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Evaluation of Gløshaugen wind conditions

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MASTER THESIS

for

Student
Alejandro Lopez Pareja

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Urban Wind – Gløshaugen area

The presence of buildings significantly changes the local wind climate. The factors that make up the outer atmosphere of the buildings are: the direction of the wind, its velocity, air pollution, rain-drops and debris lifted and transported with the wind, and sunshine. Each of these factors depends on the shape, size and orientation of buildings to the direction of wind flow and their interaction with surrounding buildings or other landscape elements in the environment (Blocken and Carmeliet 2004). The urban terrain and the associated complexities therein, present significant challenges for the deployment of small wind turbines. In particular, a considerable amount of uncertainty is attributable to the lack of understanding concerning how the wind within urban environments affects turbine productivity. Current wind turbine power output measurements (particularly for small/micro wind turbines) are based on an average wind speed over an observation period, with limited accountability of the variability of wind speed within the observation time frame.

For the present work we suggest to do a Site analysis of the Gløshaugen area following the Measnet (2009) guidelines. Wind data at this location is available from a ZephIR 300 Lidar. The Site analysis is to be considered as input for an evaluation of the performance of our new Primus Wind Power AIR-40 wind turbine. This wind turbine will be deployed at the roof of one of the Department's buildings and tested for functionality. The efficiency of the turbine shall be measured and the chosen location of the turbine is to be evaluated

References:

Blocken B., Carmeliet J., Pedestrian wind environment around buildings: Literature review and practical examples. J. Therm. Envel. Build. Sci. 28(2). (2004)
Measnet - Evaluation of site-specific wind condition, Measuring Network of Wind Energy Institute (2009)

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☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
X Field work

Department of Energy and Process Engineering, 03.02.2016

Olav Bolland
Department Head

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Evaluation of Gløshaugen Wind Conditions

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NTNU Norwegian University of Science and Technology, 2016

TEP4925 Engineering Fluid Mechanics, Master's Thesis

Abstract

It is very important to know the wind conditions when, for example, designing buildings. In this paper, the results focus on the wind conditions needed to decide if it is interesting and right to deploy some wind turbines at the roofs of Gløshaugen's buildings in order to the university becomes energy self-sufficient; or at least more independent by generating part of its own energy. To do that, a ZephIR 300 Lidar takes wind conditions data that is analyzed and present here. Moreover, an AIR-40 wind turbine is deployed at the roof of one of the Department's buildings. It takes some data such as power output and wind speed. The results show a 6.2 m/s of averaged wind speed, with 225º predominant direction according to both, the Lidar and the weather station located next to the wind turbine. This wind is stronger during winter months and very weak during the summer. The wind turbine has a C_p maximum of 0.35 and a maximum power output of 250 W with a wind speed of 11m/s. After analyzing all costs, the results evidence that it is not economically profitable to deploy wind turbines to save money, unless that the main goal is to depend less from the grid and be greener.

I. INTRODUCTION

The generation of energy from wind is gaining more importance every year because, among other features, is efficient and renewable. The production of wind energy is thriving considerably and it is expected an increase in its production even greater in the coming years. In fact, the world installed more than 432 GW of power production in 2015. This is why a Site analysis of the Gløshaugen is required, to see whether it is economically profitable to install wind turbines or not. To do that, we analyze the data from a ZephIR 300 Lidar following the MEASNET (2009) guidelines.

In addition, it is deployed and tested for functionality a Primus Wind Power AIR 40 wind. Before the deployment, some tests took place in a wind tunnel to ensure the correct operation of the turbine and measure instruments. Afterward, it is interesting to compare all the data collected from the Lidar to the one from the wind turbine to double-check if the results are as expected.

1.1 Site description

Gløshaugen is located in Trondheim, Sør-Trøndelag (Norway). Many buildings in the university influence the wind flow. This fact makes the wind different in each emplacement. However, this thesis will summarize and describe the wind measured at 120 meters above the ground, which means 170 meters above the sea; because the wind is less affected by the buildings at this height and summarize in a better way the wind behaviour. The measure instrument is a ZephIR 300 Lidar, properly calibrated. Since the amount of collected data is not enough to have a right idea of long-period conditions (there is only 4 months of data), more data from other place is used to correlate long-term data. This second place is Voll, and is located 2.6 km southeast of Gløshaugen. The wind conditions in Voll are very similar to the place of study. The weather station in Voll is an Automatic Weather Station has taken data for more than 10 years.

Figure 1: Map of the area surrounding Gløshaugen

Figure 2: Wind turbine at Gløshaugen

The wind turbine is set at the roof of one of the Department's buildings.

1.2 Wind profile and distribution

The instrument used to measure the wind characteristics takes all the data at different heights. This is very important because there are many buildings that significantly modify the direction and wind speed surround it at different heights.

Even though MEASNET demands 30 years of study to be accurate, only 6 years are analysed due to the lack of data. This means that although there is data from Voll weather station of 10 years, there is almost no difference between analysing data of 6 years or 10 years. In addition, the instruments used to measure the last 6 years are more accurate that the ones used previously.

The sampling rate of the Lidar is 50 Hz, taken data every one second and making a 10 minutes averaging [1]. This is the recommended averaging time according to DNV-RP-C205 for describing environmental conditions and environmental loads [2]. This data, which includes wind speed (**U**) and wind direction, is the normal distribution around a mean value and a standard deviation **σ**, deviation that describes the turbulence of the wind. In order to get the most accurate distribution possible, wind data over long periods with the slightest lack of data are desirable.

