Application of the obstacle element in the WAsP (Wind Atlas Analysis and Application Program) flow model

M. Hradil
Czech Hydrometeorological Institute, Branch Brno[1]

A b s t r a c t : Apart from orography and surface roughness various obstacles affect the input meteorological data and may play an important role when modelling the wind speed and direction in a complex terrain. One of the tools enabling to describe and, as the case might be, eliminate the effect of the obstacles is the WAsP model, product of the Risoe National Laboratory in Denmark. The Czech Hydrometeorological Institute (CHMI) has used the WAsP model for a number of years to solve the meteorology issues of designing the of wind power plants; by way of an example of projects from the Protivanov locality (49°28′38″N, 16°49′54″ E) in the Drahanská Uplands we show how the obstacles, namely buildings in the vicinity of the station, affect the quality of extrapolation of the parameters of wind speed and wind power density. Apart from standard measurements conducted at a CHMI permanent meteorological station at 10 m above the terrain, two special-purpose tower measurements have been conducted at 40 m and 55 m above the terrain for several years in this locality. These ambulant measurements enabled to verify the model calculations and methods. In this case for heights of 10–55 m above the terrain, relatively strongly influenced by obstacles, we saw a typical error of estimation of 15–20% in the mean wind speed; for the wind power density, and/or the expected annual production of energy the error of estimation may even be 50–80%.

Key words: wind modelling, wind power, meteorological tower, WAsP, obstacle, porosity

1. Introduction

The key data for wind power plant investments are the exactly defined parameters of the wind speed and expected production of energy in the locality. For tentative pre-estimations we can use the results of area processing of the wind speed in the Czech Republic (*Šefter, 1991; Štekl, 1995; Štekl*

[1] Kroftova 43, 616 67 Brno, Czech Republic; e-mail: hradil@chmi.cz

et al., 2004; Climate Atlas of the Czechia, 2007 etc.). However, concrete localities frequently have specific properties which incorporate the detailed effects of orography, surface roughness and in some cases particularly the obstacles in the vicinity of the measuring points from where the data are model-extrapolated to the surroundings. That is why they require a more detailed and individual approach and for the model calculations preferably a dense network of meteorological stations. In this connection by no means negligible is the gradual automation of approximately one half of the volunteer climatology stations of the network of the CHMI which has been ongoing since 1998 and which has considerably extended the set of data obtained by means of objective continual measurements of wind speed and direction. A higher density of good-quality input data makes it possible to give precision to model calculations which have been used in this branch in our country to an increasing extent since ca the 1990's.

At present the CHMI is elaborating the demands in the area of wind power using the WAsP computer programme (www.wasp.dk) set up at the Risoe National Laboratory, part of the Technical University of Denmark (DTU). WAsP is a PC programme for predicting wind parameters and production of energy by wind power plants (*Mortensen et al., 1993*). The programme was also used for the wind atlas of Central Europe (*Dobesch and Kury, 1997*). With some restrictions the programme can be used generally – from the construction of wind roses, analyses of vertical profiles of wind speed, modification of the flow speed behind a three-dimensional obstacle etc. The prediction is based on input data of the wind speed and direction from the station in the region. There is no strict requirement for the distance of the meteorological station, but it should be located in comparable terrain and wind conditions; therefore the similarity principle, in some cases giving preference to similar properties of the terrain over the distance of the station from the site of calculations, should hold (*Landberg et al., 2003*). WAsP contains three partial models – complex terrain flow model, roughness change model and a model for sheltering obstacles. The basic statistical tool for the description of sets of wind speed values is the Weibull two-parameter distribution. Some aspects of practical applications of the programme, including comparisons with other similar tools, have already been published in our country (*Hošek, 2000; Štekl and Hošek, 2001*); to a lesser extent attention has been paid to analyses of the effect of obstacles in the vicinity of meteorological stations on the results of the calculations.

