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# AN EXPERIMENTAL EVALUATION OF RESOURCES AND THE POTENTIAL FOR USING THE KINETIC ENERGY OF WIND TO PRODUCE ELECTRICITY

# EKSPERYMENTALNA OCENA ZASOBÓW I MOŻLIWOŚCI WYKORZYSTANIA ENERGII KINETYCZNEJ WIATRU DO PRODUKCJI ENERGII ELEKTRYCZNEJ

A b s t r a c t

This article presents the results of a three-year study of local wind energy resources. The results were analyzed in espect to their compliance with the Weibull distribution model. The objective was to determine whether the actual distributions differ from the theoretical ones which are available in the IMGP studies. The potential for meeting electricity needs was determined on the basis of an assessment of local kinetic energy wind resources. This was based on producing wind energy for buildings that have no possibility of connecting to the grid. Several variants were considered in terms of demand for electricity at different buildings.

*Keywords*: *kinetic energy of wind*, *conversion of the kinetic energy of wind into electrical energy*, *the potential for meeting the electricity needs of a building*

S t r e s z c z e n i e

W artykule przedstawiono wyniki trzyletnich badań lokalnych zasobów energii wiatru. Wyniki badań poddano analizie z punktu widzenia ich zgodności z rozkładem Weibulla. Analiza miała na celu określenie o ile rozkłady rzeczywiste różnią się od rozkładów teoretycznych dostępnych w opracowaniach IMGP. Na podstawie oceny lokalnych zasobów energii kinetycznej wiatru wskazano możliwości zaspakajania potrzeb na energię elektryczną w oparciu o energię wiatru w budynkach nie mających możliwości przyłączenia do sieci elektrycznej. Rozważono kilka wariantów budynku różniących się zapotrzebowaniem na energię elektryczną.

*Słowa kluczowe*: *energia kinetyczna wiatru*, *konwersja energii kinetycznej wiatru na energię elektryczną*, *możliwości zaspokojenia potrzeb budynku na energię elektryczną*

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## 1. Introduction

Estimating the potential for electricity generation from wind energy is a fundamental issue of today but any decision relating to the level of investment in wind energy is fraught with difficulty. Assessing wind energy resources is a complicated task due to its stochastic nature.

A preliminary assessment of wind energy resources may be based on meteorological data. Meteorological stations are mainly located at large distances from one another, are often sited in the vicinity of trees and tall aerodynamic buildings, and do not have measuring equipment working continuously. This means that the average wind speed reported in the literature (climate maps) can significantly differ from the average velocity defined more precisely for energy purposes. Furthermore, the climatic zone in which Poland resides can see significant changes in meteorological conditions in consecutive years. Therefore, any analysis of results of observations should be based on long-term studies, the standard period being for three--years. A series of annual measurements are the minimum required. The most favourable elevation for measurements is taken at the height of the projected axis of the wind turbine rotor above ground level. However, measurements conducted in meteorological stations are usually carried out at a lower height, as wind measurements at high altitudes are costlier due to the fact that they require a high mast with a complex construction. Therefore, wind speed recordings taken at much lower elevations than the actual or intended height of the nacelle of the wind turbine have to be extrapolated for higher altitudes. It is a very difficult task and feasible only in approximate terms. This is due to the fact that, in changing the wind profile in relation to height, it is also necessary to take into account the formation and development of the land and the atmospheric stratification conditions [1].

This article explores the issue in the light of experimental studies.

## 2. Studies of the kinetic energy of wind

Studies of the kinetic energy of wind were made in the Subcarpathian province at location 304 m above sea level. According to the six-class roughness model by Żmuda [2], the area on which the measurements were undertaken correspond to the roughness class 2 scale. An anemometer LB-747 was used to measure the wind speed. The measurements were sent from the device in a digital format to the data collection master system of an LB-486 converter. The measurements were undertaken over a three-years period from the beginning of 2007 to the end of 2009.

