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RESEARCHES CONCERNING THE INTEGRATION OF WIND TURBINES IN URBAN ENVIRONMENT

Emanuela Sorina POP[1], Emilia CAMPEAN[2]

[1] Technical University of Cluj-Napoca, emanuelapop13@gmail.com,

[2]Technical University of Cluj-Napoca,emicampean@gmail.com

Abstract: *The problem of reducing non-renewable energy consumption has led to the development and implementation of new solutions that provide green energy both for industrial consumers and for those living in urban and rural areas. The urban environment has a fluctuating wind regime which is influenced by many aspects, therefore the paper is meant to present the outcomes of a research carried out on the built environment, as well as a set of rules and recommendations for installing wind turbines in such an environment. Furthermore the paper presents the technology trends and recent developments in small capacity wind turbines at a global level.*

Keywords*: small wind turbine, urban environment, wind regime, power coefficient*

1. Introduction

With the new policy to reduce consumption of non-renewable energy, the market of small wind turbines that are network connected has grown considerably from year to year. This growth has emerged due to the rise in conventional energy prices, as well as due to the increased demand for energy equally in residential, industrial and urban areas. The most developed markets in such wind turbines are located in the US, Canada and Australia.
Urban wind turbine development has gained greater importance in recent years, and studies show that turbines mounted on tall buildings can provide a considerable amount of green energy and carbon savings.

2. Urban regime

The physical phenomenon which is manifested through the guided air circulation in the earth's atmosphere is called wind. The wind is the movement of air from a high pressure area to a low pressure area. The wind is characterized by the blowing direction and its intensity (blowing speed) [1]. Surface winds are influenced by the local topography of the area and are slowed down by obstacles and the rough surface of the Earth.
In terms of structure, the physical phenomenon of wind can be divided into three main categories, such as laminar wind, turbulent wind and gusting wind [2]:

- The laminar wind is characterized by a slow travel of air, at low and uniform speeds, in the form of parallel waves that go in the same direction and with the same speed. It is specific to smooth land areas, for example fields, where the friction force is small.
- The turbulent wind is formed due to the high friction of the air flow with the earth's surface, frequently forming eddies and vortices. These are characterized by high oscillations of wind speed and direction in small intervals of time.
- The gusting wind shows large oscillations of speed and direction within very little time, that is 5 to 10 minutes or less.

2.1. Parameters that influence the wind

The winds that occur in a particular location are influenced by its coordinates (latitude and longitude), their speed depending on altitude, season, surface roughness and the urban or rural positioning. Even without obstacles, the presence of the Earth's surface determines the velocity variation in height. Figure 1 shows the distribution of the wind relative to the surface roughness, z_0.

Roughness and size classes can be taken from Table1 [3]. In Figure 1 it can be seen the influence the ground has on the speed, which is greatly influenced in the range of 0-25 m. Thus we can say that in order to obtain the best possible efficiency for a wind turbine, its location is recommended to be at a height where the wind speed is higher [1].

