The effect of urban buildings on the implementation of small wind turbines

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Abstract. The paper presents the main factors that can influence the location of a wind turbine (building shape, construction height, direction and wind speed) aiming to increase its performance. Thus, three types of buildings with various shapes and heights, which can be found in the urban environment (houses, offices and hotels) are presented in a case study, numerical simulations being carried out using the ANSYS software. The aerodynamic tunnel is customized for each building while maintaining a proportion of the building and the space needed to analyse it. All buildings are rotated to the wind direction and not to the theoretical North. The objective of this paper is to identify the area of the building in which an increase of the airflow is obtained, which allows to increase the performances of the wind turbine. The results allow formulating recommendations for the implementation location and types of units that should be installed.

1. Introduction
The literature suggests that, theoretically, the wind potential exceeds, in a significant way, the global energy demand; however approx. 2-3% of global electricity demand is obtained from wind power, despite the fact that, over the last two decades, the generation capacity of wind energy has increased by 27% [1].

The energy performance of buildings is an increasingly pressing need of the present times, as reflected in the 2013/31 / EU Directive, which stipulates that, starting from 2021, the buildings will be Nearly Zero Energy Buildings (nZEB) through the efficient use of renewable energy resources (including wind energy) [1].

Although many countries have an increasing interest in producing energy on renewable basis, in some countries the electricity generation from wind power still has a negative perception due to the variability of wind potential and its low value that limits the implementation of wind systems in the urban environment. Along with these impediments, the built environment has also a major influence on the good functioning of a wind system. For the architectural acceptance of the wind systems implemented in the urban environment, it is necessary to collaborate with the architects to build buildings that have integrated wind turbines (WT) into their structure. Concepts of this type are already implemented at Council House 2 - Melbourne [2], Mercy Housing - Chicago [3] or Wrigley Hall - Arizona [4], which produce electric power at lower wind speeds by using turbulent airflows [5, 6, 7]. An incorrect setup of the wind system on the roof can lead to a considerable decrease in WT power even under favourable wind conditions, a statement already proved in the literature [8, 9].
The methodology, which is based on common shapes of symmetrical building roofs [10], involves the modelling of the architectural forms specific to the implementation area and the analysis of the airflows dynamics; therefore, the impact of building architecture on the wind potential behaviour has an important role in this analysis, CFD software being usually used to identify the disturbing areas and to optimally place a wind system.

As presented in [11], a wind system integrated in the urban environment can be a cheap option for energy generation, the renewable energy source being directly influenced by the building shape and the intensity of the wind turbulences [12].

This paper addresses four factors that can influence the implementation location of a low capacity WT (building shape and height, wind direction and speed) by using CFD software to analyse the airflow behaviour in the building vicinity. Thus, the optimal location of the wind system is identified in order to get a full capacity operation. The study is based on the weather data presented in [13]. The conclusions include recommendations for the identification of the WT optimal location under specific wind potential and buildings with different shapes.

2. Problem formulation

The paper analyses the influence of the main factors on the positioning of a low capacity wind turbine in order to obtain higher WT performances. These factors refer to the type and shape of the building, the height of construction and the wind speed; another factor would be the wind direction that will be neglected in this study as the building will be placed in the wind tunnel towards wind.

The paper presents as a case study three types of urban buildings placed under a known wind speed. The analysis will be carried out on buildings with various shapes and heights that can be found in almost any type of urban environment. These buildings will be imported [14] into the wind tunnel and placed under an airflow of minimum 2 m/s speed (the speed at which a small wind system usually starts to produce energy) and maximum 6 m/s [13], values that cover the wind potential from Brasov County at 12 m from the ground. The optimal WT location of the wind systems is proposed based on the numerical simulations with the ANSYS software.

The aerodynamic tunnel was customized for each building, keeping a proportion between the building and the space needed to analyse it (Figure 1), ensuring a proper airflow around the building. All buildings were rotated in the direction of the wind rather than towards the theoretical North. As the WT will be mounted on the roof, the behaviour of the air currents in the XZ plane (in a section along the X axis) will be further analysed.

The objective of this paper is to identify the area of the building in which an increase of the airflow is obtained, with less roughness, allowing the wind turbine performance to be increased. The results will allow to formulate recommendations for the implementation location, the types and number of WT that should be installed.
3. Airflow formulation and recommendations regarding the implementation location

As presented in Figure 1, the air flows from left to right, the buildings being oriented to be analysed according to specific weather data, with a wind direction from N-NNW to SSW-S (see [13]). The buildings placed in the wind tunnel have different destinations: office buildings, family homes, hotels.

To achieve the aerodynamic tunnel, proportional values are assigned to the buildings dimensions. The results are based on the assumption of no roughness, the buildings being isolated.

3.1. Office building

The aerodynamic tunnel for the analysis of an office building (Figure 2) with the dimensions at the base of X=40 m, Y=20 m and Z=80 m has the length X=720 m, width Y=240 m, and height Z=240 m.