A wind distribution is a histogram that shows the frequency of discrete wind velocity ranges within the sample and may include both short and long periods. The expressions, which gives a good fit to wind data, are Weibull, Rayleight and Gumbel; but the one that fits better is the Weibull distribution [3], this can be expressed as:

$$p\left(\frac{u}{U}\right) = k\Gamma\left(1+\frac{1}{k}\right)\left\{\frac{u}{U}\Gamma\left(1+\frac{1}{k}\right)\right\}^{k-1} e^{-\left\{\frac{u}{U}\Gamma\left(1+\frac{1}{k}\right)\right\}^{k}} \quad (1)$$

where u is the unsteady wind speed component and U is the mean value, $p\left(\frac{u}{U}\right)$ is the non-dimensional probability density distribution, k is a factor that determines the shape of the curve and $\Gamma\left(1+\frac{1}{k}\right)$ is the value of the Gamma function for $\left(1+\frac{1}{k}\right)$. And according to the deduction of "The Wind Power and UK Wind Speed Database programs" [3]:

$$k = \left(\frac{0{,}9874}{\frac{\sigma}{U}}\right)^{1{,}0983} \quad (2)$$

1.3 Wind power

Wind power is the transformation of the kinetic energy of the wind into electrical energy. The power contained in the wind follows the next formula:

$$P = \frac{1}{2}\cdot\rho\cdot U^3\cdot\pi\cdot r^2 \quad (3)$$

where P (W) is power, ρ (kg/m^3)is the air density and r (m) is the rotor radius.

The performance of the blades determine how wind creates lift forces along the airfoils, and these forces induce a torque on the rotor of the turbine. The performance of the blades is defined by the coefficient C_p, which is the is division between the electricity produced by the total energy available in the wind at that speed.

$$C_p = \frac{P_{mechanical}}{\frac{1}{2}\rho\cdot A\cdot U^3} \quad (4)$$

where A is the rotor area. This coefficient, according to the Benz law, has a maximum theoretical value of 0.59. Derived through annular stream tube control volume analysis as shown in [4].

In addition, the power performance of a wind turbine can be plotted as a curve $P_w(U)$. This varies with the wind speed whose values are between the cut-in-speed, which is the minimum speed at which the turbine generate power, and the rated wind speed, where maximum output power occurs. This curve has normally a cube shape between these two points; above the rated wind, speed point the performance is limited usually with pitch control. Then, the power output is theoretically constant up to the cut-out-speed, when the power generation ceases.

II. METHODS

2.1 ZephIR 300 Lidar

One of the best instrument available measures the wind speed and wind direction. This is the ZephIR 300 Lidar, which is able to measure at different heights simultaneously up to 200 m. Although in this case, it only measures up to 120 m. It measures successfully wind speeds with an averaged difference of just 0.4% for a sustained period of time and across all measured speeds [5].

The Lidar sets up onshore, in Gløshaugen, in vertical position to measure horizontal wind speeds and direction. It connects wirelessly (Wi-Fi) to a computer where the data can be taken to later analysis. The software to read the data and show it is Windographer, which also allows extrapolating data by correlating the target data to a reference data. The reference data used is from the Automatic Weather Station in Voll.

The data obtained from the Lidar is 4 months data, while the data from Voll is 6 years data. By using Windographer, 4 months data extrapolates up to 6 years data. These data correlates using Linear Least Squares (LLS) method with the following errors: Mean Bias Error (0.93%), Mean Absolute Error (~24%), Distribution Error (20.9%). These errors could seem high, but it is important to remember that the data of the Lidar recorded only during the winter months; and therefore it does not take into consideration, as reference, the opposite conditions during summer time. In addition, by correlating this data, this 4 winter months become data not only of 1 year, but of 6 years. So it is expected this error to be high. If only this 4 months period in Gløshaugen is compared to the same period in Voll, data matches with an error smaller than 4 % in both speed and wind direction. Nevertheless, this is not the matter of this study and this knowledge is only used to validate that Voll wind conditions fit with Gløshaugen wind conditions.

2.2 Primus Air-40

The model of the wind turbine chosen to deploy at the roof of one of the Department's buildings is the Primus Air-40. This choice fits with the possible future purpose of installing a small farm in the university because of its low weight, good performance and its possibility of pairing with solar photovoltaic panels. It has a 1.17 m rotor diameter. The alternator is a permanent magnet brushless with a rectifier that converts the voltage to DC ahead of the battery terminals. It has also a microprocessor-based smart controller.

The controller optimizes the power production during the charging mode by adjusting the alternator load constantly, and therefore the stator voltage that is directly proportional to the rotational speed of the turbine. It means that the turbine works in the most efficient way independent of the system voltage or external load. When the battery is full, the microprocessor stops or reduce the speed of the rotor.

In theory, the turbine starts producing energy when the wind speed is 3.1 m/s, achieving the optimal point at 4.5 m/s. The maximum power output comes with 11 m/s and it is 250 W. For higher wind speeds, the wind turbine generates a constant value of 200 W. When the wind speed is over 22 m/s, the wind turbine activates the over-speed protection and it stops the power generation with its electronic torque control. The maximum wind speed that supports the turbine without breaking is 49.2 m/s.

