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To cite this article: M Filipowicz *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **214** 012122

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Study of building integrated wind turbines operation on the example of Center of Energy AGH

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Abstract. The worldwide growing demand for energy from renewable sources is observed. This fact is related to a number of factors, especially environmental ones. The renewable energy sector, which can be seen in the most dynamic development is wind energy. This is due to the construction of huge wind turbines, whose power exceeds one megawatts. The main problem that should be solved is to find a proper location for such turbines. Generally, wind turbines are located off-shore and on-shore. The most favourable are off-shore because of better wind condition what relates to power generation. Notwithstanding, it is possible to install smaller turbines in urban areas: so-called wind turbines in built-up areas or integrate wind turbines with buildings (BIWT). However, it is needed to be aware of many problems of above mentioned installations. The article presents an overview and data related to operation of wind turbines integrated with the Center of Energy AGH building.

1. Introduction

Most of energy consumed in the world is used for the buildings' needs. Recently, an architectural trend to replace energy-consuming buildings by self-sufficient energy buildings has appeared. An example of such solution is installation of building integrated wind turbines (BIWT). Studies show that such wind turbine installations may satisfy up to 20% of the building's energy needs [1]. The main problem with implementing this technology is to design a suitable building shape to get an area with appropriate wind parameters. In [2] it has been shown that wind speed could be increased by up to 40% only by design an optimal building geometry. One of the methods used to solve this problem is CFD (Computational Fluid Dynamics). In general, placing turbines in built-up areas, as well as their integration with buildings, is a more complicated problem than their location in the undeveloped areas. This is due to the disturbance of the air movement by surrounding structures [3].

There are three types of turbines which are located in built-up areas [3, 4]:

- Building integrated wind turbines (BIWT), those turbines are attached to the building but not necessarily connected to them,
- Building mounted wind turbines (BMWT), those turbines are connected to the structure of the building. Mostly, buildings have a tower shape. Its geometry has to be able to provide to install turbines and have to be vibration-, load- and noise-proof. Most common are turbines installed on building's roof or walls.
- Building augmented wind turbines (BAWT), in such case, building is purposely used to profile and strengthen wind flow through the installed turbine. This effect is achieved by a special roof construction which is used as a flow concentrator or mounted turbines on the roof edge. An



example is a profiled roof structure (sail shape or diffusor) designed to increase wind speed at the turbine.

There are two basic types of turbines used in those applications – with vertical and horizontal rotation axis. Each of those have advantages and disadvantages.

In order to strengthen the wind flows near the buildings, it is necessary to design them in a special way. There are many factors which have impact on wind flow. The geometry of building, its height, width, location, positioning, construction etc. have to be analysed. The effects that should be noticed are channelling of wind flow, terrain roughness, turbulence or wind blasts. Collecting of meteorological data for at least 10 years is required to carry out such analysis [5]. A proper shape of a building is the important way to increase wind speed near a wind turbine. It has been argued that rectangular and concave buildings, as opposite to round ones, are capable to cause strong vertical air movements that should be successfully used by turbines. It is also possible to adapt the form of the building to get the channel flow (e.g. through the tapered arrangement of buildings, causing the flow increase due to the Bernoulli effect) [4]. An interesting concept seems to be the formation of building façade elements, to achieve strengthen wind flow. The solution described in [6] is characterised by use of dedicated guide vanes with small turbines installed between them. CFD analysis and aerodynamic tunnel testing confirm the possibility of up to twice wind speed between the guide vanes, allowing to multiply power generation.

For turbines placed near the edge roof, special attention on the variable direction of air flow in this area is necessary [1]. Such turbines required special shape of the blades. It is also important to ensure that the installed turbine is not in a turbulent zone caused by surrounding buildings or trees.

To maximize usage of distorted winds by neighbouring obstacles, turbine construction is optimised – especially blades. The example is the cross flex construction, described in [7], where a combination of specially profiled, twisted blades are used. A number of additional advantages and problems related to this technology are presented in [8]. Many of those solutions are new technologies, with high investment risk and not optimally using available wind resources.

