UNIVERSITY
OF GÄVLE

DEPARTMENT OF TECHNOLOGY AND BUILT ENVIRONMENT

Case study wind turbine at Läkerol Arena

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PREFACE

Along this project we have received a lot of help and information from many people and we are thankful for the assistance they gave to us.

Firstly, we would like to thank Hans Wigo and Leif Claesson, who have been working and carrying out this project with us in the wind tunnel, and have given us the opportunity of working and learning in the wind tunnel.

In the same way, we would like to thank Mathias Cehlin for all the help, solutions and contacts we took from him.

Finally, thank to Mattias Gustafsson for giving us the opportunity of working for Gävle Energi, doing this interesting project.

ABSTRACT

The following study has for aim to check the possibility of install two wind turbines on the top of the roof of the Läkerol Arena situated in the city of Gävle, Sweden. For this, several data have to be measured in order to calculate the maximum output possible to get, the optimal point of the roof and the kind of turbine used.

The measurement of all these data has been processed in the wind tunnel of the University of Gävle. It permitted to pick up thirteen different positions on the roof of the Läkerol Arena model at the scale 1:200. The wind tunnel investigation has been done for thirteen points, at three different heights and for the eight directions of the wind rose; whether 312 positions. These measurements gave the velocity of the points and the turbulences.

The extrapolation of the wind data over Valbo provides site-specific estimates of wind speed and direction characteristics that has been used to predict the annual energy output for a proposed wind turbine. Different turbines have been tested to enable Gavle Energi Company to make a comparison.

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INTRODUCTION

As told previously, the aim of the thesis is to make the study of the installation of two wind turbines at the Läkerol Arena. The company Gävle Energi, responsible of the project, gave two wishes to respect. First, the turbines have to be installed in front of the building in order to be visible for the visitors of the Läkerol Arena. The second is the kind of turbine. In effect, a Vertical Axe Wind Turbine should be used.

Figure 1. Photomontage of the Läkerol Arena

The Läkerol Arena

The Läkerol Arena was build up in 1967 with the name *Gavlerinken,* then in 2005 the municipality of Gävle sold the arena to Brynäs IF witch rebuild it and sold the naming rights to Leak Candy Company, manufacturer of the Läkerol pastilles. Then the arena reopened the November 13, 2006. The drawings of the new building have been given by the manager during the visit of the place.

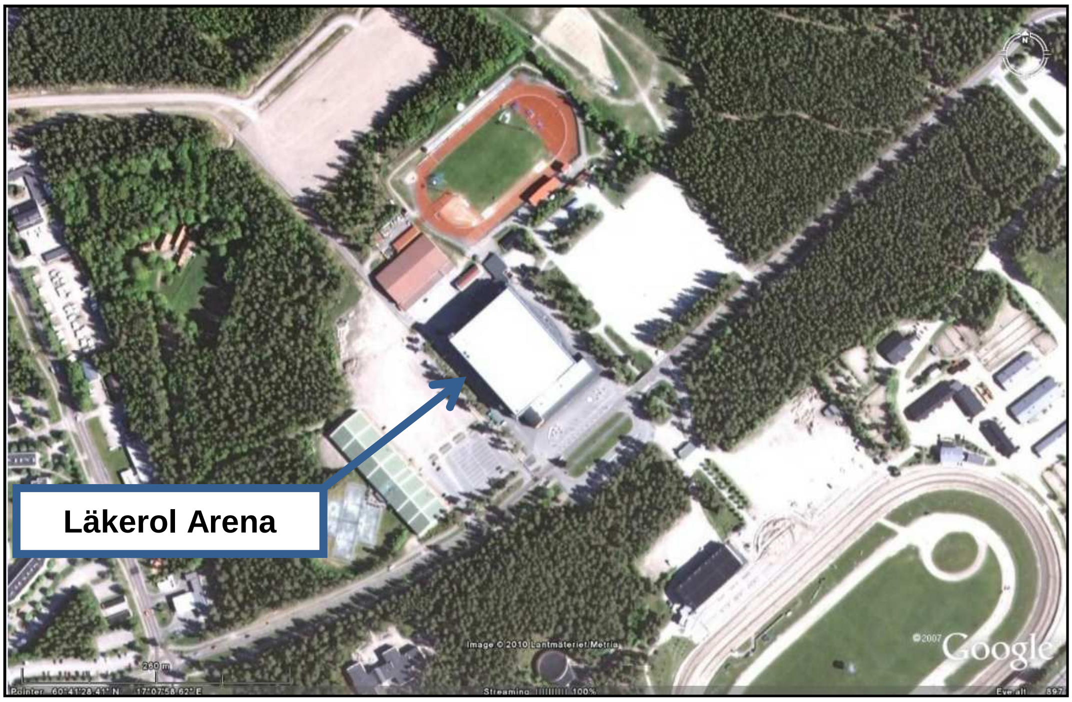


Figure 2. Satellite view of the Arena

Vertical Axis Wind Turbine (VAWT)

The following explanation about VAWT has been taken from the English website www.reuk.co.uk. This support is one of the examples of the British knowledge using in this report. Some other British studies can be found later in the process and result part. (Warwick Microwind Trial project).

Vertical Axis Wind Turbines are not as efficient as the more common Horizontal Axis Wind Turbines, but they do offer benefits in low wind situations. They also tend to be safer, easier to build, can be mounted close to the ground, and handles turbulence much better. The commonest VAWT is a Savonius VAWT which is an extended version of an anemometer (wind speed measuring tool). VAWTs can offer up to 30% efficiency and they work equally well no matter which direction the wind is coming from.

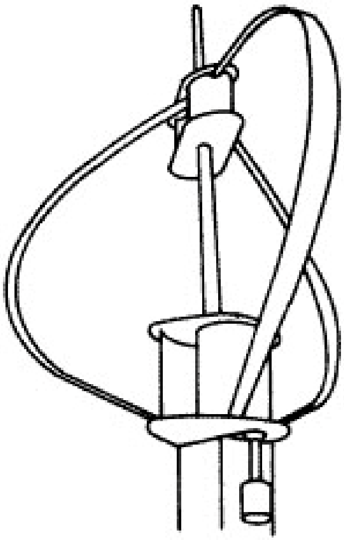


Figure 3. Darrieus wind turbine

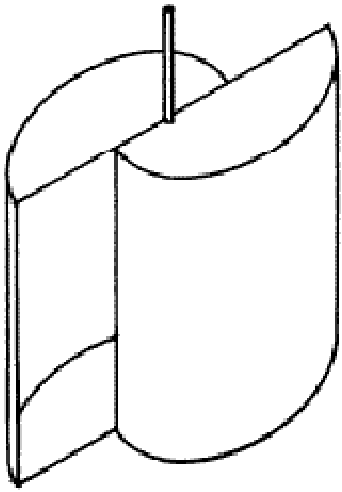


Figure 4. Savonius wind turbine

There are two main types of VAWT, the Darrieus which uses lift forces generated by aerofoils, and the Savonius which uses drag forces. A variant of the Darrieus type wind turbine is the Giromill.

Darrieus wind turbine

A Darrieus is a type of vertical axis wind turbine (VAWT) generator. Unlike the Savonius wind turbine, the Darrieus is a lift-type VAWT. Rather than collecting the wind in cupsdragging the turbine around, a Darrieus uses lift forces generated by the wind hitting aerofoils to create rotation.

Figure 5. Darrieus wind turbine

A Darrieus wind turbine can spin at many times the speed of the wind hitting it. Hence a Darrieus wind turbine generates less torque than a Savonius but it rotates much faster. This makes Darrieus wind turbines much better suited to electricity generation rather than water pumping and similar activities. The centrifugal forces generated by a Darrieus turbine are very large and act on the turbine blades which therefore have to be very strong - however the forces on the bearings and generator are usually lower than are the case with a Savonius.

Darrieus wind turbines are not self-starting. Therefore a small powered motor is required to start off the rotation, and then when it has enough speed the wind passing across the aerofoils starts to generate torque and the rotor is driven around by the wind. An alternative is shown in the illustration above. Two small Savonius rotors are mounted on the shaft of the Darrieus turbine to start rotation. These slow down the Darrieus turbine when it gets going however they make the whole device a lot simpler and easier to maintain.

Savonius wind turbine

A Savonius is a type of vertical axis wind turbine (VAWT) generator. The Savonius is a drag-type VAWT which operates in the same way as a cup anemometer (pictured next). Savonius wind turbines typically only have an efficiency of around 15% - i.e. just 15% of the wind energy hitting the rotor is turned into rotational mechanical energy. This is much less than can be achieved with a Darrieus wind turbine which uses lift rather than drag.

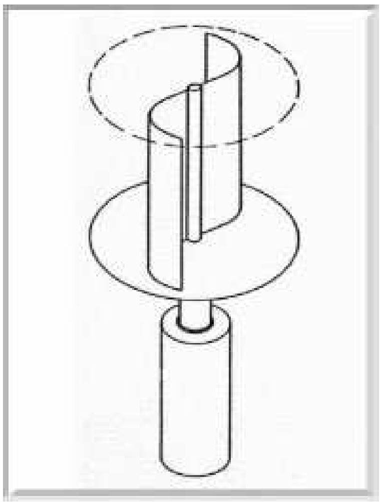


Figure 6. Savonius wind turbine

The speed of the cups of a cup anemometer (and a Savonius wind turbine) cannot rotate faster than the speed of the wind and so they have a tip speed ratio (TSR) of 1 or below. Therefore Savonius type vertical axis wind turbines turn slowly but generate a high torque.

This does not make them very suitable for electricity generation since turbine generators need to be turned at hundreds of RPM to generate high voltages and currents. A gearbox could be employed but the added resistance would leave the Savonius requiring a very strong wind to get spinning. It typically would not self-start.

Figure 7. A cup anemometer

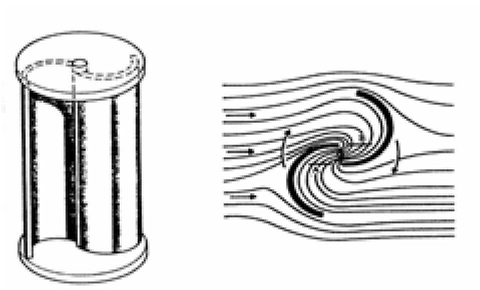


Figure 8. Savonius flow

Savonius wind turbines are ideally suited to applications such as pumping water and grinding grain for which slow rotation and high torque are essential. Because of the torque yield of a Savonius wind turbine, the bearings used must be very sturdy and may require servicing every couple of years.

UGE K4 by Green Urban Energy

Figure 9 UGE K4

The UGE 1k and 4 k are a new kind of Darrieus wind turbine. In February 2010, we received IEC certifications for our turbines' power performance, becoming one of the first manufacturers in the world to do so. Beyond that, UGE has also had third party test agencies independently confirm its turbines' safety, sound, and vibration levels.

Among the certifications already carried by UGE's turbines are:

- **Safety** Certifications (European Conformity (CE) and IEC 61400-2)
- **Power Performance** Certifications (IEC 61400-12)
- **Noise Level** Certifications (IEC 61400-11)
- **Vibration Level** Certifications (ISO-2631)

Physical	
Mill Dimensions	3m wide x 4.4m tall
Swept Area	8.8 m²
Tower height	7m standard, others available
Gross Weight	444 kg
System Information	
Brake System	Electronic over speed protection (MPPT)
Blades	
Blade Rated RPM	125 rpm
Blade Composition	Carbon fiber and fiberglass

Performance	
Cut-in wind speed	3.5 m/s (7.8 mph)
Cut-out wind speed	30 m/s (67 mph)
Rated wind speed	12 m/s
Max (survival) wind speed	50 m/s (110 mph)
Noise within 3 meters @ <7 m/s	39 dB
Noise within 3 meters @ 7-10 m/s	45 dB
Noise within 3 meters @ 10-13 m/s	50 dB
Generator	
Type	Permanent magnet
Temperature Range	-40C to 115C (-40F to 230F)
Drive System	Direct drive
Revolutions per minute (RPM)	125 rpm

Table 1. Characteristics of the UGE K4

Gavle Energi AB

Gävle Energi AB and its subsidiaries produce distribute and sell electricity, heating, cooling, telecommunications and data communications. The company is a wholly owned subsidiary of Gävle Stadshus AB, which is wholly owned by the Municipality of Gävle. The Group includes the parent company Gävle Energi AB, as well as the wholly owned subsidiaries Gävle Kraftvärme AB, Gävle Energisystem AB and AB Sätraåsen. The parent company also owns 59% of shares in Bionär Närvärme AB.

The Group's total receipts increased by 9% (11%) and amounted to SEK 1 003 (920) million. Bionär, Communications and Electricity Trading are the three areas that experienced the most significant sales growth. This growth is mainly attributable to Gävle Energi's growing market share, but is also a result of the town of Gävle increasing in size.

The Group has a key role in the development and production of renewable energy. The investment in biofuel power and heating in Johannes and the expansion of Bionär Närvärme AB are completely in line with the measures necessary to reduce climate impact. The planned cooperation further boost with Korsnäs AB in respect of a new biofuel based power and heating plant will provide further conditions for production of renewable energy. Work is in progress to build a new hydroelectric power station in Forsbacka to replace existing facilities.

Figure 10. Domestic installation

In another hand, Gävle Energi AB is trying to manage new kind of energy as the domestic wind power trough project as the one presented here. Only few domestic wind turbines have been installed on Swedish buildings. This sector of activity needs more attention, more researches and knowledge.

The aim of this thesis project has been to answer to the following questions:

- What is the design of the wind rose over Gävle?
- Comparing the wind rose for Gävle and the Läkerol arena, is the side of the main entrance the best place to install the wind turbines?
- How the wind is blowing around and above the building?
- How the corners and the edges of the building are affecting the wind conditions?
- Witch high of mast will permit to produce more energy?
- According to the British study, is the centre of the roof the best location?
- Witch place of the roof offers the best electricity production?
- How much electricity can be expected?
- Is it possible to find other more efficient turbines?

Theory

Wind profiles

The Logarithmic wind profile

Wind speed increases approximately logarithmically with height. The logarithmic wind profile is a semi-empirical relation used to illustrate the vertical distribution of a horizontal wind blowing.

It can be useful in the case of an extrapolation of wind data. It permits to know the velocity of the air flow at a height *z* (u_z) knowing the wind speed at specific height (u_*). Usually, the formula is used for the installation of wind turbines, in meteorology studies or for atmospheric pollution dispersion models. The equation is the following:

$$\mathrm{u(z)} = \frac{u(*)}{k}\left[\ln\left(\frac{z-d}{z0}\right) + \psi(z, z0, L)\right]$$

The term on the left-hand side of the equal sign is the wind speed relative to the surface speed as a function of height (z). The friction velocity (u_*) is the square-root of the kinematic stress, and k is the Von Karman's constant. The value of this constant is 0.41. The ψ term is the modification due to atmospheric stratification *(L)*. When the atmospheric stratification is neutral ($z/L = 0$), there is no stratification, and the stability term *(ψ)* is zero. The friction velocity (u_*) and roughness length (z_o) are functions of wind speed, atmospheric stratification, and sea state. *(d)* Represents the zero-plane displacement. It is the height where the wind speed becomes equal to zero. It is in general 2/3 of the average height of the roughness.

Wind profile power law

The wind profile power law or time averaged velocity profile is similar to the Logarithmic wind profile. The difference comes from the utilisation or not of the surrounding roughness. Both relations are coming from the fact the wind speed are increasing with the height.

As for the Logarithmic Win Profile, this mathematical formula is available for the surface layer of the atmospheric boundary layer. It has the same function but includes less precision. However it is really useful when some data are missing about the roughness area or the stability of the atmosphere *(ψ).*

The wind profile power law relationship is the following:

$$\frac{u(z)}{u(*)} = \left(\frac{z}{z*}\right)^{\propto} \Leftrightarrow u(z) = u(*) * \left(\frac{z}{z*}\right)^{\propto}$$

On this formula, the wind speed at a z height *u(z)*, given in meter per second, is the product of the known wind speed at a reference height *u(*)* and the ratio of the two height up to a coefficient *(α)*. This exponent is an empirically derived coefficient which varies with the roughness of the area. The different coefficients for the diverse roughness class are presented in the following table.

Roughness class	**slightly rough**	**moderately rough**	**rough**	**very rough**
Type of terrain	ice, snow, water	grassland/farmland	park/suburban area	forest/City area
coefficient *(α)*	0,08 - 0,12	0,12 - 0,18	0,18 - 0,24	0,24 - 0,40

Table 2. Coefficients alpha for the different roughness class

The wind tunnel investigation on model can permit to find out the alpha coefficient. Therefore, it is really important to have a good modelling of the roughness area.

Betz' Law

Assumptions

For the Betz' Law some assumptions are taken:

- The turbine doesn't have hub. As well it has infinite number or blades which have no drag.
- The flow is, axial for the horizontal-axis turbine, and perpendicular to the axe in a vertical-axis turbine.
- The control volume analysis must be follow conservation equation:

$$Flow_{in} = Flow_{out}$$

- The flow is no compressible, so the density stays constant.
- There is no heat transfer from the turbine to the flow, or from the flow to the turbine.

- For both, vertical-axis and horizontal-axis turbines, the area S in the calculations will be the swept area.

Betz' Law calculations

Next scheme, Betz' tube, shows how a flow is blowing through a horizontal axe turbine:

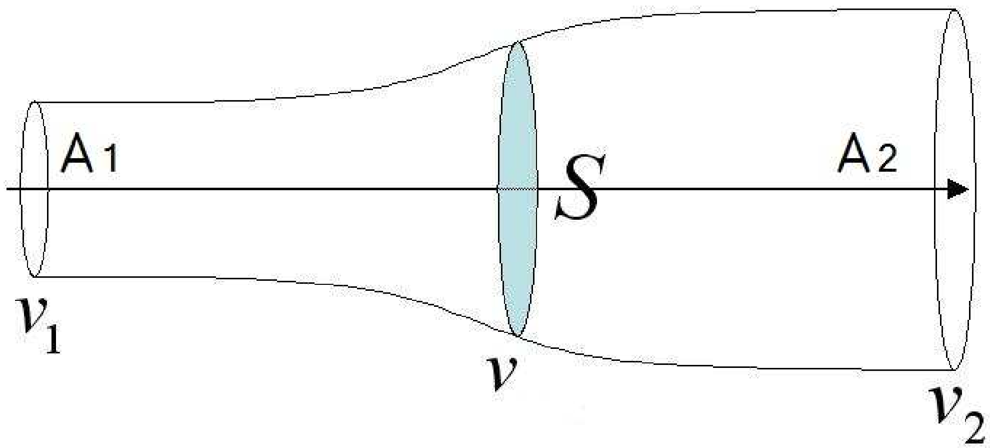


Figure 11. Betz' Law

Mass flow through the turbine:

$$\dot{m} = \frac{m}{t} = \rho \cdot A_1 \cdot v_1 = \rho \cdot S \cdot v = \rho \cdot A_2 \cdot v_2 \qquad (1)$$

Force done for the flow in the turbine:

$$F = m \cdot a = m \cdot \frac{dv}{dt} = \frac{m}{dt} dv = \dot{m} \cdot \Delta v = \rho \cdot S \cdot v \cdot (v_1 - v_2) \qquad (2)$$

Work done for the wind:

$$dE = F \cdot dx \quad (3)$$

Power content in the flow:

$$P = \frac{dE}{dt} = F \cdot \frac{dx}{dt} = F \cdot v$$

$$\xrightarrow{Including\ equation\ number\ (2):}$$

$$P = \rho \cdot S \cdot v \cdot (v_1 - v_2) \cdot v = \rho \cdot S \cdot v^2 \cdot (v_1 - v_2) \qquad (4)$$

Power applying the conservation of the energy equation:

$$P = \frac{\Delta E}{\Delta t} = \frac{1}{2} \cdot \dot{m} \cdot (v_1^2 - v_2^2) = \frac{1}{2} \cdot \rho \cdot S \cdot v \cdot (v_1^2 - v_2^2) \qquad (5)$$

$$\xrightarrow{(4)=(3)}$$

$$\frac{1}{2} \cdot \rho \cdot S \cdot v \cdot (v_1^2 - v_2^2) = \rho \cdot S \cdot v^2 \cdot (v_1 - v_2)$$

$$\frac{1}{2} \cdot (v_1^2 - v_2^2) = \frac{1}{2} \cdot (v_1 - v_2) \cdot (v_1 + v_2) = v \cdot (v_1 - v_2)$$

