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VERTICALLY AND HORIZONTALLY MOUNTED WIND MILLS

Wind Energy Production in Tampere University of Applied Sciences

Ekaterina Evdokimova

Bachelor's thesis
May 2013
Degree Programme in Environmental Engineering
Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences

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ABSTRACT

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The purpose of this thesis was to gather information about vertical and horizontal wind mills and to complete a research on wind power production by wind mills which were installed in Tampere University of Applied Sciences. The horizontally mounted wind mill Windspot 3.5 and vertically mounted wind mill Cypress were installed in summer 2011 but they started functioning and supplying energy only during 2012.

In the theoretical part of this thesis wind speed and wind power production is discussed, various factors which could influence wind mills or energy extraction are also analyzed. In particular technical characteristics and power production of Windspot 3.5 and Cypress was taken into consideration. The data which was used in this study (wind speed, temperature, humidity) was collected from Tampere-Pirkkalan lentoasema and on-the-spot measurements were performed by Davis Vantage Pro 2 weather station. The total power production was calculated for April 2012 for horizontally mounted wind mill because performance of vertically mounted wind mill was not stable and therefore reliable enough for the research, however analysis of historical background of wind conditions includes data from 1980 till 2011.

As a result of the research efficiency of Windspot 3.5 within wind conditions during April 2012 was calculated. The final value was 2.6 % which means that conditions allow us to extract a certain amount wind energy but this wind mill has extracted only 2,6% of it. Since the average performance of a wind mill goes up to 20%, this result is not positive.

Further research is required to improve those results, since amount of produced energy with horizontal wind mill is not enough even for its own maintenance. In this thesis such measures as replacement and weather conditions analysis are suggested. However, it was figured out that replacement of wind mills is quite complicated issue due to helicopter routes and restrictions coming with that. Taking this issue into consideration, a conclusion that these wind turbines should be used mainly for study purpose rather than reliable energy supply was made. Although, author of the thesis sees a possibility of improving turbines performance by concentrating on Finnish weather conditions and it influence on power production by these particular wind turbines.

Key words: wind power production, wind speed, Windspot 3.5 wind turbine, Cypress CWT-301B wind turbine

CONTENTS

ABBREVIATIONS AND TERMS

TAMK	Tampere University of Applied Sciences
m	meter
kg	kilogram
m/s	meters per second
W	watt
kWh	kilowatt-hour
P	power
ρ	air density
A	area
V	speed
m	mass
v	velocity
r	radius
W	work
F	force
s	distance
Cp	efficiency coefficient
K	Weibull coefficient

1 INTRODUCTION

Wind power technology has a history of many centuries. Historical researches claim that wind machines which used the power of the wind existed back to the time of the ancient Egyptians. The Persians created windmills in the 7th century AD for milling and irrigation and rustic mills similar to these early vertical axis designs can still be found there today. In Europe the first windmills were seen much later, probably having been introduced by the English on their return from the crusades in the Middle East or possibly transferred to Southern Europe by the Muslims after their conquest of the Iberian Peninsula. It was in Europe that much of the subsequent technical development took place. By the late part of the 13th century the typical ‘European windmill’ had been developed and this became the norm until further developments were introduced during the 18th century. At the end of the 19th century there were more than 30,000 windmills in Europe, used primarily for the milling of grain and water pumping. Nowadays we use windmills for getting the most valuable thing nowadays: energy. There are many modifications and technologies in wind power production which already exist and each year people invent more and more. It all happens for the same purpose: to get energy out of unlimited source such as wind. (Baker, n.d.)

Cypress CWT-301B Wind Turbine (picture 1) is a battery charged vertically mounted wind turbine for the rooftops. It is designed for locations, where the top of the mast is not occupied by for antennas, radars etc. This turbine has been made and installed by Cypress Wind Turbines Oy in 2011. This company also installed Cypress CWT-H04G horizontally mounted wind turbine near Särkänniemi Adventure Park in Tampere.

PICTURE 1. Cypress Wind Turbine (Christophe Sterkens 2012)

Windspot 3.5 Wind Turbine (picture 2) has been delivered by Spanish renewable energy company Sonkyo Energy Oy. It is a small up-wind horizontal rotor wind turbine for homes, telecommunications towers, water pumping, etc

PICTURE 2. Windspot 3.5 Wind Turbine (Christophe Sterkens 2012)

Those wind turbines are connected to the main electricity grid of the Tampere University of Applied Sciences. They have two main purposes: one is obviously energy production and another is research of renewable energy.

I intend to examine and monitor wind power production by Windspot 3.5 horizontally mounted wind turbine which was installed in summer 2011 on the territory of Tampere University of Applied Sciences next to the greenhouse and I-building. In order to get this chance, I became a participant of Opi Enempi project, which was created in a co-operation between the European Regional Development found and TAMK. The aim of the project was to create a new learning environment by using modern technologies from the fields of energy and environmental technology.

I consider myself to be very lucky to get a chance to work with such advanced technology in renewable energy production. I am going to focus on analyzing this wind turbine from the point of possible and actual power production. For this I would need to study manuals and main characteristics of turbines. I also intent to complete a comprehensive analysis or wind forecast in Tampere and precisely wind speed characteristics on the spot where they have been installed. I would like to find out what average possible power production by those wind mills is theoretical and what is actual. If there will be any difference between those values I am planning to figure out the reasons for that.

Undoubtedly, weather has a huge influence on wind energy production. One of my aims in this final thesis was to find out affect of Finnish weather on such turbines. I was planning to use data of wind speed in Tampere dating starting from back to 1989 up to nowadays. Also next to the wind turbines wireless weather station Davis Vantage Pro 2 that combines rain collector, temperature and humidity sensors and anemometer into one package was installed.

As an outcome I was hoping to be able to present reliable data on energy supply by Windspot 3.5 which could be used for practical and teaching purposes. I'd like to include in my research all possible variants of influencing energy production through weather and to calculate their degree of importance and affect on wind turbines. Knowledge of possibilities of power supply in current environment is a key component to its successful usage and development.