2.3 Wind turbine performance.

The wind turbine performance was tested in the wind tunnel before the deployment at the roof. The wind turbine generates 250 W with the best performance and a wind speed of 12 m/s according to the company. Above that wind speed, the power output is constant and equal to 210 W. The wind turbine is connected to a lead acid battery of 12 V through 6 mm^2 section wires. The wind turbine can supply power at different voltages (12 V, 24 V and 48 V), so this battery fits properly. The potentiometer of the wind turbine adjusts the desired voltage. The wires section needs to be so big because the current that circulates through them is up to 13 A approximately, so this makes loses as low as possible.

Because the turbine stops when it detects that the battery is full to not damage it, a thermal load of $1\ \Omega$ (rated output: 300W) is connected, so the excess of energy is burned.

In order to measure the power output, the configuration uses both, a voltmeter and ammeter. We cannot measure the mechanical torque of the turbine because the turbine includes its shaft in the turbine house casing, making it impossible to connect a torque gauge. As well, with this configuration, the loses of the turbine generator are also included in the measures, giving the correct power output, that is to say, the electric power output. The measure instruments wire to a DAQ-box, which connects to a field computer that record the data. A programme in LabVIEW transforms the analogue signals into digital ones. It only records average values of each parameter every 10 minutes to later analysis. The accuracy of the ammeter and voltmeter must be better than 0.1 A and 0.1 V respectively. These accurate instruments need also to have a very low level of noise so it does not disturb the measurements. The reason for this need is that the ammeter range from a few tenths of amperes to 10 A and the voltmeter from 12 V to 14 V in most cases.

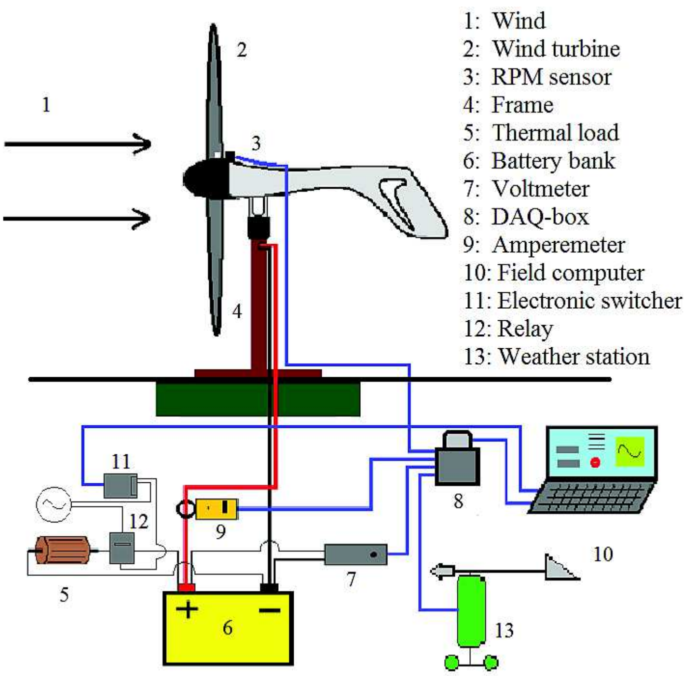

Figure 3: Wind turbine performance

Because the turbine needs to detect a minimum voltage between both terminals of the battery to start generating power, the battery voltage must be always above 10.5 V. Although the recommendable minimum voltage is 11.9 V, so the battery does not damage, as this value represents the battery to 0% charge. This is not possible if the resistance burns energy constantly; since the turbine does not generate power due to the lack of wind, (wind speed must be higher than 3.1 m/s). This is why there is a relay between the battery and the resistance. This relay activates when 230V of AC current flows through it. A National instrument device (NI 9481) and the software LabVIEW control when this AC current flows or not, so the relay will actuated in the same way. This device turns on when the voltage that it reads in the DAQ-box is above 13.5 V, so the battery will never be full when the turbine is working. Furthermore, the switcher will turn off when the voltage goes under 12 V, so the battery will not be empty. We have applied a safety margin to these values. Moreover, these values need to be 0.27 and 0.24 respectively (these are the equivalent output of the voltmeter).

Just to mention that the voltage read by the voltmeter when the turbine is operating is larger than the battery one, since the voltage read is the one generated by the turbine.

All these devices are in a weatherproof box to ensure that they do not suffer any damages during operation, but not the resistance because of the heat released because of the Joule effect. Additionally, the wind turbine rests on a bar of 3 meters high, which improves the wind conditions. The figure 3 is an electric scheme of the performance described in this point. A weather station wires up also to the DAQ-box to record speed and direction of the wind.

III. RESULTS

3.1 Weather conditions

3.1.1 Mean wind speed analysis

The first part of the analysis shows the data of the wind speed, statistically analyzed for one year, and the wind speed along one day respectively. Although it will be analyzed and described later, Figure 4 shows that the wind speed during summer months is not as high as the wind speed during winter months, especially February and March. Figure 5 shows how, during the noon and the following five hours, it is windier than the rest of the day. This average data and all the data analyzed in the following points comes out from the correlated data between the Lidar and the weather station at Voll for 6 years; this has been discuss yet.