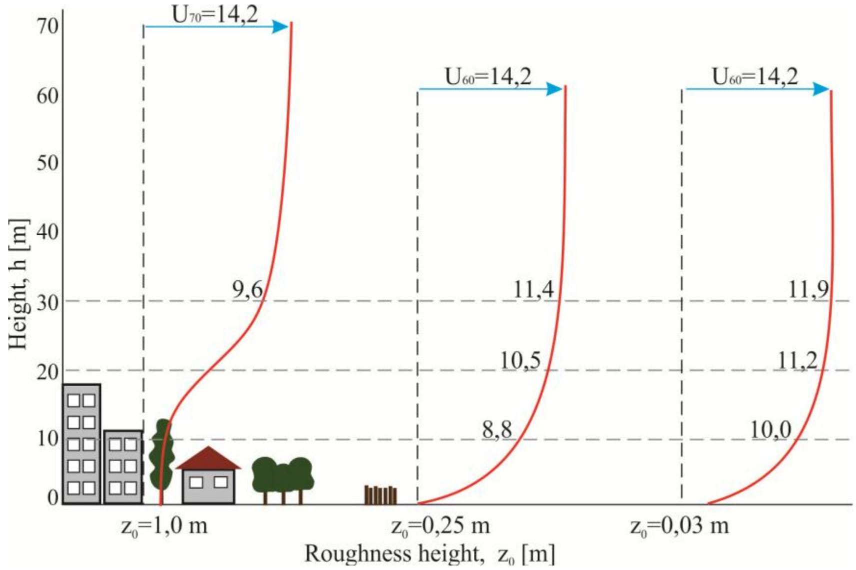

Fig. 1. The influence of ground on the wind speed

TABLE1: Surface roughness classes and their length

Roughness class	Roughness length (m)	Surface type
0	0.0002	Water surface: seas and lakes
0.5	0.0024	Smooth open ground such as: concrete, airport runways, mowed grass, etc.
1	0.03	Open agricultural fields without built fences or hedges, perhaps with by buildings and mild hills in the distance
1.5	0.055	Agricultural land with several buildings and up to 8 m high fences in less than 1 km
2	0.1	Agricultural land with several buildings and up to 8 m high fences in less than 500 m
2.5	0.2	Agricultural land with many trees, shrubs and plants, or 8m high hedges in approx. 250 m
3	0.4	Cities, villages, agricultural land, with many hedges, woods, rough and uneven terrain
3.5	0.6	Big cities with tall buildings
4	1.6	Big cities with tall buildings and skyscrapers

Wind profile is strongly influenced by the presence of obstacles in the vicinity of which turbulence is created. The influence of an obstacle on the performance of a turbine is shown in Figure 2. It is noted that the top of the hill is favorable for the location of a turbine, due to the acceleration of wind speed.

As previously discussed, at ground level the wind is strongly influenced by obstacles, as well as by the surface roughness. We can say that the wind changes its speed with increasing height, and the higher it is, the wind is more constant in terms of the direction and intensity.

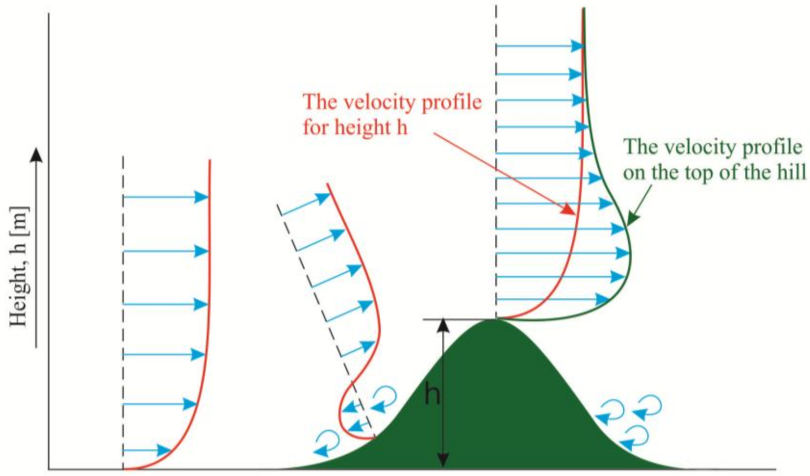

Fig. 2. The influence of a hill on airflows

In order to calculate the increase in wind speed relative to the height, the logarithmic law shall be applied, where speed over a certain height is calculated in relation to the reference speed corresponding to a reference height taken from the databases, which is typically 10m, 25m or 45m, and the roughness is specific to the chosen location [4].

$$U_2 = U_1 \frac{\ln\left(\frac{h_2}{z_0}\right)}{\ln\left(\frac{h_1}{z_0}\right)} \tag{1}$$

where $\boldsymbol{U_1}$ is the wind speed at a reference height $\boldsymbol{h_1}$ and $\boldsymbol{z_0}$ is the roughness taken from the previous table.