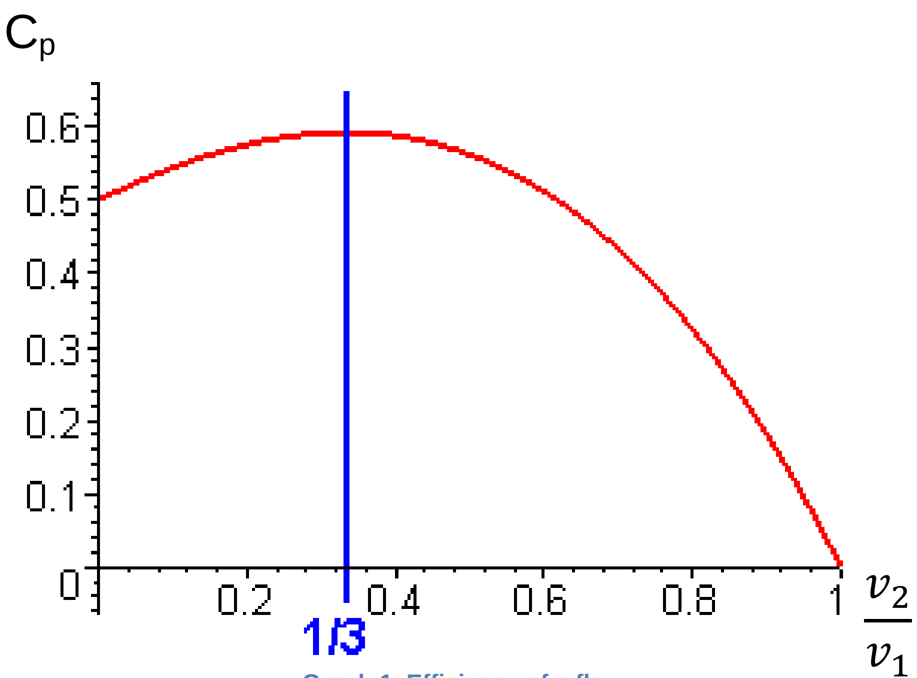
$$v = \frac{1}{2} \cdot (v_1 + v_2) \qquad (6)$$

Coming back to equation number (5):

$$P = \frac{1}{2} \cdot \rho \cdot S \cdot v \cdot (v_1^2 - v_2^2)$$

Including number (6):

$$P = \frac{1}{4} \cdot \rho \cdot S \cdot (v_1 + v_2) \cdot (v_1^2 - v_2^2) = \frac{1}{4} \cdot \rho \cdot S \cdot v_1^3 \cdot \left(1 - \left(\frac{v_2}{v_1}\right)^2 + \left(\frac{v_2}{v_1}\right) - \left(\frac{v_2}{v_1}\right)^3\right) \qquad (7)$$



Graph 1. Efficiency of a flow

Differentiating *P* respect $\frac{v_2}{v_1}$, taken *ρ*, *S* and v_1 as constants, gives the maximum value at $\frac{v_2}{v_1} = \frac{1}{3}$. Substituting this value in (7) gives:

$$P_{MAX} = \frac{16}{27} \cdot \frac{1}{2} \cdot \rho \cdot S \cdot v_1^3 \qquad (8)$$

Then, the power coefficient is defined as:

$$C_p = \frac{P}{P_{MAX}} = \frac{16}{27} = 0.593$$

Process and results

As the installation of domestic wind turbines is not developed in Sweden, the necessity of looking for some information was obligatory. Therefore the United Kingdom model has been looked through the Warwick Microwind Trial project.

Warwick Microwind Trial project

Introduction

Warwick Microwind Trial is a project, realized in United Kingdom, which studies the installation of different types of small turbines, from 5 manufacturers, along 30 different places.

Figure 12. Places of the Warwick Microwind Trial

In this project, a specific method (NOABL) was used predicting the wind speed. It is focused in the output prediction, but in the same way, there are publications about the human behaviour related with the wind mills, the better places to install them, the surrounding of his places and so on. Some recommendations can be applied and taken into account for Läkerol installation:

- Usually, the turbines power curves (output estimations) from the manufactures are optimistic and require significant justification and caution.

- Especially in small installations, the consumption of the turbine and its systems has to be taken into account.

- Wind flows more efficiently around a house in a urban area (the middle of the city, figure 14) than in a isolated building (in the middle the mountain, without forest, figure 13).

Figure 14. Urban installation in Pamplona

Figure 13. Installation in an insulated building

- Some results for Speed-up:

    - Pitched roof of isolated house causes wind speed-up. This speed-up is reduced when embedded in an urban area (depending on building spacing).

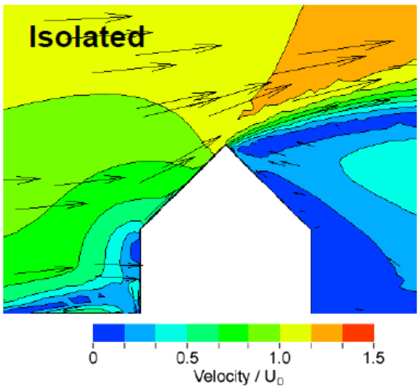


Figure 15. Isolated building

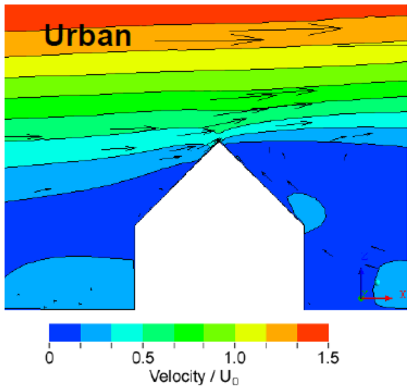


Figure 16. Urban building

- o When the wind is parallel to ridgeline, house shape is the most important factor.

- o When the wind is perpendicular to the ridgeline, building stagger dominates.

- o Influence of shape depends on wind direction; influence of stagger and spacing, and to a lesser extent, curvature of a street, do not.

- o Maximum wind speed at turbine:
  - ~0.5Umeanat 1.3 ×building height a.g.l.
  - ~0.3Umeanat building height a.g.l.

- When wind is blowing along ridgeline, maximum speed-up occurs at downstream end.

- Flatter roof buildings tend to give greater wind speed-up than pitched roof.

- Sitting on house critical must be above roofline.

- Onsite measurement campaigns urgently needed to validate predictions.

All these publications, data and information is gotten from the official website of Warwick Microwind Trial is a project: www.warwickwindtrials.org.uk

Wind tunnel investigation

The second part of the thesis was to simulate the wind blowing on the top of the roof of the arena. For this, the possibility to use the wind tunnel of the University of Gävle has been given. This one is situated on the Brynäs part of the city, behind the train station.

The National Swedish Institute

The National Swedish Institute for Building Research conducts a continuous sectorial programme. The Institute was established in 1960, although activities were carried out for a rather long time in other form previous to this date. The Institute moved to Gävle in 1976 as a result of regional development policy enacted by the Swedish Parliament.

The establishment was placed under the Ministry of Housing and Physical Planning. The Government appoints the Board and the Institute's Director. Financial support came mainly from the state, but the Institute also carried out certain commissioned research work. It was, with its 170 employees, the largest unit within Swedish Building Research. Despite this, the Institute received only 20 percent of the State's support for such research. The remaining 80 percent is distributed by the Swedish Council for Building Research in Stockholm to other specialized research institutes, institutions at universities and to independent scientist and consultants.

Since few years ago, the University of Gävle owned the building of the Institute, it permits the students to pursue research and thesis project in different domains.

The Institute's research activities are carried out in eight divisions. Living conditions and housing planning, Housing market and housing policy, Housing and settlement studies. Urban and regional research, Impact of policy instruments on building, Building materials and structures, Building climatology and installations and Energy conservation.

There is also a division for Measuring and computer services, a small unit for Economic research, an Administration and an Information division.

The wind tunnel laboratory is placed in the Building climatology and installations sector. In this sector, the interaction between climate, buildings, installations and the indoor environment are the main objects of the research. This includes both a technical approach to planning and to installations and behavioural research on human reaction to the physical environment.

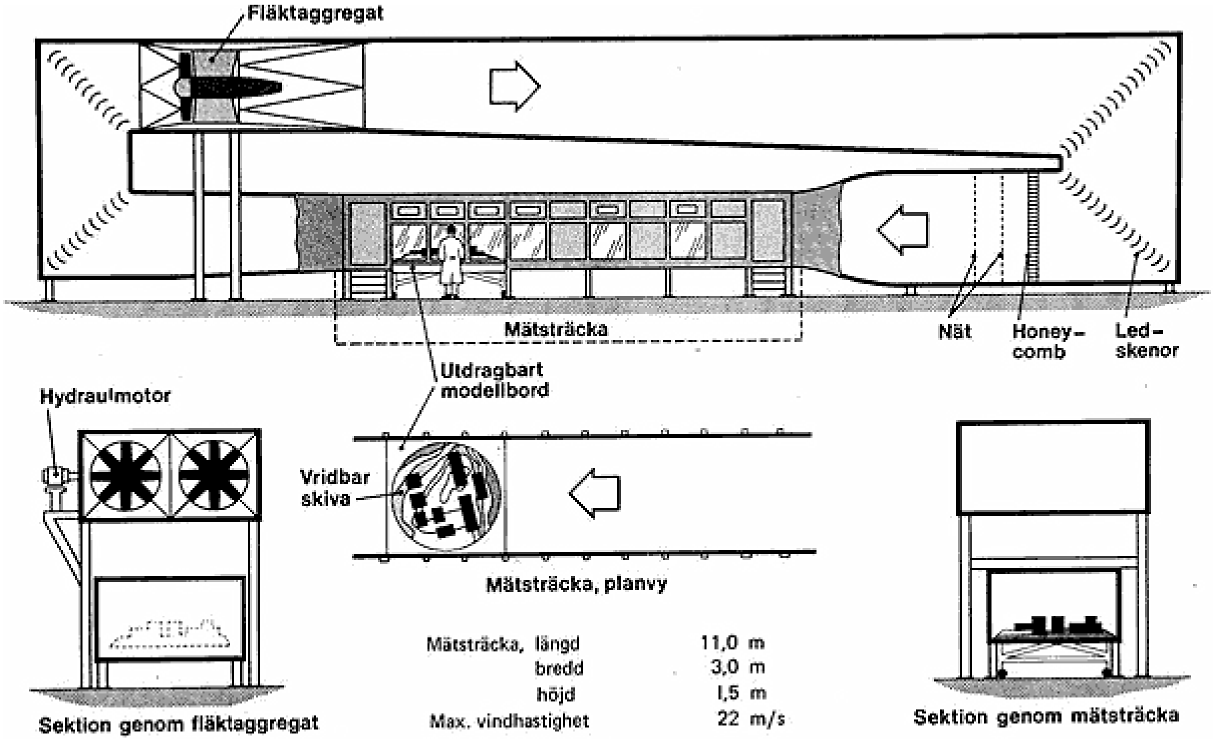


Figure 17. Wind tunnel scheme

The wind tunnel was completed in 1979, it has a cross-section area of 3*1.5m^2, a maximum wind speed of 22 m/s provided by two 1.5 meter-diameter axial-flows fan and a motor power of 45 KW. It is designed for model studies of wind effects on buildings and wind conditions in built-up areas. It is also used for wind loads, wind-induced air infiltration, air flows around the building and dispersion of air pollutants in the immediate vicinity of a chimney or motorway. The model scale usually lies between 1:50 and 1:500.

Figure 18. Wind tunnel turbine

Construction of the model

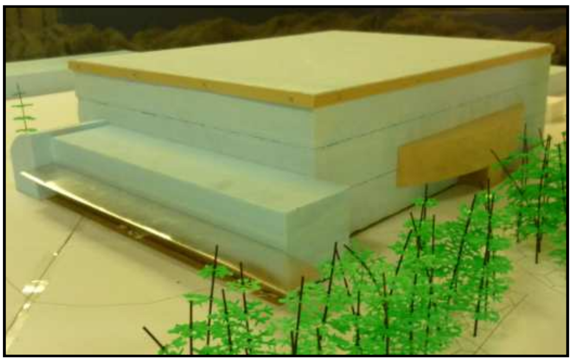


Figure 19. Model of Läkerol Arena

To be able to use the wind tunnel, we had to build up a model of the Läkerol Arena and of the roughness area as well. The considered area around the building is given by the scale using for the building. After some meetings with Hans and Leif, it was decided to take a scale of 1:200 for the model. It means that the dimensions of the building, before 98m*76m*28m became

490mm*380mm*140mm for the model. This model has been build up by a model carpenter in different material. The main corps is making of blue polystyrene the sides and the lights are made of wood and the first roof, above the hall is making with a piece of steel.

This model will be located in the middle of a 2.8m diameter wood circle. This means that the roughness area around the Läkerol must have a diameter of 560 m. To complete this zone it was used the software Google Earth. A satellite view of the Läkerol Arena was taken, showing the different part of roughness (forest, parking, and stadium). It was also possible to appreciate the ground level in the city of Gävle.

Figure 20. Google Earth

After having determined an image of the Läkerol arena and its roughness zone, the software AutoCAD was apply to drawn a circle with the appropriate scale. Then it was easy to draw the different zones of roughness and the different highs of the ground.

Once, the two data were put in common, it was printed using the new plotter of the University. This one is able to print on the A0 format. However, it was needed to print the whole model (model together with roughness area). Then it was decided to separate the circle into 11 different PDF files.

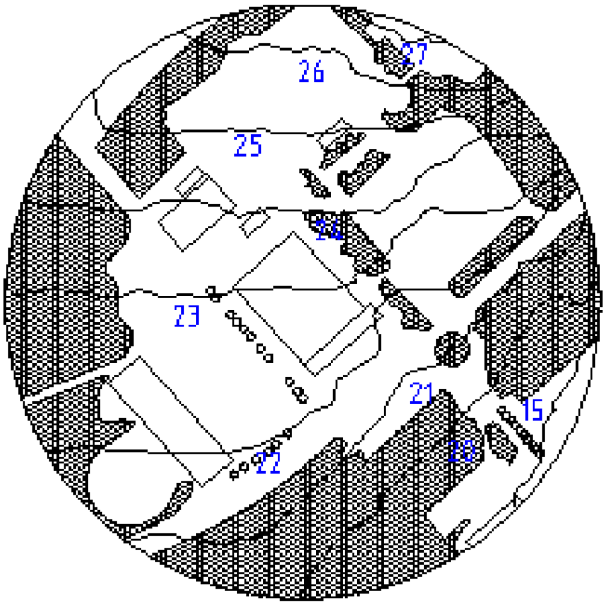


Figure 21. Ground level map

The next work was to take the wood circle support and to put together the eleven part of the drawing. Once this done, it was able to build the model up on it. The trees around the arena were modelling by small plastic trees and the small forest area as well; whereas the larger forests were modelling with steel wool. This permits to give the appropriate size of the trees. In effect, the ground level was respected, giving different size of trees.

As you can see in the following image, the ground level is from 18 meters to 27 meters. It is a total difference of 9 meters, which represents 4.5 centimetres of the model. It means that when the ground level is one meter higher, the size of the trees is increased in 0.5 centimetres.

Simulation

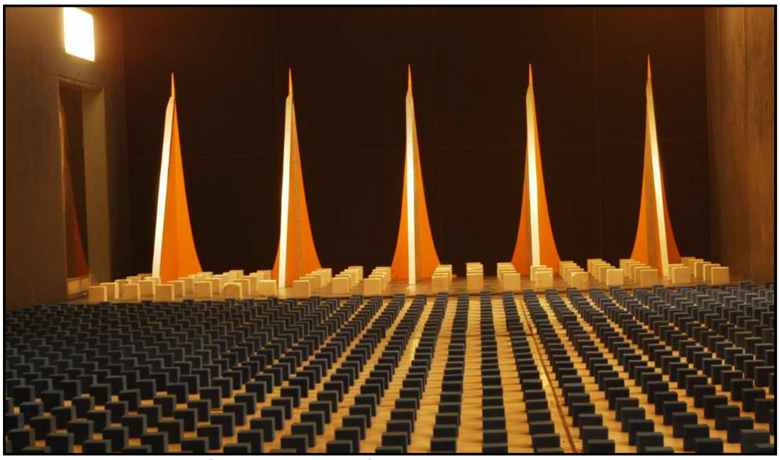


Figure 22. roughness area

In the same time, there were several cubes and fins in the front part of the wind tunnel to simulate an area larger around the Läkerol Arena. Noticeably the arena is not situated into the city, however the surrounding is not just making of parking, stadium and the sea. Many houses and buildings can be found as well, for instance, there is the Sätra neighbourhood. The installation of this roughness part in the front part of the wind tunnel will change the wind profile. It will permit us to have a wind profile coefficient (α) closer to the reality. The calculation of this one will be establish later.

Figure 23. View of wind tunnel

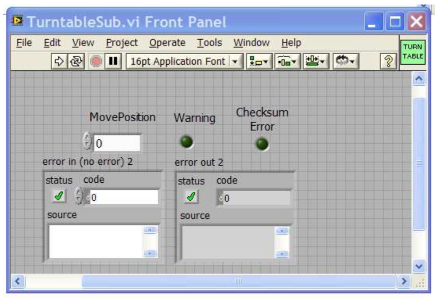


Figure 24. Control panel to turning the model.

Then the model has been placed on a platform into the wind tunnel. This one being able to move according to a vertical axe, which permit to set the top of our wood support at the same level than the floor of the wind tunnel. The possibility to rotate the platform allowed the change of the direction of the model in default of being able to change the direction of the blowing wind. Thus, it was able to measure some points in different part of the roof of the arena.

In the previous screen-print is presented the software used to turn the platform of the model. It was, in a first time, necessary to set a zero position. The north has been chosen to set this zero. Then, the turntable worked with the following coordinate.

Direction	N	NE	E	SE	S	SW	W	NW
Angle (°)	0	45	90	135	180 or -180	-135	-90	-45

Table 3. Table of the coordinate

As told previously, Mattias Gustafsson and the company Gävle Energi had a defined idea about the placement of the two vertical wind turbines. It has been set since the beginning that the turbines would be situated in front of the building in order to be visible by the population of Gävle and the visitors of hockey match. In another hand, measurement in many different points was defined. These measurements could let appreciate the best position for installing the turbine.

Therefore, 13 different points in the top of the model have been chosen; representing 13 different possibilities to install a wind turbine. Thus even if an idea where the turbines will be placed was already set. We can observe the position of these points in the following picture.

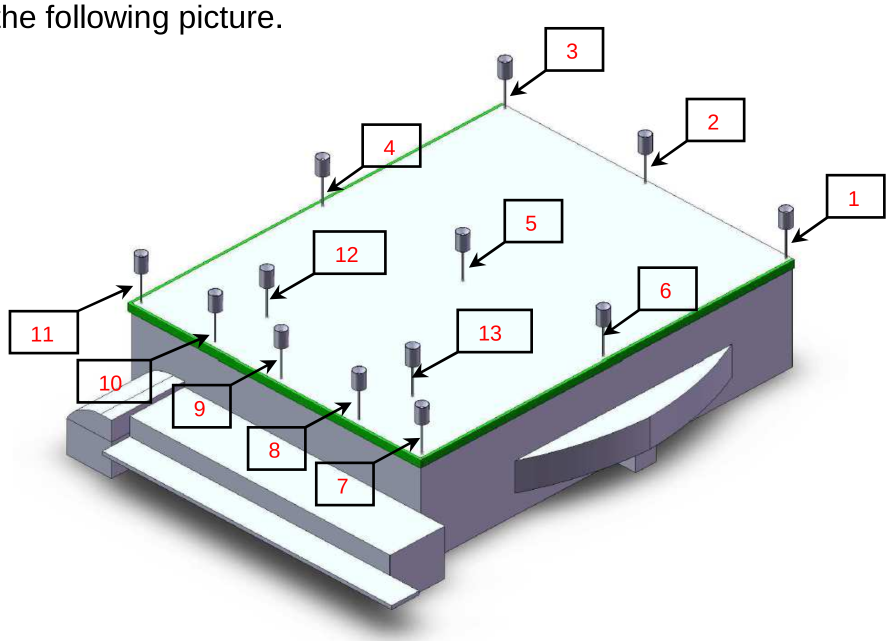


Figure 25. The model of the Arena with the 13 points

First, it can be seen see that more measurements have been taken in front of the building for the reason told before. Then, one point in the middle of the roof has been placed to confirm or refute the theory seen in the Warwick Wind Trials document. It was also placed four others points in the border of the roof. Two in the back and two in the middle axe. Finally, the points 12 and 13 have been measuring after all the other points. It is the result of a meeting with the teacher and engineer Kjell Westberg.