In general, obstacles are three-dimensional structures such as buildings, trees etc. which are relatively close to the place of wind measurements (order of 10^1 to 10^2 m) and therefore could distort the wind speed values. In theory such cases should not arise but in practice it was sometimes necessary – especially in the volunteer network of meteorological stations – to make a compromise when installing the meteorological sensors; that was in cases where the effect of some close structures on the airflow was not quite negligible. For understandable reasons the required obstacle parameters in historical data series were not monitored in most cases; at the present time (September 2008), as a component of metadata of the CLIDATA data base system, each climatology station is assigned to describe the obstacles. A specific case of an obstacle, relatively frequent before the year 2000 even at professional meteorological stations of the CHMI network, was to place the wind-measuring sensor on the roof of the building. *Landberg (2000)* analysed this specific problem in relation to the WAsP model on the basis of field measurements and model experiments. Incorporating the effect of obstacles into the WAsP calculations is not obligatory. The prerequisite is the accurate information about the parameters of these structures in the surroundings of the respective site at the time of the measurements and this information is not always available. On the other hand, we can naturally assume that if the effect of the obstacles at the measuring points is not incorporated in the calculation, all the model-extrapolated values are to a certain extent distorted. The aim of this paper is to attempt to quantify the magnitude of this distortion adopting a typical example.

2. Materials and methods

The obstacle model of the WAsP programme is based on the correlations obtained by modelling and experiments in a wind tunnel published by *Perera (1981)*. Fig. 1 shows the general pattern of the relative reduction of wind speed near an infinitely long two-dimensional obstacle of zero porosity along this source. The reduction of wind speed can be approximately quantified only within a certain distance from the obstacle; in its close vicinity (hatched part) the wind speed is considerably affected by the detailed geometry of the obstacle and therefore no realistic model results can be expected.

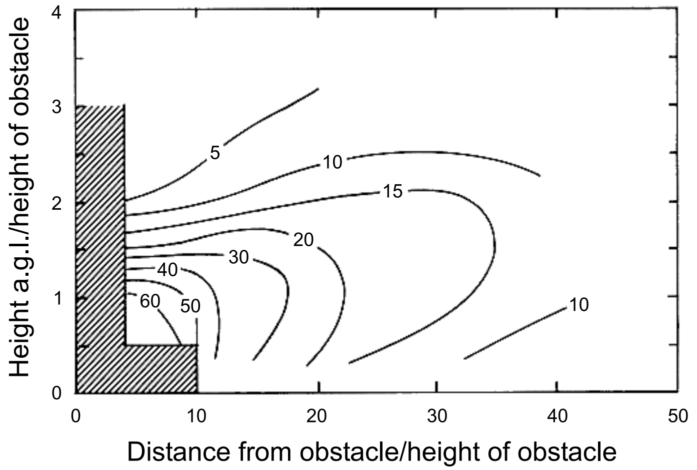

Fig. 1. Reduction of wind speed (%) due to shelter from an infinitely long two-dimensional obstacle of zero porosity. Based on the expressions given by *Perera (1981)*.

We must also point out that the model does not solve the wind direction modification in the vicinity of the obstacles but only the speed.

Not every terrain obstacle can be defined in all the details and must be schematised and simplified in a certain way. In the WAsP programme the obstacle is specified by its relative position to the centre of the coordinate system identical with the position of the wind sensor at the meteorological station, in general as a rectangular structure in the ground plan (Fig. 2). It is further characterised by its main dimensions (height, depth) and porosity; altogether an obstacle is definitely determined by the following seven parameters:

α_1 angle from the north to the first nearest corner of the obstacle (°)

α_2 angle from the north to the second nearest corner of the obstacle (°)

R_1 distance to the first nearest corner of the obstacle (m)

R_2 distance to the second nearest corner of the obstacle (m)

h height of obstacle (m)

d depth of obstacle (m)

p porosity (fraction 0–1)

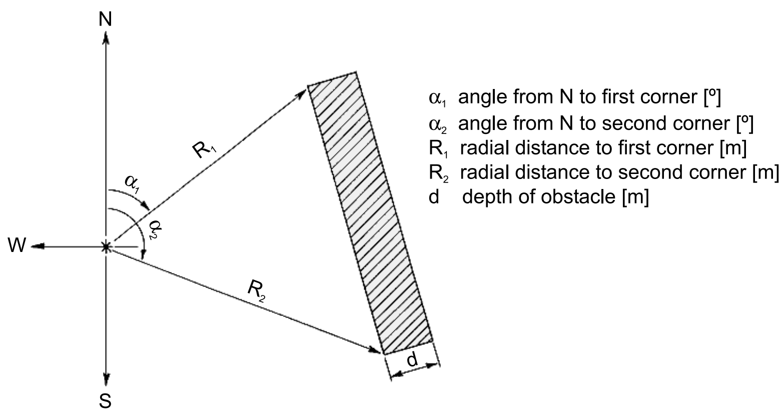

Fig. 2. Quantities that specify a single obstacle and that must be input into WAsP. Obstacles are specified as rectangular boxes relative to the site: by two angles, two radii, their height, depth and porosity.