2 THEORY

2.1. Wind

The wind is a result of variations in air pressure which in their order exist due to variations in solar radiation and heating. Warm air layers are moving up and cooler air layers are replacing it. After all wind is just this process of replacement of air masses, nevertheless it is the main component of atmospheric circulation. There are also localized wind patterns due the effects of temperature differences between land and seas, or mountains and valleys. (Ashby, 2008)

Wind speed is proportional to the height above ground. The reason for this is the roughness of ground; all objects such as vegetation and houses are decreasing wind speed. Wind is classified according to its speed, origin and geography. Wind speed data can be found from wind atlases or from the meteorology institutes. However, due to poor research and measurements currently we don't have a reliable wind speed data of all regions of the world. Although it has been proven that average annual wind speed is 4-5 m/s in most regions of the world and in this case small-scale wind powered electricity generation is an attractive option. I say accurate wind speed data is a key component for successful wind power planning and production. In Finland wind speed data could be found from Finnish Wind Atlas web page or from Finnish Meteorological Institute. On the map below (figure 1) we can see what wind speed we had in different regions of Finland in January 2012 on the height of 50 m above the ground.

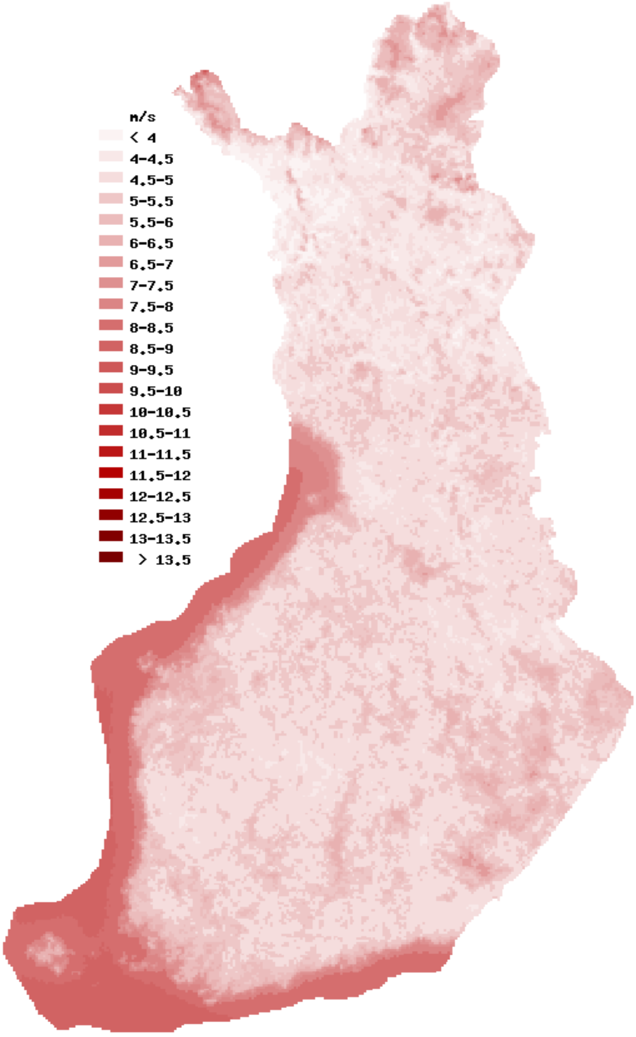

FIGURE 1. Wind speed in Finland in January 2012, 50 m above the ground.

However variance of wind speed data doesn't stop the wind power production from developing and each year a strong annual growth in this type of renewable energy production could be found. Following chart (figure 2) demonstrates how installed wind capacity has increased during last 15 years.

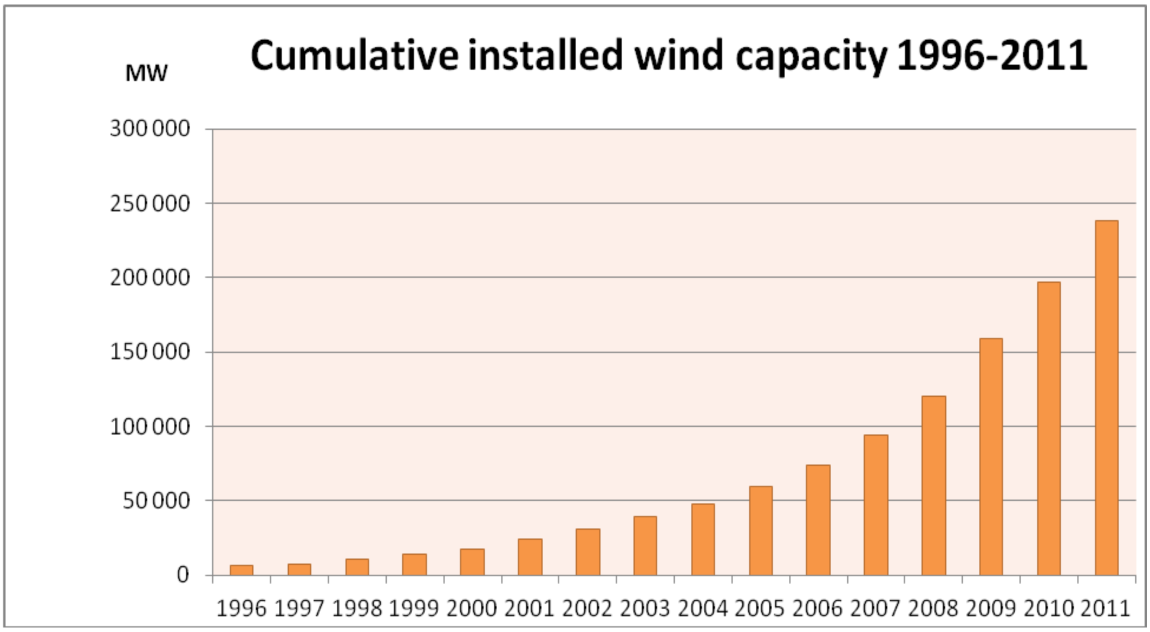

FIGURE 2. Cumulative installed wind capacity 1996-2011

The absolute leader of wind power production is China. This country has cumulative wind capacity of 62,733 MW. Finland unfortunately is only on 35th place among nations which use this source of energy, its cumulative capacity was only 197 MW in 2011. ("Worldwide Electricity Production From Renewable Energy Sources: Stats and Figures Series: Fourteenth Inventory – Edition 2012, 4)