More data about the fixation can be found later, in the part "installation of the turbine".

Measurements

For all these points, three different measurements at three different heights have been taken. It is necessary to precise one thing; if the exact wind speed in the middle of the wind turbine is desired, the half of the height of the turbine's rotor has to be added to know the measurement height. It can be seen on the figure 25 than the rotor of the turbine has a height of 5 meters. So, it had to add around 2.5 meters. Therefore, the height of the measurement will be the following.

The first at 35mm above the roof of the model which stand for a mast of 5 meters; the second at 45 mm above the roof which represent a mast of 7 meters.

Finally, one last height at 55 mm above the roof which represent a mast of 9 meters as showed on the figure 25.

It had also to be taken measurements for the eight different orientations. So 13 points * 3 different heights * 8 directions = 312 measurements.

These measurements have been taken with 300 rotations per minutes, which match with a velocity of 8.13 meters per second or around 30 kilometres per hour.

The software created by one person of the wind tunnel building, permitted us to have three different data.

The first and more important is the velocity of the wind in meter per second; the second is the turbulences in meter per second and the third in the relative turbulences in percentage.

All these information has been stored in an excel file which permit to treated them later. All the measurements were taken with the same process.

A hot wire has been used, working on a vertical axe.

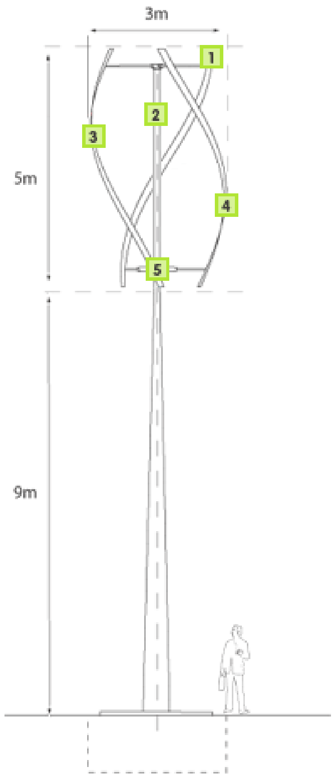


Figure 26. Scheme of the turbine

The hot wire anemometer

The hot wire anemometers use a very fine wire on the order of several micrometers; electrically heated up to some temperature above the ambient. Air flowing past the wire has a cooling effect on the wire.

The electrical resistance of most metals is dependent upon the temperature of the metal, thus a relationship can be obtained between the resistance of the wire and the flow velocity. The voltage output from these anemometers is thus the result of some sort of circuit within the device trying to maintain the specific variable (current, voltage or temperature) constant.

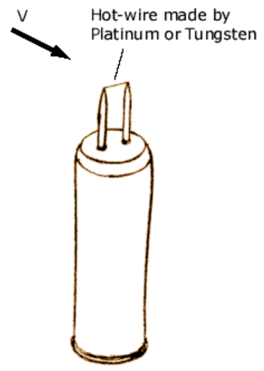


Figure 27 Scheme of the hot wire

The Hot Wire Anemometer is one of the most famous thermal anemometers. It can measure the velocity of several fluids. The extremity of this one is really sensitive and delicate. It is most often composed of Platinum or Tungsten. This subtle part of the sensor permits an extremely high frequency response.

The core of the anemometer is an exposed hot wire either heated up by a constant current or maintained at a constant temperature. In either case, the heat lost to fluid convection is a function of the fluid velocity.

The Hot-Wire schema and its support are bellow.

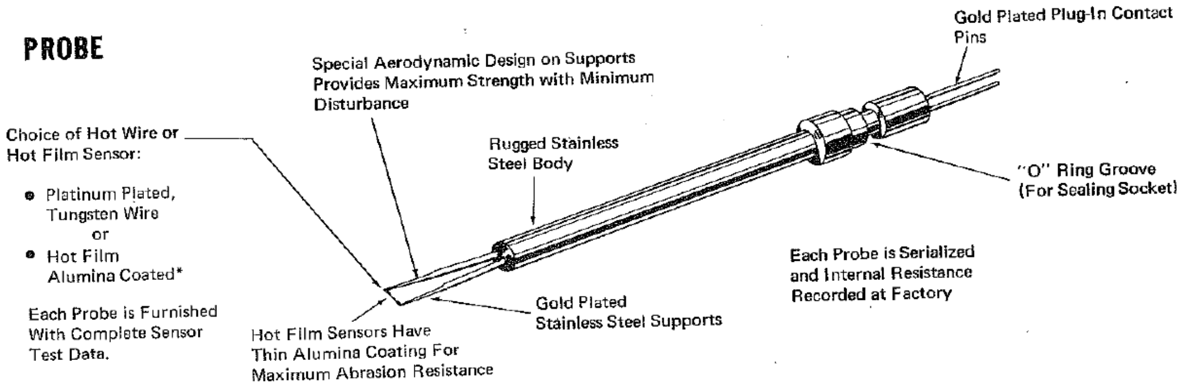


Figure 28. Hot wire description

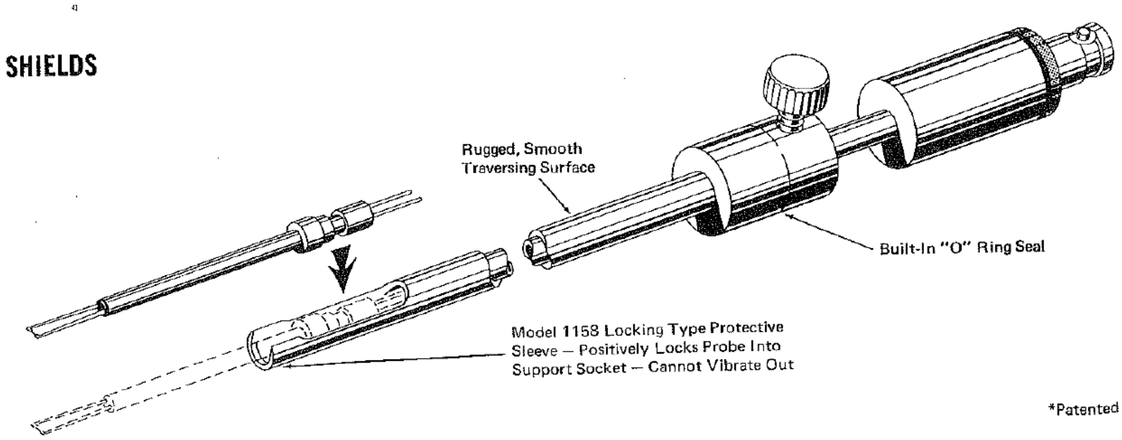


Figure 29. Scheme of the hot wire holder

Typically, the anemometer wire is made of platinum or tungsten and is 4 to 10 µm in diameter and 1 mm in length.

Process of measurement

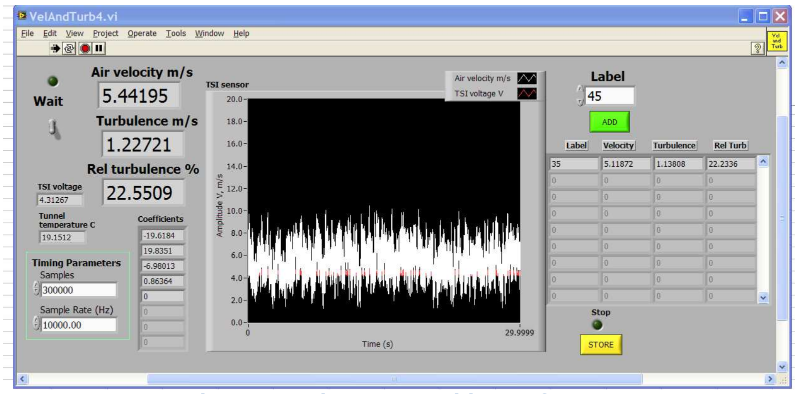


Figure 30. The zero position software

A fictive zero position has been fixed at a distance of 35 mm above the roof of the model. Then trough the SetPostE2 software we moved the position of the hot wire 10 mm up to get the measurement at 45 mm and 20 mm to get the 55 mm measurement.

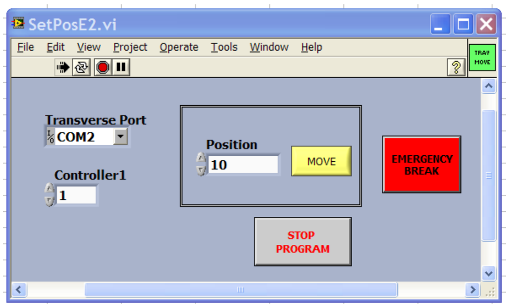


Figure 31. SetPostE2 software

All the treatment and the tables of the measurements can be observed in the next part and in the Appendix A.

Modelling 3D

A three dimensions model of the Läkerol Arena via SOLIDWORKS has permitted to appreciate better results of the wind tunnel. It is presented into eight pages in the Appendix B.

Figure 32. SolidWorks

Each document represents one orientation; the 3D arena model is turned in the good direction to understand better the graph approached. One shows the wind speed for the three different heights for the 13 points. The other let see the turbulences for the same points.

13 wind turbines have been placed on the top of the model with a reference number. It permits to appreciate the different curves and to see the dimensions of the turbine compared to the building. In the left bottom of the page it is also possible to perceive the wind rose of Gävle.

The following example shows the Läkerol Arena with the 13 positions of measurements. The wind turbines as the model have been modelling with SolidWorks.

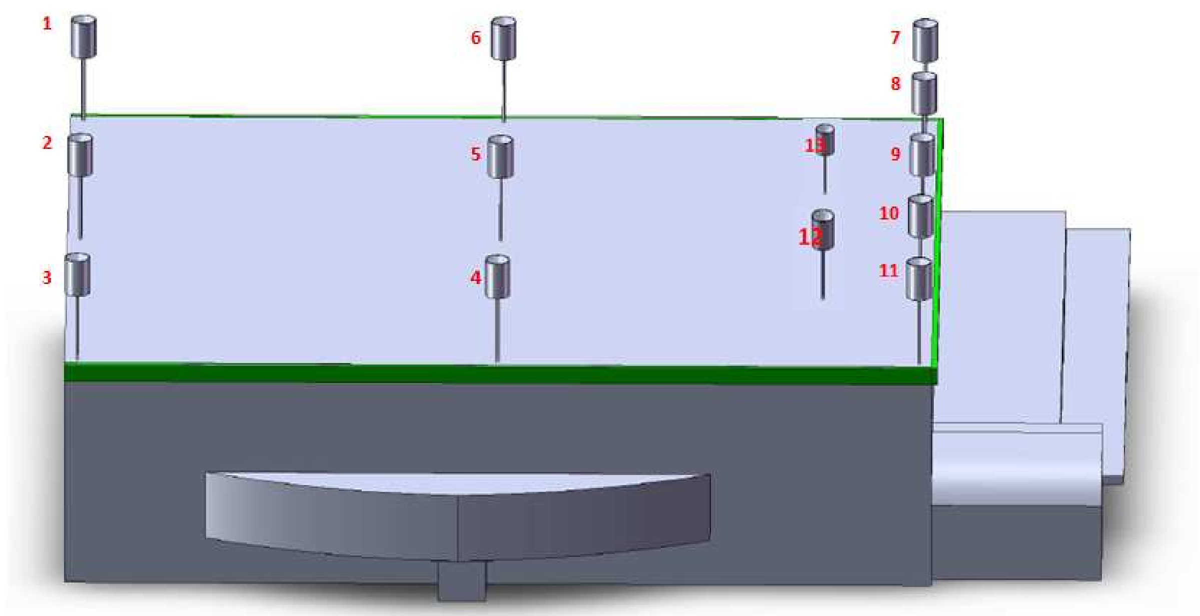


Figure 33. Model of the Läkerol Arena

The wind is blowing from the South West. This face of the building is on the side of the car park. The wind rose illustrates that the wind comes more than 24 % of the time in this direction. As it can be seen, it is the most important direction. So the results will have an important impact on the final outcome.

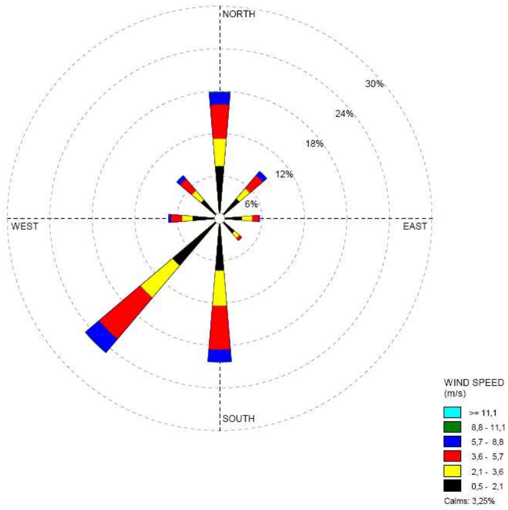
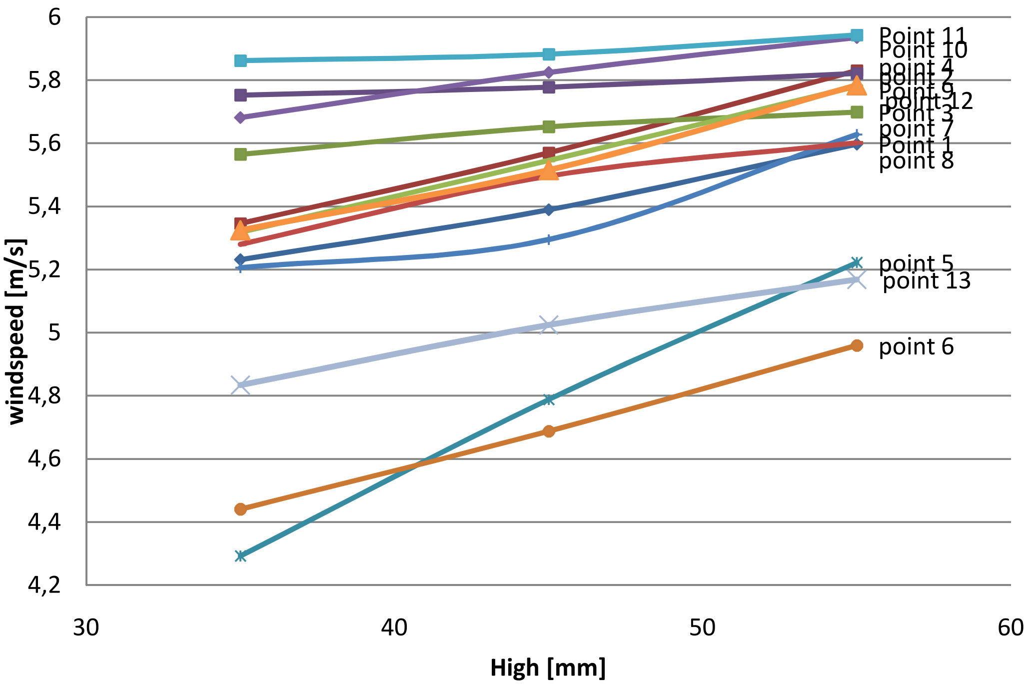


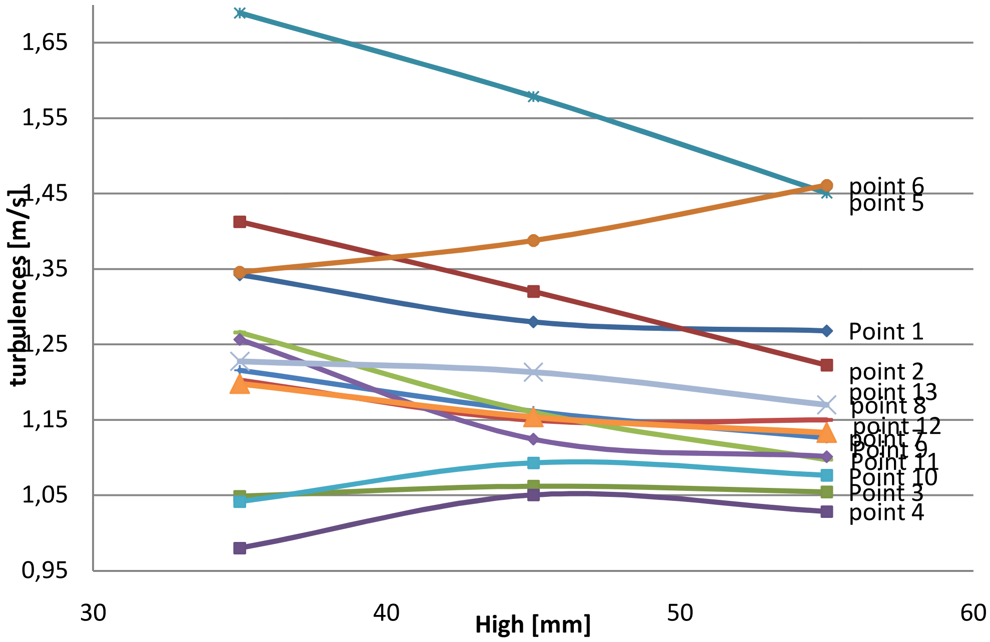
Figure 34. Wind rose of Gävle

This first graph shows the wind speed (m/s) in function of the height of the measurement above the model of the Läkerol Arena. Let us remain than the three different heights above the model are 35mm, 45mm and 55mm, what correspond to a mast of 7m, 9m and 11m. The first comment is that the higher the mast is, the faster the wind will blow. This confirmed the Logarithmic velocity profile enounced in the theory part.



Graph 2. Wind speed at the South West direction

The second graph shows the turbulences (m/s) in function of the same height of measurement. It is really interesting to compare the both graphs.



Graph 3. Turbulences on the South West direction

It can be observed that when the turbulences are high, the wind speed is low. On this example it is possible to see that with the turbines number 6 and 5. On the other hand, the turbulences of these two points are high because of the shape of the building. We can find the same configuration on the other face of the building when the wind is blowing perpendicularly. A further explanation of the influence of the building on the wind speed will be found later in the report, in the discussion part.

Wind data investigation

Once the simulation over and all the measurements done, it was necessary to know how fast and from where the wind is blowing in Gävle. This data will permit to know how much energy could be gotten with the Urban Green Energy turbine on the top of the roof of the Läkerol Arena.

The wind rose

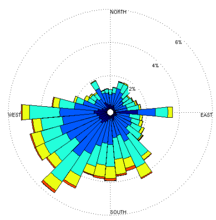


Figure 35. Wind rose

The wind rose has been made via the freeware WRPLOT View given by the Lakes Environmental Company specialized in the air dispersion modelling software to consulting companies, industries, governmental agencies and academia. This freeware use only meteorological data with the format Scram or Samson.

Unfortunately these kinds of data are paying and difficult to find for Sweden. Another solution was to change an Excel file into a Samson one. For this an hourly data measurement of the wind speed and the direction into or around Gävle was needed.

Some data from the Swedish Meteorological Institute (SMHI) has been found. This Excel file represents the meteorological data of a virtual mast located in Valbo at 10 meters high above the ground for a period of more than six years.

However the freeware accepted only an Excel file with five years data, which represents around 44000 lines. So only the years 2003 to 2007 have been chosen. The Excel file needed to be fixed because some errors appeared.

The result under can be seen. There is the wind rose for Valbo, at 10 meter high during the year 2003 to 2007 for 36 directions.