2.2. Factors influencing the placement of turbines in urban areas

Knowing the wind regime is the most important aspect when seeking to install a wind turbine. Wind regime refers to the annual average wind speed for a given location, which is a necessary aspect in choosing the type of turbine, the setup location, etc. in a way that the investment will be profitable. The wind potential of a site is determined by analyzing the annual average wind speed on a 10-year period [1], thus yielding the frequency of certain wind speeds, the monthly distribution of speeds, as well as the most common wind directions. These data are in the form of diagrams, like those shown in Figure 3, and they are calculated for a location in the UK.

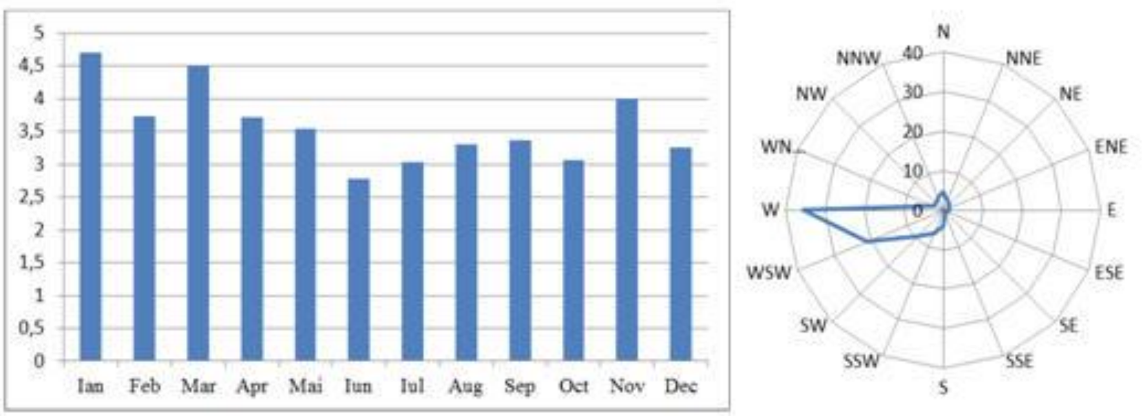

Fig. 3. Monthly distribution of wind speed and wind rose

The urban environment has a fluctuating, turbulent and gusting wind regime, caused by various obstacles, buildings, etc. In order to achieve a cost effective investment by installing a wind turbine, it is recommended that the average wind speed to be 5.5 m/s. Therefore in most cases, in urban areas it is recommended the installation of wind turbines at greater heights, due to the fact that with increasing height the wind speed increases as well, but also because of prevailing wind directions that are not influenced by any obstacles. It is known that winds with a speed between 6 m/s and 9 m/s are mostly coming from the west and southwest, and those exceeding 9 m/s are predominantly coming from the west[5].
As mentioned before, buildings can play an important role for the installation of wind turbines, in such a way that there are situations in which the wind speed can be accelerated, for example if the roof is tilted to the prevailing wind direction(Figure 4). Wind flow around a classical building can be seen in Figure 5.

Fig. 4. The influence of the roof in the placement of a wind turbine [5]