The average monthly wind speed was calculated as an arithmetic average of the daily average, while the daily average was calculated as an arithmetic average of the measurements taken every 10 minutes throughout the day and night.

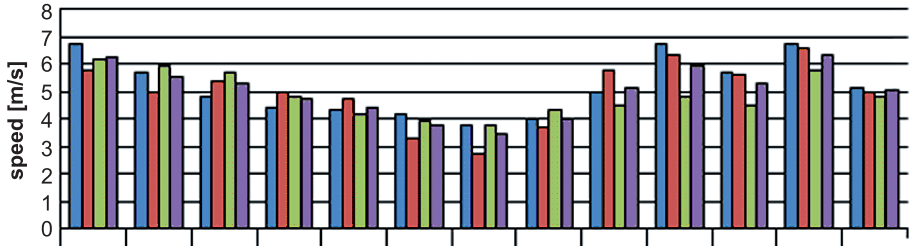
According to the Institute's data readings, it is necessary to interpolate an average wind speed in the measurements. For this region, the measurements should be about 4 m/s [3].

Wind power depends on the wind speed to the third power [4]. In accordance with this and assuming the same air density, the following ratio occurs:

$$\frac{\text{energy}_{V=4.0\,\text{m/s}}}{\text{energy}_{V=5{,}03\,\text{m/s}}} = \frac{4^3}{5.03^3} = \frac{64}{127.3} = \frac{1}{2} \tag{1}$$

$$\text{energy}_{V=4.0} = \frac{1}{2}\text{energy}_{V=5.3} \tag{2}$$

Therefore, the increase of wind speed by a factor of 25.75% from 4 m/s to 5.03 m/s will result in a two-fold increase in wind energy.




| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2007 | 6.7 | 5.7 | 4.8 | 4.4 | 4.3 | 4.2 | 3.8 | 4 | 5 | 6.7 | 5.7 | 6.7 | 5.16 |
| 2008 | 5.8 | 5 | 5.4 | 5 | 4.7 | 3.3 | 2.7 | 3.7 | 5.8 | 6.3 | 5.6 | 6.6 | 4.99 |
| 2009 | 6.2 | 5.9 | 5.7 | 4.8 | 4.2 | 3.9 | 3.8 | 4.3 | 4.5 | 4.8 | 4.5 | 5.8 | 4.85 |
| average | 6.23 | 5.53 | 5.3 | 4.73 | 4.4 | 3.8 | 3.43 | 4 | 5.1 | 5.93 | 5.27 | 6.37 | 5.03 |

Fig. 1. Distribution of monthly average wind speed measurements for three consecutive years, and the three-year average

The expected number of hours of wind activity at a certain speed at a given average wind speed can be determined by the Weibull distribution model in graphical or tabular format [5].

As can be seen in Figure 2a, the actual distribution of wind speed in a given area and in a given year may significantly differ from one calculated by the Weibull distribution graph

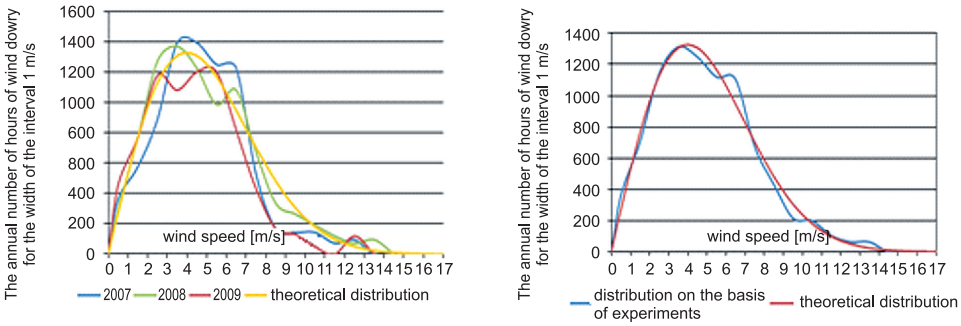



Fig. 2. a) Distributions recorded on the basis of actual measurements for three consecutive years of readings; b) The annual number of hours of wind activity for three years as averaged measurements (blue curve), together with the theoretical Waibulla distribution (red curve)

(yellow curve). However, measurements taken and then averaged out over a longer period of years bring the results of the experiment closer to a theoretical Waibull distribution curve – as shown in Figure 2b.