The angles are measured from the north in azimuth angle. The porosity is set as the decimal number between zero and one. A completely wind-pervious structure assigns a porosity of 1, a completely impervious structure (wall, building) assigns zero porosity; the porosity of trees (forest) may fluctuate in dependence on the species, season of the year, leaves etc. (*Dellwik et al., 2005; Stuart, 2004*).

Projects situated in the Protivanov region (former district of Prostějov) in the Drahanská Uplands were selected to monitor in detail the effect of obstacles on the accuracy of model calculations. The Drahanská Uplands is a geomorphological unit belonging to the sub-system of the Brno uplands (*Demek and Mackovčin, 2006*). Extensive remains of a levelled surface form the character of the landscape; the altitude in the region ranges mostly between 650 and 700 m. The CHMI meteorological station in Protivanov (indicative of the World Meteorological Organisation (WMO) 11716, altitude 674 m, geographical latitude 49°28′38″, geographical longitude 16°49′54″) is an example of a location where the effect of obstacles in the vicinity of the anemometer is not quite negligible (Fig. 3). The station is situated in the garden of a family house on the south-west outskirts of the town, ca. 500 m from the centre. There is a number of mostly ground-floor houses with gardens in the close vicinity, particularly north and west of the station. The south and south-east horizon is open and the wind flow from these directions is not affected by obstacles. In the area of interest there are two other localities, apart from the permanent CHMI meteorological station, where ambulant tower measurements of the wind direction and speed were conducted (Table 1, Fig. 5) and which can be used to verify the calculations and/or calibration of the model.

Measuring point No. 2 is located ca. 1 km east-south-east of the centre of Protivanov, outside of the built-up area. In the closest vicinity (in the order of up to 10^2 m) there are no obstacles, only fields and meadows. The eastern outskirt of the town (agricultural structures) is ca 600 m distant from the tower, ca. 400 m to the south and north-east of the tower is the forest edge.

Measuring point No. 3 is located on a small elevation ca. 500 m north-east of the town Drahany, altitude of the terrain is ca 645 m. The edge of a relatively extensive forest is ca. 300 m north and east of the place of measurements.

The basic orography of the project was created by means of a global digital elevation model (DEM) generated by interferometric radar used onboard the Endeavour shuttle mission in February 2000 (Shuttle Radar Topography

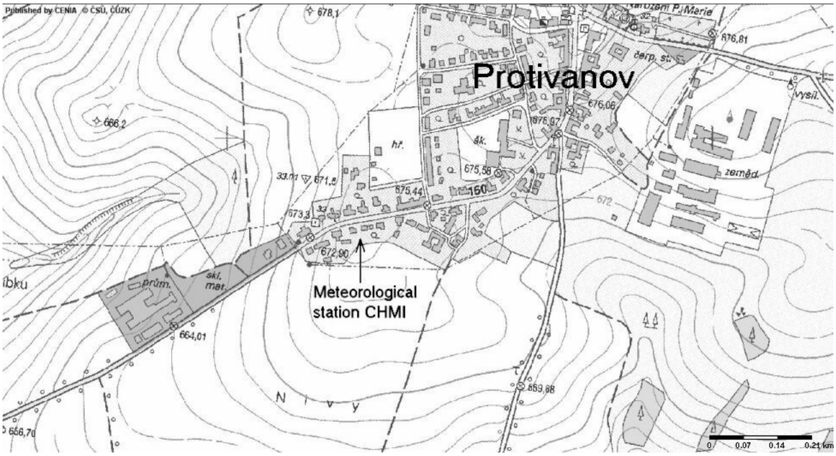

Fig. 3. Location of the meteorological station CHMI 11716 Protivanov.

