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SMALL WIND TURBINES FOR URBAN LOCATIONS

M. GHEORGHE[1] C. JALIU[1]

Abstract: *The paper presents the critical analysis of small wind turbines for urban environment, both with horizontal and vertical axes. The basic idea and the purpose of this paper are to analyse and highlight the particularities and the functionality of vertical axis wind turbines, the most efficient ones in the urban environment. The study investigates the wind potential for the configuration of the buildings in the architectural structure of Avantgarden district located in northern Brașov. A simplified building model was generated in the SOLIDWORKS software to study the flow behaviour on 3 heights starting at 0 m, 15 m and 20 m. The results show the optimal area available for the turbine location. This study shows the influence of the building configuration on the wind flow and on the energy conversion, implicitly.*

Key words: *wind turbine, urban, air flow, simulation.*

1. Introduction

From early history, people used wind energy. The steam engine replaced the European windmills for water pumping, and in the 1930s the Rural Electricity Administration brought cheap electric energy to most rural areas.

However, industrialization also sparked the development of larger wind turbines to generate electricity. Industry growth has responded positively to political incentives [13]. Wind power is widely used today, and new wind turbines are being built around the world, with wind power being the fastest growing energy source in recent years. Most turbines produce energy over 25% of the time, this percentage rising in the winter when the winds are stronger. Small turbines (less than 100 kilowatts) are used for homes and dwellings, telecommunication vessels or water pumping.

Although there are important types such as new vertical-axis (VAWT) and horizontal-axis (HAWT) turbines with multiple blades, the differences between most wind turbines are subtle [2].

Wind turbines have been built in almost all configurations that can be imagined.

Over the years, the construction design of wind turbines has been tested and patented, but not all have entered the wind turbine market, some being efficient in an urban environment but with less efficiency compared to those located in wind farms.

The great advantages of wind turbines in urban environments are related to the small size and power at which these wind turbines start [6]. This paper presents the critical

[1] "Renewable energy systems and recycling" Research Centre, *Transilvania* University of Braşov.

analysis of small wind turbines for urban environment, both HAWT and VAWT. The aim is to analyze and highlight the particularities and the functionality of VAWT, the most efficient turbines in the urban environment. Reference will be made to a case study implemented in the Brașov urban area on a building type II, namely terraced buildings that allow a smooth flow of air masses. Air flow analysis and the optimal location of a small vertical axis turbine will be presented in the last part of the paper.

2. Critical Analysis of Small Wind Turbines for Urban Environment

Europe is an old continent with historic buildings and an early architectural development, and, therefore, the need for integration of wind energy into the already built environment is growing. The fact that the cities we live in are energized by the national grid can open the wind energy to be introduced into an existing urban architectural environment [11, 17]. However, the urban environment has many restrictions when it comes to implementing wind turbines. Most wind turbines mounted on buildings in urban contexts are both HAWT and VAWT examples. The choices of the type and the design are made according to the customized characteristics depending on the area and the type of wind available in the chosen areas. The advantages and disadvantages of the two major categories of turbines will be further discussed.

2.1. Advantages and disadvantages of wind turbines with horizontal axis

Undoubtedly, the biggest advantage of a HAWT is the power it produces. This type of turbine is installed on pillars, at high heights, where it benefits from a wind of at least 2-3 times stronger, evenly and steadily, than the installation on the same place but on the ground [2, 4, 5, 12].

HAWTs have much higher efficiency, generating electricity using up to 50-55% of available wind energy compared to 15-20% for VAWT [10].

The main disadvantages are the relatively limited energy resource, inconsistent due to the variation in wind speed and the number of possible implementation locations. Few places on Earth provide the possibility of producing enough electricity using only wind power [4, 8]. Moreover, the HAWTs must always be geared to the direction of the wind by using systems that orientate the nacelle towards wind and the blades depending on wind intensity. Another disadvantage refers to the noise they produce.

