ANALYSIS OF FACTORS AFFECTING WIND-ENERGY POTENTIAL IN LOW BUILT-UP URBAN ENVIRONMENTS

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ABSTRACT. Analysis of factors affecting wind-energy potential in low built-up urban environments. This study is concerned with the examination of roughness factor affecting wind potential in low built-up urban areas (e.g. subdivision, light industrial area). The test interval is the transition between summer and winter, as a secondary wind maximum period. The ten-minute data-pairs empirical distribution was approached by several theoretical distributions where a fitting test research was also performed. Extrapolation to higher levels is possible by defining the Hellmann exponent. The wind speed in respective height and the specific wind power are derived from it. Knowing the daily progress of the Hellmann exponent value, more accurate estimation can be given of the wind potential calculated to different heights according to the measuring point. The results were compared to the surface cover of the surrounding area as well as to the literary alpha values.

Keywords: wind energy, urban environment

1. INTRODUCTION

One of the most important question of today's society is what kind of energy sources could substitute or replace the shortage caused by fossil fuel reserves reduction, as well as how could be reduce the environmental pollution caused by them. The last years of the 20th century, which were characterized by throughout and increasing researches of renewable energy resources, there were such estimates that after the depletion of fossil reserves the shortage could mostly be replaced by renewable energy sources. In the early 2010s such prognosis came out that the so called „green energy" can only be used as complementary resources (Lázár, 2011).Due to the increasing specific energy demand, it's getting harder to meet the population needs. Failures of the continuous supply can lead to consumers' dissatisfaction. This accelerated process caused by the rising energy prices can be observed in recent years. The use of household scale renewable energy installations are more and more perspective. The energy stored in such

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systems (capacitors, accumulators) not only reduces the overhead costs of a given household but also make it partially independent of the supplier. The profitable conditions of the wind generators planted on the roof level are to achieve the utmost working hours. The direct and indirect impacts on meteorological parameters of different urban built-up zones are separately various (Stewart - Oke 2010).Wind climatology studies that referring to Hungary cover a wide spectrum, since comprehensive description of the issue can be given by complex statistical analysis (Tar, 1983; Wágner - Papp, 1984; Tar, 1991; Tar, 1999; Makra et. al 2000a), by modelling (Radics, 2003; Radics - Bartholy, 2005) and by remote sensing techniques (Varga - Németh, 2005; Varga - Németh - Dobi, 2006). In this study the effect of urban environment on wind system is examined.

2. MATERIALS AND METHODS

Our data come from a measurement tower fitted with wind speed and direction sensors. The data base covers the term between 2 October 2013 and 10 January 2014. We chose this period because of the secondary wind maximum is in the above-mentioned period (primary wind maximum – in March, secondary wind maximum – in November and tertiary wind maximum – in July) (Tar et. al, 2005). The station is situated in the west of Debrecen (Fig. 1.). The geographic latitude and longitude are 47.530 N and 21.577 E. The height of the tower is 20 meters, at 10 meters and 20 meters shovel anemometers, at 20 meters a wind direction sensor was planted that is connected to the CR1000 data logger produced by Campbell Scientific Ltd. The wind speed is measured by 1 second sampling and10 minutes averaging, the wind direction is measured by 10 minutes sampling and recording.

Table 1.The sensor parameters are shown in

Sensor /data logger	Operating temperature range	Accuracy of measurement	Measurement range
A100R	-30 °C +50 °C	1% ± 0.1 ms^{-1}	>70 ms^{-1}
W200P	-50 °C +70 °C	± 0.2°	0-360°

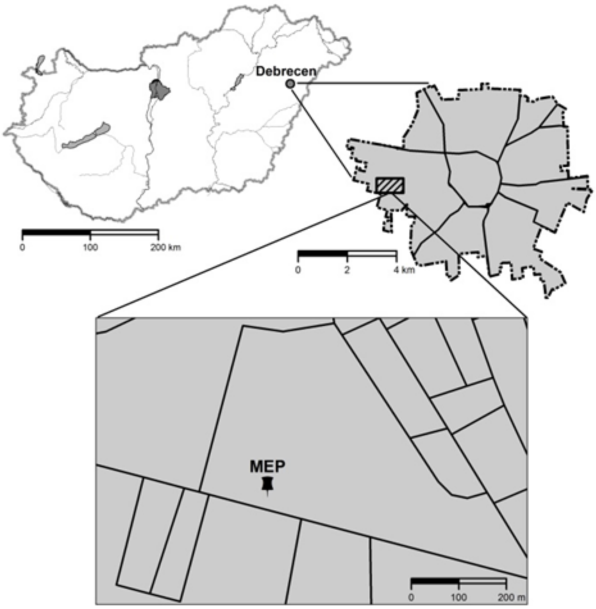

Fig.1. Position of the measuring point (MEP –Megújuló Energiapark)