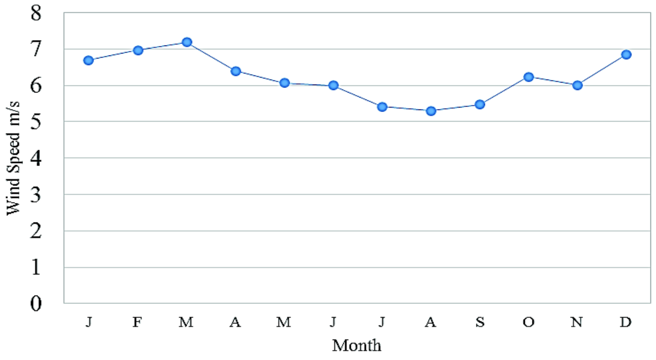

Figure 4: Monthly mean wind speed profile

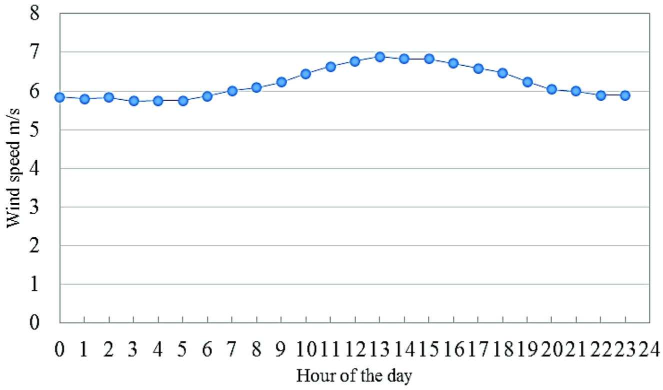

Figure 5: Diurnal mean wind speed profile

3.1.2 Annual mean wind speed

As commented before, this analysis represents the correlated data between the Lidar and the weather station at Voll for 6 years.

The annual wind speed is the averaging of all the data along 1 year. The Table 1 illustrates the annual mean wind speed from 2010 to 2015, including so far 2016. It also shows the average of the whole period, with a value of 6.2 m/s. The year with highest speed was 2015 with a value of 6.5 m/s, while the less windy year was 2010, with an average of 5.8 m/s.

The Figure 7 represents data from year 2010 to 2015 with the mean daily values along each month. There is a pattern during these years, the highest wind speed occurs from February to April.

The pattern indicates that the wind speed usually decreases up to 5 m/s approximately during the summer months, that is to say, since May until September or October, depends on the year. It is around November when the wind speed increases again but it does not reach as high values as February or March. An exception of this, which modifies a lot the average, are 2010 and 2012 when the wind speed did not achieve the usual value and kept around 5.5 m/s on average.

As the height is around 50 m above the ground, the air density is not very high. As consequence, the wind power density and the wind power class are low. According to the PNL classification system [6], it gives an annual average of class 2. However, some months are as high as class 3.

The highest wind speed day averaged was in November 2013, when the wind speed went up to 15 m/s on average. However, the highest value averaged (10 minutes average) is 26 m/s in December 2015. Additionally, the lowest daily averaged value is 1 m/s in April 2011.

Year	Wind Speed [m/s]	Wind Power Class
2010	5.8	2
2011	6.4	3
2012	6.1	2
2013	6.1	2
2014	6.3	2
2015	6.5	3
2016	6.4	3
All	6.2	2

Table 1: Diurnal mean wind speed and class profile

3.1.3 Monthly variation of the mean wind speed

The Figure 6 shows the mean wind speed variations of the correlated data between the Lidar and the weather station at Voll for 6 years. Lower speeds occurs during the summer, around August and September. Higher speeds occurs during February and March.

Except 2010, there is a pattern. This pattern reflect the behave of the wind during the year; during the first months of the year (especially in March) the wind speed is very high, but during the summer is when the lowest point of wind speed takes place, and the wind hardly reaches 5.5

m/s of speed. Afterwards, the wind increases up to 7.5 m/s approximately, just before dropping a little bit around January.

Here we have analyzed 6 years, but according to MEASNET, we should analyzed more than 30 years of meteorological data to be able to consider it as representative of a place. Therefore, we could be more accurate when talking about different seasons. According to "Havforskningsinstituttet", it is typical in Norway that the winter months are stronger; and this is remarkable in this place.

3.1.4 Hourly variation of the mean wind speed

Figure 5 analyses the hourly variation of the mean wind speed during one day. This is the result of averaging all the values of the wind speed, at every hour, during the period from 2010 to 2015 of the correlated data between the Lidar and the weather station at Voll. The wind speed average is, as also shows the Table 1, 6.2 m/s. The wind speed from 9:00 p.m. to 7:00 a.m. is 5.9 m/s approximately; but at 8:00 a.m., it start to increase until 1:00 p.m., when it reaches the highest wind speed of 7 m/s. At that point, the wind speed decreases until 9:00 p.m., when it reaches 5.9 m/s again.

Figure 6 shows the mentioned cycle of windy winters and low wind speeds during summers.

3.1.5 Weibull function predictions

The Figure 8 shows the comparison between the Weibull predictions and the data extrapolated in Gløshaugen. This data represents wind speeds in different columns with an interval of 1 m/s. It shows the probability that a given wind speed to occur. Besides these data columns, there is also a line, which represents the Weibull probability function. This line shows the ability of the Weibull function to predict values with a similar frequency distribution.

As we can see, the function does not fit very well. For lower and higher values, the Weibull function predicts values higher than what the collected data describes.