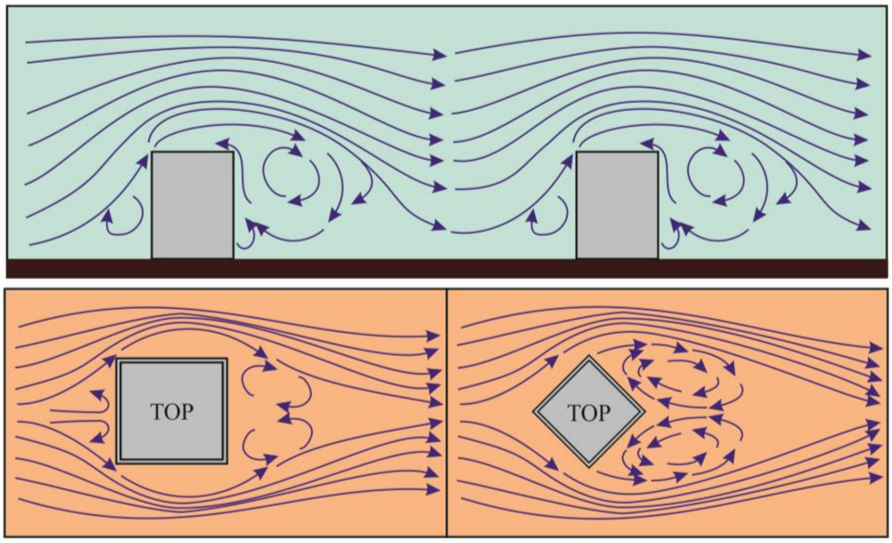

Fig. 5. Wind flow around buildings - different views

Figure 6 shows the wind flow simulation around a building that was achieved by means of FLUENT software. Wind flow around a building becomes distorted and turbulent. Wind intensity is evidenced

by the size of the arrows. The short blue arrows represent a weak wind flow. As the arrows size increases, the greater the winds speed. The yellow arrow area is characterized by the strongest wind that mostly has a constant direction.
When placing a turbine it is recommended to choose the highest building in the area, and that is also far enough from other buildings. Proper placement of turbines affects turbine efficiency and increases the amount of energy generated. Also, the positioning of turbines in the vicinity of a building requires a set distance that is ten times greater than the height of the building Figure 7[6].

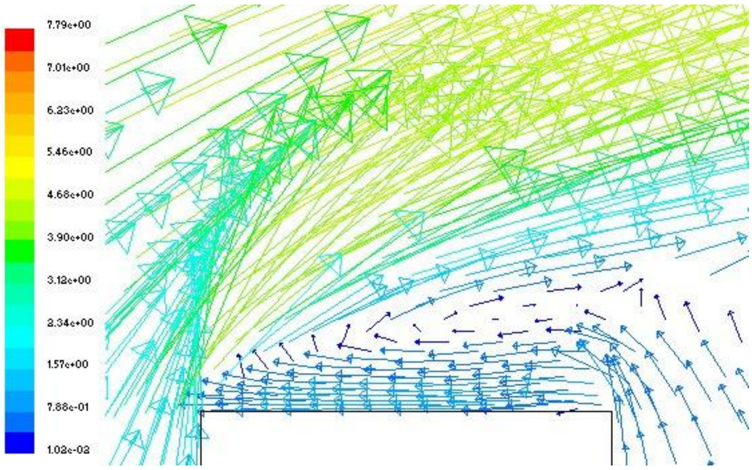

Fig. 6. The wind flow around a building [7]

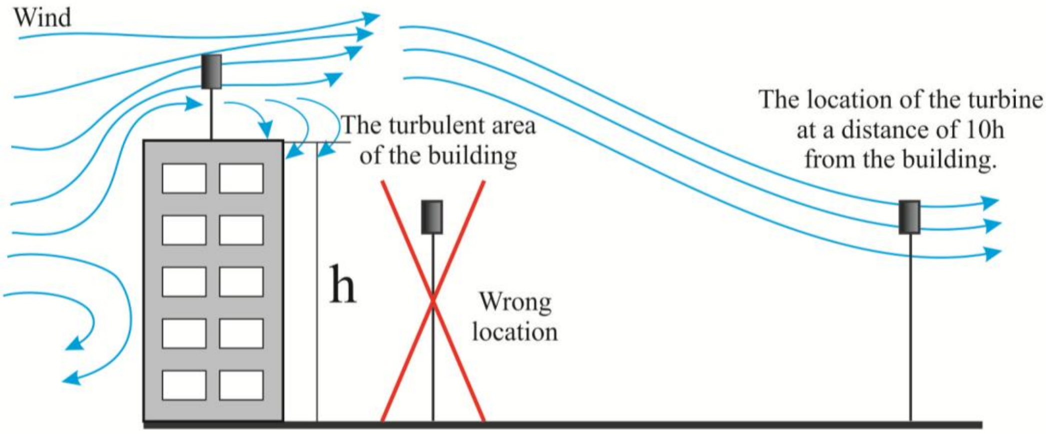

Fig. 7. Proper placement of a wind turbine in an urban area

The energy generated by wind turbines has a largely positive effect on the environment by participating in the reduction of gas emissions greenhouse, but it can also create issues related to overall environmental impact.
The most common of these issues are public safety threatened by damage of the wind turbines, noise, visual effect, the flickering effect and the reflected light from the pale, vibrations, biodiversity and birds.
Based on the information discussed above, we can now formulate a set of recommendations for placing a wind turbine in an urban area:

- The annual wind speed for the given location should be minimum 5.5 m/s;
- The turbine tower or building roof should be about 50% higher than neighboring objects;
- The turbine must be positioned as close to the center of the roof;
- The turbine must be oriented in the most common wind direction;

- The lowest position of the rotor should be above the roof at least at 30% over the building height;
- where possible, it is recommended the placing of a slope on the building, in order to increase the wind speed;
- The strength of the roof must be sufficient in order to withstand the static and dynamic forces produced by the turbine;
- It is recommended placing more than one turbine in the same location, so that the energy production will be increased;
- The amount of energy produced is sufficient for the needs of the area;
- Necessary measures should be considered in order to mitigate shading, flicker, noise and vibration;
- The placement of any wind turbine should be followed after its integration in the urban area and once the acceptance of neighbors has been given.

3. Markets and applications of small power wind turbines

Applications that use wind turbines are becoming increasingly diverse. In Table 2 we can see applications for wind turbines depending on their capacity.
In Europe, the interest is for integrating of wind turbines in urban areas, and constantly seeking for solutions to cope with the turbulent and denatured wind flow in the cities. Among these solutions is noticed the increased interest in integrating wind turbines into buildings as part of the structure or its facade.
The European leader in micro-energy is the UK, currently with nine companies that produce small power wind turbines, but which have a number of prototypes in development. It is a very dynamic market, with over 3,500small and micro turbines installed only in 2007, and according to the British Association of Wind Energy (ABEE) is supposed to be possible to install micro and small turbines so that by 2020 to generate 1200 MW.

TABLE2: Applications for wind turbines based on their capacity

Rated power	**Applications off the grid**								**Grid applications**						
PN < 1 kW	x	x	x	x	x	x			x	x	x	x			
1 kW< PN < 7 kW	x	x	x	x	x	x	x			x	x	x	x	x	x
7 kW< PN < 50 kW					x	x	x	x				x	x	x	x
50kW< PN<100 kW							x	x						x	x
Aplications	Boats	Signals	Lantern	Isolated houses	Farms	Pumping water	Isolated villages	Mini Network	Lantern	Mounted on buildings	Housing	Public centers	Car parks	Industrial	Farms

Other important countries for developing small wind turbines are Netherlands, which have different systems of promoting them and Spain where it was formed a group within the Association of Producers of Renewable Energies (APER) dealing with generating problem for small wind turbines. The goals of this group are to inform the public about this technology, the voice of the industry of small wind turbines by public and private entities, to try to obtain necessary conditions favorable for the development of technology, in terms of financial and legal [8, 9, 10] .

As noted above, the worldwide leader in the development of small power turbines is the US, with a growing market with nearly 15-20% per year, with installed capacity of about 35 MW. Rural households are the most common applications for small wind systems. Canadian small wind turbine market is also important, with an installed between 1.8-4.5 MW.