2.2. Advantages and disadvantages of wind turbine with vertical axis

Over traditional horizontal wind turbines, the VAWTs have some clear and indisputable advantages that make them suitable for urban areas: important parts of the turbines can be located on the land, such as: generator, speed increaser and other functional components, no nacelle and massive tower being needed; besides, they don’t need so much wind to generate energy, so they are allowed to be implemented closer to the ground. Therefore, the VAWTs are easy to maintain and can be installed on chimneys and similar high structures, the noise being in the range of 5-6 dB.

Furthermore, the turbines don't need a special wind direction tracking mechanism, and they can be grouped together closer to wind farms, saving space. This is not due to the fact that these turbines are smaller, but rather because of the air slowing down of the horizontal turbines, forcing designers to separate them ten times their width [5, 6]. Vertical turbines are robust, quiet, omni-directional, and they do not create so much stress on the support structure. The simplicity of design and the fact that it can operate in areas where wind speed is reduced (annual average speeds of 3-4 m/s) makes this turbine a practical solution in terms of energy supply for individual dwellings.

One major disadvantage of VAWT is connected to the wind speeds in the boundary layer with the soil surface, which are small. So, it saves the tower construction but it loses the power developed in the turbine. Moreover, some types of turbines (Darrieus or Evence) do not ensure start, an auxiliary engine that starts the turbine or a smaller Savonius type turbine being required. The high power turbines require support cables that considerably increase the support fingerprint. The replacement of the main axial bearing requires the complete disassembly of the wind turbine, which generates additional costs [1]. Other major inconveniences for early models (Savonius, Darrieus, giromill and cycloturbines) include the pulsating torque that can be produced during each revolution and the immense bending moments on the pallet. More recent projects have solved the problem using torque of helical blades almost similar to Gorlov water turbines [6]. During wind movement, VAWT experience less drag and this difference in drag helps the turbines rotate. But due to drag, the efficiency of these types of turbines is less than 70%, taking into account the first type of turbine previously presented [7].

Tests in the wind tunnel show that vertical turbines reduce burst fluctuations throughout turbine operation, while radial aerodynamic forces and traction forces are extremely variable for these turbines [4].

When it comes to the evaluation of renewable energy, it can primarily take into account the cost to which it is generated. The discussion is about two major factors: the initial cost per W power and the unit cost per kWh produced by the wind turbine. Taking into account that these two major factors are at an affordable rate, the conclusion is that small-scale wind turbines have the potential to become a source of energy [3, 14].

The conclusion drawn from the comparative analysis presented above is that VAWT is the type of turbine that is optimal for the urban environment, proved by the high number of VAWT that are already installed on buildings [9]. Thus, several examples of VAWT implemented in the urban environment are presented in Figure 1: Darrieus wind turbines implemented on the ground, at an IT company in Cluj Napoca (a), and in the urban-industrial area of Barcelona, Spain (b) [15]; Savonius wind turbines implemented in the downtown area in Birmingham, U.K. serving in public transport (c) and on the top of a textile factory in Milan, Italy (d) [17].

3. Case-study: Analysis of VAWT Implementation in Brașov Urban Environment

Romania, located in an area of interference with the high-density air masses, has a good wind potential as a whole. The configuration of the relief that compiles the territory of the country implies obvious changes in wind speed from one region to another, causing its uneven distribution. A map of wind potential was published by www. meteoblue.ro [16] from which one can extract input data to generate a case study on air turbulence that is formed in the Brașov area.

a) 
b) 
c) 

d) 

Fig. 1. *Darrieus (a, b)* [15] *Savonius (c, d)* [17] *wind turbine examples*

3.1. Analysis of the wind potential in Brașov area

This chapter provides the results of a wind survey around a type 1 building in the Avantgarden 1 residential complex (Figure 2) to choose the best location for a small wind turbine. The results have been achieved through computerized fluid dynamics techniques. A simple mapping of the annual wind potential in the North Brașov area is proposed along with the annual average of the wind direction and a case study is presented. Reference is made to wind potential estimation for a complex of 4 flat-roofed terraces buildings, which allow easy placement and a good position for maintenance of small turbines [15].