Contrary, for the most common speeds, the Weibull function predicts lower values.

The most usual wind speeds are those between 4 m/s and 8 m/s with a probability of occurrence of almost 7 %. For instance, wind speeds higher than 15 m/s do not occur that often (<0.1 % probability). The same happen with low wind speeds, speeds lower than 2 m/s have a probability of 1% approximately.

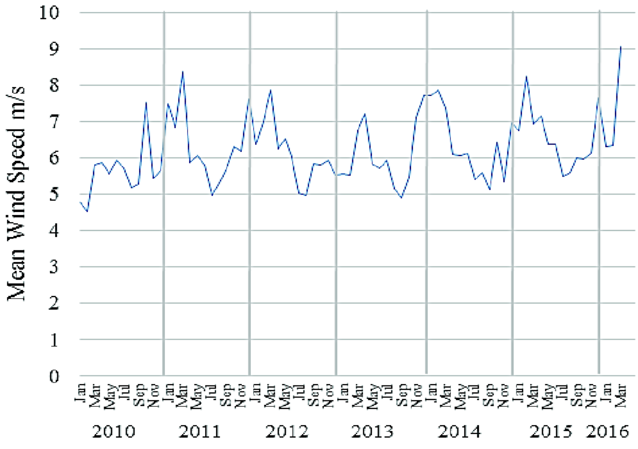

Figure 6: Monthly mean wind speed per year

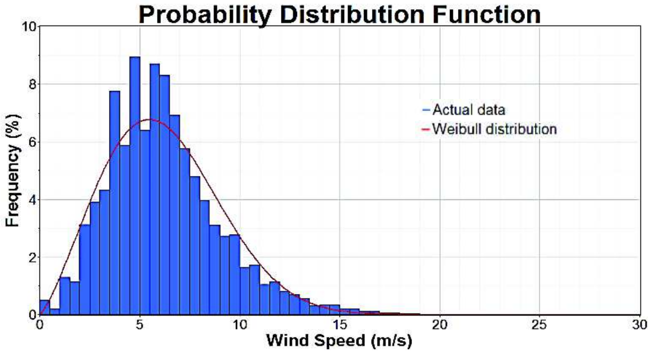

Figure 7: Weibull probability distribution

Regarding the optimal wind speed for the AIR 40 wind turbine, 4.5 m/s is almost the most frequent wind speed because it has a frequency of 6.5 %. It means that the power output should be around its maximum value or lower due to its constant value of 200 W for wind speeds higher than 12 m/s.

3.1.6 Wind energy density

The wind energy density indicates how much energy is available at the site for conversion by a wind turbine. We analyze the power class and introduce the wind power density (WPD) values according to the PNL classification system. The Table 2 shows the WPD values of each months and the wind power class. The average annual values matches with the one shown in Table 1.

The best month is March with a WPD average of 436 W/m^2, and class 4. Although this is the best month, this is not very high. The annual average is class 2 as said before, and a WPD of 275 W/m^2. The worst months are July, August and September with 190 W/m^2 approximately; it means class 1. This power density is not enough and can represent a problem to generate energy from wind. Winter months are class 3, so it gives a WPD around 380 W/m^2.

Month	WPD [W/m^2]	Wind Power Class
Jan	348	3
Feb	393	3
Mar	436	4
April	298	2
May	257	2
Jun	248	2
Jul	193	1
Aug	189	1
Sep	195	1
Oct	280	2
Nov	253	2
Dec	375	3
All	275	2

Table 2: Monthly WPD and winter class

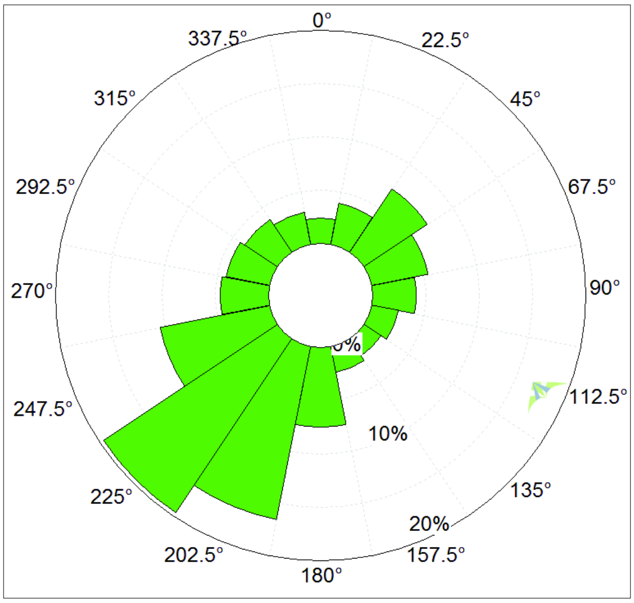

Figure 8: Wind direction probability

3.1.7 Wind direction frequency

The Figure 8 describes the wind direction and its probability to take place. There is a predominant direction at 225º with a probability of 20 %. However, it suffers some deviations and this direction can turn into 180º or 47º with still a high probability (10 %). The opposite direction (45º) has also a high chance to occur with a 7 %.

Moreover, there are more direction but they have only a probability lower than 3 %, so they do not take much prominence. The wind turbine deployed at the roof is able to change its direction to improve the efficiency when generating energy. This makes that the wind direction does not take much interest when talking about energy generation with this wind turbine. However, it takes a special interest when talking about the wind conditions in Gløshaugen.