The power in the wind is proportional to:

• area of windmill being swept by the wind
• cube of the wind speed
• air density - which varies with altitude

The formula used for calculating the power in the wind is shown below in equation (1) and (2):

$$\text{Power} = \frac{\text{density of air} \times \text{swept area} \times \text{velocity cubed}}{2} \qquad (1)$$

$$P = \frac{\rho \times A \times V^3}{2} \qquad (2)$$

$\boldsymbol{P}$ is power in watts (W)

$\boldsymbol{\rho}$ is the air density in kilograms per cubic meter (kg/m^3)

$\boldsymbol{A}$ is the swept rotor area in square meters (m^2)

$\boldsymbol{V}$ is the wind speed in meters per second (m/s)

Here we can see that the wind power is directly to the cube of the wind speed which is very significant and happens to be one of the main laws while calculating wind energy production. With other words, if the wind speed doubles then the power in the wind increases by a factor of eight. A simple conclusion that a site for wind power plant should have a relatively high mean wind speed could be made.

Although a very important point is that equitation above gives us the power in the wind, however, the actual power that could be obtained from the wind is significantly smaller than this figure suggests. The actual power can be influenced by many factors: type of machine and rotor, the sophistication of blade design, losses due to friction, and the losses in energy accumulation or transportation. And those are only factors concerning the machinery; there are also physical limits of power that could be extracted from the wind by wind mills or other devices.

There are several formulas which are used for creation of the one above (2). Under constant acceleration, the kinetic energy of an object having mass *m* and velocity *v* is equal to the work done *W* in displacing that object from rest to a distance *s* under a force *F* as shown in formula (3) :

$$E = W = F \times s \tag{3}$$

Here we can use Newton's law as well, which is:

$$F = m \times a \tag{4}$$

By combining two formulas above we get:

$$E = s \times m \times a \tag{5}$$

By adding the third equation of motion:

$$v^2 = u^2 + 2 \times a \times s \tag{6}$$

We can define acceleration as:

$$a = \frac{(v^2 - u^2)}{2 \times s} \tag{7}$$

Since initial velocity *u* of wind is zero, formula can be modified:

$$a = \frac{v^2}{2 \times s} \tag{8}$$

Now we can modify equation (5) and define kinetic energy of a mass in motion as demonstrated in equation (9):

$$E = \frac{1}{2} \times m \times v^2 \tag{9}$$

The power of wind is rated according to the change of energy (10):

$$P = \frac{dE}{dt} = \frac{1}{2} \times v^2 \times \frac{dm}{dt} \tag{10}$$

Talking about rates, we have here a mass flow rate (11) and rate of change of distance (12):

$$\frac{dm}{dt} = \rho \times A \times \frac{dx}{dt} \tag{11}$$

$$\frac{dx}{dt} = v \tag{12}$$

By combining (11) and (12) we get (13):

$$\frac{dm}{dt} = \rho \times A \times v \tag{13}$$

At the same time, getting back to the equation (10) and with result that we got from equation (13) we can see the same formula as in equations (1) and (2)

$$P = \frac{1}{2} \times v^2 \times A \times v \qquad (1); (2)$$

It has been proven theoretically that any windmill can only realistically extract a maximum of 59.3% of the power from the wind which is known as the Betz limit. In reality, this figure is usually around 45% (maximum) for a large electricity producing turbine and around 30% to 40% for a wind pump. By the time we take into account the other factors in a complete wind turbine system - e.g. the gearbox, bearings, generator and so on - only 10-30% of the power of the wind is ever actually converted into usable electricity. (Burton, T. 2001, 65)

Hence, the power coefficient needs to be factored in equation (4) and the extractable power from the wind is given by:

$$P = \frac{Cp \times \rho \times A \times V^3}{2} \tag{14}$$

P is power (in watts) available from the machine

Cp is the coefficient of performance of the wind machine

What also should be kept in mind is that a wind mill will only operate at its maximum efficiency for a fraction of the time it is running, due to variations in wind speed. An approximate estimate of the power output from a wind machine can be obtained using the following equation:

$$Pavg = 0.2 \times A \times V^3 \tag{15}$$

(Windspot 3.5 user manual, 12)

Pavg is the average power output in watts over the year

V is the mean annual wind speed in m/s

2.2. Windspot 3.5 horizontally mounted wind mill

Windspot 3.5 is one of the windmills available in TAMK, one of the advantages of this particular windmill is that it requires low maintenance. At locations with 5 – 7 m/s average wind speed the 3.5KW model is capable of producing 5 – 30 KW every day. The rotor requires at least 3 m/s in order to start producing energy and the maximum speed is 200 revolutions per minute (rpm). It is made out of stainless steel, anodized aluminum and bronze; blades, however, are constructed out of polyester resin and fiber glass on order to decrease weight and provide enhance mechanical resistance. Whole construction is aiming to reduce horizontal forces as much as possible. The maximum reachable voltage for wind turbine is 500 V; if the voltage is increasing the pitch system starts to work. It protects system from damages caused by over voltages and over power. It has been estimated that strong wind is dangerous for both generator and electronics. This model is equipped with pitch system which consists of robust and dampener. When the wind turbine is turning the centrifugal force helps to change angle of attack of blades.

Average annual production of Windspot 3.5 has been tested and verified by IEMAT (Centre for energy, environmental and technological research); curve on figure 3 demonstrates how much energy could be obtained starting from the minimum wind speed till the maximum.