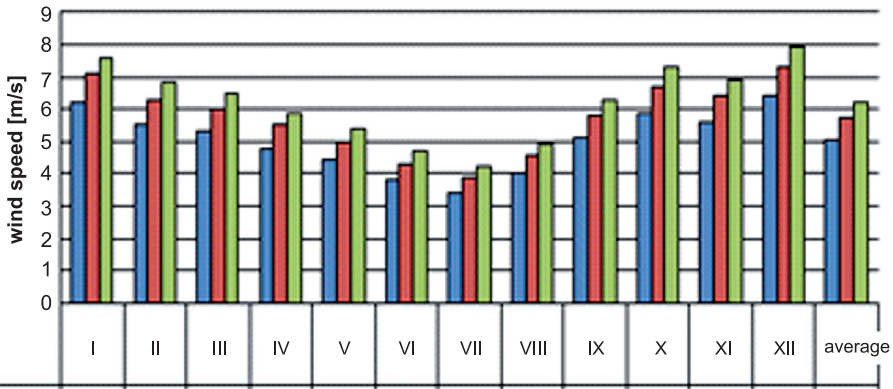
In relation to the three-year average wind speeds, it is important to ascertain what kind of fluctuations occur in individual months and in different years (Table 1).

Table 1

**Fluctuations in wind speed in different months of the year compared to the three-year average**

| Three-year average | Monthly wind speed | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
| | 6.2 | 5.5 | 5.3 | 4.8 | 4.4 | 3.8 | 3.4 | 4 | 5.1 | 5.9 | 5.6 | 6.4 |
| | % | | | | | | | | | | | |
| 2007 | +1.5 | +3.6 | –9.5 | –8.4 | –2.3 | +10.5 | +11.7 | 0 | –3.9 | +11.6 | +5.5 | +3 |
| 2008 | –12.2 | –9.1 | +1.8 | +4.1 | +6.8 | –13.2 | –20.6 | +7.7 | +11.5 | +5 | +3.7 | +1.5 |
| 2009 | –6.1 | +7.2 | +7.5 | 0 | –4.6 | +2.6 | +11.7 | +7.5 | –11.8 | –18.6 | –19.6 | –9.4 |

As can be seen, the deviation from the three-year average (about 94%) does not exceed +/–15% most of the time. The displacement values in the remaining period of time does not exceed 21%. These deviation rates show what to expect in terms of variations in practice.




| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 m | 6.2 | 5.5 | 5.3 | 4.8 | 4.4 | 3.8 | 3.4 | 4 | 5.1 | 5.9 | 5.6 | 6.4 | 5.03 |
| 20 m | 7.1 | 6.3 | 6 | 5.5 | 5 | 4.3 | 3.9 | 4.6 | 5.8 | 6.7 | 6.4 | 7.3 | 5.74 |
| 30 m | 7.6 | 6.8 | 6.5 | 5.9 | 5.4 | 4.7 | 4.2 | 4.9 | 6.3 | 7.3 | 6.9 | 7.9 | 6.2 |

Fig. 3. Extrapolation for the area of roughness class 2 and averaging time 1 h

Wind speed measurements are usually conducted at a lower altitude than the anticipated/planned height of a wind turbine nacelle of. However, the approximate wind speed at a height above or below the height at which measurements were conducted for this study can be calculated from Sutton's power-law formula [4, 5].

Figure 3 shows the approximate wind speed at a height of 20 and 30 m above ground level, as calculated by Sutton's power-law formula.