3.1.8 Data comparison: Weather station vs Lidar

In this point, the data recorded from the weather station next to the wind turbine is analyzed and compared to the data from the Lidar. The goal is to see how the surroundings of the wind turbine area affect the wind.

To carry out this task, a short period is analyzed. It is better if a windy period is taken into consideration, so there is more data available. A windy day is chosen to analyze the Lidar data at 20 m; the height that is more approximated to the wind turbine height (15 m building and 4 m frame).

The wind direction is the first important topic. There is a difference smaller than 5% between both measurements for the main direction. For example, taken a random day, according to the Lidar the main direction is 355º. Figure 9 shows Lidar direction results. In Figure 9 the yellow point represents the Lidar location and the red point the wind turbine location.

According to the weather station next to the wind turbine, the main direction is around 0º. It means that the difference between the two directions is 10º (< 4 % difference). The difference can be attributed to error measurements and the building surroundings but it is almost the same. As Figure 9 shows, in the case of the wind turbine there is no obstacles in directions from 330º to 150º; in the case of the Lidar in directions between 0º and 150º. Remember that the Lidar is measuring at 20 meters, this means 6 meter higher than the building around it; so only other buildings may disturb the wind flow.

However, for wind directions between 150º and 330º the flow is disturbed in different ways. In the Lidar case, the 'central building' disturb the flow; in the case of the wind turbine, there is a field between the directions 200º and 250º which does not disturb the wind. Only the building 'Hovedbygningen' disturbs the flow. Finally, two structures (white in the schema) affect the wind for the wind turbine in two particular directions; these two particular direction are further explained by comparing speeds in Figure 11 and 12.

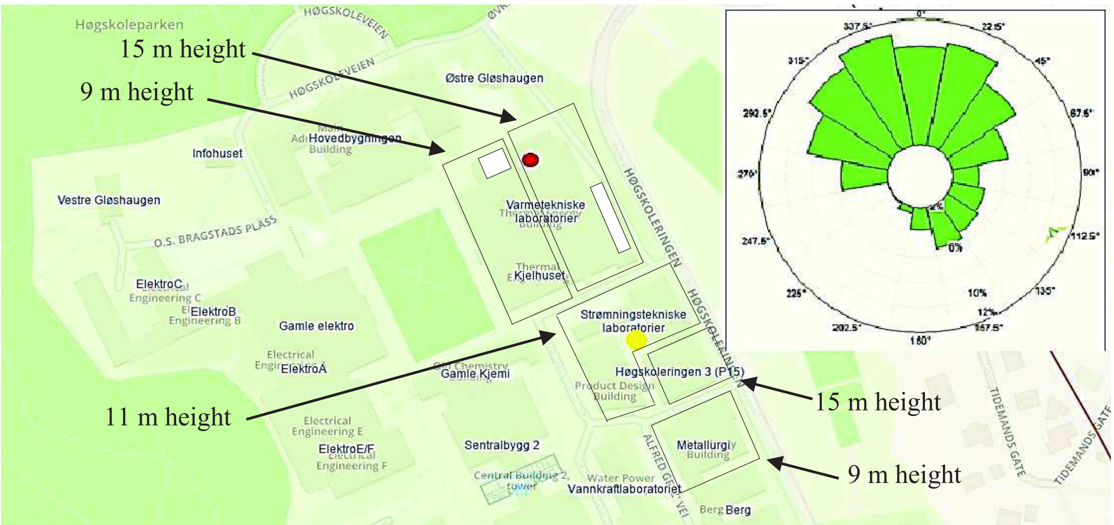

Figure 9: Wind direction analysis

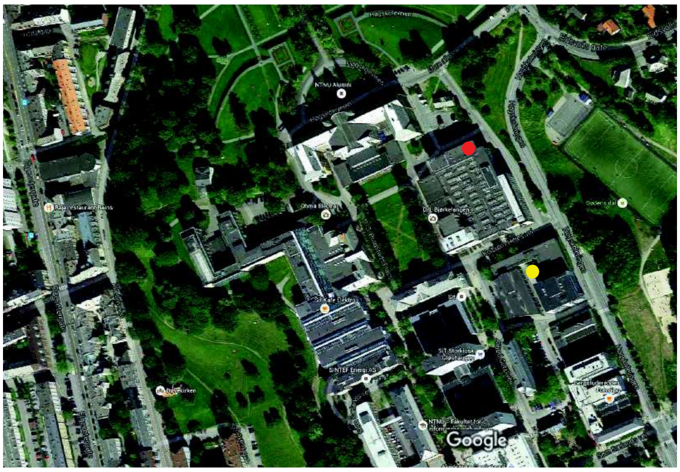

Figure 10: University image

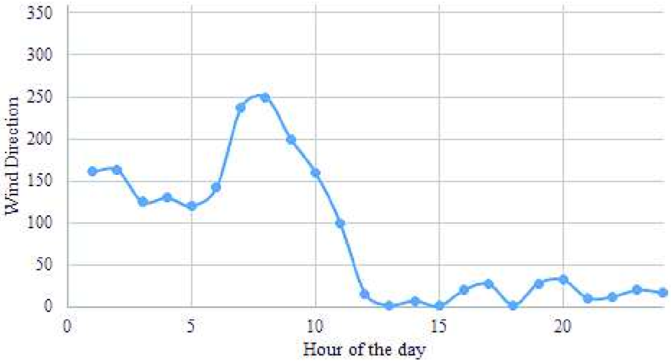

Figure 11: Wind speed comparison

All this means that in the case of directions between 330º and 150º the wind is the same. However, in other cases it must be studied because of its differences.