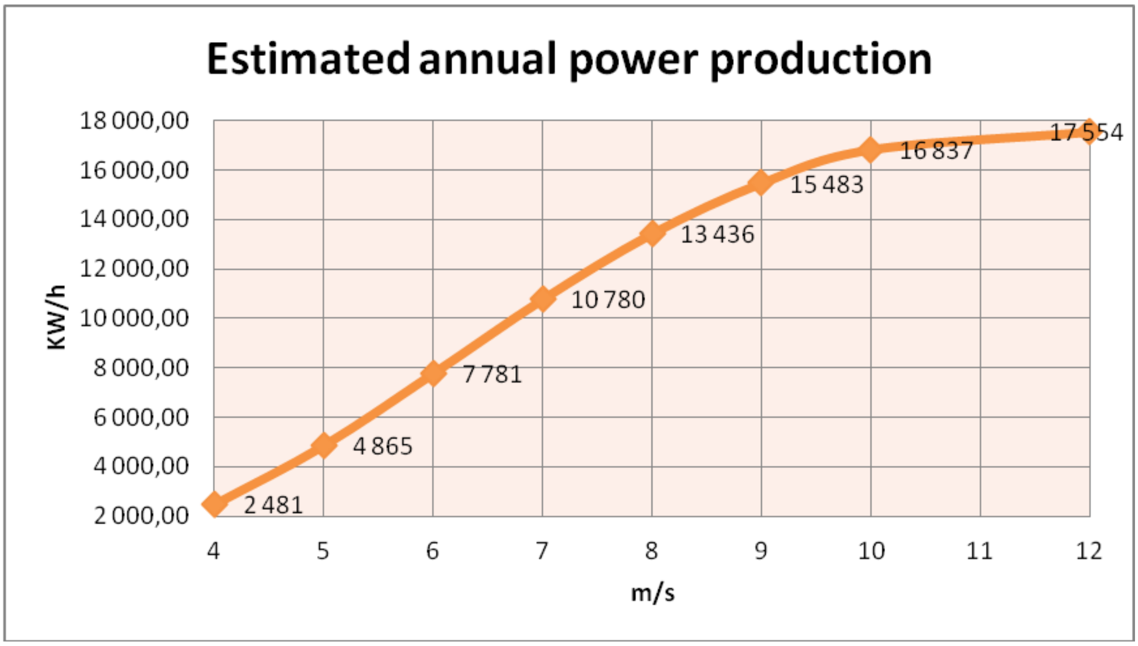

FIGURE 3. Estimated annual power production by Windspot 3.5

The formula for generated power has been demonstrated already in section 2.1 Wind. However, in user manual, Windspot manufacturers suggest another formula for power production by their products. It is based on Weibull's probability distribution which will be further discussed in following chapters.

$$f(x; C; k) = \frac{k}{c} \times \left(\frac{x}{c}\right)^{k-1} \times e^{(x/c)^k} \tag{16}$$

C is the scale parameter

k is the parameter of the shape

2.2.1 Energy production by Windspot 3.5

On the webpage of SONKYO energy an online energy calculation module can be found. It could be used in order to obtain an idea what amount of energy can be calculated by a wind mill.

Input data of the energy calculation module:

Average wind speed: Accuracy if this data totally depends on the time span during which measurements were taken. The most reliable is annual or monthly data since wind’s characteristics might change due to the season of the year or time of the day. It also has to meet the requirements of a Weibull distribution (two fine-tune parameters C and k).

The Weibull k: This is a factor that models the form of the Weibull probability distribution.

TABLE 1. The Weibull coefficient.

k	Territory
2	land
3	coast
4	island

The fewer obstacles there are, the less dispersion there is in the wind speed. k = 2 is normally used for installations on land, k = 3 for installations on the coast and k = 4 for installations on islands.

Height of emplacement: The height of the installation has a negative effect on energy production, since this means a decrease in air density.

Wind shear factor: This is a correction factor of wind speed when this data has been taken at a height which is different from the axis of the wind turbine. It has been assumed that the distribution of wind speed that follows a potential law with the following wind shear factors: 0.18 for normal installations, 0.22 for very rough terrain or with high turbulence and 0.11 for very fl at terrain with little roughness or open sea.

Height of the anemometer: Height of the anemometer at which the wind speed has been measured. If the exact data is not known, use the same value as the supposed height of the tower.

Height of the tower: Height at which the Windspot will be placed.

Turbulence factor: The turbulence factor takes into account the turbulence and other factors of variability of performance. A value between 0 and 5% should be used.

TABLE 2. Turbulence classification

Turbulence factor	**Terrain**
0	clear
1-2	average
3	uneven
4	rough
5	insufficient clearance

Output data of the energy calculation module will provide information about:

- Average wind speed on the axis: Average wind speed at the height of the axis of the wind turbine calculated from the average measured by the anemometer corrected by the wind shear factor.

- Density correction factor: This corrects the density of the air depending on the height of emplacement. The lower the height, the more energy produced.

- Operation time: Percentage of the time during which the wind turbine produces energy, taking into account that it begins to generate only at 3 m/s.

- Equivalent hours: This represents the number of hours per year that the wind turbine would be producing at nominal power to generate the same quantity of energy as that obtained.

- Average power: Average power to produce the same quantity of energy as that obtained during the period considered.

- Daily energy: Average energy generated per day.

- Annual energy: Average energy generated per year.

3 WIND SPEED DATA

3.1. Wind speed survey

Before installing a wind turbine a wind speed survey should be conducted at the exact location of the proposed turbine. Both historical data research and on-the-spot measurements should be taken in order to make data as reliable as possible. While historical data may show an average wind speed of say 5 m/s in some region, the real value in exact location could be very different because of the effects of surrounding buildings and trees and wind direction. Wind speeds around the world are typically modeled with the help of the Weibull Distribution - a statistical tool which predicts how frequently different wind speeds occur at a location with a known average wind speed. For example, low wind speeds happen to be much more frequent than high wind speeds. The real distribution of wind speeds at a particular spot can be very different and so the power output predicted by a wind turbine manufacturer (using the Weibull Distribution) may well be inaccurate. (Rinne, H 2008,16-23)