Table 1. Wind measurements in the Drahanská Uplands region (IAP AS CR – Institute of Atmospheric Physics, Academy of Sciences of the Czech Republic, ELDACO – ELDACO Brno, Inc., a firm engaged in the field of wind energy)

No.	Location	Guarantee	Terrain elevation a.s.l.	Height of anemometer a.g.l.	Period of measurement	Sampling interval
1	Protivanov, CHMI	CHMI	675	10	Continuously	15 minutes
2	Protivanov, tower	IAP AS CR	686	40	2000/2001	5 minutes
3	Drahany, tower	ELDACO	650	55	2004/2005	10 minutes

Mission, SRTM). The individual datasets for Central Europe, indicated as type SRTM3 and available on the NASA server (`ftp://e0srp01u.ecs.nasa.gov/srtm/version2/`), cover an area that stretches from one degree of geographical latitude to one degree of geographical longitude and 3″ horizontal resolution, i.e. ca. 90 meters. Each dataset is therefore formed by a grid of 1201×1201 pixels. At the present time these data exist in a so-called modified version denoted as version2 (version2, edited). *Farr and Kobrick (2000)*, for instance, describe the SRTM in greater detail. For control purposes the SRTM altimetry was compared by superposition with other suitable map sources, including portal maps of public administration of the Czech Republic (`http://geoportal.cenia.cz/mapmaker/cenia/portal/`) and for the given purpose we see the conformity of the products. Since the WAsP model requires a more detailed description of the close vicinity of the studied sites (*Mortensen and Petersen, 1998*), the altimetry was locally complemented from detailed maps with contour lines less than 10 meters apart using the inbuilt WAsP MapEditor. This tool was also used for detailed digitisation of the z_0 roughness parameter (Fig. 4), according to the methods used to generate the European Wind Atlas (*Troen and Petersen, 1989).*

Fig. 6 shows the obstacles in the surroundings of the wind-measuring sensor at the CHMI station in Protivanov viewed in a WAsP environment. On the basis of field research the nearest important structures (houses) were parametrised as obstacles.

If there are more obstacles in a line near the meteorological station, according to recommended methods and practical experience, viewed in WAsP only the nearest obstacles have an effect. A combination of a number of

z_0 [m]	Terrain surface characteristics	Roughness Class
1.00	city	
0.80	forest	
0.50	suburbs	
0.40		**3** (0.40 m)
0.30	shelter belts	
0.20	many trees and/or bushes	
0.10	farmland with closed appearance	**2** (0.10 m)
0.05	farmland with open appearance	
0.03	farmland with very few buildings/trees	**1** (0.03 m)
0.02	airport areas with buildings and trees	
0.01	airport runway areas	
0.008	mown grass	
0.005	bare soil (smooth)	
0.001	snow surfaces (smooth)	
0.0003	sand surfaces (smooth)	
0.0002		**0** (0.0002 m)
0.0001	water areas (lakes, fjords, open sea)	

Fig. 4. Relation between the roughness length z_0, terrain surface characteristics and roughness class given in the *European Wind Atlas, 1989*.

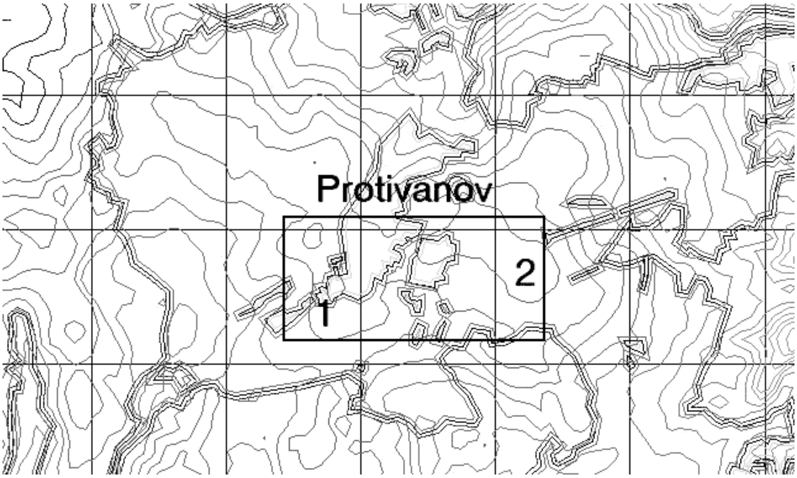

Fig. 5. Orography and roughness layers in the area approx. 6×3.5 km^2 near Protivanov viewed in WAsP. The smaller rectangle covers an area of 2×0.9 km^2 for detailed calculation with a 10 m resolution in the horizontal. Numbers 1 and 2 correspond to the sites with wind measurements according to Table 1 (site 3 is situated outside of the map area).