2. Description of wind turbines installation

The paper analyses the operation of the BIWT installation located on the façade of Center of Energy AGH building. Two different turbines – horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT) are installed. Location of the turbines is shown in Figure 1. The basic parameters of the described turbines are shown in Table 1.

Table 1. The basic parameters of the wind turbines installed on the facade of Center of Energy AGH building.

	HAWT	VAWT
Type	Ventus Energia, Swind New 1500	Hipar, Ecorote 600
Wind speed of start-up [m/s]	2.3	1.2
Power [kW]	1.5	0.65
Nominal wind speed [m/s]	10	12
Wind speed of break on	-	25 m/s
Size [m]	Diameter 2.2 m	Diameter 1.0 m High 1.5 m
Changing blade angle	Yes, in range of +/- 40 degree	No
Changing the position of the turbine nacelle	Yes, in range of +/- 10 degree	-
Number of blades	3	4

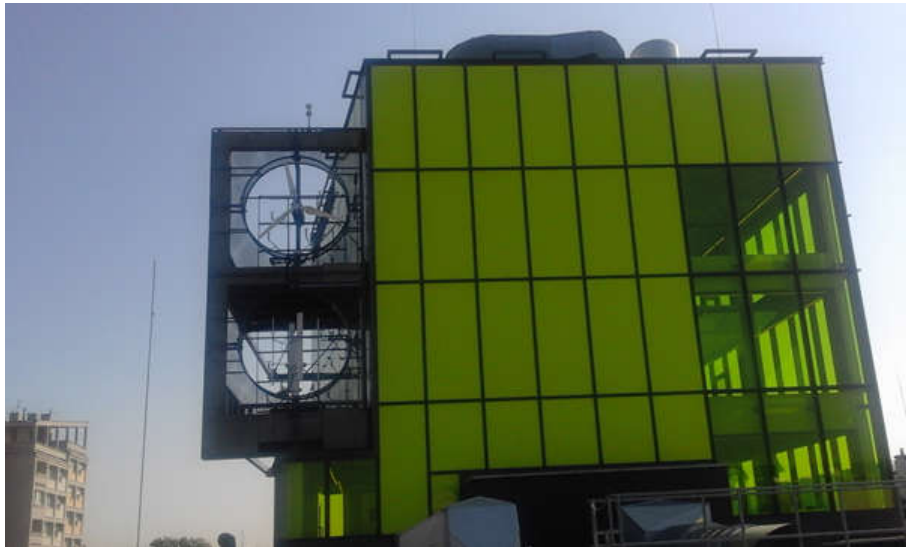


Figure 1. Turbines configuration on the facade of Center of Energy building (at the top horizontal axis wind turbine, at the bottom vertical axis wind turbine).

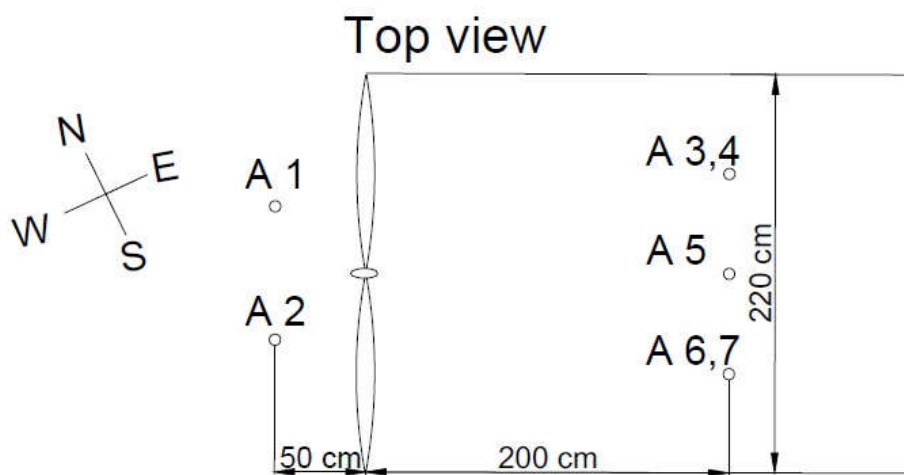


Figure 2. Schematic diagram of anemometers location in front of and behind the turbine, A1-A7 shows anemometers.