![Figure 2. Example of an office building [14]](image)

Considering a wind speed of 2 m/s, it can be observed that, in the roof area (Figure 3a), there are turbulences created by the shape of the roof, which amplifies the wind speed of approx. 2.5 times. In this case, it can be also noticed that turbulent airflows appear in the side parts of the building (Figure 3b), although the facade has a circular surface.

Due to the reduced roof dimensions, it is recommended to implement wind turbines with the rotor diameter of up to 5 m, on a tower of approx. 7 - 9 m.

![Figure 3. The behaviour of the airflows around the office building in the aerodynamic tunnel at a wind speed of 2 m/s: view in the ZX plane and b) view in the XY plane, at 5 m from the ground](image)

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Considering a wind speed of 2 m/s, it can be observed that, in the roof area (Figure 3a), there are turbulences created by the shape of the roof, which amplifies the wind speed of approx. 2.5 times. In this case, it can be also noticed that turbulent airflows appear in the side parts of the building (Figure 3b), although the facade has a circular surface.

Due to the reduced roof dimensions, it is recommended to implement wind turbines with the rotor diameter of up to 5 m, on a tower of approx. 7 - 9 m.

![Figure 4. Example of an apartment building [14]](image)
Figure 5. The behaviour of the airflows around the apartment building in the aerodynamic tunnel at a wind speed of 6 m/s: a) view in the ZX plane and b) view in the XY plane at 17 m above the ground

3.2. Apartment building
A building with apartments of a parallelepiped shape (Figure 4) is further considered [14], having the following dimensions X=70 m, Y=20 m and Z=50 m. The aerodynamic tunnel used in the CFD analysis is X=150 m long, Y=100 m wide and Z=150 m high.

According to Figure 5, the wind speed is amplified by approx. 4 times in the terrace area, the wind speed being of 6 m/s. Therefore, it is recommended to use wind turbines with vertical axis, with a diameter of up to 4 m, and a 5 m tower (reaching a height of 9 - 10 m from the roof terrace). Besides, the vertical axis wind turbines are preferred in the urban environment to the horizontal ones as their noise during operation is smaller.

Figure 6. Example of a hotel [14].

Figure 7. The behaviour of the airflows around the hotel in the aerodynamic tunnel at a wind speed of 6 m/s: a) view in the ZX plane and b) view in the XY plane at 50 m above the ground
3.3. Hotel

The hotel from Figure 6 [14] has a geometric footprint on the ground made up of triangles and rectangles, with straight and oblique external walls, having the dimensions X=40 m, Y=60 m and Z=100 m. The building is placed into an aerodynamic tunnel with the length X=300 m, width Y=180 m, and height Z=250 m.

This type of building amplifies the wind about 3 times (Figure 7), the considered wind speed being of 6 m/s.

For this type of building it is recommended to use vertical axis wind turbines of 5 kW nominal power, whose cut-in speed is of 1 m/s, WT that can be mounted on the edge of the hotel upper terrace.

4. Conclusions and discussions

The optimal location for mounting wind systems on buildings depends on the variables affecting the wind flow. The effect of the shape and height of the building as well as the wind velocity on the behaviour of the air currents is analysed in the paper at the contact with the considered building in order to highlight the optimal location for the wind turbines.

In all cases, the area with the peak intensity of the air turbulences extends above the roof to about 1/4 of the building height, which means that the wind systems should be positioned so as to benefit of wind amplification; however, the support tower should not be overly high to avoid the occurrence of vibrations in the anchorage.

The shapes of all investigated buildings have an influence on wind speed, amplifying the wind potential. It can be concluded that the height of the building, on which the wind turbines are installed, is important, thus eliminating or diminishing the effect of the surrounding buildings on the wind potential.

For the buildings whose side walls are vertical, the wind has turbulences at the edges, where wind systems with vertical axes are recommended to be installed; if the building side wall is oblique, a higher wind is gained to the inside of the building, where wind systems with vertical axes should be installed.

Regardless of the building shape, the wind has a higher speed on the building terrace / roof than on its sides.

The circular shapes, compared to the straight ones, allow a smoother wind flow and, therefore, an easier wind amplification.

Due to the complexity of the urban environment, these studies must be conducted in a simplified manner by considering fixed values for all variables, the only variable that can alter the results being the locally wind potential.

The analysis highlights the influence of the building on the amount of captured wind energy, depending on the location of wind systems on the roof or its sides.

The main conclusions of the paper can be formulated as follows:

- buildings can influence through their various shapes the amount of energy captured by the turbines installed on them; therefore, they should be designed from the project stage to allow wind potential amplification;
- vertical and / or horizontal axes wind turbines can be installed on almost any type of building, taking into account the tower height on which they are mounted that allows the WT operation at nominal power;
- vertical axes wind turbines are recommended to be installed on the sides of the buildings, wherever allowed; these turbines are silent, start at lower wind speeds and are easier to be architecturally accepted;
- wind systems of different types and sizes, can be mounted on buildings of different shapes while maintaining the environment aesthetics;
- both the architectural shapes in the installation area and the wind potential of that area are important for the maximization of the energy potential of a wind system installed in the urban environment.
5. References

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