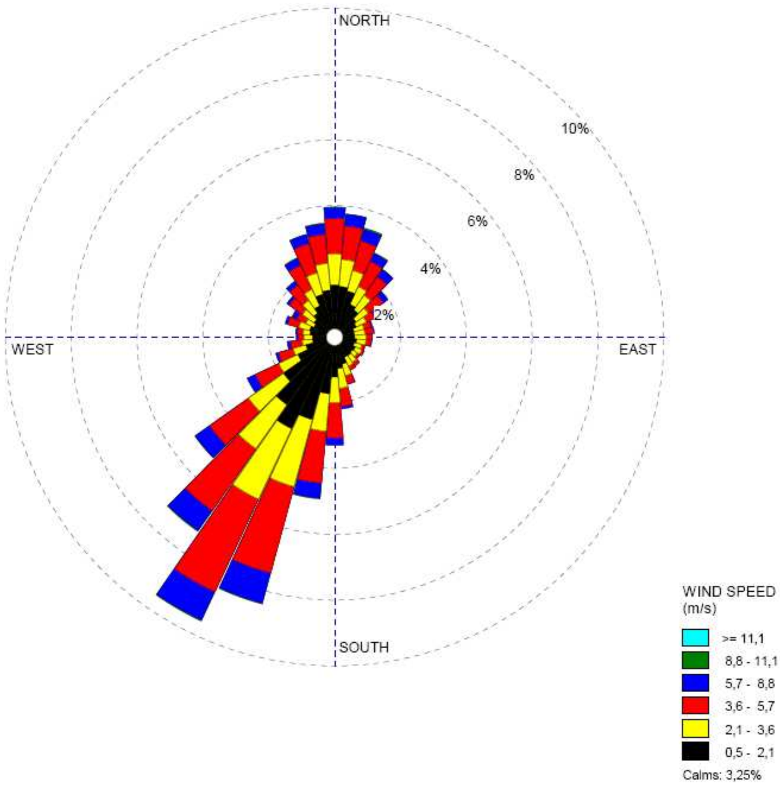


Figure 36. Wind rose of Valbo with 36 directions

Later, a wind rose presenting only the height well known directions (N/NW/W/SW/S/SE/E/NE) has been used. This permits to compare the data from the wind tunnel with the wind data.

All the wind rose per year can be find in the Appendix C.

The extrapolation

Then an extrapolation of these five years data was needed. Effectively, it can easily be assumed than the data from Valbo are suitable for Gävle because the Läkerol Arena is situated approximately at five kilometres from Valbo. Moreover the data has been calculated by a meteorological simulation, which has a bit less precision than a real manometer.

The data of the SMHI has been calculated trough a virtual mast placed at Valbo. It is an automatic station data which work with satellite and radar imagery. The best estimation of a meteorological parameter is given by combining all available observations of that variable in an analysis. The analysis is made on a grid where every value represents the mean for a grid square. In that process the quality and the representatively of each observation is taken into account.

That means that an observation at a large distance from the square will have less influence on the value than an observation close to it. However, no one other data were available

Nevertheless, the virtual mast was situated at ten meters high. The Läkerol arena plus the mast and the half of the high of the turbine head leads to a high of 35 meter minimum. Therefore, three different extrapolations will be done; 35 meters high, 37 meters high and 39 meters high.

So the extrapolation does not change the direction or the repartition of the wind, it just increases its velocity with the height.

We can compare this second wind rose after extrapolation.

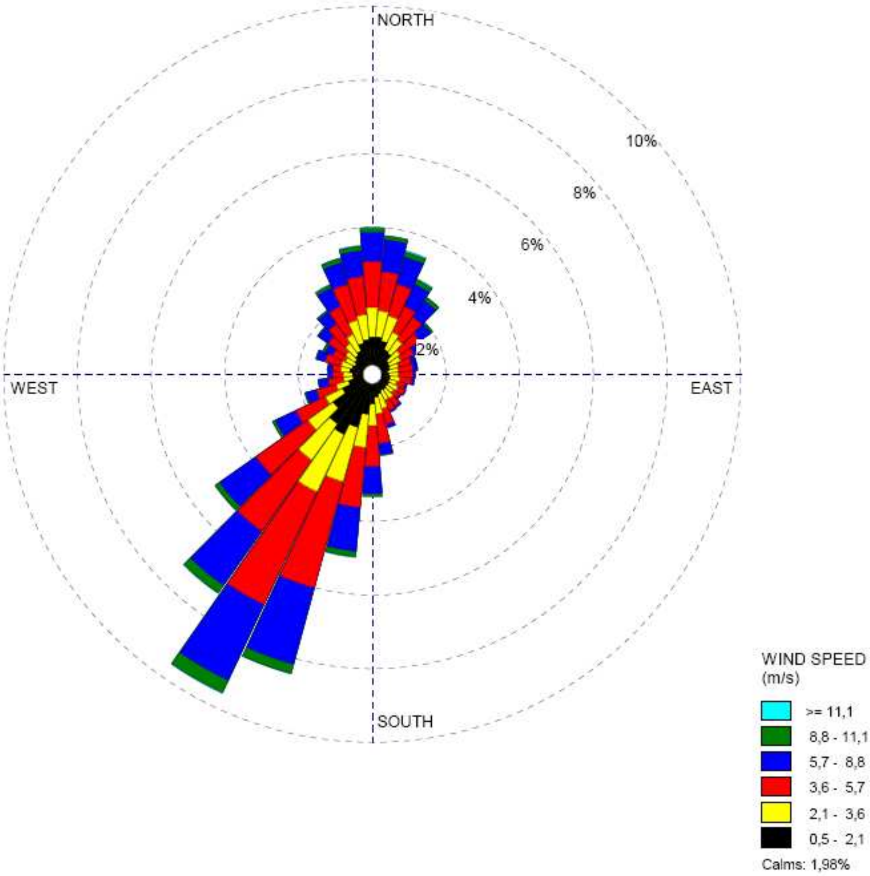


Figure 37. Wind rose after extrapolation

As observed, the wind speed after extrapolation is higher. The amount of calm is going from 2.25% to 1.98%; and the wind speed average from 2.98m/s to 3.90m/s.

Wind profile

As told in the theory part, the suitable formula to extrapolate a wind data to another height is the Logarithmic Wind Profile.

The problem in our case is the diversity of the roughness area. Approximately half of the surrounding of the building is flat and composed of car park, stadium or hippodrome. The other half is a quite high roughness composed more often of 15 meters high trees.

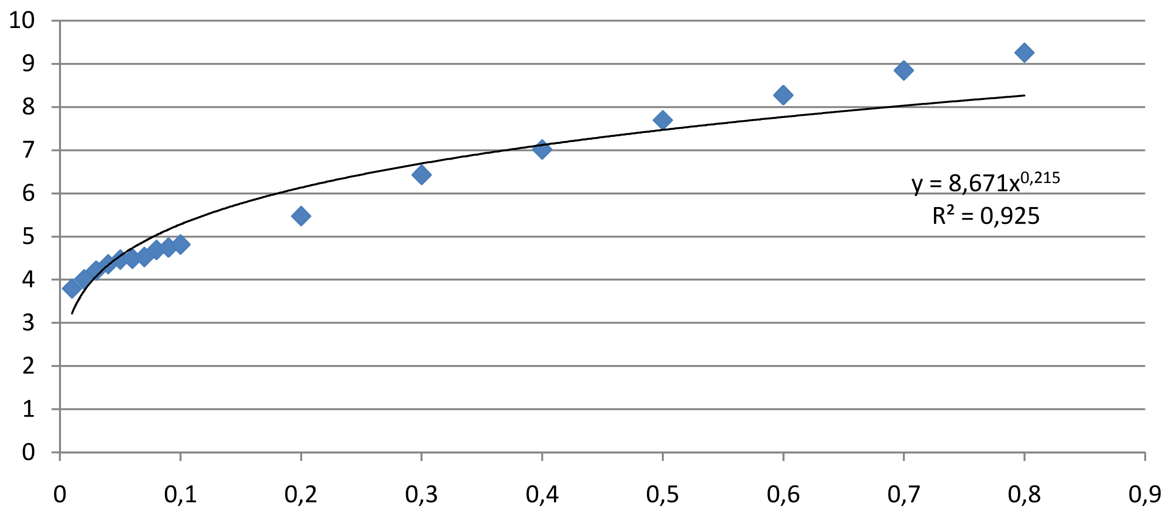
Moreover the existing wind data has been taken by a virtual mast at a height of 10 meters in Valbo. Thus, a variation of the ground level and a difference between the roughness are making the calculation really difficult. However, it is not impossible. The two options should be to install an anemometer in the top of the roof of the arena. This one would have to measure the velocity of the wind during one whole year. The second solution would be to ask a meteorological company as SMHI to ask the data of a virtual mast close to the

Figure 38. Anemometer

Läkerol Arena in Gävle. By default of time and money, the assumption than the roughness and the level of the ground between Valbo and Gävle are the same, can be done.

For our case, the wind profile exponent should varies between 0.2 and 0.4 because the Läkerol arena is situated is a really roughness area with forest surrounding. The wind profile chosen for our project is the following. This one has an alpha coefficient of 0.215.

As shown is the theory part, this alpha coefficient correspond to a rough area.



Graph 4. Wind profile into the wind tunnel

This coefficient has been done by Excel after taking measurements of the wind speed inside the wind tunnel without the model on the platform. Later Hans did these measurements again and confirm the good results of the work done.

The alpha coefficient permits to calculate the three coefficients needed for the extrapolation of the wind data at 3 different heights trough the following formula.

$$\mathrm{u(z)} = u(*) * \left(\frac{z}{z\,*}\right)^{\propto}$$

$$\mathrm{u(z)} = u(*) * \left(\frac{10}{35}\right)^{0.21}$$

$$\mathrm{u(z)} = u(*) * 1.30$$

The different hight coefficient and the wind speed average per high can be found in the following table.

High	Coefficient	Wind speed avarage
35m	1,3091	3,9011
37m	1,3248	3,9480
39m	1,3399	3,9930

Table 4. Hight Coefficients

These coefficients set a good extrapolation of the wind at the suitable heights. Later, these new data will permit and to compare the results and to get the maximum output point.

Maximum output point

In this part of the report, how the maximum output for each point in the roof of the Läkerol Arena is calculated, for the 3 highs established, as is explained previously.

To make it more clear, the next schema shows in a simple way the process.

Figure 39. General schema of the data treatment

Wind coefficients from the wind tunnel

To make useful the data taken in the wind tunnel coefficients were set using the next formula in Excel:

$$Coefficient\ of\ concentration = \frac{Wind\ Speed\ with\ the\ Model}{Wind\ Speed\ without\ the\ Model}$$

With this coefficient is possible to know if in the point analyzed, the wind is blowing faster or not that it would do in the same place, with the same height and without the model.

Wind speed with the model is gotten from the wind tunnel using the hot wire. There is one different wind speed for the 13 points, 3 different high and for the 8 different directions selected. It gives a table for each point. For example for point number 1:

North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	5.393	1.023	18.979	0.904
	45	5.422	0.995	18.352	0.899
	55	5.495	1.010	18.388	0.900
North-East					
	35	5.764	1.191	20.660	0.967
	45	5.783	1.133	19.594	0.958
	55	5.833	1.209	20.738	0.956
East					
	35	5.219	1.234	23.597	0.875
	45	5.312	1.157	21.780	0.880
	55	5.518	1.160	21.036	0.904
South-East					
	35	4.585	1.280	27.937	0.769
	45	4.650	1.263	27.161	0.770
	55	5.005	1.280	25.582	0.820
South					
	35	5.402	1.157	21.420	0.906
	45	5.528	1.107	20.025	0.916
	55	5.555	1.154	20.776	0.910
South-West					
	35	5.231	1.342	25.659	0.877
	45	5.389	1.279	23.750	0.893
	55	5.597	1.267	22.651	0.917
West					
	35	5.302	1.207	22.769	0.889
	45	5.436	1.232	22.67	0.901
	55	5.762	1.222	21.21	0.944
North-West					
	35	4.953	1.264	25.525	0.834
	45	5.029	1.280	25.447	0.833
	55	5.188	1.249	24.083	0.850

Table 5. Example for the point number one

Wind speed without roughness is gotten extrapolating the hourly wind information from Valbo to 35, 37 and 39 meters high in the Ice Hockey Building place as is explained in the previous headline "Extrapolated wind data from Valbo".

It is possible to find these coefficients in the Appendix D.

Data Treatment

During this part of the process, the Wind data table of the velocity in the Läkerol place is modified taking into account the factor of concentration.

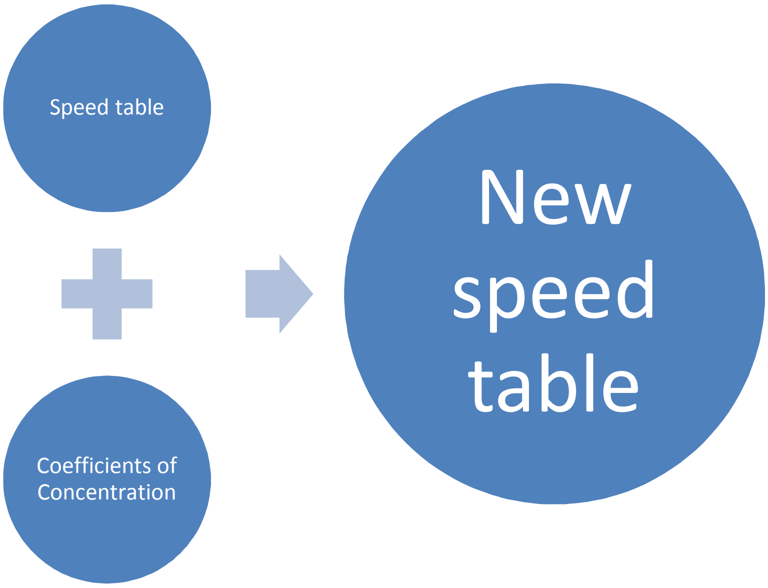


Figure 40. Scheme of the use of the concentration factor

It gives a new table with the same number of data, with a new speed values and with 13 columns (one per each point). The function used to modify the value is shown in the Appendix E and the new table is found in the file "Wind data 2003-2007 extrapolation".

A good example can be the next. This is for the point number 1 with a mast of 7 meters. In the figure 41, "wind speed" is one hourly datum from the in the file Wind data 2003-2007 extrapolation. This speed has associated a direction, like is show in the table 6. Then, the velocity will be multiplied for the corresponding factor of concentration gotten from the table (yellow background data) taking into account the cardinal direction.

An example here:

Wind Direction		Wind Velocity	Point 1
260	West	2	1.779
250	West	2	1.779
230	South_West	1.9	1.668

Table 6. Example the utilisation of the factor of concentration

For the first row:

Direction west → Coefficient= 0.889607883 → Wind speed for Point 1 = 1.779
2 x 0.889607883=1.779

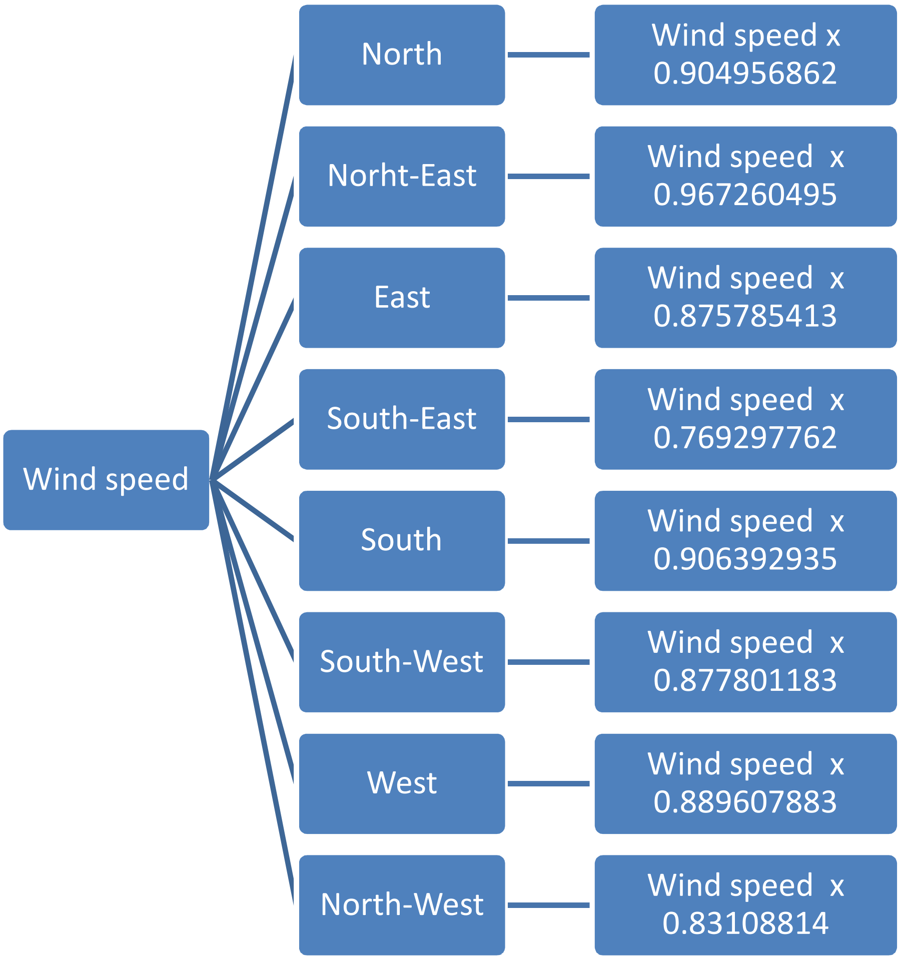


Figure 41. Example for the point number one

Output

To get the output of the turbine, the next schema was taken:

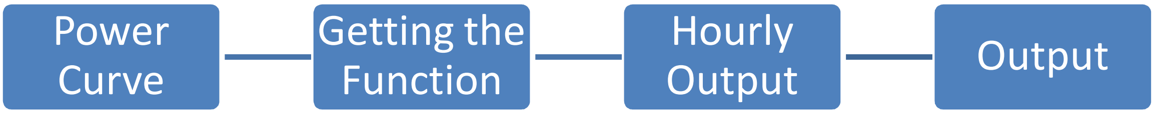
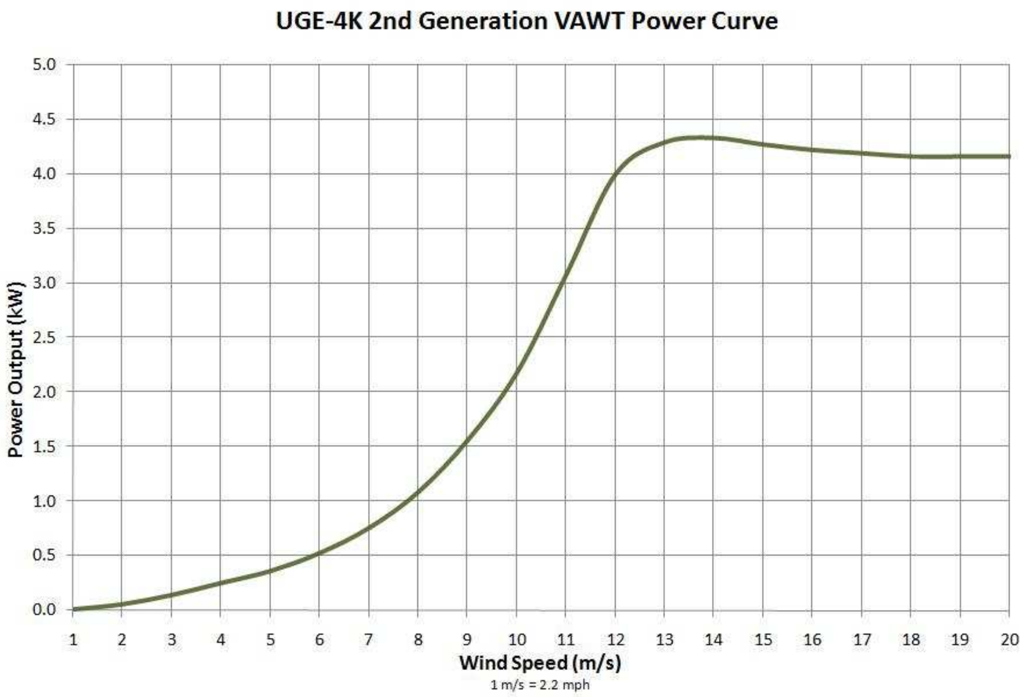


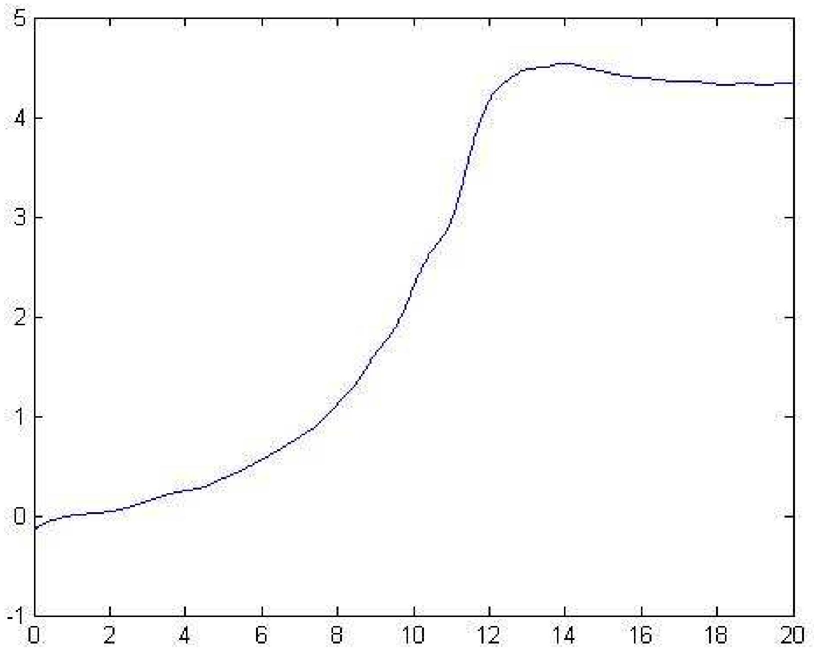
Figure 42. Scheme of the output process

As is written before, Urban Green Energy's UGE-4K turbine is the choice of Gävle Energi. From the website of the company (www.urbangreenenergy.com) , the power curve was gotten.