Wind turbines are placed in designed technological holes on the façade of the CE AGH building. This building is located on Czarnowiejska Street in Krakow. The turbines are oriented in the north-west direction (Figure 2).

At the top level horizontal axis wind turbine is placed. This turbine is equipped with an electromagnetic clutch that activates or disconnects the power generator at predetermined turbine speeds.

At the bottom level the vertical axis wind turbine is placed.

Except the turbines, the installation is equipped with number of additional components. The main element is a dedicated automation system that monitors the operation of both turbines and collects all the operational parameters. Included, the meteorological station delivers information about air temperature and humidity, wind speed and its direction. In the front of each turbine two anemometers measuring the speed of wind blowing into the turbine are installed. In addition, a sliding sensor array consisting of 7 anemometers is located behind each turbine (Figure 2).

The anemometers allow to determine the amount of wind energy used by a given turbine. The turbines installation is equipped with breaks, tachometers, vibration sensors, torque sensors and sound sensors. Therefore, this installation differs from typical wind turbine installations due to the expanded data acquisition system and the auxiliary components. Installation can deliver electricity into the power grid or store energy in the storage system. Moreover, the generator can be connected to the electronic load allowing for controlling power output from the turbines.

3. Results

The test was carried out on September 14, 2017, between 7.10 pm and 7.30 pm. At that time, a storm was taking place in the research city during which the rotational speed of the vertical wind turbine caused activation of its safety brake. Wind speed at the time of the analysis was 2-3 times higher than while normal operation of the turbines, which causes its uneven operation and possibility of brake activation. This time was selected to analyse the operation of the vertical axis wind turbine in conditions close to critical conditions (i.e. conditions, when emergency break is activated).

As result of research it has been proven, that velocity of wind sufficient to launch the vertical axis turbine is 10 m/s (Figure 3) while wind direction was south-west. After overcoming initial motion resistance, the turbine quickly increased its rotational speed to around 300 rpm. Operation of vertical axis turbine has negligible impact on sound intensity near turbine. Results of vertical axis wind turbine operation are shown in Figure 3.