Figure 10 clarify what was explain before about the surroundings. See point *3.1.9* to know more about how to do a deeper study.

The Figure 12 shows averaged wind speed values along one day for both measure instruments.

According to the wind speed, from 12:00 until the end of the day, there is no considerable difference. This is because the wind came from 10º, and it is not affected in any of the cases by any building; as explained before.

On the other hand, from the beginning of the day until 12:00 approximately the difference is from 3 m/s in the case of the weather station next to the wind turbine to 9 m/s in the case of the Lidar. This difference is justified by the wind direction at that time. The wind direction was 120º, and it means that the Lidar has no obstacles as shown in Figure 10. Nevertheless, in the case of the wind turbine, the white structure is an obstacle in the direction of the wind at that time. This obstacle reduces the wind speed considerably as the Figure 12 describes. Figure 11 shows the evolution of the wind direction along the day according to the weather station measurements

At 7:00, the wind direction is 250º. This means that the other white structure affects the wind turbine measurements by decreasing the wind speed around 3 m/s.

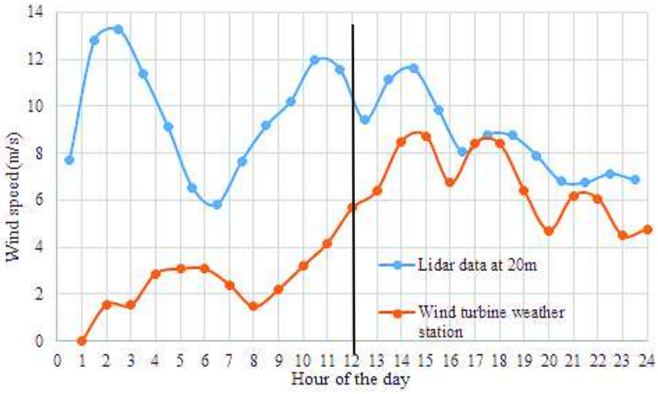

Figure 12: Wind speed comparison

However, the Lidar has no obstacles that modify its wind conditions at that direction and it comes out with different wind speeds.

3.1.9 Further analysis

This point resumes some recommendation in the case one would want to analyze deeper in this topic about the wind flow analysis and how the surroundings affect the wind turbine or even where to deploy exactly the wind turbine in order to maximize the wind in that point.

The first step would be to take more data from the weather station next to the wind turbine. This data should be big enough to have recorded winds in all directions and different speeds in each direction. It would take special interest to compare them to the information from the Lidar.

Then, the Lidar measurements at 50 meter height should be taken as the 'real' wind. So any deviation from this wind should be analyze.

One way to improve this study is to add more weather station to measure direction and wind speed in other points. These stations should be in strategic points.

After recording all the data, a pattern of this flow could be created.

3.2 Wind turbine test

3.2.1 Power performance

According to the wind turbine brochure [8] of the wind turbine, the Power Output vs Wind Speed plot should be like the Figure 10. However, after recording all the data of the wind turbine installed at the roof and comparing it with the wind speed also recorded, the power performance differs slightly. The Figure 11 shows the sample taken during 2 weeks in the month of april, so no high wind speed take place. The data recorded and analyzed matches with the one taken from the Lidar. It indicates that the instruments have small errors.

Additionally, the wind speed measured by the weather station and the air density given by the ZephIR Lidar 300 give the power contained in the wind according to the formula (3). Because the air density is function on air pressure (which means height) and temperature, it changes constantly. Although I consider it constant along one day because of its small changes (< 2%) along the same day. The Figure 12 shows the data from the power generated by the wind turbine and the power that should generate according to the specifications given by the company.

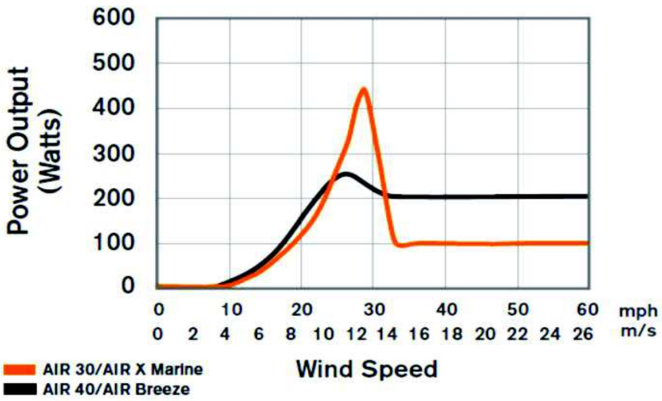

Figure 13: Power performance

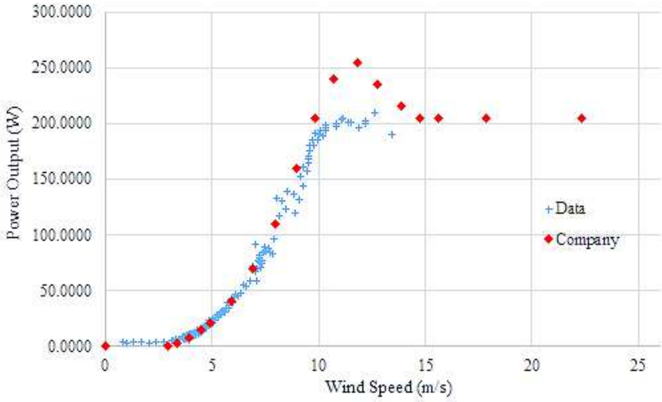

Figure 14: (Power output vs wind speed) Wind power and generated power

It matches perfectly up to speeds around 9 m/s where the wind turbine does not give as much power as it should.