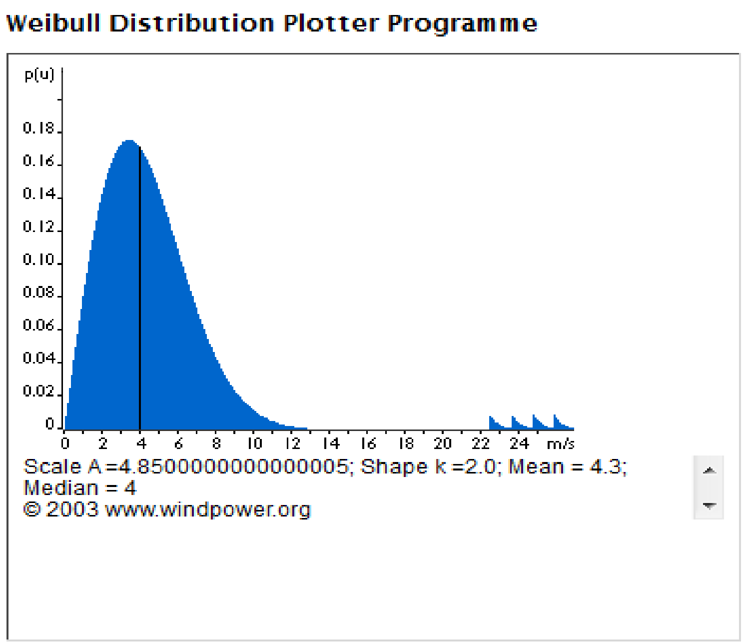

FIGURE 1. Weibull distribution

Above figure 4 demonstrates an example of the Weibull Distribution of Wind Speeds for a site with an average wind speed 4,3 meters per second. It demonstrates visually how low and moderate winds are very common, and that strong gales are relatively rare.

The line at 4 meters per second marks the median wind speed. 50% of the time the wind is lower than the median and 50% of the time it is stronger than the median.

The shape of the Weibull Distribution depends on a parameter called the Weibull k. In Northern Europe and most other locations around the world this value is approximately 2. Standard performance figures provided by wind turbine manufacturers typically use value of 2 making this distribution a Rayleigh Distribution. (Rinne, H 2008, 98-102)

The higher the value of k (from 2 to 4 table 1) the higher the median wind speed, for example locations with lots of low wind speeds as well as some very strong winds would have a value of shape of below 2, locations with fairly consistent wind speeds around the median would have a shape value of 3.

3.2. Historical background

For the historical background I have used wind speed data from 1980 till 2011 from Tampere-Pirkkalan lentoasema. The measurements were taken 8 times per day each 3 hours. The measurements of wind speed and wind direction were taken during 10 min and average result is presented in the appendix 1 and 2. This information is certainly important for historical background but it is not reliable enough because of the huge difference in distance between the measurement device and the actual position of the wind turbine. I believe that this data should be used for statistical analysis of the wind behavior during the year.

Figure 5 demonstrates wind speed during 1980-1999 years, overall average wind speed is 3,21 m/s and during those years it has been stable, difference between the minimal and maximum average wind speed is only 1,05 m/s. The decrease of wind speed starting from 1995 could be caused by natural reasons but it also could be influenced by the construction boom due to the industrial and economical development of Tampere. A lot of new buildings happened to become obstacles for the wind.

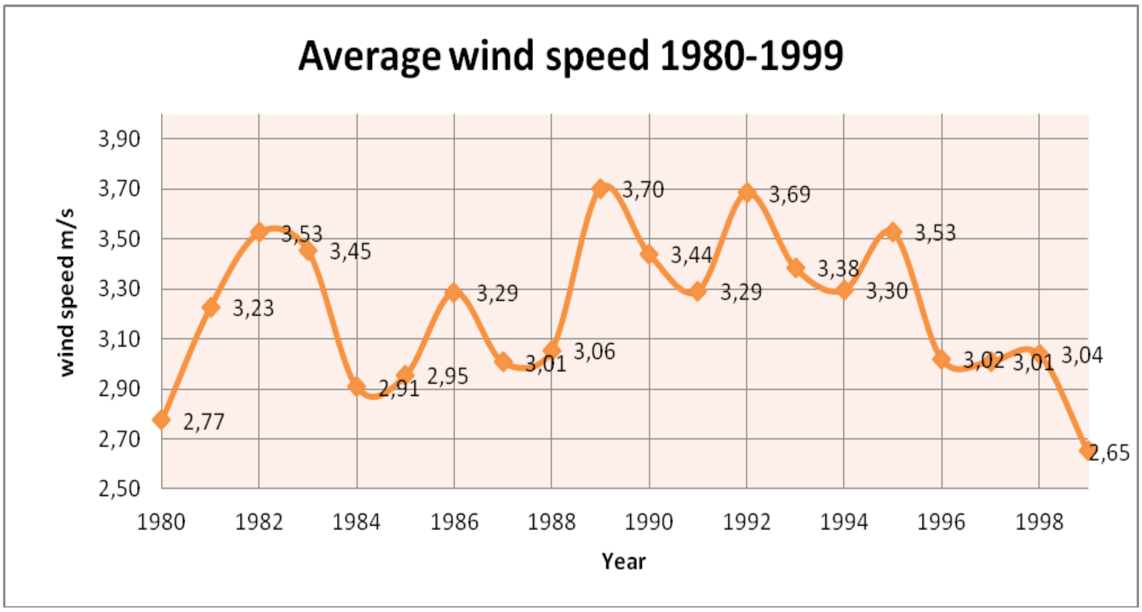

FIGURE 5. Average wind speed 1980-1999. Data from Tampere-Pirkkalan lentoasema

As for figure 6, it demonstrates average wind speed during 2000-2011. Here we certainly can see the decrease of wind speed and overall average wind speed during those years is 2,58 what is 0,63 less that during the previous decade .