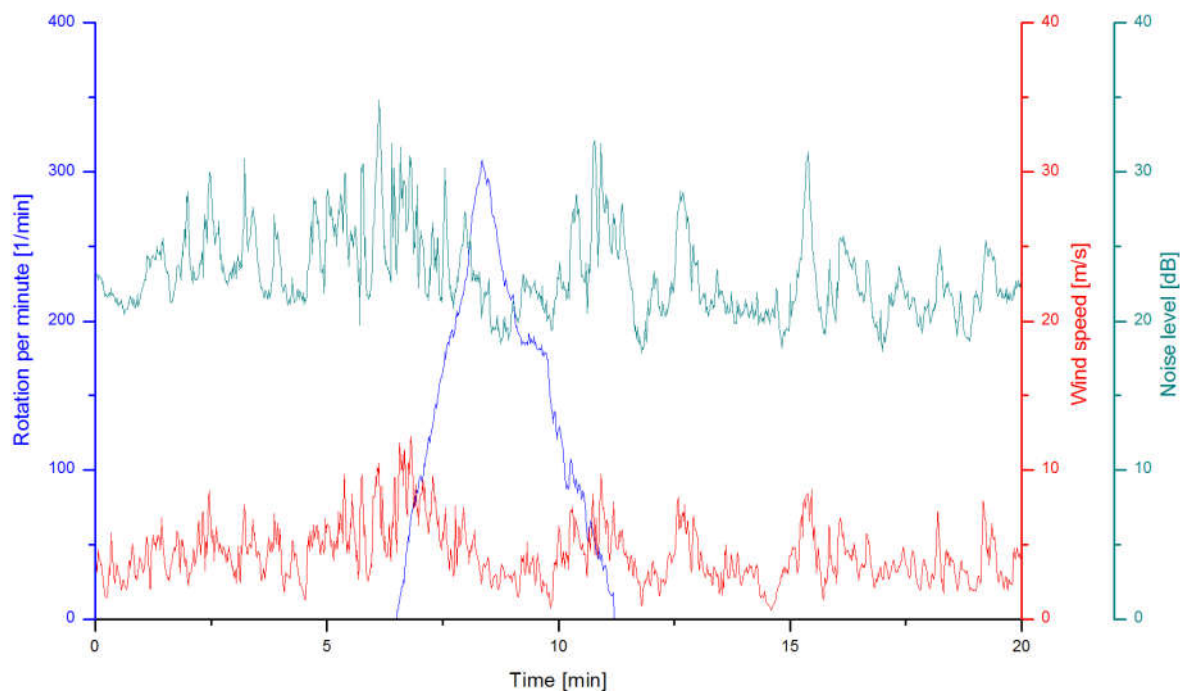


Figure 3. Operation of the vertical axis wind turbine.

For the sake of locating vertical axis turbine in façade technological holes, its operation is limited by wind direction. Without any obstacles, wind velocity sufficient to start turbine operation is around 1.2 m/s and optimal wind direction is north-west.

In case of horizontal axis wind turbine (Figure 4), rotational speed is proportional to wind speed. When wind speed is around 10 m/s, turbine exceeded rotational speed equal 750 rpm which caused launchment of emergency brake and exclusion of turbine for a minute. Operation of the horizontal axis turbine has negligible impact on sound intensity near turbine which is shown at the time when brake was active. Results of the analyses are shown in Figure 4.