The most efficient points are the one contained in the curve supplied by the company. The wind turbine data recorded follows this most efficient curve by changing the load of the generator up to 200W, when it is not possible to get more power by adjusting the generator load. This is why the maximum power generated by the wind turbine during the test is not as high as the one supplied by the company data. It is owing to the different air density in each case. The test performed by the company is one of the best possible scenes, and the density is high to maximize the power output. Contrary, during the recorded test, the temperature was around 15 ºC, which does not favors a high density. It is also important to remember that the height of the deployed turbine is 75 meter above the sea level approximately, and this is an important factor too. The test of the company correspond to the sea level to maximize the air density.

This comparison prove that not all the power contained in the wind is use to generate energy. It depends on many factors such as air density or wind speed among others. This is why a coefficient C_p is useful. The Figure 13 shows the evolution of C_p along different wind speeds. The maximum achievable power factor is 59.26 %, and its name is Betz limit.

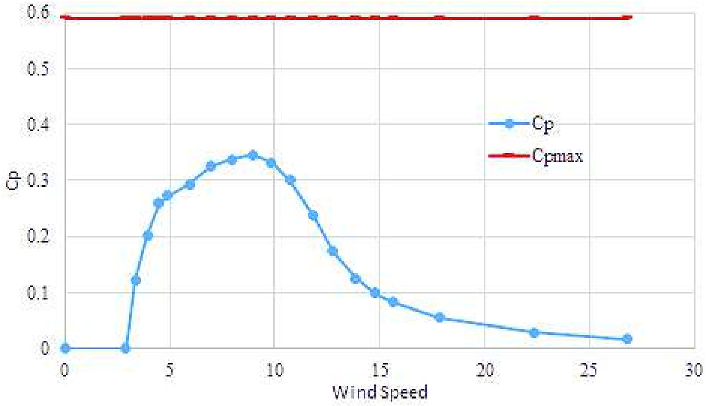

Figure 15: C_p vs Wind Speed

The maximum achievable in this case is 35 % at 8.95 m/s. The measurements include data of the power generated according to the company with an air density of 1.2466 Kg/m^3. This corresponds with a temperature of 10 ºC. Moreover, the power here compared is the electrical power output which include also the generator loses; the C_p comparing the mechanical power is higher but unknown.

3.2.2 Energy estimation

If we correlate the power output curve and the average wind obtained in Gløshaugen along the years, we get the following data:

Average wind speed (m/s)	Power at that wind speed (W)	Monthly Energy (kWh)
6.2	65	46.8

Table 3: Monthly energy generation

The average data is the one of the correlated data between the Lidar and the weather station at Voll for 6 years because it is the most precise data when referring to the university in general, not a roof in particular.

Which means that this wind turbine generates 562 kWh/year.

The annual energy consumption of Gløshaugen [8] in 2012 was 62,405,546 kWh. This means that this university needs around 11,000 wind turbines to be energy self-sufficient.

The cost of each wind turbine, without considering the batteries, is 800$. It gives a budget of 9 million dollars and its life is 20 years.

In Trondheim, the price of the electricity is around 0.26 NOK/kWh. It means that annually the university intend 2 million dollars to pay the electricity budget. The payback of the investment is 4.5 years.

IV. CONCLUSION

The data recollected reflects the wind conditions at the university; this study is useful, among other things, to know how this wind affects the buildings. The average wind speed is 6.2 m/s along the last 6 years with a main direction of 225º. This wind is stronger during the winter months and weaker during the summer, fact that is usual in Norway.

The wind turbine has a good efficiency and is able to give 250 W of power at 11 m/s wind speed. This makes this wind turbine very appropriate to deploy it and use it in the university, where the wind speeds are, during the winter, not much higher. This wind turbine will operate at a wind speed of 6.2 m/s given a power output of 50W. Of course, this is the average and the wind speed oscillates.

It is also important to mention that the power output data recorded is not as high as the one supplied by the company because of variations in height and temperature, which varies the air density and therefore the power output.

However, after calculating the chance of deploying small turbines (like the AIR 40); the study comes out with the conclusion that the university needs 11,000 wind turbines. This fact makes impossible to transform the university in self-sufficient with the only use of wind turbines because of the lack of enough area to install them.

Could be considered to build 5% of these wind turbines (500 approximately) and reduce the energy dependence.

If the goal is to be greener, it can work; but if the goal is to improve the efficiency and to save money, this is not a good solution. The payback is 4.5 years; but this is only without the batteries, which would increase this time up to 10 years.

The C_p of the air temperature is quite high (35%) compare with other turbines in the market. The power output also matches very well with the plot given by the company, which is important because it represents an efficient wind turbine.

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