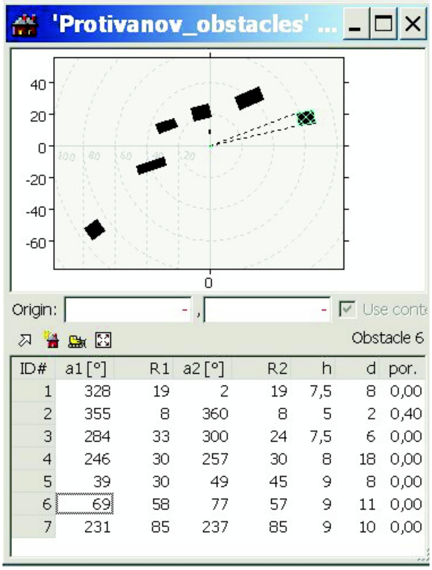

Fig. 6. Obstacles near the Protivanov CHMI meteorological station as viewed in WAsP.

nearer and more distant obstacles shading one another causes interferences which impair the quality of the model calculation. It would be preferable to include the more distant obstacles in the model only as surface roughness and this method was applied in the present project. It was not necessary to construct obstacles for measuring points 2 and 3 according to Table 1; there are no important structures in the vicinity of these points and also the sensors were installed in heights above the terrain several times higher than at the CHMI station.

Model calculations were implemented in several variants. In the first group we used CHMI and IAF AS CR measurements (stations No. 1 and 2, Table 1); in the second group we used the measurements of CHMI and the ELDACO firm (stations No. 1 and 3, Table 1), with data corresponding to the period when measurements in both stations were simultaneous. In both cases the measurements were conducted for about one year. Each calculation was carried out both with and without the applied obstacle for the CHMI station. One locality in the model was a source locality (station) while the other one was used to verify the extrapolated values and this order was changed as necessary. Standard setup of the model parameters was used to calculate all the characteristics.

3. Results and discussion

3.1. Extrapolated data from the Protivanov station, CHMI (No. 1 – Table 1) for the point Protivanov, tower (2)

The locations are ca. 1800 m distant, the height of measurements at the CHMI station is 10 m above the terrain, 40 m above the terrain on the tower. Computing with obstacles the mean speed at 40 m above the terrain was 5.39 m/s (the real speed measured was 5.43 m/s), and only 4.61 m/s if we do not take the obstacles into account (Table 2, 3), so that the influence of obstacles is evident. Measured mean wind speed at the CHMI station (No. 1, Table 1) includes effects of real obstacles near the wind mast and is under the theoretical mean wind speed at the same place, but without obstacles. In the event when there is no obstacle group, the WAsP model assumes that there are no obstacles and there is no "correction" of measured wind speed (or some statistics of measured wind speed). Also the extrapolated values in the surrounding are then more or less lower than in case of including obstacle group into computation.

To evaluate the accuracy of computing the energy characteristics, also the wind power densities were compared based on the real measured and

Table 2. Measured and extrapolated data for the Protivanov station, tower (input data from Protivanov, CHMI, computing with obstacles)

Sector	Measured				Extrapolated from WAsP			
	Mean speed (m/s)	Power (W/m^2)	Weibull-A (m/s)	Weibull-k	Mean speed (m/s)	Power (W/m^2)	Weibull-A (m/s)	Weibull-k
1 (N)	3.43	52	3.9	1.81	4.31	84	4.9	2.26
2 (NE)	5.07	173	5.7	1.77	6.27	230	7.1	2.63
3 (E)	3.66	50	4.1	2.35	4.10	65	4.6	2.57
4 (SE)	6.58	251	7.4	2.87	6.12	209	6.9	2.74
5 (S)	6.06	207	6.8	2.65	5.32	138	5.9	2.61
6 (SW)	4.62	87	5.2	2.88	4.22	75	4.8	2.41
7 (W)	5.56	168	6.3	2.47	5.21	140	5.9	2.42
8 (NW)	5.98	214	6.7	2.39	6.27	260	7.1	2.23
All	5.43	172	6.2	2.22	5.39	162	6.1	2.30

Table 3. Measured and extrapolated data for the Protivanov station, tower (input data from Protivanov, CHMI, computing without obstacles)