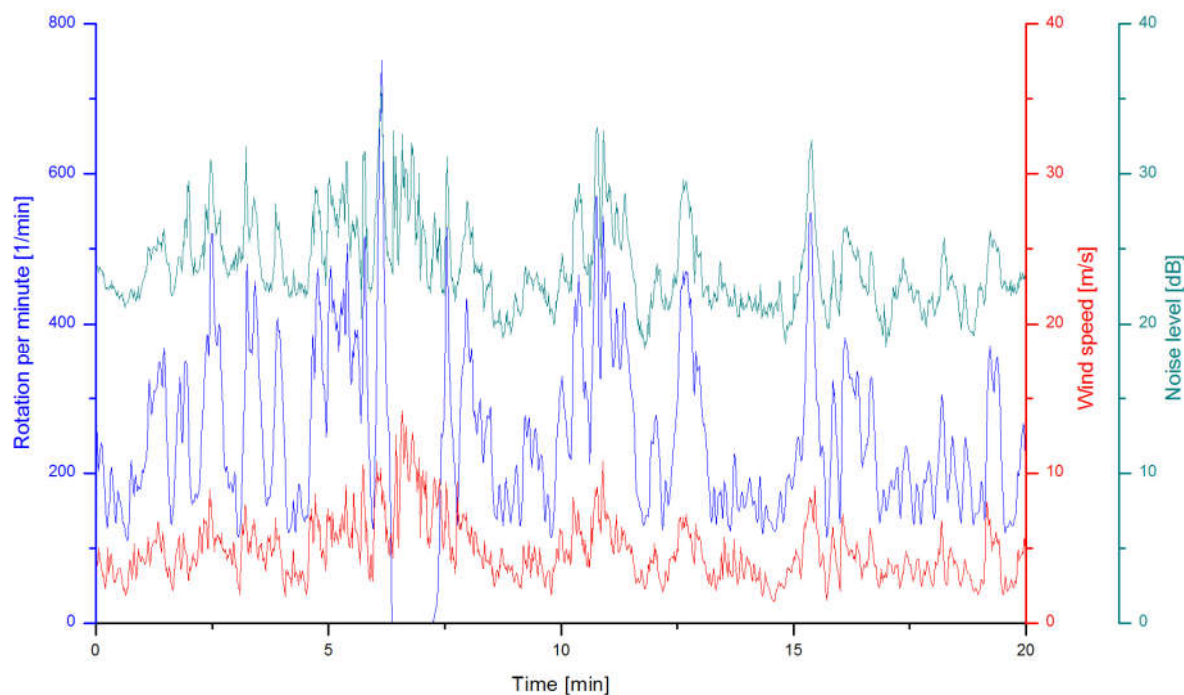


Figure 4. Operation of the horizontal axis wind turbine.

Increasing wind speed causes rapidly growth of power and, therefore, amount of energy. Power generator starts its operation at the time when rotational speed exceeds 120 rpm and for 750 rpm reaches level of 400 W. Power generated by HAWT in time is presented in Figure 5.

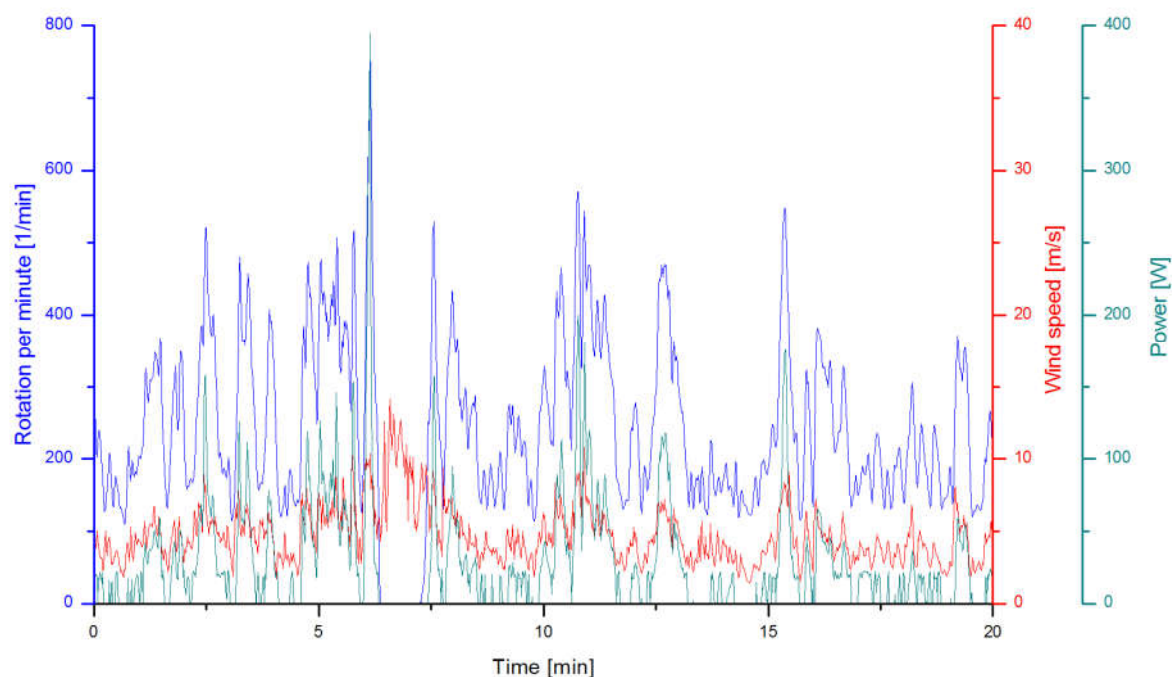


Figure. 5. Power generated by horizontal axis wind turbine.