## 3. The concept of using wind power plant

Furnished with the average annual wind speeds and applying the Weibull distribution formula, we can determine the production output of electricity by a wind power plant and then identify the most suitable location to meet the required electricity energy needs of the building in question.

Figure 4 shows the power generation characteristics of commercial, catalogue standard power wind turbines with respective outputs of 1 kW; 2 kW; 3 kW; 1.8 kW; 1 kW; 3.2 kW.

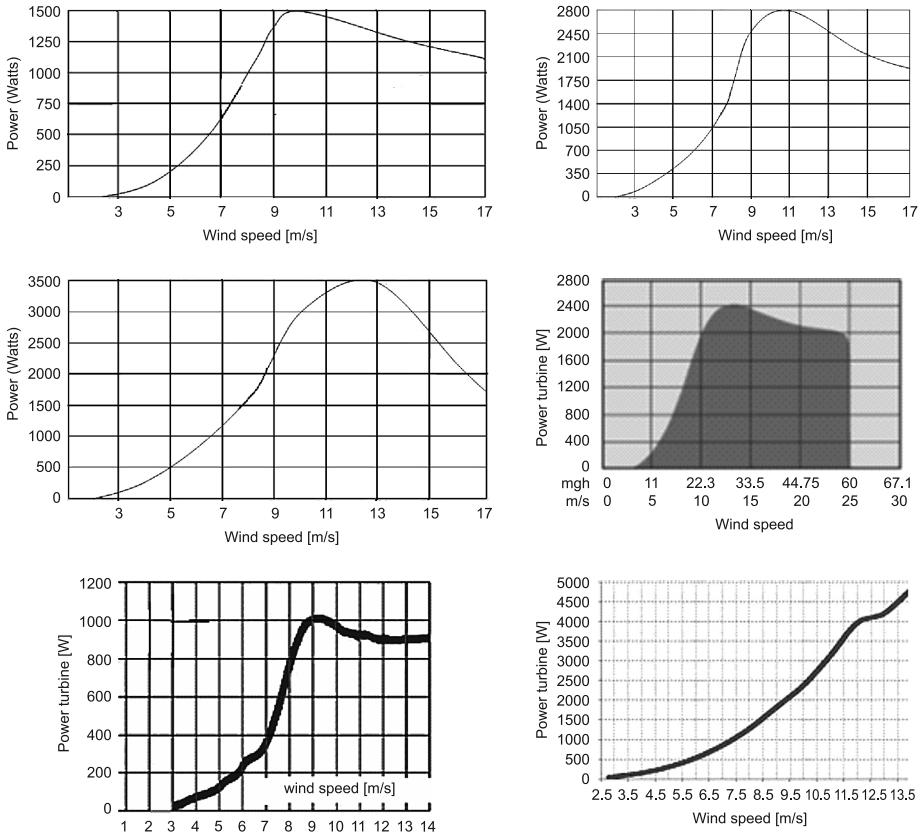



Fig. 4. Power characteristics of a wind turbine with a power output of 1 kW; 2 kW; 3 kW; 1.8 kW; 1 kW; 3.2 kW [6, 7]

Figure 5 shows the energy production levels of electricity, depending on the elevation of the wind turbines nacelle with the power characteristics as shown in Fig. 4, at a wind speed of 5 m/s at 10 m above ground level.