Graph 5. Power curve of the UGE 4K

To use the data of the new speed data table in the curve, it was necessary to get the function of the curve. To do it, the software MATLAB was chosen. All the algorithms needed to fit the function are written in the Appendix E. The graph obtained is the next one:



Graph 6. Curve obtained with Matlab

The graph is fit using the command "spline". Other methods were taken into account, like for instance "polyfit". Finally, the "spline" command was taken because, despite of looking a bit fragmented, and taken into account that the data was taken by hand, the possible error is assumable. This is set dividing the graph in 28 parts (each one defined by a polynomial function of third degree in a continuous way, even in the first and in the second derivate) and this is the reason because it looks irregular. The whole Matlab program can be found in the Appendix E.

Finally the total sum for the 5 years was done getting the total output for each position:

	7m	9m	11m
Point 1	10996	11486	12156
Point 2	11086	11917	12820
Point 3	11907	12458	12928
Point 4	11482	11955	12391
Point 5	9103,9	10298	11412
Point 6	9549,1	10194	11001
Point 7	11115	10827	11752
Point 8	9832,3	10899	11607
Point 9	9748,4	10538	11574
Point 10	10436	11090	12066
Point 11	11104	11564	12164
Point 12	13113	14175	15299
Point 13	11926	13028	13964

Table 7. Five years output in kWh

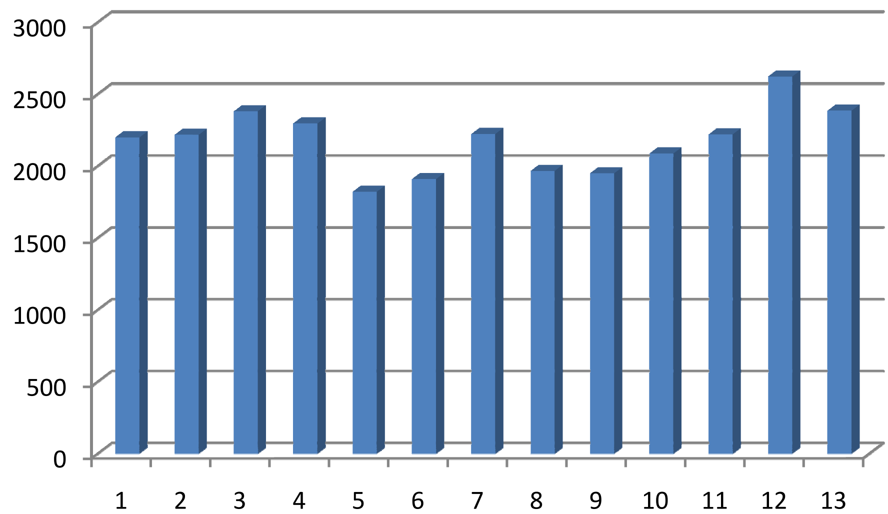
The average per year is given in the next table, in red the highest values for each mast high, and in blue, the lowest ones:

	7m	9m	11m
Point 1	2199.2	2297.2	2431.2
Point 2	2217.2	2383.4	2564
Point 3	2381.4	2491.6	2585.6
Point 4	2296.4	2391	2478.2
Point 5	1820.78	2059.6	2282.4
Point 6	1909.82	2038.8	2200.2
Point 7	2223	2165.4	2350.4
Point 8	1966.46	2179.8	2321.4
Point 9	1949.68	2107.6	2314.8
Point 10	2087.2	2218	2413.2
Point 11	2220.8	2312.8	2432.8
Point 12	2622.6	2835	3059.8
Point 13	2385.2	2605.6	2792.8

Table 8. Energy per year in kWh

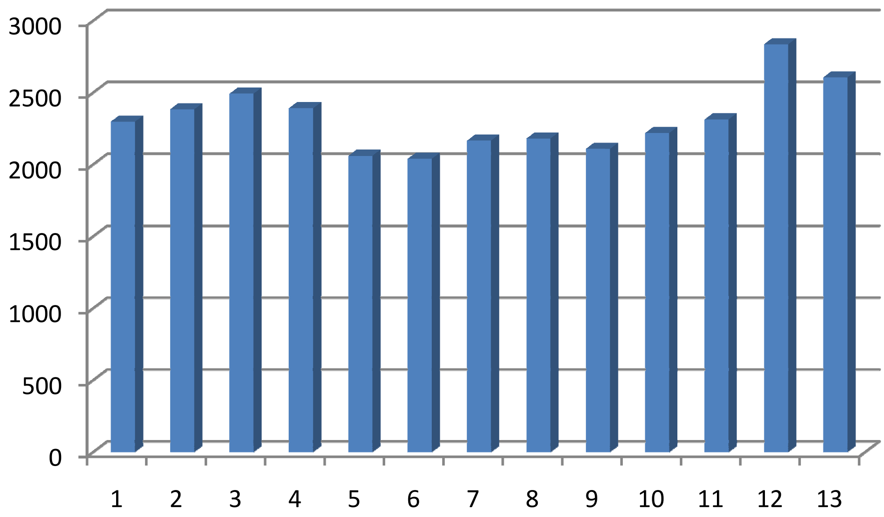
Next graphs show the information of the previous table in a clearest way:

At a high of 7 meters:



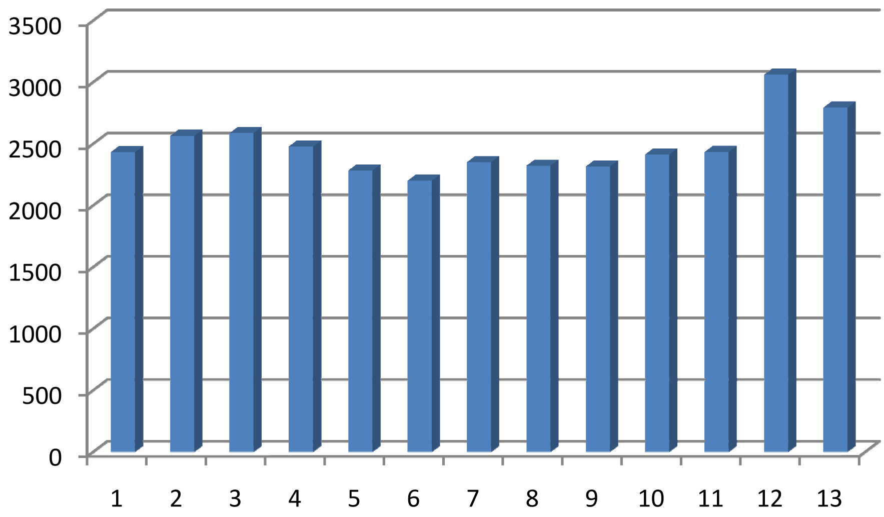
Graph 7. Comparison at 7 meters high

At a high of 9 meters:



Graph 8. Comparison at 9 meters high

At a high of 11 meters:



Graph 9. Comparison at 11 meters high

Here is a table to comparing the energy gained depending on the height of the tower for one year:

	7m	9m	11m
Point 1	0	98	232
Point 2	0	166.2	346.8
Point 3	0	110.2	204.2
Point 4	0	94.6	181.8
Point 5	0	238.82	461.62
Point 6	0	128.98	290.38
Point 7	0	-57.6	127.4
Point 8	0	213.34	354.94
Point 9	0	157.92	365.12
Point 10	0	130.8	326
Point 11	0	92	212
Point 12	0	212.4	437.2
Point 13	0	220.4	407.6

Table 9. Energy gained depending on the height

In all the cases, the energy is incremented according to the height except in point number 7, with the red background in the table.

All this calculations are done without take into account the controlling system. In the next point it is studied.

Controlling system

Next draw shows the scheme facility by Urban Green Energy in its website. It is a AC-AC controller system.

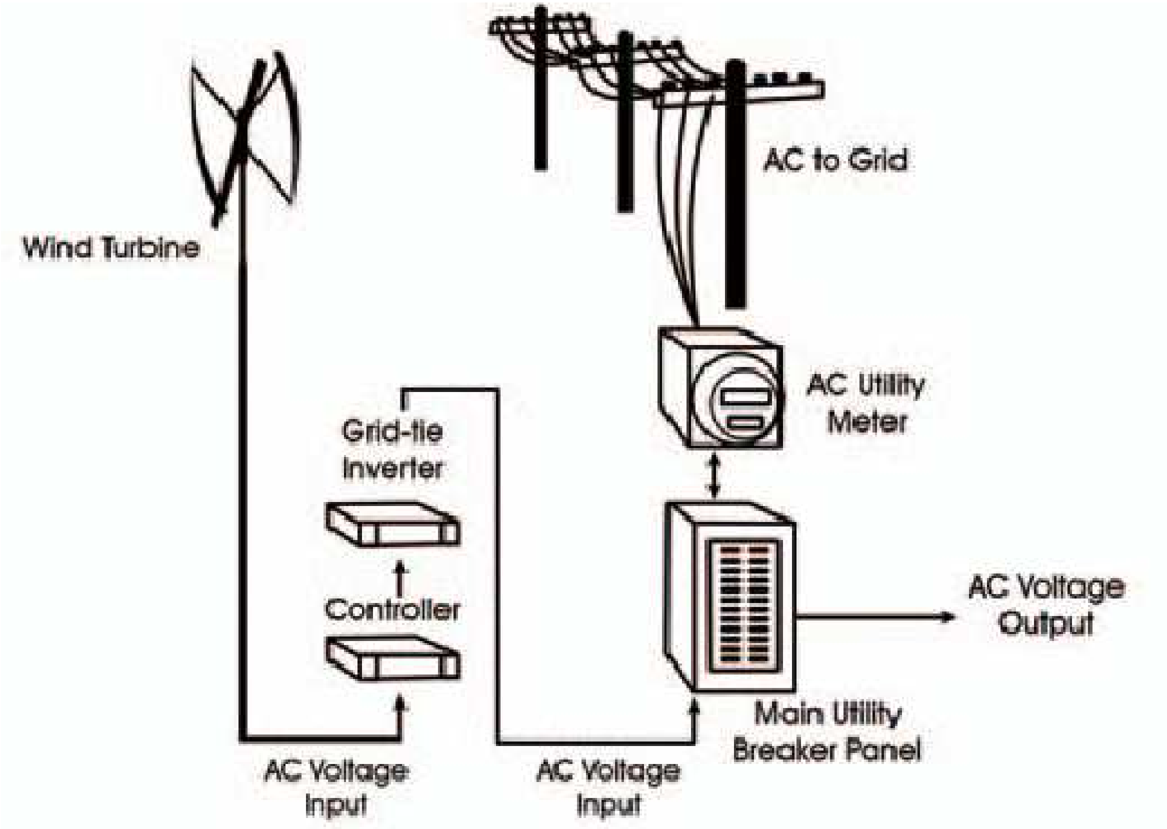


Figure 43. Controlling system

Anyway Urban Green Energy uses a Wind Interface Box and a Grid-tie Inverter form the company Power-One; www.power-one.com. They facility all the devices of the last scheme in just two components:

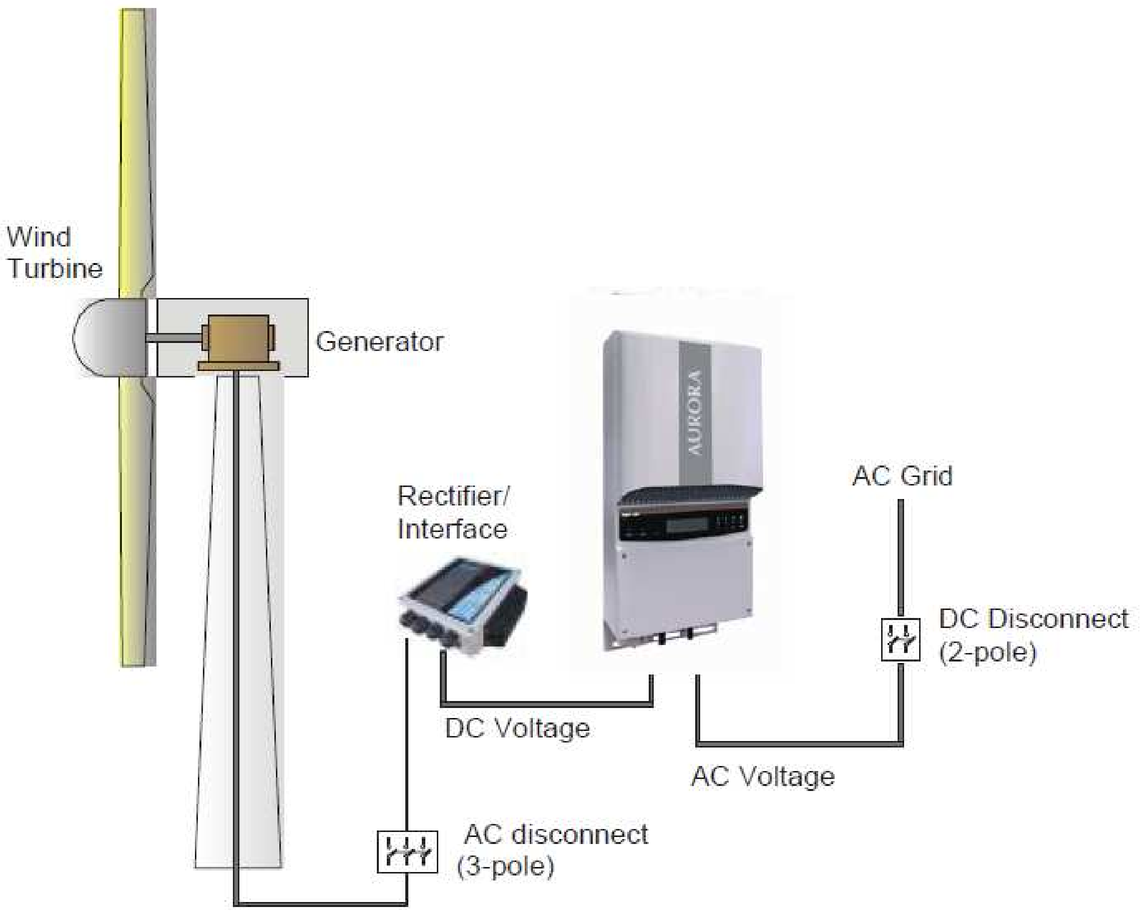


Figure 44. Controlling system

Here there are the names of the devices, and in the file "controlling system" is possible to find all the information around them.

Wind Interface Box: (Power-One Aurora PVI-7200)
Output: 0-600Vdc

Grid-tie Inverter: (Power-One Aurora PVI-4200)
Input: 50 - 580Vdc

From the user manual, it is taken that the maximum consume of the system is 8w. This power during 5 years gives:

$$8w \cdot 24h \cdot 365days \cdot 5years = 350400w = 350.4kwh$$

It means less than 4% in the worst position (Point 5, tower high 7m). It will be neglected in the results.

Output – Betz' Law

To get an idea about how efficient is the turbine in the position comparing with the theorical maximum gotten from Betz' Law next calculations are done. To calculate it, the wind averages are given in the Table 10.

The equation is:

$$P_{MAX} = \frac{16}{27} \cdot \frac{1}{2} \cdot \rho \cdot S \cdot v_1^3$$

Swept Area:

Figure 45. Photo of the turbine

Turbine dimension:
High=4.2m.
Width=2.7m.

Swept Area:

$$S = \text{High} \cdot \frac{\text{Width}}{2}$$

$S=5.775m^2$

Wind Speed Average, taken from the wind rose, is showed here:

High of the mast	Wind Speed Average
7 meters	3.92731634
9 meters	3.97451944
11 meters	4.01976019

Table 10. Average of the wind speed

The density of the air is taken like 1.20 kg/m^3. Then, the theoricaly maximum output for the turbine for the three different highs is during 5 years is:

High of the mast	Power [w]	Energy [Kwh]
7 meters	124.379014	1062.6943
9 meters	128.917933	1101.47482
11 meters	133.370535	1139.51785

Table 11. Energy obtained using Betz law

Turbulences

At the same time the velocity of each point was taken, the value of the turbulences was taken and stored in EXCEL tables like absolute value of the average of the turbulences and in the same way the relative turbulences:

$$Relative\ tubulences = \left(\frac{Average\ of\ the\ turbulences(m/s)}{Average\ of\ the\ velocity\ (m/s)}\right)$$

All the tables are included in the Appendix D.

To try to get more information about how the wind is blowing, some visual techniques were taken.