Rotational speed of the turbine oscillates, which is caused by the fact of launching electromagnetic clutch and starting power generating when the rotation exceeds 120 rpm. Another factor is variability of wind velocity and its direction.

Dependence between wind speed in front of the turbine (anemometers A1, A2, see Figure 2) and its power for two months of operation is shown in the Figure 6. Preliminary data analysis suppose correlation between those values which may be described in two variants. First, when wind blows in front of turbine, power depends of wind speed in third power. This part is represented with points with power over 30 W. Second variant is represented by measurements taken while wind blown not parallel to the wind turbine. In this variant exact correlation is at the moment difficult to determine due to poor statistics of data.

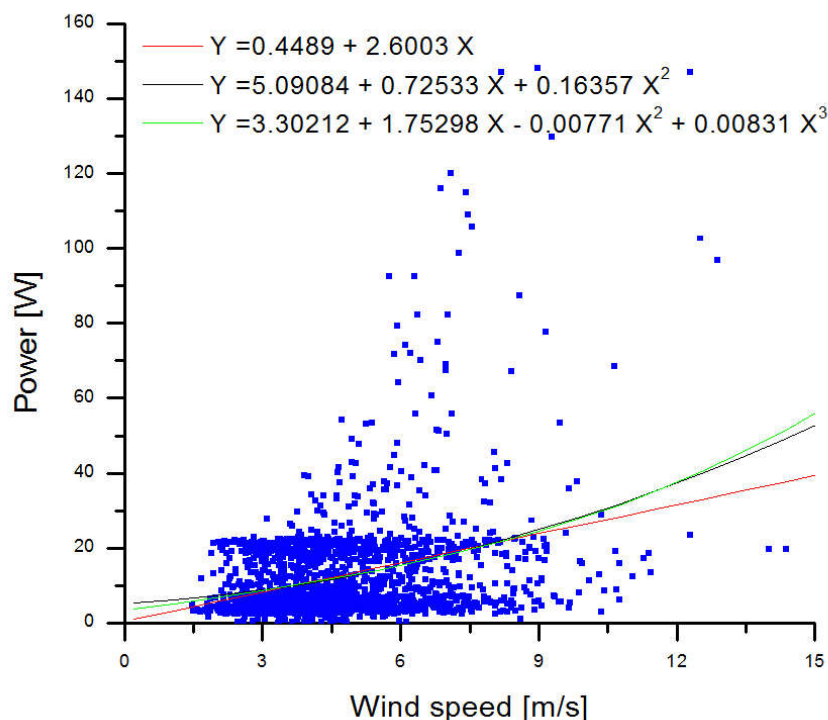


Figure 6. Power of wind turbine depending on wind speed in front of turbine.

Comparison of wind speed in front of turbine and vibrations of turbine (Figure 7) shows that vibration does not depend of wind speed while wind speed is under 5 m/s – it is caused by natural frequency of building. For higher wind speed, frequency strongly depends of it and wind direction, which is caused of turbulences caused by building geometry.

Figure 8 shows the dependence of the wind speed behind the turbine and the wind speed in front of the turbine. In most cases the wind speed in front of turbine is much higher than behind turbine. However, from the available data, there is some deviation towards higher wind speeds behind the turbine than in front of. This is caused by disturbances of wind flow along building facade or distorted wind direction. Additionally, there is a straight-line boundary $Y = 0.8 + 1.4 X$, which with some exceptions, is not exceeded.