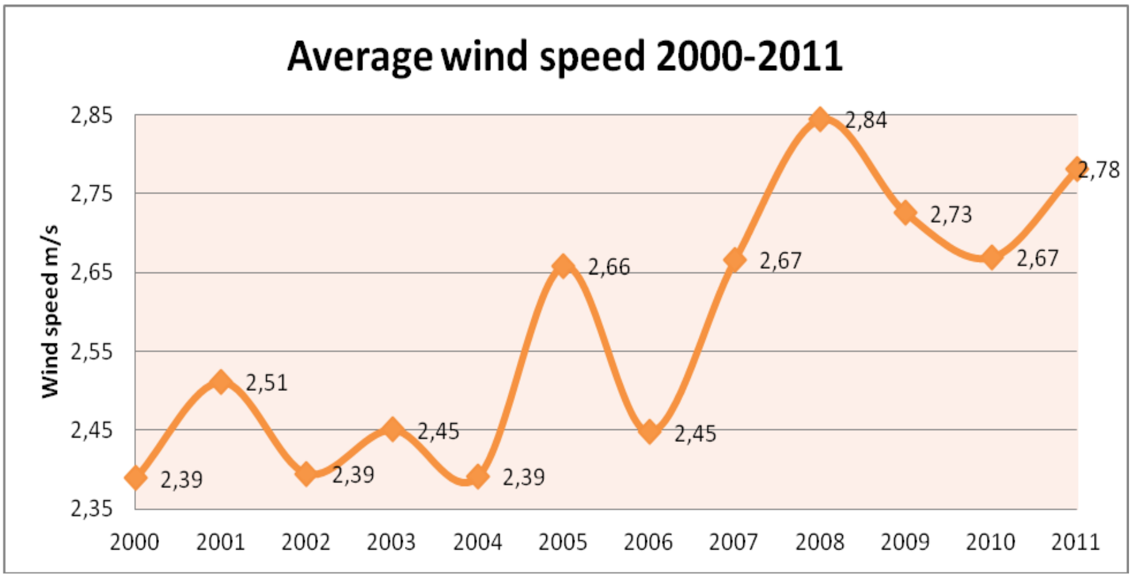

FIGURE 6. Average wind speed 2000-2011. Data from Tampere-Pirkkalan lentoasema

Figure 7 demonstrates graphical analysis of wind speed during different seasons during last 11 years. Data was taken from Tampere-Pirkkalan lentoasema. I cannot see any difference which could be worth taking into consideration at this stage.

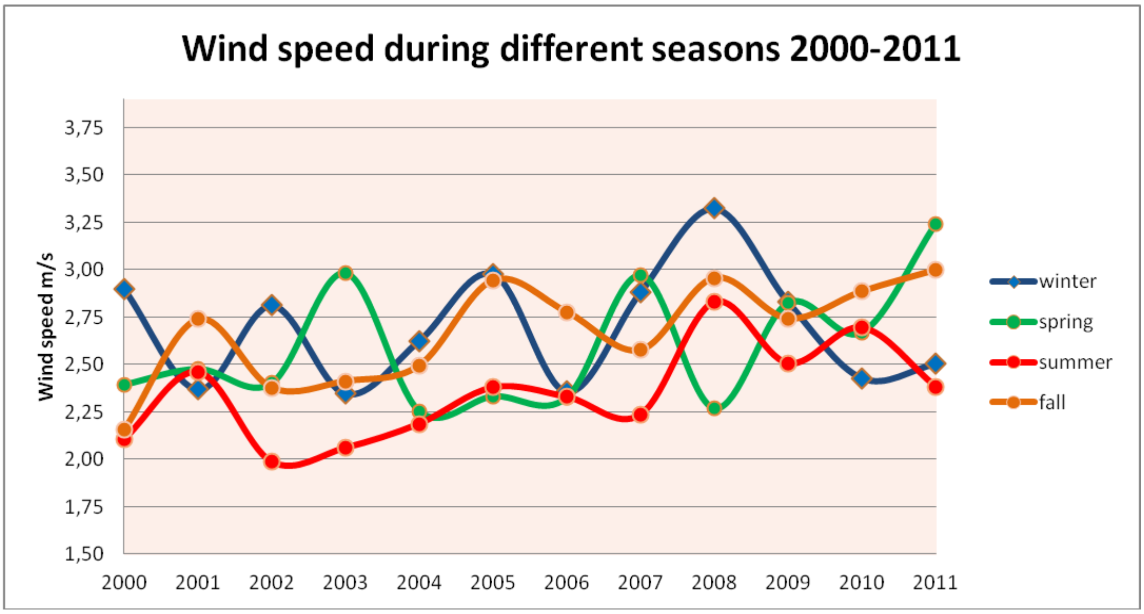

FIGURE 7. Average wind speed during different seasons 2000-2011. Data from Tampere - Pirkkalan lentoasema.

3.1. Davis Vantage Pro 2 weather station data

For measuring exact wind speed and other needed values on the roof next to wind turbines wireless weather station Davis Vantage Pro 2 that combines rain collector, temperature and humidity sensors and anemometer into one package was installed. This device produces reliable data which most certainly can be used for calculations.

Unfortunately, it has not been connected to the computer what made extraction of data from it impossible. In order to get reliable numbers data should be collected for months and even better for years. I leave it for continuation of Opi Enempi project to collect data from this device and use it for calculating theoretical energy output.

However, I did try to collect average wind speed data from this device for April 2012. The results are shown in figure 8.

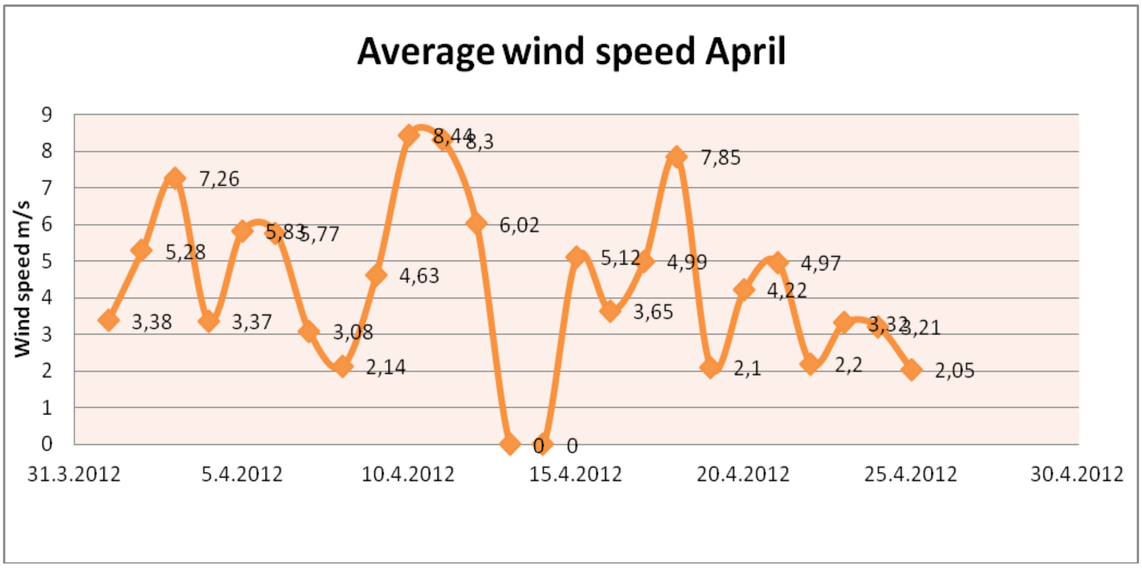

FIGURE 8. Average wind speed in April

Overall average wind speed is 4,28 m/s which is a good result because Windspot 3,5 starts operating at 3 m/s.