Sector	Measured				Extrapolated from WasP			
	Mean speed (m/s)	Power (W/m^2)	Weibull-A (m/s)	Weibull-k	Mean speed (m/s)	Power (W/m^2)	Weibull-A (m/s)	Weibull-k
1 (N)	3.43	52	3.9	1.81	2.82	24	3.2	2.20
2 (NE)	5.07	173	5.7	1.77	4.37	79	4.9	2.59
3 (E)	3.66	50	4.1	2.35	3.81	51	4.3	2.66
4 (SE)	6.58	251	7.4	2.87	6.12	208	6.9	2.74
5 (S)	6.06	207	6.8	2.65	5.28	138	5.9	2.61
6 (SW)	4.62	87	5.2	2.88	3.92	59	4.4	2.44
7 (W)	5.56	168	6.3	2.47	4.23	75	4.8	2.41
8 (NW)	5.98	214	6.7	2.39	4.47	94	5.1	2.26
All	5.43	172	6.2	2.22	4.61	104	5.2	2.22

model-extrapolated wind speeds. The wind power density (power, W/m^2) is not a simple function of the total mean wind speed (*Šefter, 1991*), but is dependent on the internal structure of data, i.e. the distribution of "immediate" wind speeds measured in the individual short time intervals. Due to the cubic power the highest values of immediate speeds are given greater preference and, with the same average wind speeds over a certain longer period, the respective wind power densities (wind energy) may differ considerably. With an obstacle included in the model, the mean wind power density was 162 W/m^2, with no obstacle it was 104 W/m^2, and based on real computed wind speed values it was 172 W/m^2.

The scale parameter (Weibull-A) and the shape parameter (Weibull-k) of the two-parameter Weibull distribution were computed as well.

3.2. Data extrapolated from the Protivanov station, tower (2) for Protivanov, CHMI (1)

This variant was used for a more detailed quantification of differences between the real and model-extrapolated mean wind speed values in the individual sectors. In this case the source meteorological station was locality 2 (Protivanov, tower). Computing was simulated for a point identical to the position of the wind sensor of the Protivanov meteorological station, CHMI, both with and without the effect of obstacles. The model estimation of the total mean wind speed at this point is 3.55 m/s and 4.13 m/s (variant with and without the obstacles, respectively). The real value is 3.50 m/s. In five of the eight sectors, computation with an obstacle was more accurate; it was worse only once – with a north-east wind. In the south-east (SE) and south (S) sectors unaffected by obstacles, the results were identical. The difference was most pronounced in the north-west sector – the datum of computation with obstacles was by 0.1 m/s (5%) lower than the real computed mean wind speed in this sector; computation without obstacles by 1.2 m/s (35%) higher (Fig. 7).

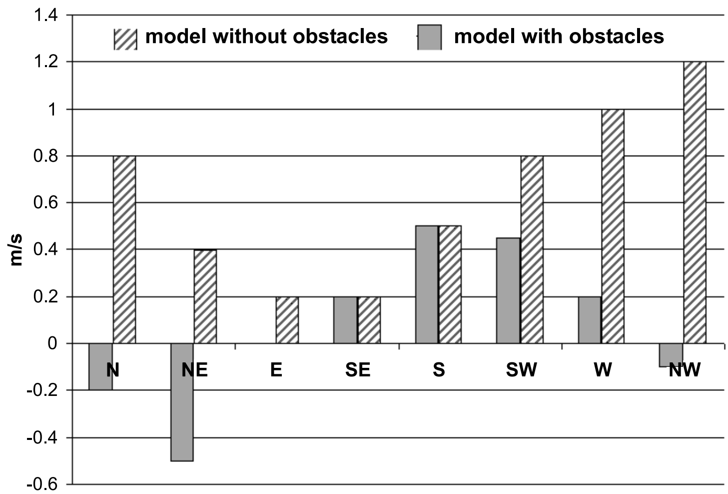

Fig. 7. Sector-wise differences between the measured and extrapolated values of mean wind speed. Extrapolation performed by WAsP from station 2 to station 1 according to Table 1.

3.3. Data extrapolated from the Protivanov station, CHMI (1) for Drahany, tower (3)

The measuring sites are ca. 6800 m distant; the height of measuring at the CHMI station was 10 m above the terrain, on the tower 55 m above the terrain. The mean computed wind speed of the model with obstacles 55 m above the terrain was 6.27 m/s (real speed 6.30 m/s); without obstacles it was only 5.16 m/s (Table 4, 5).