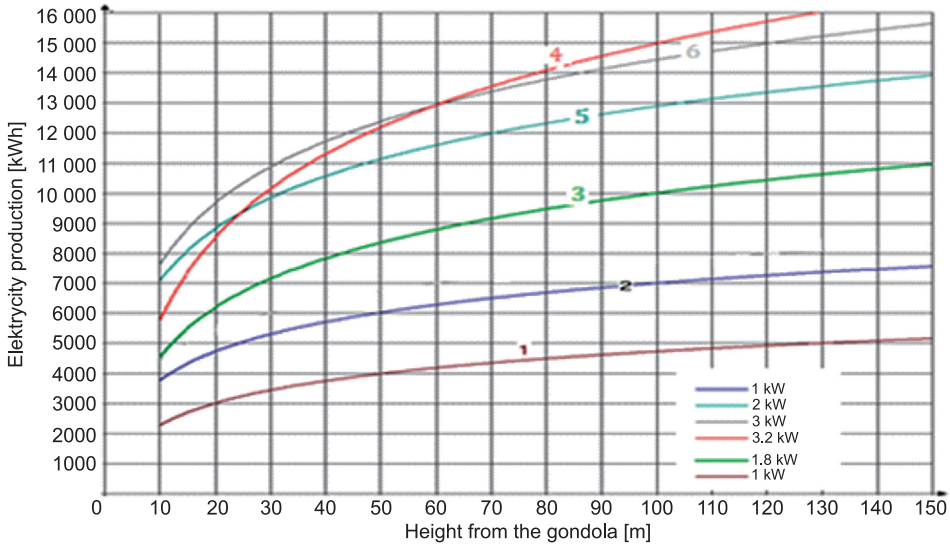



Fig. 5. Wind power plant electricity generation with the nacelle at different elevations

Curves 2, 5, 6 show production levels of electricity for a wind power plant from the same manufacturer, with the same startup speed and respective capacity – 2 m/s of 1, 2, 3 kW. Graph 1 shows the production of energy by another manufacturer's wind turbine, albeit, similar to Graph 2 with a power of 1 kW, but a take-off speed of 3 m/s. Graph 4 shows the production of electricity with a capacity of 3.2 kW and a starting speed of 3 m/s. As can be seen from Fig. 7, it is not always the case that the greater the power of a wind turbine, the greater is the production of electricity.

Table 2

**Production of electricity in thousands of kWh per year, depending on the average wind speed and plant power**

| Wind speed [m/s] | Power wind power plant | | | | | |
|---|---|---|---|---|---|---|
| | 1 [kW] | 2 [kW] | 3 [kW] | 5 [kW] | 10 [kW] | 20 [kW] |
| 4 | 1–1.5 | 2–3 | 2–4 | 4–7 | 5–9 | 6–10 |
| 4,5 | 1.5–2 | 3–4 | 3–5 | 5–9 | 7–13 | 9–14 |
| 5 | 2–2.5 | 4–5 | 4–6 | 7–12 | 10–16 | 13–17 |
| 5,5 | 2–3 | 5–6 | 5–7 | 8–13 | 14–20 | 15–20 |
| 6 | 2.5–4 | 6–7 | 6–8 | 10–14 | 18–26 | 18–22 |
| 6,5 | 3–5 | 7–8 | 7–9 | 12–16 | 23–29 | 21–26 |
| 7 | 4–6 | 8–9 | 8–10 | 14–17 | 26–32 | 28–34 |

## 4. The accumulation of electrical energy

In the case of an independent (autonomous) power system in a detached house, electricity demand throughout the year can only be met by using batteries of a sufficiently large capacity – preferably located in the building. This is because, in winter, low temperatures cause a deterioration in energy recovery efficiency levels.