The first idea was to use a smoke generator and take pictures and videos. The result was pictures like the next one, taken with a wind speed of 2 m/s in a south-west direction:

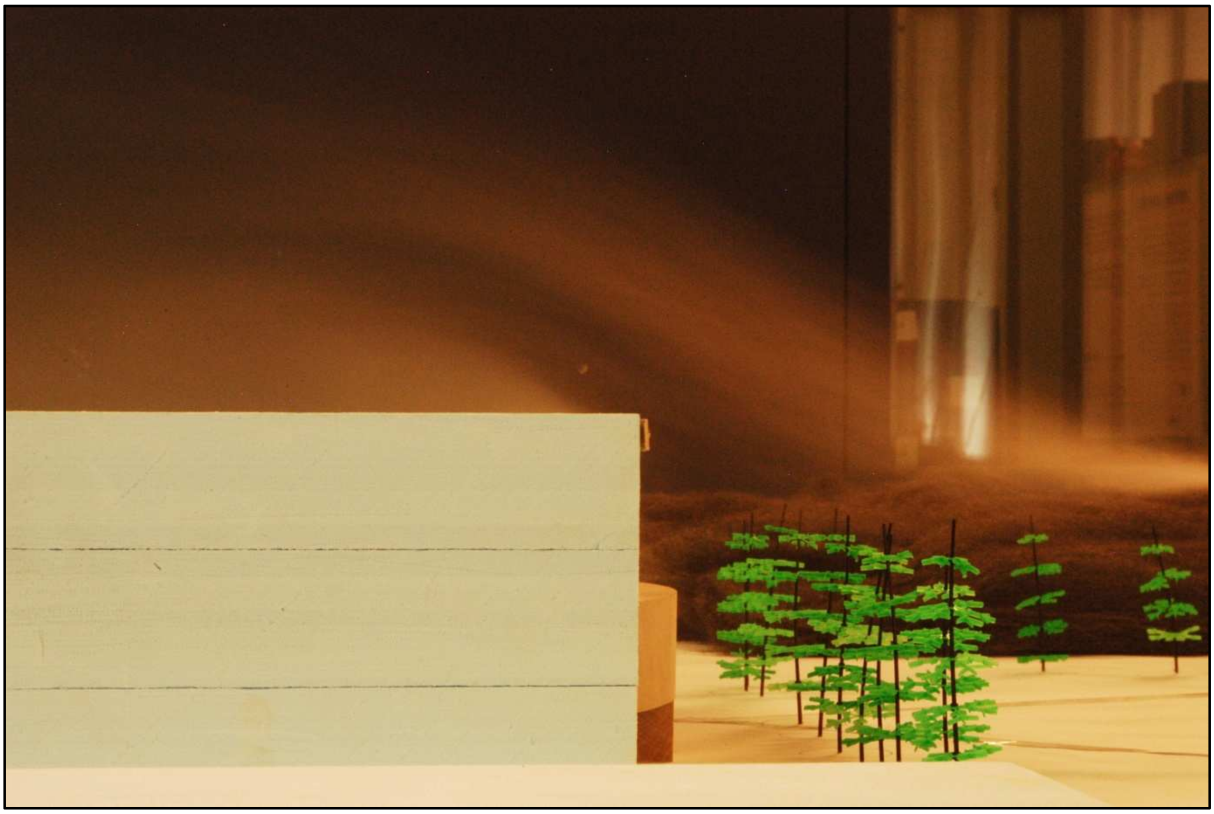


Figure 46. Photo of the smoke test

The problem with this system was that the image takes the whole width of the smoke, and it could be more interesting if the smoke would be only focused in just one point. To solve this problem a laser device was installed in the roof of the wind tunnel. This laser project a thick fringe of green colour. Turning off the lights to get a higher contrast and running again the smoke, more clear flows was possible to obtain. This was the result:

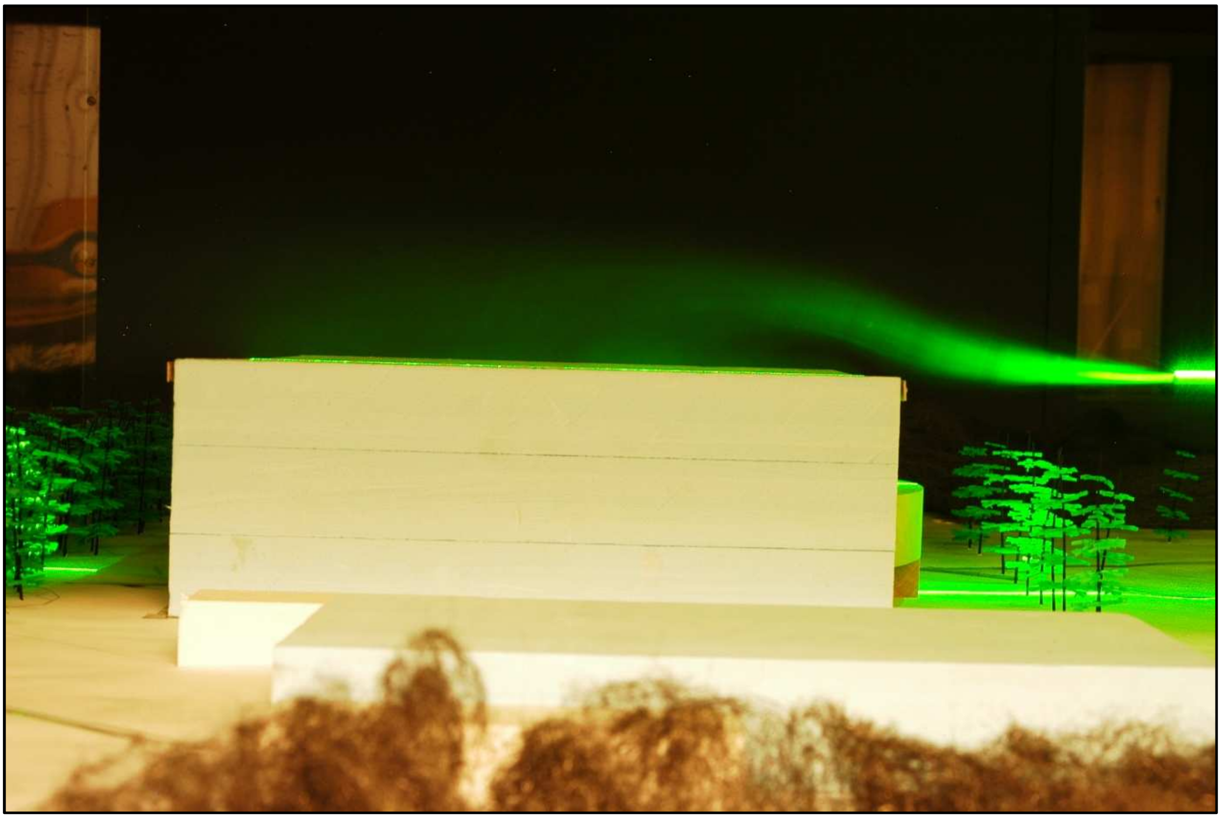


Figure 47. Photo of the smoke test with laser

All of these pictures are possible to find in the folders smoke and laser, called like “East 7”; wind direction: East and point analized: 7.

All the treatment of these photos can be found in the “Discussion” part and the conclusions in the part “Conclusions”

Economic Study

As long the electrical consumption of the Läkerol Arena was not facility, a price of 0.75 SEK/KWh is taken.

Furthermore, for all the calculations is necessary the prices of all the installation. They were taken from Urban Green Energy:

Turbine (Required):

- UGE-4K: 151048 SEK

Controller (One Required per Turbine)

- UGE-4K (Grid-Tie): 5522 SEK

Diversion Load (One recommended for grid-tie Turbines)

- UGE-4K: 4900 SEK

Inverter (One recommended per turbine. Required for AC power):

- UGE-4K (Grid-Tie): 23645 SEK

High of the mast (m.)	Price of the mast (SEK)	Total price (SEK)
5.5	19522	204637
7	20378	205493
8	*26289*	211404
9	No provided	
11	*31500*	216615
13	29167	214282

Table 12. Prices for the heights

All this prices don't include a special discount if the whole pack is bought. The highs of 8 and 11 meters have a higher price because they are not able like a standard option.

The prices for 9 meters height were not provided.

To calculate how profitable the installation of the different masts is, next formula is used:

$$Year\ to\ recuperate\ the\ investment = \frac{Investment}{Energy\ per\ year \cdot Electricity\ price}$$

Then, for the point 12 and 13 and the 3 different highs here are them payback:

	7 meters tower	9 meters tower	11 meters tower
Point 12	104.4729149	No provided	94.39179031
Point 13	114.8711499	No provided	103.4159267

Table 13. Payback

Installation of the turbine

The Läkerol Arena

The 25th of March, a meeting at the Läkerol Arena was set. Several aims were expected at the end of this meeting. The visit of the rooftop was the occasion to take some pictures and to appreciate the landscape around the Läkerol Arena. The first comments were that the top of trees were situated around 10 meters above the roof. The roughness area around is not so high. Approximately the half of the area is car parking for the visitor of hockey match. In the north stand a large stadium as well. This would be a positive point for the installation of wind turbines.

The second point of the meeting was to visit the ventilation room. In effect this one has enough space to install the equipment for the turbines. Everything contents in the nacelle for the case of a large wind turbine (gearbox) and the connexion to the grid. In this room we could also see the structure of the building.

This one is building on a strong structure of 52 columns (11 columns in the width and 15 columns in the length). As the drawing shows, these columns hold many truss enough strong to support the weight of two domestic turbines.

Figure 49. Photo of the column

Figure 48. Structure of the buiding

The disposition of the column would signify than the turbines will be installed on the border of the roof or in one of the many truss of the building.

Information from the Manufacturer

The manufacturer shows a table to facility the installation and the calculations of the load. It is possible to find the whole table, with all the information in the File Loads. Anyway here is the most useful information for this project:

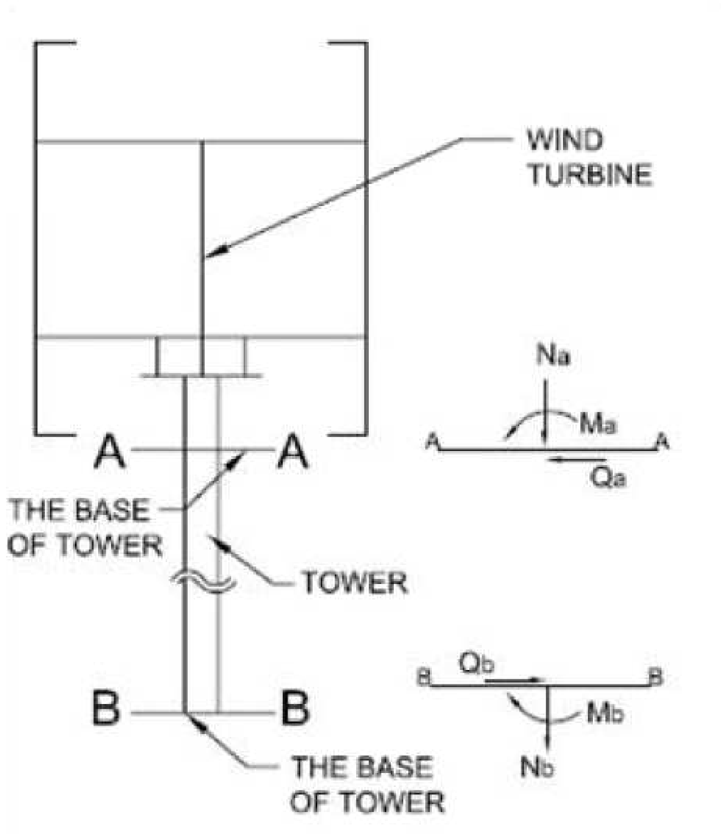


Figure 50. Diagram of the loads

M and Q change when the direction of the wind changes. As well, they change at the B-B plane for the different highs.

8 Meter Tower	
Nmax (KN)	8.25
Qmax (KN)	12.75
Mmax (KN·m)	56.10
11 Meter Tower	
Nmax (KN)	9.92
Qmax (KN)	15.51
Mmax (KN·m)	89.93

Table 14. Loads

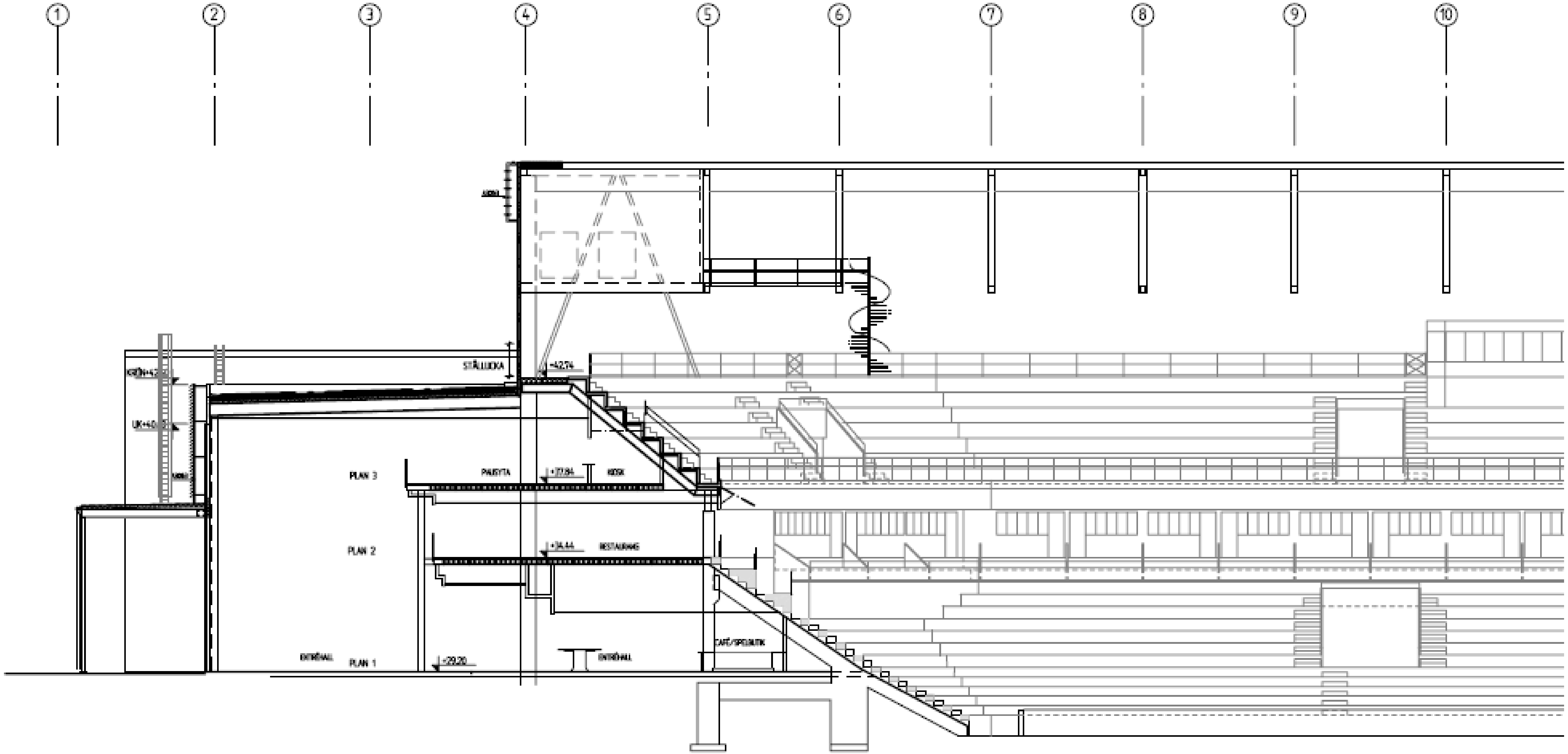


Figure 51 - scheme R302-7

This point of the project was not studied in depth, because there was not enough time, and it was needed a strongest knowledge, and it would take too much time as well. Anyway, some conclusions were taken after the meeting with Kjell Westberg, responsible of the ceiling structure of the Läkerol Arena.

The first idea of the company was to install the turbines in the front side of the building, just because of marketing reasons. Anyway, after the meeting, this idea was rejected, because, from Kjell's point of view, the capacity of the front truss (truss situated in the section 4 of the draw R302-7, figure 51) was almost 100% in use, so the addition of the load of the turbines is almost impossible.

It was suggested to study the installation in the second truss (truss situated in the section 5 of the draw R302-7, figure 51).

Comparing 4K-UGE with other turbines

Here is possible to find with output we would get with other turbines.

The calculations have been done with the same Matlab program used for the turbine 4K-UGE. It is possible to find it in the Appendix F. To use the same program the only thing that has to be changed is just the data of the Power Curve of the new turbines.

The turbines are analyzed one by one. And the results are showed in tables, firstly the 5 years output table and then a table comparing the values of the new turbine with the 4K-UGE in this way:

$$Difference\,[\%] = \frac{Energy\ of\ the\ turbine}{Energy\ 4K\_turbine} * 100$$

Finally for each turbine there is a graph showing the outputs for the Point 12 for the 3 high:

4K-UGE vs. Ampair 6000

Table of output

	7m	9m	11m
Point 1	16300	17257	18540
Point 2	16503	18125	19891
Point 3	18115	19175	20083
Point 4	17273	18181	19022
Point 5	12680	14944	17108
Point 6	13522	14734	16277
Point 7	16569	15988	17808
Point 8	14072	16113	17479
Point 9	13895	15429	17432
Point 10	15226	16487	18385
Point 11	16529	17405	18558
Point 12	20457	22549	24733
Point 13	18102	20252	22061

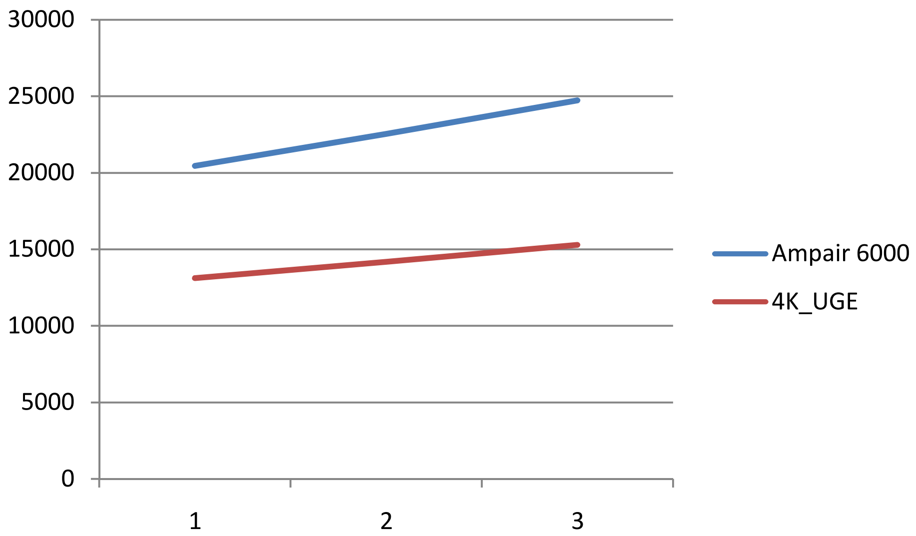
Table 15. Table of output

Table of the differences

	7m	9m	11m
Point 1	148.2	150.2	152.5
Point 2	148.9	152.1	155.2
Point 3	152.1	153.9	155.3
Point 4	150.4	152.1	153.5
Point 5	139.3	145.1	149.9
Point 6	141.6	144.5	148.0
Point 7	149.1	147.7	151.5
Point 8	143.1	147.8	150.6
Point 9	142.5	146.4	150.6
Point 10	145.9	148.7	152.4
Point 11	148.9	150.5	152.6
Point 12	156.0	159.1	161.7
Point 13	151.8	155.4	158.0

Table 16. Table of differences

Graph of point number 12



Graph 10. Point number 12

4K-UGE vs. AV-7

Table of output

	7m	9m	11m
Point 1	73637	76593	80448
Point 2	73096	78303	83308
Point 3	78007	81049	83559
Point 4	74851	77929	80579
Point 5	60098	68616	75744
Point 6	63788	68246	73456
Point 7	74509	72870	78164
Point 8	66590	73236	77425
Point 9	66126	71044	77033
Point 10	69475	73659	79444
Point 11	72657	75713	79353
Point 12	85166	90618	95744
Point 13	79594	85556	90233

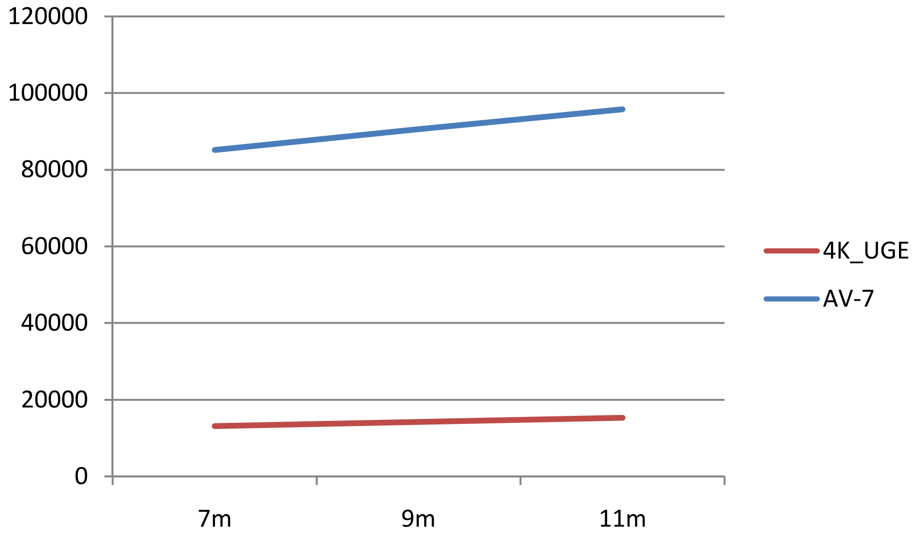
Table 17. Table of differences

Table of the differences

	7m	9m	11m
Point 1	669.7	666.8	661.8
Point 2	659.4	657.1	649.8
Point 3	655.1	650.6	646.3
Point 4	651.9	651.9	650.3
Point 5	660.1	666.3	663.7
Point 6	668.0	669.5	667.7
Point 7	670.3	673.0	665.1
Point 8	677.3	672.0	667.1
Point 9	678.3	674.2	665.6
Point 10	665.7	664.2	658.4
Point 11	654.3	654.7	652.4
Point 12	649.5	639.3	625.8
Point 13	667.4	656.7	646.2

Table 18. Table of differences

Graph of point number 12



Graph 11. Point number 12

4K-UGE vs. Bornay 3000

Table of output

	7m	9m	11m
Point 1	18822	19623	20689
Point 2	18794	20184	21598
Point 3	20141	20999	21715
Point 4	19373	20179	20891
Point 5	15436	17577	19452
Point 6	16305	17437	18798
Point 7	19047	18589	20057
Point 8	16936	18695	19839
Point 9	16805	18115	19762
Point 10	17813	18907	20475
Point 11	18770	19555	20529
Point 12	22109	23687	25247
Point 13	20404	22093	23463