3.1 Technological trends and recent developments in urban wind turbines

The development trends of small capacity wind turbines have revealed the predominant use of three blades in their construction, a rotor diameter of up to 10 m and a total height of the turbine between 12 to 24 m [8].
The focus is on increasing the efficiency of wind rotor, in particular by developing the blade profile, choice of materials with appropriate properties and manufacturing processes by adopting advanced technologies. These technologies aim to optimize the manufacturing time, reduce the manufacturing costs, but also the possibilities for large and average scale repeatability [11].
The majority of small capacity wind turbine are using synchronous generators with permanent magnet by rare earth and radial flow directly coupled. Rare-earth permanent magnets possess superior magnetic properties and provide more efficient technical parameters relative to induction or synchronous generators with electromagnetic excitation. Synchronous generators with permanent magnets are widely used in applications connected to the network, but ensures to generators a lower weight and lower cost.
Technological developments and the opportunity of using wind energy to generate electricity for own consumption led to increased interest in the construction of green buildings, which in addition to other renewable and environmentally friendly have integrated wind turbines to secure a percentage of energy needs. Such projects are still quite rare, due to high costs, and material and technological possibilities. Most projects of this type we find in the US and England [12, 13, 14, 15].
The first building in the world with integrated wind turbines, which ranks first among the world green building is Bahrain World Trade Center (Figure 8). The building consists of two twin towers, connected by three arms on which are installed horizontal axis wind turbines. The building shape is designed to accelerate wind speed and to channel the flow of the turbines [17].
In the US we meet the project from the roof of Oklahoma Medical Research Foundation (Figure 8b), which has integrated 18 vertical axis wind turbines with a 5.6 m tall and 4.5 kW power each. Maximum power plant capacity is 85500 kWh per year calculated for the operation of turbines for 1000 hours, under ideal conditions. Wind turbines have the cut in speed and start delivering power from a wind speed of 4 m/s [20].

a

b

Fig. 8. a - Bahrain World Trade Center, Bahrain [16], **b -**Oklahoma Medical Research Foundation, SUA [17]

Other examples that successfully use integrated wind turbines into buildings are Strata Tower, London (Figure 9), Tower Pearl River, Guangzhou, China (Figure 9 b), Tower Cis, Manchester, England and Waugh Thistleton Residential Tower, London (Figure 9 c).

a **b** **c**

Fig. 9. a -Strata Tower, London[18], **b-** Tower Pearl River, Guangzhou, China [19], **c-**Waugh Thistleton Residential Tower, London [20]

Technological trends and recent developments in wind turbines can be summarized as follows:

- Vibration reduction in order to reduce noise;
- Blade design and manufacturing technologies;
- Self-protection for extreme winds;
- Adapting a single model to be used outside the network or connected to the network;
- Visually Integrating the small capacity wind turbines in urban or rural areas;
- Integration of turbines in the built environment for applications like street lighting;
- Electronics designed to meet safety standards and sustainability.

4. Application for wind turbine selection for a given location

Based on the researches, on the identified recommendations for installing a wind turbine in urban areas was conducted to a web application that will provide the user a list of optimal wind turbines for installation on the established location, based on some criteria. The developed application uses two databases, one with small capacity wind turbines on the market, selected based on the manufacturer's technical characteristics, distribution opportunities and efficiency and a database with the wind regime for different locations.
The user must enter some information about the desired location of installing a wind turbine, Figure 10 a, following a few simple steps and with a minimum baggage of information related to the problem. Finally the application will provide a list of turbines optimized for installation, along with their technical specifications Figure 10 b.
The working mode and the algorithm for calculating in the application has been explained in paper [21] and based on calculations and conditions the application displays a list of turbines optimized for installation (Figure 4.5). In addition to the manufacturer's specifications displayed in the main screen, the user has the possibility to open a PDF file containing all the data provided by the manufacturer of the selected turbine type.

5. Conclusions

Increasing awareness of the effects caused by fossil fuels, global warming, and accelerated reduction of conventional energy resources with the increasing prices, led to the development of small capacity turbines.
The simple structure, compact design, low noise, low gauge etc. of small capacity wind turbines, are vital for electrical energy production systems in rural areas or in cities, where you cannot install large capacity turbines, due to space constraints and noise.
High capacity wind turbines are placed in optimal wind conditions to extract enough energy, while low-capacity wind turbines have to produce energy not always in favorable conditions.
The gained efficiency of wind turbines is influenced by both chosen turbine model, location and the wind regime. The produced electricity is proportional to the increasing cube of the wind speed, and to get a good produced energy yield some rules must be respected for installing the turbine.

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a b

Fig. 10 a - Programme input**, b -** Programme output

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