The most commonly used method by wind energy estimations is the Hellmann exponential method:

$$\frac{v_1}{v_2} = \left(\frac{z_1}{z_2}\right)^{\alpha}$$

where v_1 is the wind speed at z_1 elevation and v_2 at z_2 elevation, the α is the ground roughness exponent. Over the low vegetation surface the value of α derived from logarithmic approach is 0.14. This is a mostly accepted basic estimation. During the day in the convective near-surface layer we can calculate by the value of 0.07-0.1, while in case of extreme stable stratification the values of 0.25-0.35 are suggested (Weindinger et al., 2011;.Ucar-Balo, 2010, Gokce et al. 2007). In the peri-urban areas - over large roughness surfaces - the value of the average exponent is about 0.2 (0.14 to 0.26) (Emeis, 2005).The wind speed at any heights can be written by logarithmic profile by means of roughness height (z_0), average height of roughness elements (h) and displacement thickness(d):

$$U(z) = U(z_{ref}) \frac{\ln\left(\frac{z-d}{z_0}\right)}{\ln\left(\frac{z_{ref}-d}{z_0}\right)} = U(z_{ref}) \ln\left(\frac{z-d}{z_{ref}-d}\right)$$

The general form oft he logarithmic profile equation is:

$$U(z) = \frac{u_*}{\kappa} \ln\left(\frac{z-d}{z_0}\right)$$

where u* is the friction velocity, κ is an empirical constant known as the von Kármán constant and is found to have a value of κ = 0.4 (Millward-Hopkins, 2013; Zaki et al. 2011;.Tse et al. 2013,Drew et al. 2013).

3. RESULTS

After processing our measuring point data, the following results were obtained. The second summary table shows the basic statistic values. The minimum is not included in the table because in both cases the value of it is 0 ms^{-1} (calm).

Table 2. Basic statistics

	Maximum	**Average**	**Dispersion**	**Variance**	**Modus**
10 m	9.1	1.9	1.4	2.0	0.9
20 m	11.2	2.6	1.6	2.7	0.9

During the examination period, the most common wind directions are between in the SE and S, and N sectors (10-12%) (Fig. 2).

However, the different directions' average speeds, measured in the maximum 20 meters, exceed the 3.5 ms^{-1} (Fig.3).

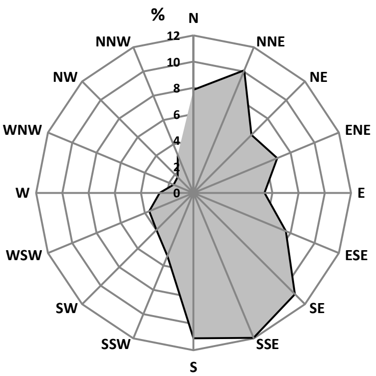

Fig.2. Relative frequency of wind directions

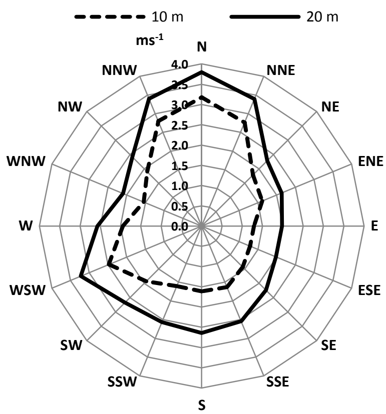

Fig.3. Average speeds of wind directions

During the given period, the roughness value derived from the Hellmann-equation is 0.27. In Fig. 4 the average values of α are presented in different directions, what shows that the largest value can be found in the southern and eastern directions, which is mainly due to the effect of the surrounding terrain objects (buildings and vegetation) (Fig.4).

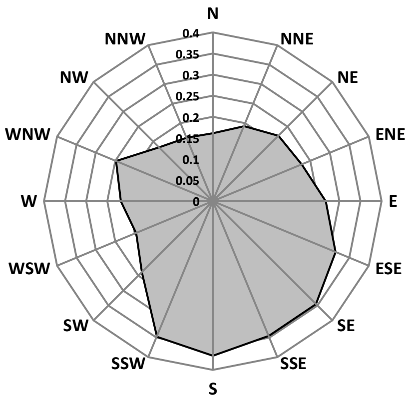

Fig. 4. α-values of wind speeds

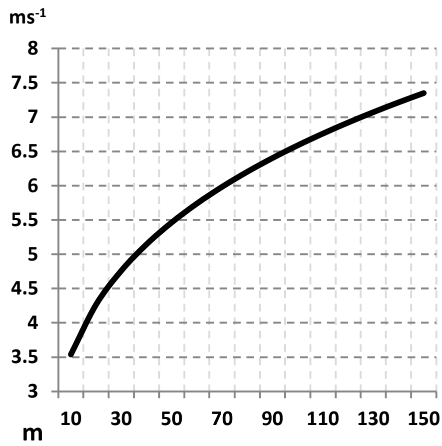

Fig. 5. Vertical wind profile

The wind speed of higher ranges can be derived from the value of *α.* The wind speed changes with height can be observed in Fig.5.