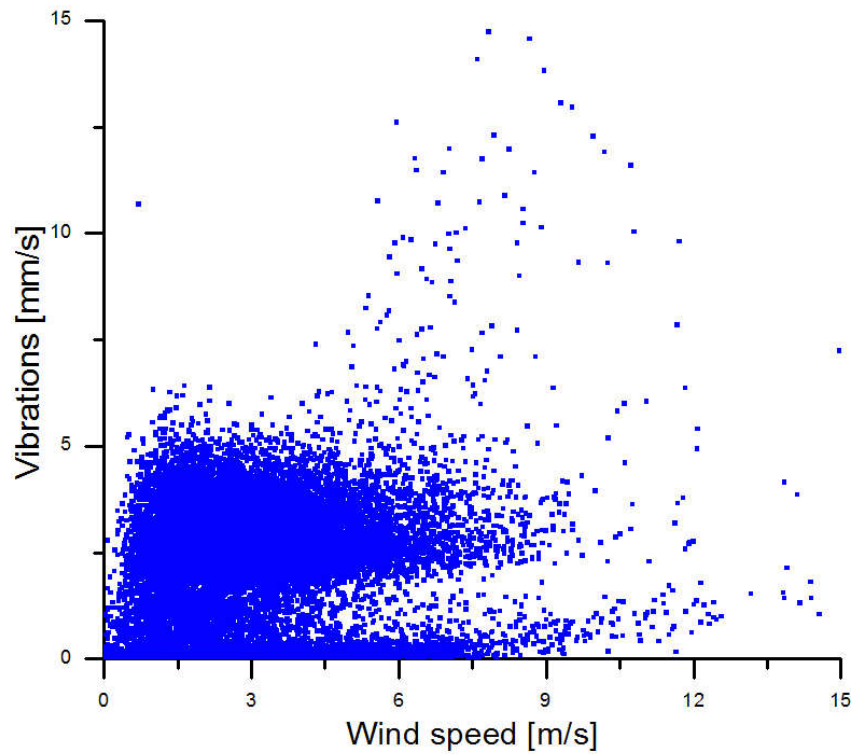


Figure 7. Vibrations of the turbine depending on wind speed in front of turbine.

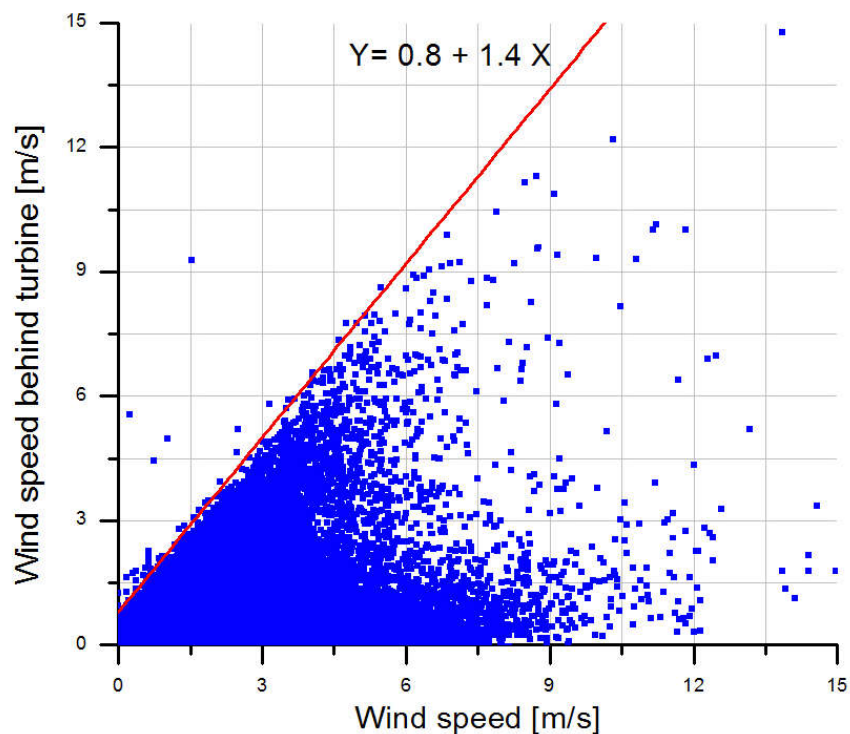


Figure 8. Wind speed behind the turbine depending on wind speed in front of turbine. Horizontal axis represents data for average value of A1 and A2 anemometers, vertical – A4 (see Figure 2).