The wind data for Brașov urban area for the year 2017 are provided by meteoblue.ro [16]: the number of days per month in which the average daily wind speed reaches a certain value is presented in Figures 3a and 3b; the wind direction is West and West-North-West, according to the wind rose from Figure 3c. The data from meteoblue.ro is strictly identified for the north Brașov area. Thus, the input wind data for the simulation in the wind test software is the West direction and the annual average wind speed of < 5 m/s. This data will be also used for the small wind turbine starting parameters.

3.2. The analysis of a wind turbine implementation location

The next step is to generate at a 1: 1 scale the type of building as in the Avantgarden architectural plan. A representative “type 1” building was built in the SOLIDWORKS software. The building has 4 floors of 3 m height each, the building having a total height of 15 m, including the extended roof. Therefore, the following wind flow study will consider a height starting from 0 meters, the ground level, up to 20 meters - the maximum height at which the wind turbines can be mounted on the roof.

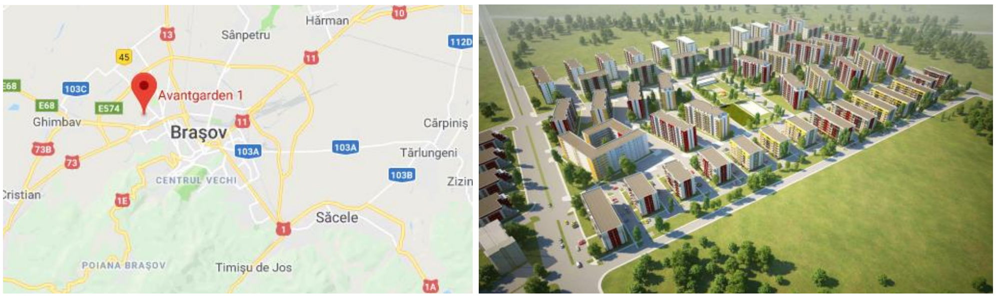


Fig. 2. *The implementation location in the north of Brașov*

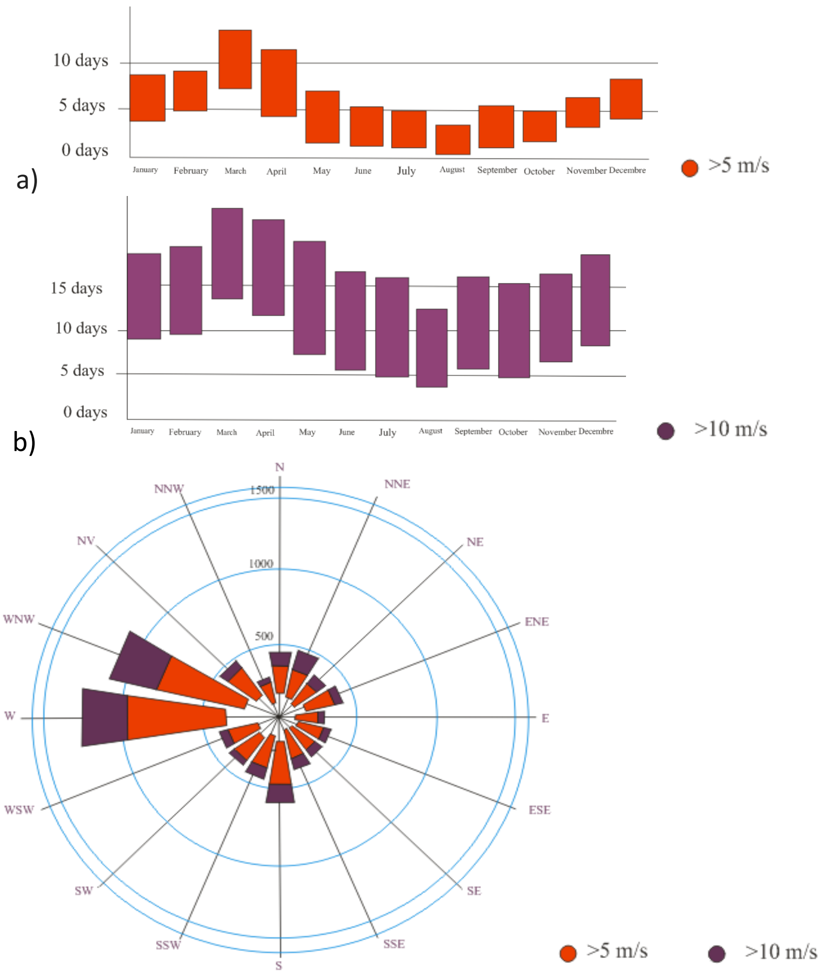
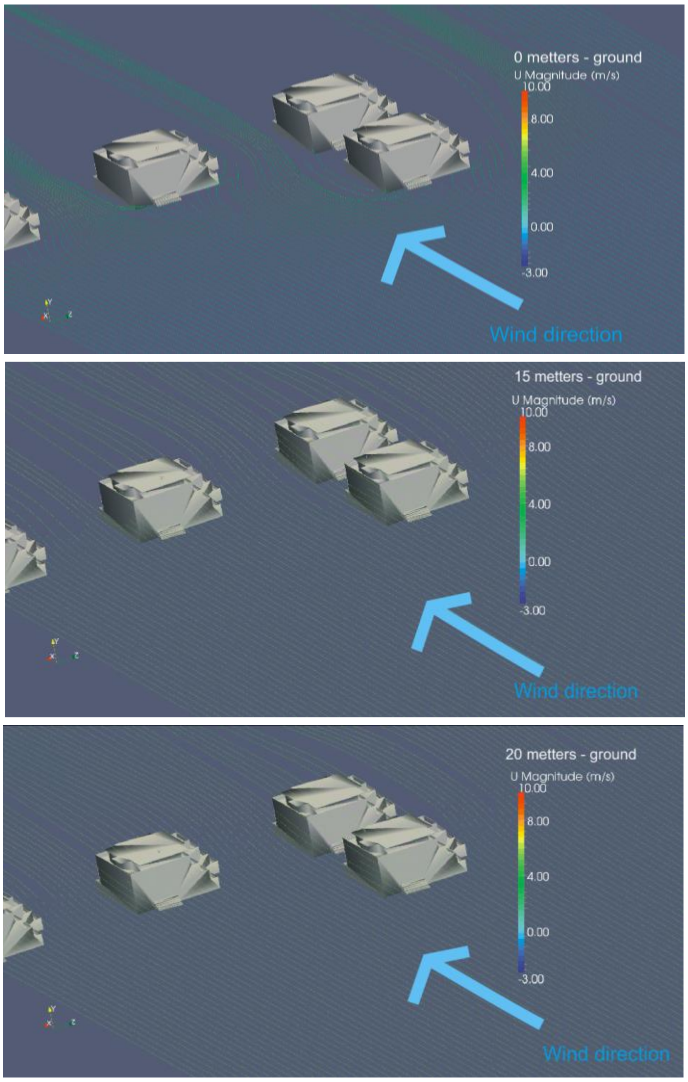


Fig. 3. *The wind speed frequency (a, b) and direction (c) for the north of Brașov* [16]

In the following figures, the wind airflow will be analysed on three areas of interest at the building level in order to select the optimal location for the VAWT implementation. A turbulent air flow is not required for VAWT functioning at optimum parameters. The movement of the air flow, constant on the vertical axis "y" that is the height of the segmented building is presented at the point 0 on the ground (Figure 4a), the point on the roof at 15 m (Figure 4b) and at 20 m by 5 m above the roof, in the area where the wind turbines can be placed on a support, Figure 4c. There is no major turbulence to change the optimum turbine parameters.



a)
b)
c)

Fig. 4. *The airflow movement from West direction for 3 heights: 0 m (a), 15 m (b) and 20 m (c)*