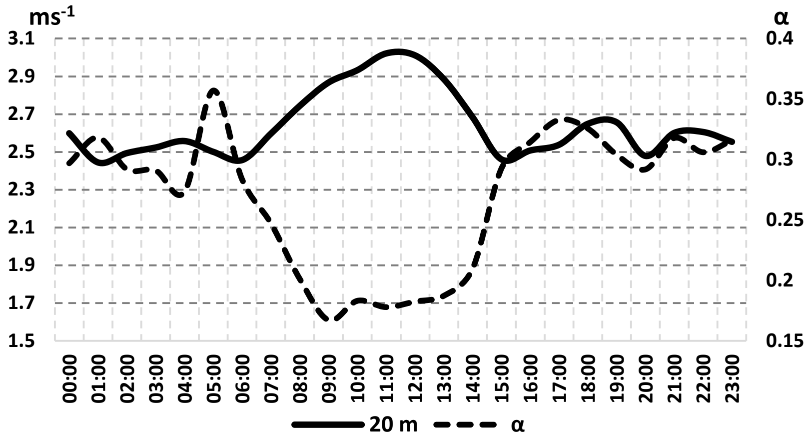

Fig. 6. The daily course of wind speed and α (mean time in UTC)

Between 6 and 15 UTC the daily course of wind speed and *α* show a reverse relation, which one is caused by the atmosphere instability in the lower layers. During the given period the maximum of *α* occurs at 5 UTC(0.36), while the minimum at 9 UTC (0.17). In the daily course of wind speed three different periods can be distinguished: the interval between 15 UTC and 6 UTC, when the average wind speed is around 2.5 ms^{-1} (± 0.2ms^{-1}), from 6 UTC to 11:30 UTC, when the wind velocity increases (≥ 2.5 and ≤3 ms^{-1}) and from11:30 UTC to 15 UTC, when the wind speed decreases (≥ 2.5 and≤ 3ms^{-1}).

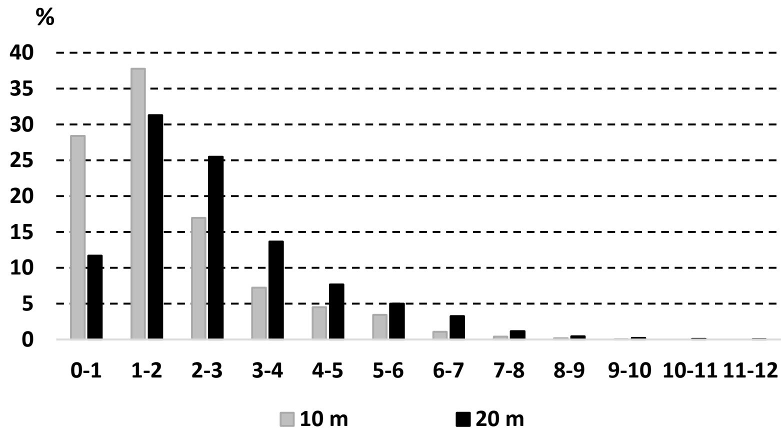

Fig. 7. Relative frequency of wind speed (ms^{-1})

The rotors of household-size wind generators are located in the measured heights (10 and 20 m) or between them since authority permits for such high structures are not necessary (that in some cases is almost impossible to obtain – for example an airport surrounding). The start-up speed of this type of wind generators are between 2 and 3 ms^{-1}, while the name-plate rating, that depends on the size and the rotor diameter is about 8-10 ms^{-1}.The distribution of wind speeds shows that the most common wind speed values are between 1-2 ms^{-1}, the number of lower and higher values of both heights are fewer. The 3 ms^{-1}greater wind speeds' occurrences are 17% at a height of 10 meters, while at 20 meters 31%.

4. CONCLUSIONS

In our study the following conclusions can be drawn:

- based on measurements of both heights the most frequently occurring wind speed value is the 0.9 ms^{-1};
- the most common wind directions: SSE, S, SE, SSE;
- the maximum values of α are between the SSW and ESE directions, which verifies the roughness value increase caused by the built-up structure;
- the average value of α (0.27) corresponds to the literature value;
- during the given period the maximum of α occurs at 5 UTC 0.36), while the minimum at 9 UTC (0.17);
- based on the distributions the most frequent wind speed values measured at both heights (10 and 20 m) are between 1 and 2 ms^{-1}, that means 38 and 31 % of the cases.

5. ADDITIONAL OBJECTS

Based on these results, the following objectives were drawn up: taking into account the over time, horizontal and vertical distribution of the roughness and wind speeds, there is a reason for performance and height comparison of different wind generators in accord with different household energy demands.

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