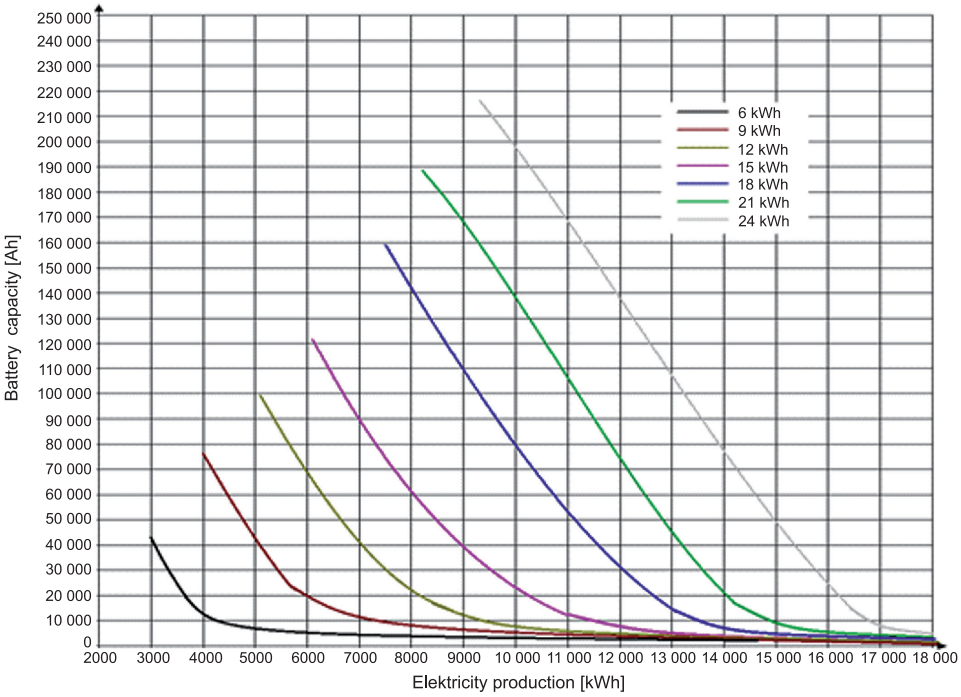



Fig. 6. The battery's running-time capacity measured against electricity production by the wind power plant, comparing results for varying daily energy demand (nominal voltage of a 12 V battery)

Figure 6 shows battery capacity dependence from electricity production of a wind power plant providing for a variety of daily energy needs.

## 5. The demand for electricity in a building

The electrical energy demand for detached houses (low energy buildings) varies depending on the cladding and the types of electrical appliances in the building. Examples of the levels of electricity demand are shown in Table 3.

As can be seen from the data in Table 3 and in Fig. 4, there is potential for an autonomous power system based on small wind turbines. However, due to the stochastic nature of wind

energy, it is necessary to supplement production, accumulation and storage of energy using batteries on a periodic basis.

Table 3

**Building demand for electricity and the battery capacity of electricity**

| Lp. | Demand for electricity | The wind turbine should produce | The amount of chemical batteries 230 [Ah], 12 [V] |
|---|---|---|---|
| 1. | 3 500 | 4 900 | 230 |
| 2. | 4 000 | 5 530 | 270 |
| 3. | 4 300 | 6 100 | 250 |
| 4. | 4 500 | 6 300 | 300 |
| 5. | 5 000 | 7 000 | 330 |
| 6. | 6 300 | 8 820 | 410 |

## 6. Conclusions

There is potential for operating a stand-alone power system derived from wind energy for single-family dwellings. The stochastic nature of wind energy requires periodic storage of and access to the energy produced.

Wind speed measurements obtained at selected measuring points, averaged out over three years, differed by 25.75% from the results detailed in the corresponding IMiGW published studies. Variations, in wind jet power show a discrepancy rate of up to 100% in some cases, because the power of the wind stream is proportional to the cube of wind speed movement in the airstream. These discrepencies can be explained because average speeds often vary to a significant degree at two distant points in a given area. It follows that the selection of locations for wind power plants requires an assessment of wind energy resources as near to the intended site as possible.

The biggest difference between the average wind speeds, averaged out for the same monthly period each year, occurred in October (almost 29%).

In contrast, the largest deviation of the average monthly wind speed for the three-year average period occurred in July 2008, when the wind speed reached 2.7 m/s and the three--year average for the month was 3.4 m/s. The wind speed difference was nearly 21%, and this difference (expressed in terms of the wind power plane) was about 80%.

It should be emphasized that a statistical distributions of wind speeds for a three-years period ought to provide a good statistical match with the theoretical Waibull distribution formula.

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