Now with all data and formula research we can move to the calculations. When calculating the theoretical wind energy production and actual output we would be able to make a conclusion about wind turbine efficiency.

4 CALCULATIONS

4.1. Power of the wind

As an example we will take April 2012 since I have collected wind speed data for it from the anemometer and the actual energy output is also available from Rejlers web resource, which is a webpage where wind speed data and energy supply by TAMK wind mills is shown.
In the table 3 we can see an average wind speed during April 2012:

TABLE 3. Average wind speed April 2012.

Date	Wind speed (m/s)
1.4.2012	3,38
2.4.2012	5,28
3.4.2012	7,26
4.4.2012	3,37
5.4.2012	5,83
6.4.2012	5,77
7.4.2012	3,08
8.4.2012	2,14
9.4.2012	4,63
10.4.2012	8,44
11.4.2012	8,3
12.4.2012	6,02
13.4.2012	0
14.4.2012	0
15.4.2012	5,12
16.4.2012	3,65
17.4.2012	4,99
18.4.2012	7,85
19.4.2012	2,1
20.4.2012	4,22

21.4.2012	4,97
22.4.2012	2,2
23.4.2012	3,32
24.4.2012	3,21
25.4.2012	2,05
Average:	4,28

It could be seen that by using the formula (2) for calculating the wind power production with this wind speed some values are still needed:

$$P = \frac{\rho \times A \times V^3}{2} \tag{2}$$

A is the swept area and it's easily calculated with formula

The swept area of the turbine can be calculated from the length of the turbine blades using the equation for the area of a circle:

$$A = \pi r^2 \tag{17}$$

where the radius is equal to the blade length (2,05 m) as shown in the figure below:

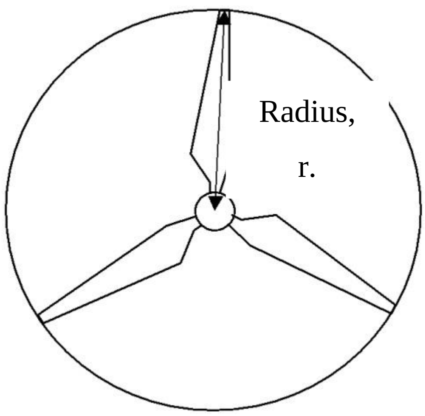

FIGURE 9. Swept area.

$$A = \pi \times 2{,}05^2 = 13{,}20 \text{ m}^2 \quad (18)$$

ρ is air density. By taking average temperature as 5 degrees Celsius, we get air density of 1,269 kg/m^3.

Now we can calculate the average wind power production (table 4): \

TABLE 4. Average wind power production

Date	**Wind speed (m/s)**	**Density of Air (t=5)**	**Area m2**	**Wind power (kWh)**
1.4.2012	3,38	1,269	13,20	1163,92
2.4.2012	5,28	1,269	13,20	4436,83
3.4.2012	7,26	1,269	13,20	11534,04
4.4.2012	3,37	1,269	13,20	1153,62
5.4.2012	5,83	1,269	13,20	5972,79
6.4.2012	5,77	1,269	13,20	5790,27
7.4.2012	3,08	1,269	13,20	880,69
8.4.2012	2,14	1,269	13,20	295,40
9.4.2012	4,63	1,269	13,20	2991,68
10.4.2012	8,44	1,269	13,20	18121,70
11.4.2012	8,3	1,269	13,20	17234,78
12.4.2012	6,02	1,269	13,20	6575,99
13.4.2012	0	1,269	13,20	0,00
14.4.2012	0	1,269	13,20	0,00
15.4.2012	5,12	1,269	13,20	4045,59
16.4.2012	3,65	1,269	13,20	1465,72
17.4.2012	4,99	1,269	13,20	3745,18
18.4.2012	7,85	1,269	13,20	14580,77
19.4.2012	2,1	1,269	13,20	279,14
20.4.2012	4,22	1,269	13,20	2265,21
21.4.2012	4,97	1,269	13,20	3700,33
22.4.2012	2,2	1,269	13,20	320,95

23.4.2012	3,32	1,269	13,20	1103,03
24.4.2012	3,21	1,269	13,20	996,98
25.4.2012	2,05	1,269	13,20	259,68
Average:	4,28		Average	4356,57

Now there is a final answer: wind speed and weather conditions are allowing to get from wind 4365,57 kWh.

4.2. Actual energy extraction

Let's not forget about different factors which affect energy extraction from wind:

- The Betz Limit with values of 0.35-0.45 even in the best designed wind turbines
- Inefficiencies in a complete wind turbine system (the generator, bearings, power transmission and so on), only 10-30% of the power of the wind becomes electricity

That is why numbers demonstrated in figure 8 are so much less than the one I have calculated above. The measured energy output by Windspot 3.5 in April (1st – 26th) is only 114,38 kWh.