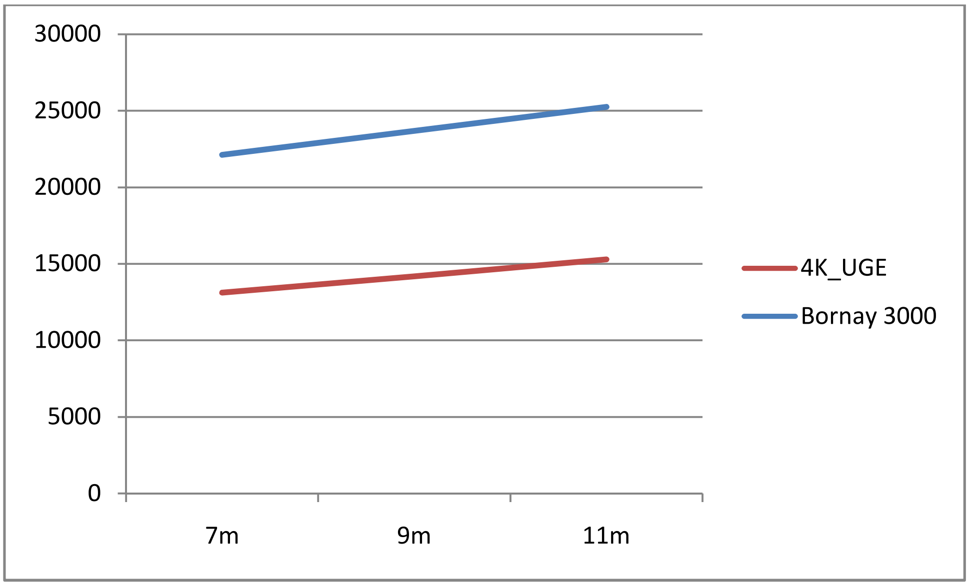
Table 19. Table of differences

Table of the differences

	7m	9m	11m
Point 1	171.2	170.8	170.2
Point 2	169.5	169.4	168.5
Point 3	169.2	168.6	168.0
Point 4	168.7	168.8	168.6
Point 5	169.6	170.7	170.5
Point 6	170.7	171.1	170.9
Point 7	171.4	171.7	170.7
Point 8	172.2	171.5	170.9
Point 9	172.4	171.9	170.7
Point 10	170.7	170.5	169.7
Point 11	169.0	169.1	168.8
Point 12	168.6	167.1	165.0
Point 13	171.1	169.6	168.0

Table 20. Table of differences

Graph of point number 12



Graph 12. Point number 12

4K-UGE vs. Bornay 6000

Table of output

	7m	9m	11m
Point 1	30667	32094	33989
Point 2	30667	33132	35664
Point 3	33070	34603	35890
Point 4	31761	33173	34428
Point 5	24810	28493	31801
Point 6	26269	28219	30605
Point 7	31069	30239	32867
Point 8	27366	30449	32471
Point 9	27119	29431	32345
Point 10	28930	30852	33627
Point 11	30659	32026	33746
Point 12	36568	39409	42248
Point 13	33451	36480	38952

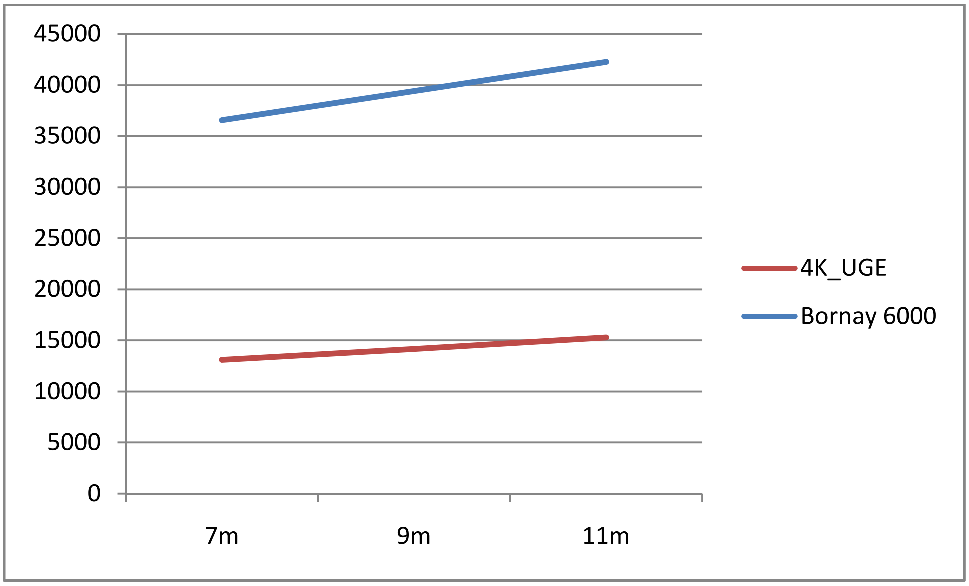
Table 21. Table of differences

Table of the differences

	7m	9m	11m
Point 1	278.9	279.4	279.6
Point 2	276.6	278.0	278.2
Point 3	277.7	277.8	277.6
Point 4	276.6	277.5	277.8
Point 5	272.5	276.7	278.7
Point 6	275.1	276.8	278.2
Point 7	279.5	279.3	279.7
Point 8	278.3	279.4	279.8
Point 9	278.2	279.3	279.5
Point 10	277.2	278.2	278.7
Point 11	276.1	276.9	277.4
Point 12	278.9	278.0	276.1
Point 13	280.5	280.0	278.9

Table 22. Table of differences

Graph of point number 12



Graph 13. Point number 12

More information about these turbines can be found in the Appendix F. In the same way, the websites of the manufactures are included.

CFD Analysis

Introduction to the CFD

Computational Fluid Dynamics (CFD) provides a qualitative and sometimes even quantitative prediction of fluid flows by means of mathematical modelling with partial differential equations, numerical methods and software tools with solvers, pre- and post processing utilities. It enables scientists and engineers to perform ‘numerical experiments ’in a ‘virtual flow laboratory’

Let us take a look of these two pictures. The first represents a real experimentation of a flow during a real experiment and the second one a CFD simulation.

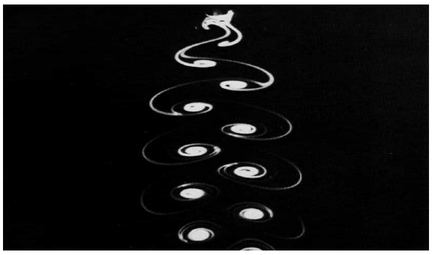


Figure 53. real experiment

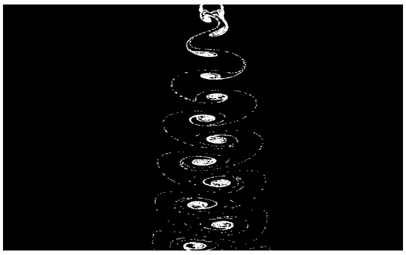


Figure 52. CFD simulation

Seeing these pictures, it is easy to understand the positive aspect that a CFD simulation could add to the project. It could permit to compare the experimentation of the wind tunnel with a numerical investigation and then to confirm the result found. Moreover, the presentation of the flows around the Läkerol Arena would be really clear.

Experimentation versus CFD simulation

The results of a CFD simulation are never 100% reliable because the input data may involve too much guessing or the mathematical model of the problem at hand may be inadequate or the accuracy of the results is limited by the available computing power.

Experiments	Simulations
Quantitative **description** of flow phenomena using measurements • for one quantity at a time • at a limited number of points and time instants • for a laboratory-scale model • for a limited range of problems and operating conditions Error sources: measurement errors, flow disturbances by the probes	Quantitative **prediction** of flow phenomena using CFD software • for all desired quantities • with high resolution in space and time • for the actual flow domain • for virtually any problem and realistic operating conditions Error sources: modeling, discretization, iteration, implementation

Table 23. Experimentation VS CFD simulation

The Läkerol project

Unfortunately, the time was not enough to realize a Computational Fluids Dynamic analysis. Whereas the 3 Dimensions model of the Läkerol Arena was already done and the roughness surrounding well known, a CFD study is really long.

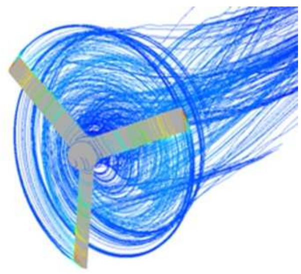


Figure 54. CFD example

First, an establishment of the Boundary and Initial Conditions should be done. The simulation generally starts from an initial solution and uses an iterative method to reach a final flow field solution.

Then, the grid which contains the flow has to be generated. This is the longer part of the work. In our case, the surrounding is making of many different kinds of roughness (parking, forest…). This will make the equation of the grid really complex.

Before to start the simulation; the establishment of the simulation strategy contenting algorithms and the input parameter should still be set.

Discussion

During this part, the all the information gotten from the previous point (Process and results) will be treat dividing it for answer the questions propose by Gävle Energi in the Project Plan.

What is the design of the wind rose over Gävle?

The data from the SMHI has been calculated trough a virtual mast placed at Valbo. It is an automatic station data which work with satellite and radar imagery. The best estimate of a meteorological parameter is given by combining all available observations of that variable in an analysis. The analysis is made on a grid where every value represents the mean for a grid square. In that process the quality and the representatively of each observation is taken into account.

The benefits of a virtual mast are the following

- Increases certainty of wind resource assessments for specific sites.
- Provides detailed and accurate information for complex onshore terrain and offshore sites.
- Saves you time and money by delaying investments in real met masts until needed.
- Enables quicker decision-making as you can receive wind resource estimates within days rather than months.
- Helps optimise your wind farm planning and performance later in the development cycle, as on-site monitored data becomes available.

The treatment of the data of SMHI permitted to get the following wind rose and the repartition of the wind speed into different classes. All these documents can be found appendix B and C.

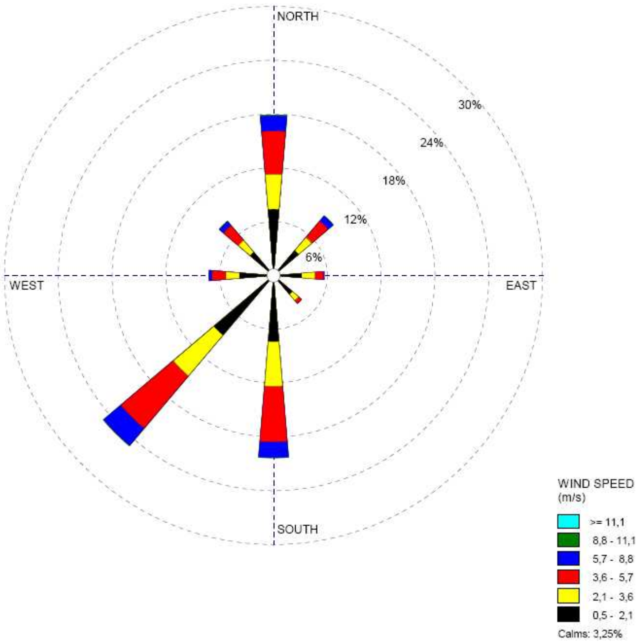
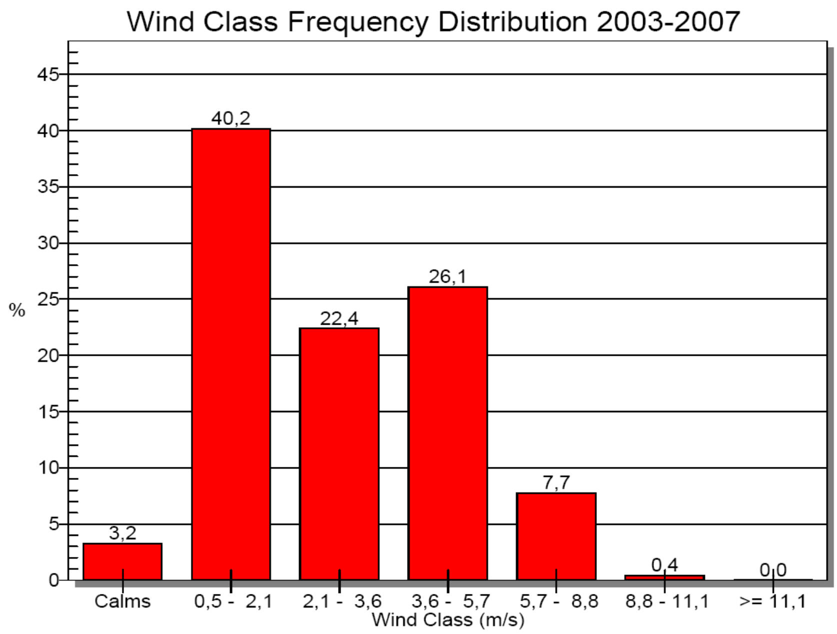


Figure 55. Wind rose over Gävle with 8 direction



Graph 14. Wind class frequency districution

Comparing the wind rose for Gävle and the Läkerol arena, is the side of the main entrance the best place install the wind turbines?

As we can see on the previous wind rose, the favourite direction of the wind is the South west. The wind is blowing from this direction approximately 25% of the time. It is easy to understand the importance of the wind data from the South West.

The next 3D modelling of the Läkerol Arena shows the building with the 8 main directions. The entrance is placed on the South East direction and the South West is at left side of the building. This is the side of the car park for the visitors. This is a positive point because trees will not be an obstacle on this important direction.

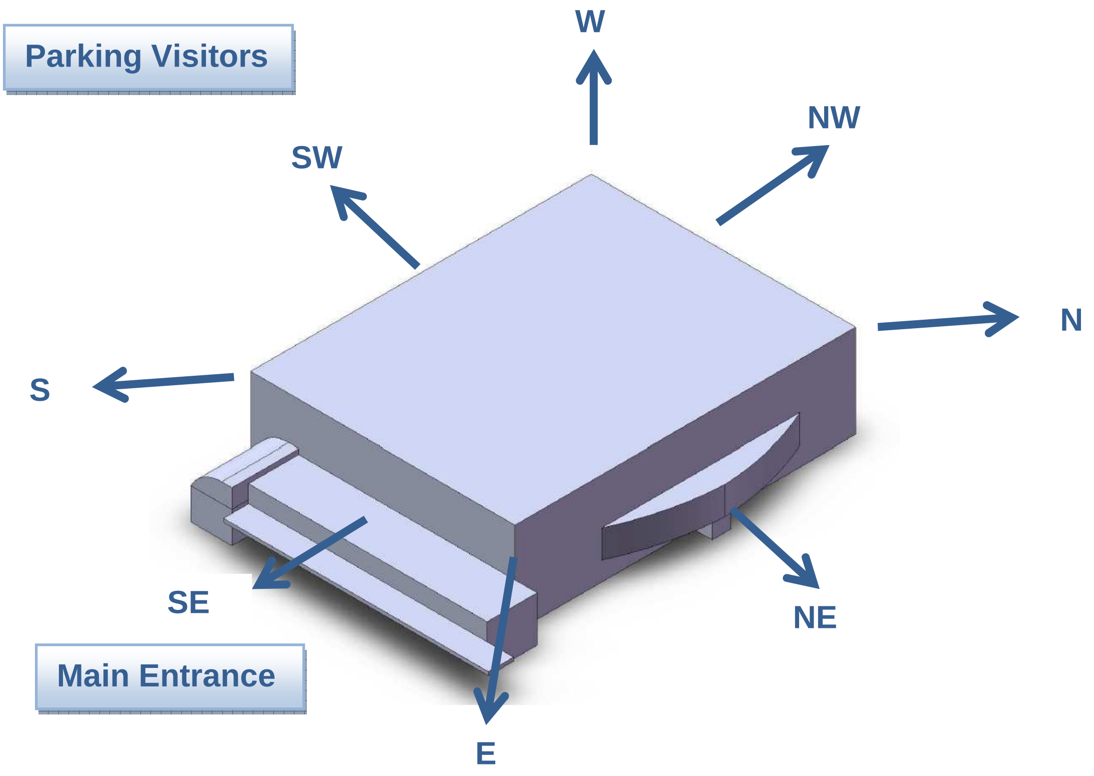


Figure 56. Direction around the Arena

The chosen of the wind turbine used will have an influence on this question. In effect, it has been decided that the two wind turbines will be placed in front of the building.

A vertical axe wind turbine is really appropriate for our situation because the wind never gets a really high velocity and secondly because the favourite wind direction is from the side of the turbines. In the case of a horizontal axe wind turbine this would be a problem. Even if the turbine could rotate, the esthetical aspect of the building should not be the same than with the VAWT.

In another hand, the fact that the wind is most often blowing from the South or South West can involve some trouble due to the shape of the building. The two next questions will permit to check this point.

The points corresponding to the main face are from 7 to 11. In the same way and despite not being in the main face, point 12 and 13 are going to be discussed here.

For the first group of points (7-11), have mostly the worst results, as is possible to see in the table 8 or in the graph 7, graph 8 and graph 9. From the point of view of the energy they are that efficiency for any of the highs. From the point of view of the installation, as was explained before and don't having done all the studies necessaries to have accurate results, it should be really complicated to install the turbines in the first truss, section 8 in the figure 51.

In a marketing point of view (a important point for the company) points number 10 and 8 would be the best because this positions give a good aesthetic and symmetry. Because of the resistance of the front truss, all of these points are not recommended.

Points 12 and 13 have the best output in all the high like the the table 8 or in the graph 7, graph 8 and graph 9 shown. So in an energy terms, these points are the best solution of the places studied in this project (maybe there other points not studied with better output).
It was suggested to install the turbines in these positions because the truss that has to hold the turbines in these positions are enough resistant.
From the point of view of the marketing, these point are worst than points 7 to 11, because is not so easy to see being close to the Läkerol Arena. Anyway, installing the turbines on a 7 to 11 meter-high towers, there would be visible from a lot of different lengths.

These points got the highest values and because of they were abtain after changing the possition of the hot wire, the results had to be check, taking again some all possitions. it was choosen the point number 5 and all the new results were close to the old ones. Futhermore, the new and old wind profiles were compared with Hand's one, and it was right as well. So the results taken for these new points (and for the old ones too)can be consider good results.

How the wind is blowing around and above the building and how the corners and the edges of the building are affecting the wind conditions?

This complex question will be answered with the help of four different supports coming from the results the wind tunnel investigation. The two first one are the curves get with the hot wire sensor. These curves show the velocity in meter per second for the tree different high above the building. The second present the turbulences for these highs. As demonstrate previously, similarities appear between the two curves. Then, it is really interesting to put in relation the two curve and the photos taken during the smoke investigation with the lazer light. The last support is the 3D modelling of the Läkerol Arena which permits to appreciate the direction where the wind comes from. The arrow shows the direction of the wind.

The presentation will be done following the height direction. For each one, the important point will be lighting, which will permit to understand better the influence of the building on the wind flows over this one.

Firstly, the direction South West, North West, North East and South East will be shown. On these directions the wind is blowing in a perpendicularly way to the building.

