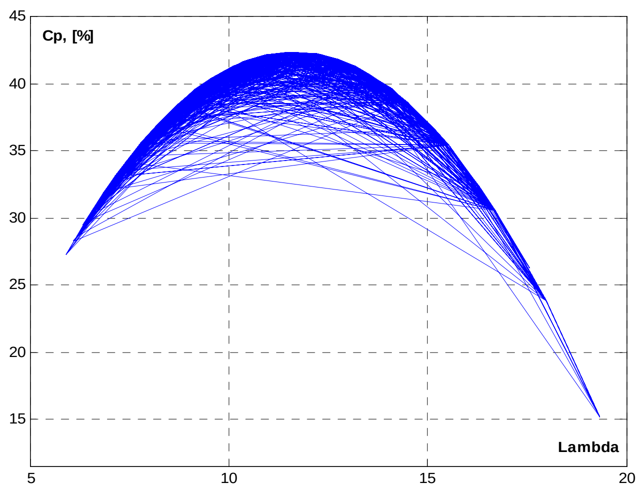


Figure 8. Dependence Cp=f(λ)

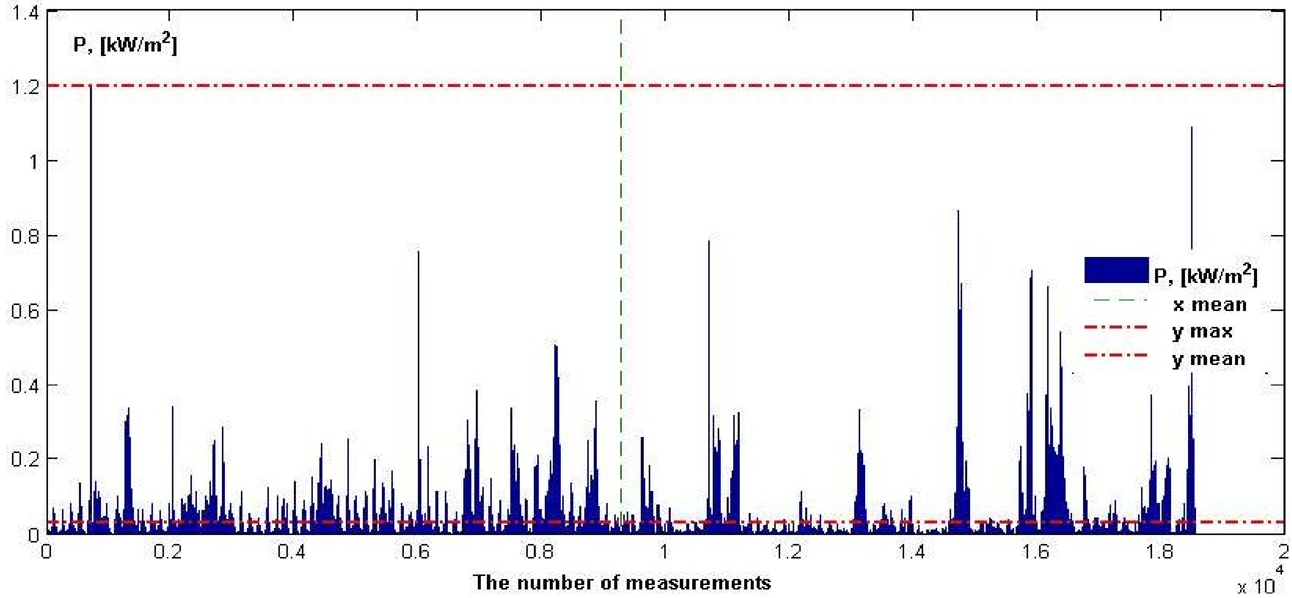
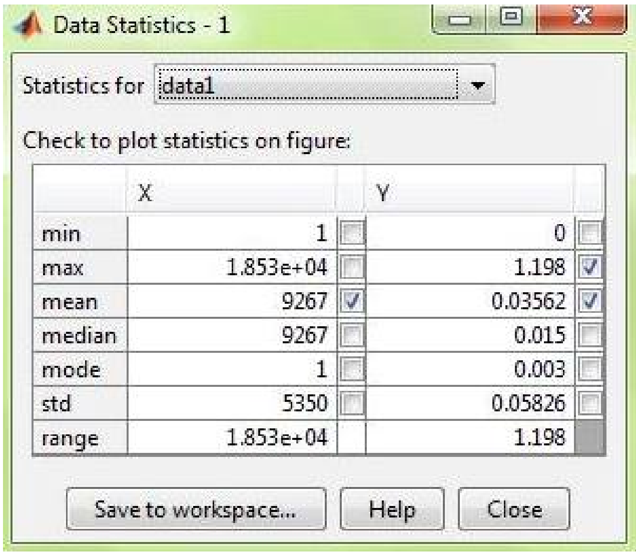


Figure 9. Density of wind energy flow and frequency of his manifestation to all 18533 measurements



	X	Y
min	1	0
max	1.853e+04	1.198
mean	9267	0.03562
median	9267	0.015
mode	1	0.003
std	5350	0.05826
range	1.853e+04	1.198

Figure 10. Statistical data of Figure 9

4. CONCLUSION

Mechanically and dynamically optimized design of the wind turbine with a vertical axis type Darius proved suitable for integration in urban environments. The structure is recommended to be a 1 kW power generator. Studies determined under what specific conditions (geographical etc.) wind turbine will operate in the best way: the highest efficiency of the turbine is Cp = 0.45, at an effective wind speed range 2.3 ÷ 12 m/s and available at 80 m in height, the turbine produces 124981 kW per year, thereby saving 7.074 tons of CO_2, NO − 1.875 tons and 5.249 tons SO_2.

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АНАЛИЗА ПЕРФОРМАНСИ МАЛИХ ВЈЕТРОЕЛЕКТРАНА ДАРИУС И ОПЦИЈЕ ЊИХОВЕ УГРАДЊЕ У ЗГРАДАМА

Сажетак: Имајући у виду ефекат употребе малих вјетрогенератора у урбаним срединама, научници, архитекти, произвођачи, инвеститори и владине институције заштите животне средине и уштеде енергије су удружили снаге на изради неколико обимних студија. Рад разматра истраживања оптимизованог дизајна Дариус турбине са 1 kW номиналне снаге у одређеној клими. За потребе студије развијен је универзални алгоритам имплементиран са кодом у C++. Тако је могуће да се утврди развијена снага турбине и њена ефикасност при факторима климатских промјена: температуре ваздуха, брзине и интензитета вјетра. Подаци мониторинга обухватају период од шест мјесеци (укупно 18 533 мерења) за специфичну климатску регију.

Кључне ријечи: Дариус мала турбина на вјетар, урбана турбина, енергија вјетра у урбаној средини.