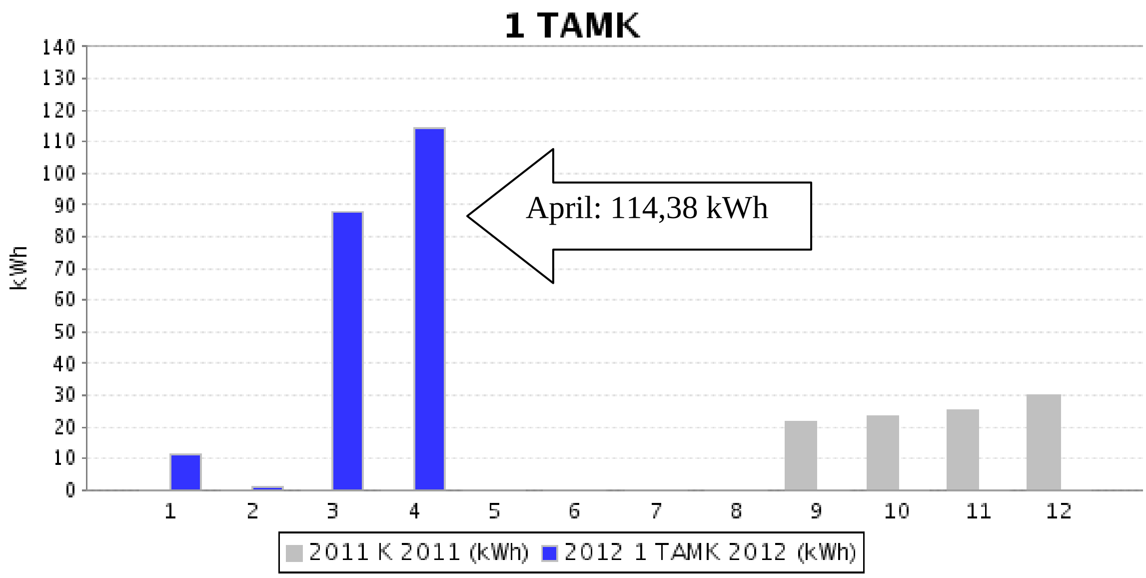

FIGURE 8. Energy production by Windspot 3.5

So the efficiency coefficient Cp is 0,026.

$$\frac{114{,}38}{4365{,}57}\ kWh = 0{,}026 = 2{,}6\%$$

In other words, only 2,6% of wind power is captured by the wind turbine. Out of possible 4365,57 kWh power production with current wind conditions, this particular wind turbine produces only 114,38 kWh.

5 DISCUSSION

After analyzing wind speed statistics and current situation I came to the unpleasant conclusion that efficiency of wind power production is questionable in Tampere, at least with small scale wind turbines. Windspot 3.5 requires at least 3 m/s to start functioning; the historical background data demonstrates that most of the time wind speed is on the edge between 4 and 3 m/s (data from Tampere-Pirkkalan lentoasema). In big scale wind turbines weather conditions other than wind speed (air density, for example) are an important factor which could considerably affect wind power production, but in case of 3.5 kWh wind turbine only wind speed plays considerable role.

However there are few ways of improving this situation such as replacing this wind turbine, for example. Places at high altitude (top of hills, roofs of high buildings, etc) with not rough terrain (small amount of trees and buildings) are the perfect variants. Also increasing height of the tower (at the moment height is 12 m but there could be 16 m possibility) is positively influencing the wind power production because wind is slowest near the ground due to friction.

The actual power extraction from Windspot 3.5 is demonstrating very low results. Efficiency of 2,6% is approximately 10 times less than average performance of a wind mill. My conclusion is that TAMK wind mills could be used mostly for studying purposes or research. When it comes to the power production, unfortunately, with such a low efficiency it is impossible to say that Windspot 3.5 wind turbine is capable of providing sufficient energy input.

Obviously, the entire world needs energy and the energy demand is growing due to increase of population. I hope it’s not just my imagination and renewable energy is slowly but surely increasing its dominance. Innovations and new technologies in renewable energy are getting governmental support and funding what has really helped to boost some renewable energy sources in the last five years or so, most notably solar and wind energy.

With well positioned small- or middle-scale wind mill it is easily possible to provide energy for household operations. Nowadays when clean environment and sustainability has become tendency of many people, wind energy definitely seems to be the right choice for many house owners who want to become environmentally friendly.

Big-scale wind mills could be used for other purposes than households, that is why wind farming is such a popular tendency in UK, USA, Denmark and many other countries, it supplies electricity to electric grids from where it is consumed by various users of electricity.

However everyone who is planning on having a wind turbine should remember that in all cases, for all types of wind mills, thoughtful positioning and wind speed research play the crucial role in the energy efficiency of wind turbines. And as final word, I have a few suggestions for continuation of the research:

- vertical wind turbine analysis
- research of influence of air humidity on energy production
- finding possible solutions for replacing the Windspot 3.5 to the place with higher wind speed
- keeping wind speed data collection from the anemometer (at least during 1 year) by connecting it to the computer

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APPENDICES

Appendix 1. Tampere-Pirkkalan lentoasema wind speed data 1980-1999

year	reading	average wind speed m/s
1979	1	2
1980	2928	2,77
1981	2920	3,23
1982	2920	3,53
1983	2920	3,45
1984	2928	2,91
1985	2920	2,95
1986	2920	3,29
1987	2920	3,01
1988	2928	3,06
1989	2920	3,70
1990	2920	3,44
1991	2920	3,29
1992	2928	3,69
1993	2920	3,38
1994	2920	3,30
1995	2920	3,53
1996	2928	3,02
1997	2920	3,01
1998	2920	3,04
1999	8129	2,65
	avg	3,21

Appendix 2. Tampere-Pirkkalan lentoasema wind speed data 2000-2011

year	**average wind speed (m/s)**				
	winter	**spring**	**summer**	**fall**	**Average**
2000	2,90	2,40	2,11	2,16	2,39
2001	2,37	2,48	2,46	2,74	2,51
2002	2,81	2,40	1,99	2,38	2,39
2003	2,35	2,98	2,06	2,41	2,45
2004	2,63	2,26	2,19	2,49	2,39
2005	2,98	2,33	2,38	2,94	2,66
2006	2,36	2,33	2,33	2,78	2,45
2007	2,88	2,97	2,24	2,58	2,67
2008	3,32	2,27	2,83	2,96	2,84
2009	2,83	2,82	2,51	2,74	2,73
2010	2,43	2,67	2,69	2,89	2,67
2011	2,50	3,24	2,38	3,00	2,78
				avg	2,58