The speed magnitude is illustrated in different colours ranging from negative values, marked in blue to the maximum positive area marked with red. The speed that was exerted in the simulations is 1-2 m/s, representing the average wind value in the Avantgarden 1 area. For each meter in height, the shape in which the air behaves is different, namely: turbulence detected at a height of 5 meters generates significant changes in the airflow. At the height of 15 m, stage 2 of the building, turbulences are reduced and the air flow is consisted. At the height of 20 m the propulsion turbulence disappears and the air mass is continuous and smooth (Figure 4c). Figure 5 presents the behaviour of the pressure exerted by the air at the moment of the impact with the building at the three heights of interest. The behaviour of the air flow is observed throughout the interaction with the architectural obstacles. The red zone indicates the positive pressure, more precisely the area where the pressure allows the wind turbines to be applied without being affected. Instead, the blue area indicates negative, reactive turbulence, where implementation of wind turbines is not indicated.

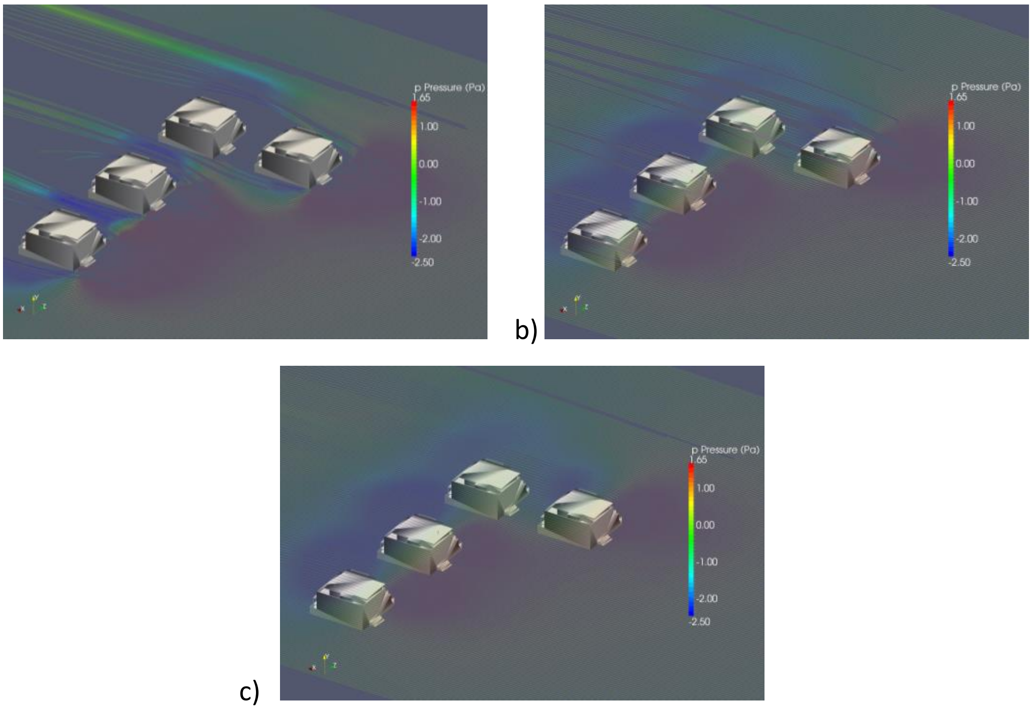


Fig. 5. *The pressure exerted by the airflow on the buildings at 0 m (a), 15 m (b) and 20m (c) height*

4. Conclusions

The conclusion of the simulations from Figure 4 is that the air has a continuous and non-turbulent flow at the heights of 15 m and 20 m. This behaviour allows the wind turbine implementation on the roof area and over the roof at 20 m above ground. Instead, Figure 5 indicates an optimal pressure for the turbine at the building's attack area, on the first half of the roof where air turbulences are not yet generated. Thus, under the wind conditions from Avantgarden 1 Brașov area, with an average wind speed of 1-2 m/s, with west annual wind predominant wind direction, the optimal location for small VAWT implementation is at heights of 15 m and 20 m in the first half of the roof towards wind. This area is characterized by the smallest quantity of airflow turbulence, and it allows optimal operation of the turbines under the imposed weather conditions.

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