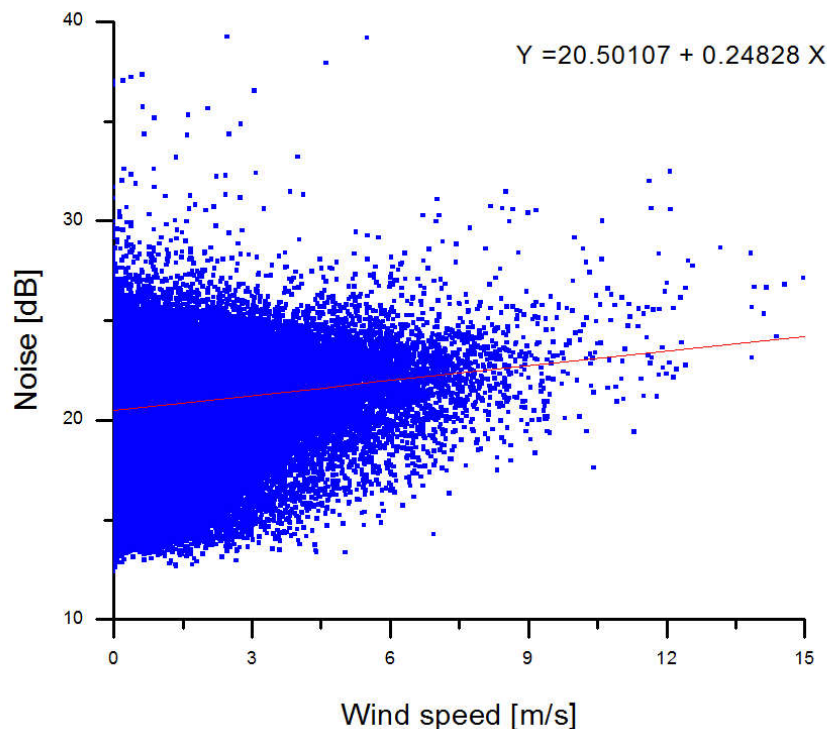


Figure 9. Noise level depending on wind speed in front of turbine.

Figure 9 shows noise level depending on wind speed in front of the turbine. General trend shows a change in noise level depending on wind speed. Of course, interpretation of this effect is difficult due to random background noise from the busy street, air-conditioning system of the building, etc. Generally, the higher the wind speed, the turbine faster rotates and produces a higher noise level.

4. Conclusions

The analyses developed in this study shows, that wind turbines on mounted on the façade operate in different way comparing standalone turbines. It is related to specific and unknown yet wind condition, mainly caused by variabilities of wind speed and direction near the edge of the building. Turbulences generated in such a location can have essential importance for stability of the turbines operation. The most important issue in locating building integrated wind turbines is to find façade turned to the most common direction of the wind. In this case, it is possible to maximize amount of generated energy in compare to other directions.

Preliminary observations show that vertical axis wind turbine is not a good solution as a façade wind turbine. To launch this turbine, wind with high velocity and suitable direction is required. It is better to install turbines with vertical axis on a roof edge, where wind direction has no negative impact on turbine operation.

Horizontal axis turbines could be sources of green energy located on building elevations.

As a result of the analysis it was also observed that the turbines operation has negligible impact on the sound intensity near turbines. This parameter strictly depends on the wind velocity, while the influence of the façade turbines is negligible and closes in 2 dB.

The full numerical model of wind interaction with the building facade is planned as a next stage of the research. It allows fully understand operation of wind turbines in such a location. Collecting of more data allows for the model validation.

Acknowledgments

This work was financially supported by the Statutory Grant of the Faculty of Energy and Fuels at AGH University of Science and Technology. The equipment of Center of Energy (Czarnowiejska 36, 30-054, Krakow, Poland) was used.

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