Simulation of the estimation of annual energy production (AEP) of the

Table 4. Measured and extrapolated data for the Drahany station, tower (input data from Protivanov, CHMI; computing with obstacles)

Sector	Measured				Extrapolated from WasP			
	Mean speed (m/s)	Power (W/m^2)	Weibull-A (m/s)	Weibull-k	Mean speed (m/s)	Power (W/m^2)	Weibull-A (m/s)	Weibull-k
1 (N)	5.41	162	6.1	2.32	5.56	188	6.3	2.14
2 (NE)	3.70	49	4.2	2.52	6.35	238	7.1	2.64
3 (E)	4.52	80	5.1	2.95	4.43	84	5.0	2.49
4 (SE)	6.69	236	7.4	3.59	5.83	182	6.6	2.69
5 (S)	6.60	246	7.4	3.04	6.33	221	7.1	2.93
6 (SW)	6.91	355	7.8	2.18	5.92	212	6.7	2.32
7 (W)	7.25	386	8.2	2.34	6.82	322	7.7	2.35
8 (NW)	6.91	277	7.7	3.13	7.08	367	8.0	2.29
All	6.30	254	7.1	2.36	6.27	253	7.1	2.31

Table 5. Measured and extrapolated data for the Drahany station, tower (input data from Protivanov, CHMI; computing without obstacles)

Sector	Measured				Extrapolated from WAsP			
	Mean speed (m/s)	Power (W/m^2)	Weibull-A (m/s)	Weibull-k	Mean speed (m/s)	Power (W/m^2)	Weibull-A (m/s)	Weibull-k
1 (N)	5.41	162	6.1	2.32	3.66	53	4.1	2.19
2(NE)	3.70	49	4.2	2.52	4.44	81	5.0	2.67
3 (E)	4.52	80	5.1	2.95	4.12	67	4.6	2.51
4 (SE)	6.69	236	7.4	3.59	5.82	182	6.5	2.68
5 (S)	6.60	246	7.4	3.04	6.31	219	7.1	2.92
6 (SW)	6.91	355	7.8	2.18	5.42	162	6.1	2.33
7 (W)	7.25	386	8.2	2.34	5.55	173	6.3	2.34
8 (NW)	6.91	277	7.7	3.13	5.02	131	5.7	2.28
All	6.30	254	7.1	2.36	5.16	143	5.8	2.28

Vestas V63 (1500 kW) wind turbine with the axis of the rotor component at a height of 60 m for the model-computed speed of 6.27 m/s, 5.16 m/s and 6.30 m/s gives 2.555 GWh, 1.414 GWh, and 2.659 GWh, respectively.

4. Conclusions

The importance of the WAsP model with obstacles was shown in the example of projects from the Protivanov region in the Drahanská Uplands.

If the effect of close obstacles is incorporated in the WAsP model computations, then in cases when meteorological measurements are more markedly affected by obstacles the estimation of parameters of wind speed improve by ca 15-20%. When the model with obstacles is applied, the extrapolated mean wind speed at 40 m above the terrain at the CHMI meteorological station was 5.39 m/s; with the same input data without obstacles it was only 4.61 m/s in contrast to the real computed speed of 5.43 m/s. In the case of extrapolation of wind power density, the difference was more pronounced – analogically with obstacles it was 162 W/m^2 in contrast to only 104 W/m^2 without obstacles and 172 W/m^2 was the wind power density computed directly from the measured data. In these cases therefore the estimation error of power and energy characteristics may be somewhere between 50 and 80%. These data were monitored for heights of measurements and extrapolation between 10 m and 55 m above the terrain. With a more detailed analysis we could achieve good results with extrapolation not only of the total mean wind speed but also the respective partial values for the individual sectors. In the case of the north-west sector, in which the effect of obstacles was the strongest, the computation without obstacles overestimated the actual value by ca 30% (by 1.2 m/s); with obstacles the difference from the mean wind speed for this direction was only –0.1 m/s (less than 5%). The present study underlines the importance of a detailed and regularly updated data base of metadata from meteorological stations as essential conditions for the future particularisation of model computations. The presented projects were selected as typical; comparable results can be documented also from other localities under different climate and wind conditions (Velké Meziříčí, Kroměříž and others).

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