South West

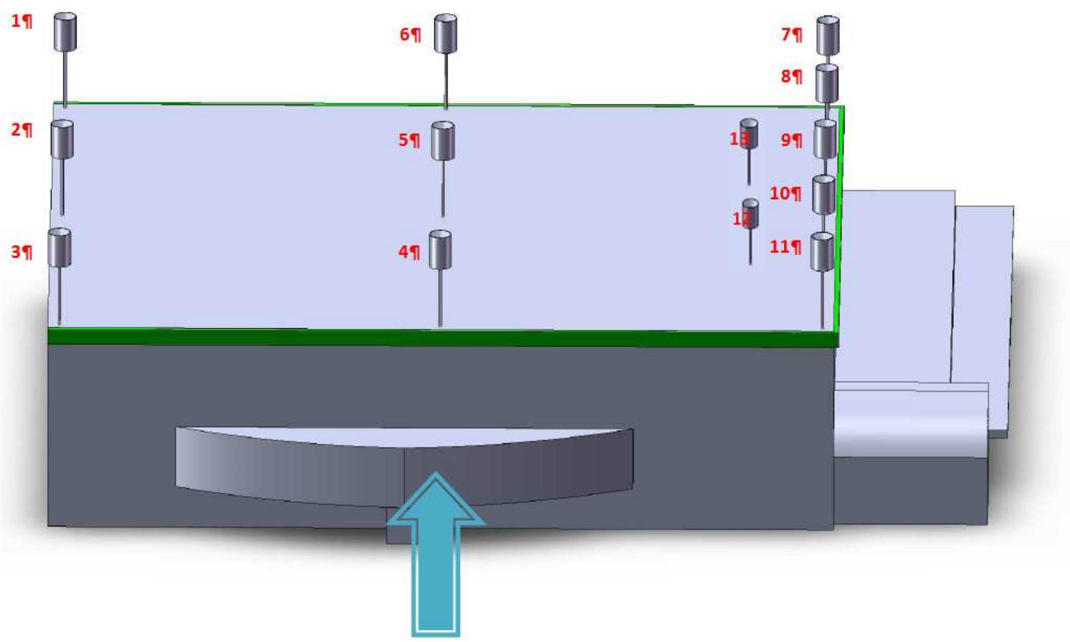
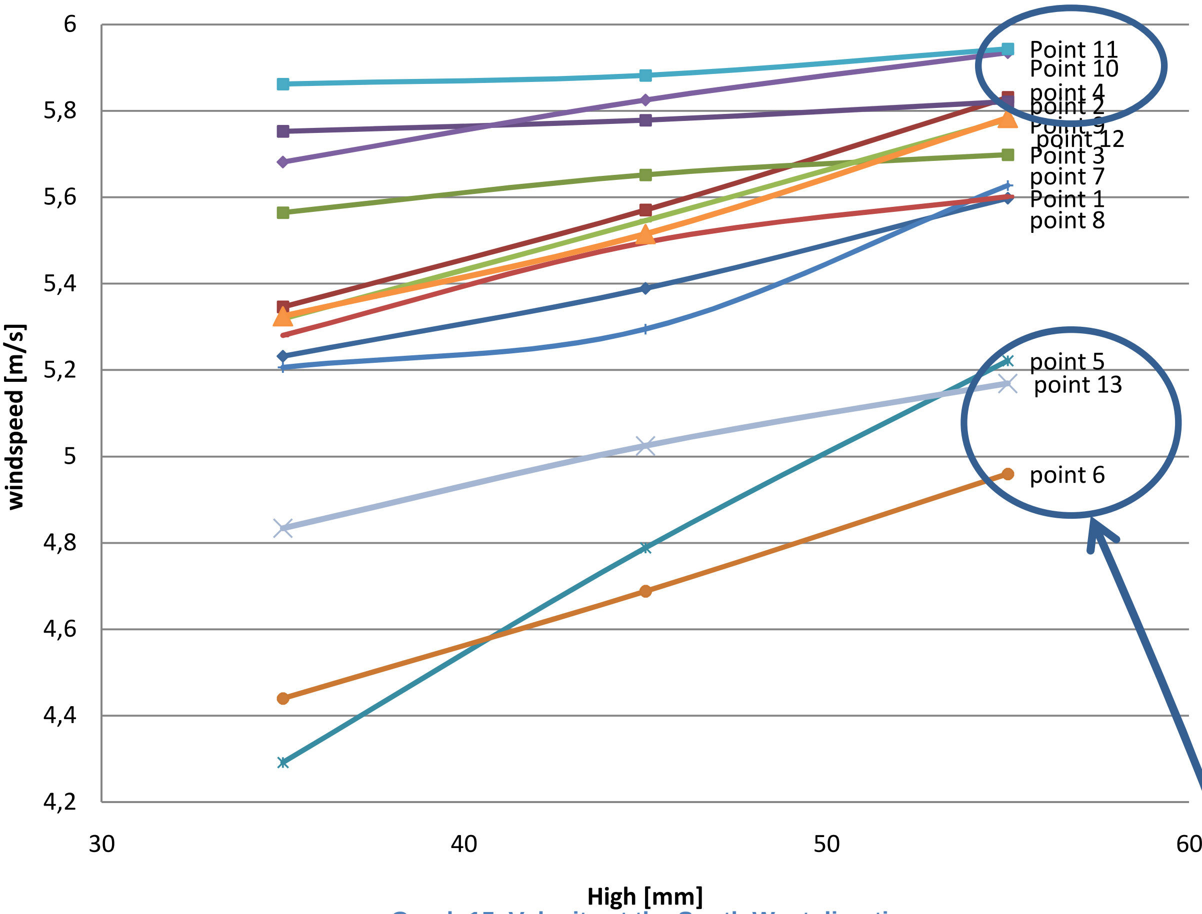
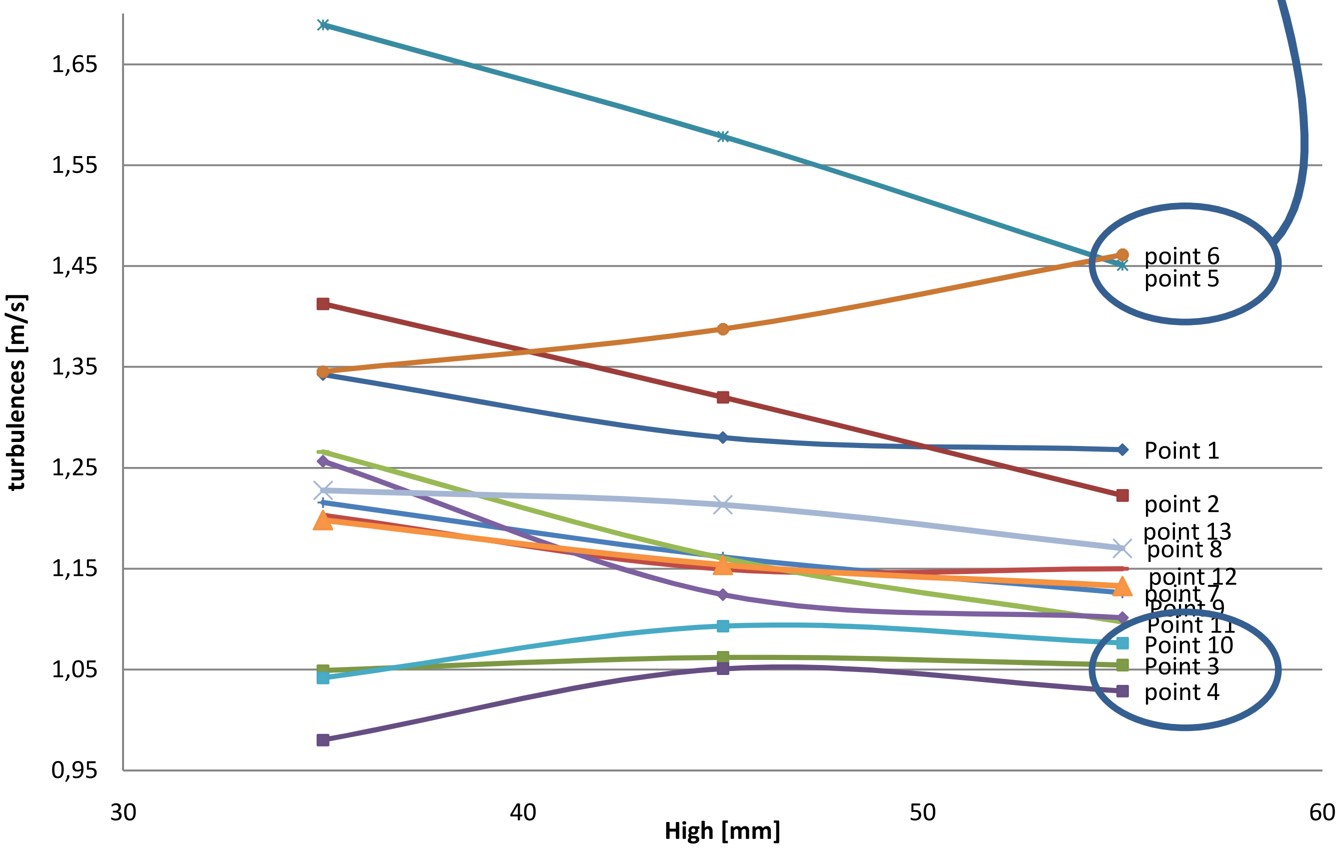


Figure 57. Direction South West



Graph 15. Velocity at the South West direction



Graph 16. Velocity at the South West direction

First, the similarities between the two curves can be remarked. When the velocity of one point is high, its turbulence will be law. The contrary is also true, when a point have a high turbulence value; it will affect the wind speed at this point. This can be appreciated on the graph before.

The next comment comes from the points 5 and 6. These two points present a low wind speed and high turbulences. However, the point number 4, situated on the same straight is the third better point. The following picture can help to understand this observable fact.

Figure 58. Smoke photo

On This picture, we can see the points 4, 5 and 6. The sheet of light is lighting only the middle of the model. It means that it is focusing on the point 4, 5 and 6. The starts red, blue and white are representing the position of the turbines and they are draw by eye.

It is clear as it can be seen at the point number 4 how just under them there is a vacuum and how they are inside the air flow. Probably the output is better in these positions because of a concentration factor. Then, we can see that the flow is getting more and more turbulent and the gap under it disappear. This explains why the point 5 and 6 present a really high turbulences and a low velocity.

The highest velocity is found for the points 11, 10 and in the same way, the points 7 and 8 present a not really high velocity and pretty high turbulences. The same thing happens with the point 13 presenting more turbulences than the 12. This can be explained by the same reasons. Thus, we can admit that the design of the wind over the Arena follow the same law for the tree different straight. This is illustrated on the following picture.

In another hand the point 1, 2 and 3 present good results.

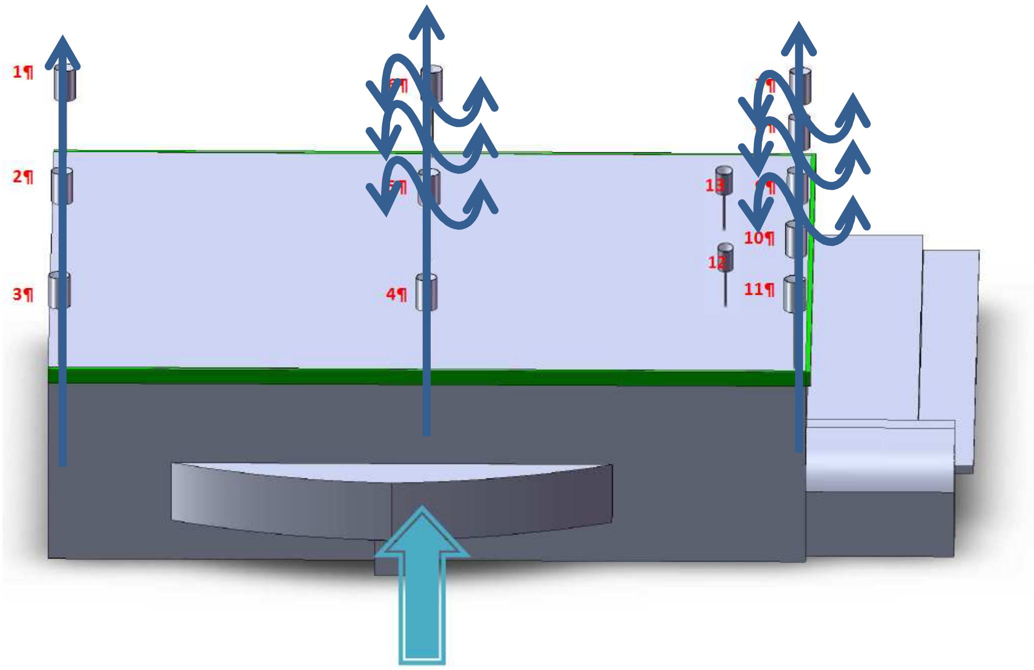


Figure 59. Draw of the turbulences

North East

The next direction chose to be study is the direction North East. The building has been rotated of 180° and the wind is now blowin g in the opposite side. The modelling of the Läkerol Arena and the two graphs can be found under.

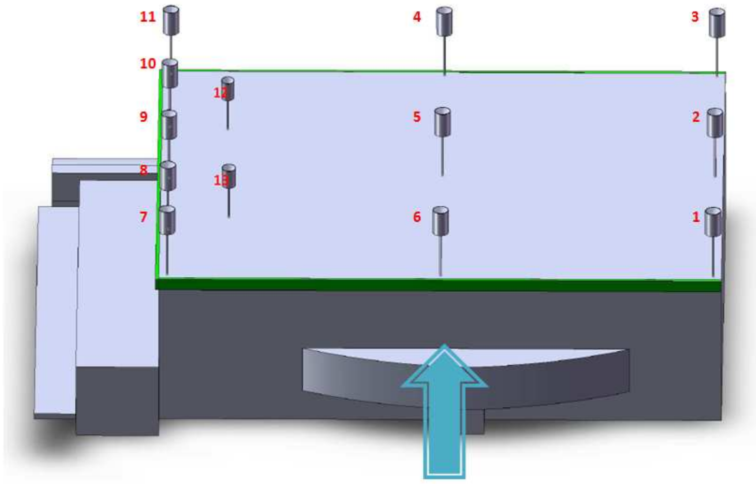
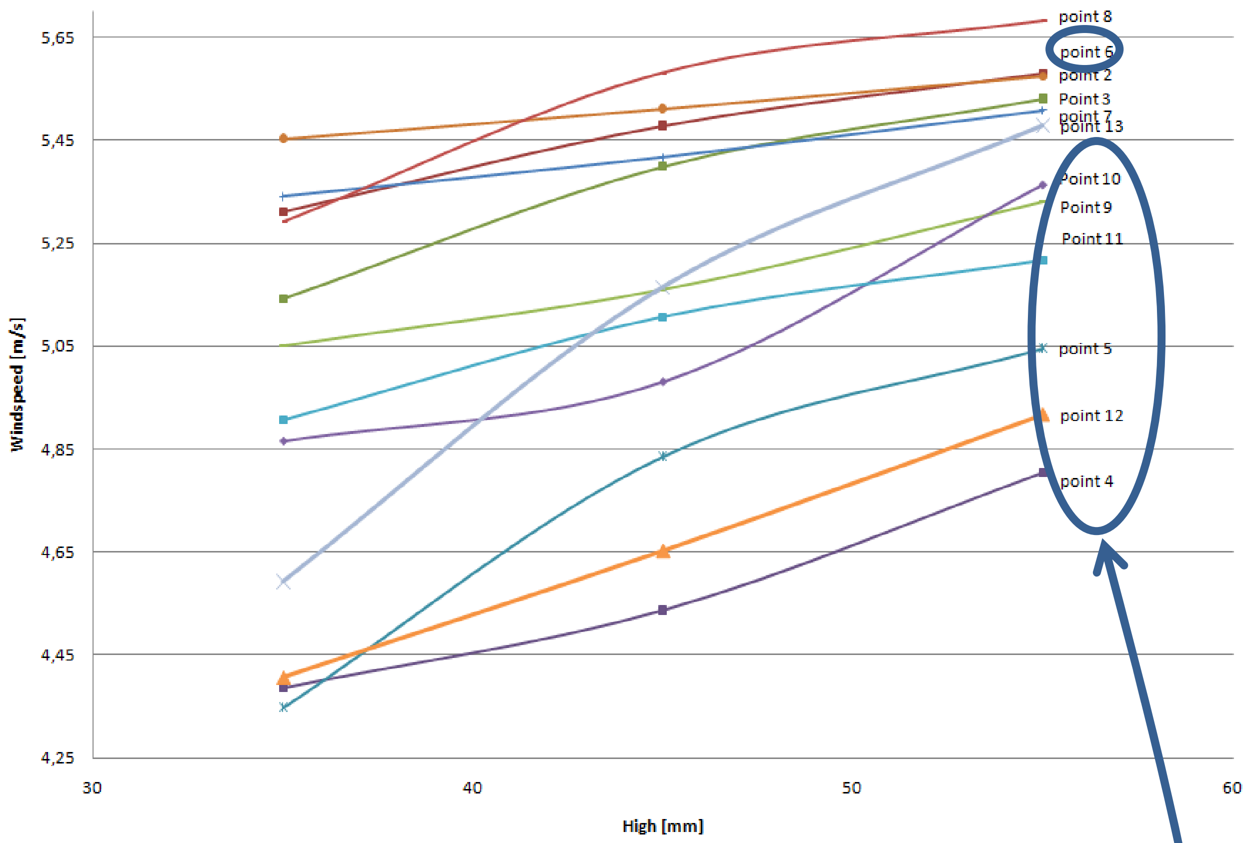
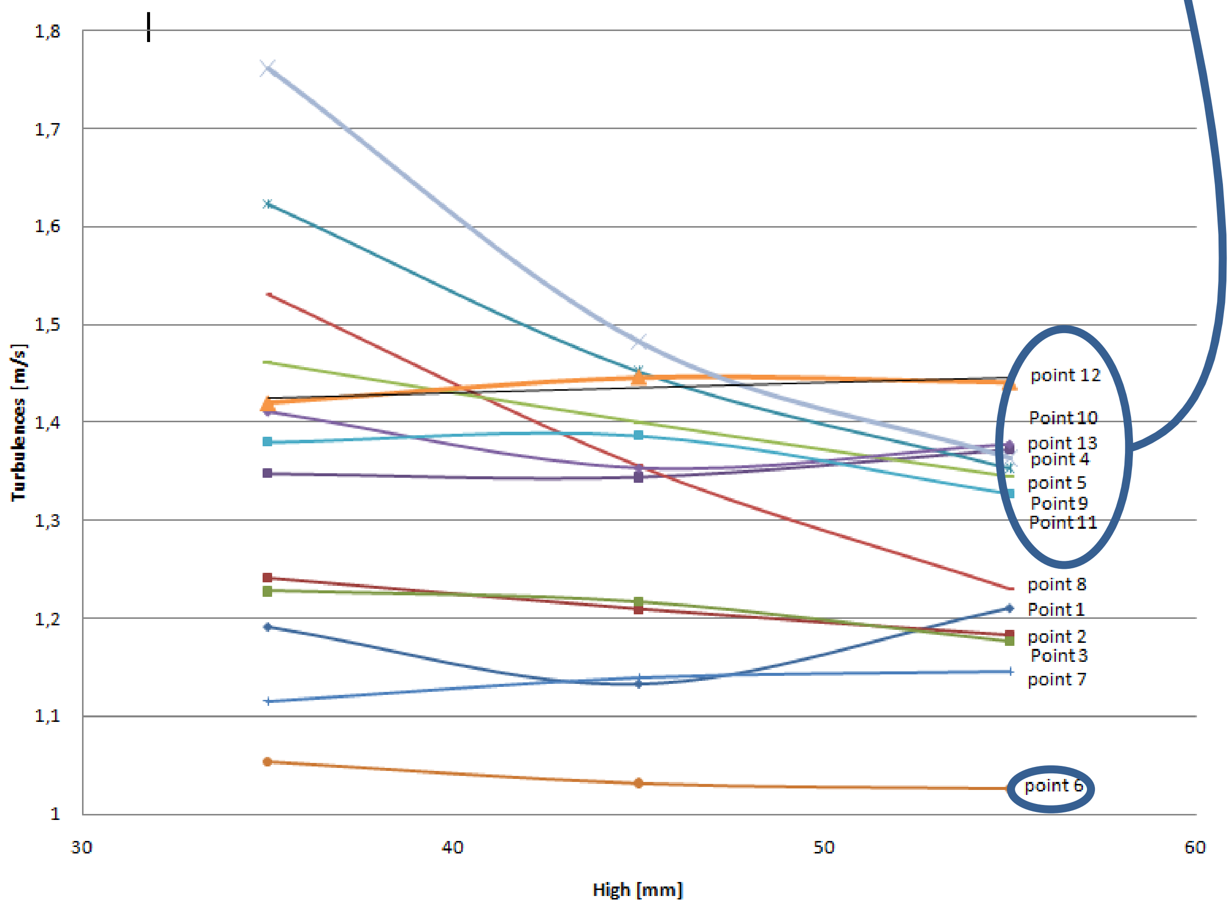


Figure 60. Model at the North East


point 8
point 6
point 2
Point 3
point 7
point 13
Point 10
Point 9
Point 11
point 5
point 12
point 4
5,65
5,45
5,25
5,05
4,85
4,65
4,45
4,25
30
40
50
60
Windspeed [m/s]
High [mm]


point 12
Point 10
point 13
point 4
point 5
Point 9
Point 11
point 8
Point 1
point 2
Point 3
point 7
point 6
1,8
1,7
1,6
1,5
1,4
1,3
1,2
1,1
1
30
40
50
60
Turbulences [m/s]
High [mm]

A lot of similarities with the South west direction can be seen. First, the point number 6 is the second better as the point number 4 for the previous direction. After that, the points number 4, 5, 10, 11, and 12; present a low velocity and a high amount of turbulences. They are all situated in the back side on the modelling.

Also, the back of the building (pt 1, 2 and 3) is less affected by the turbulences. The same thing could be seen on the South West direction.

Thus, we can say than the design of the wind over the model is the same than for the South West direction.

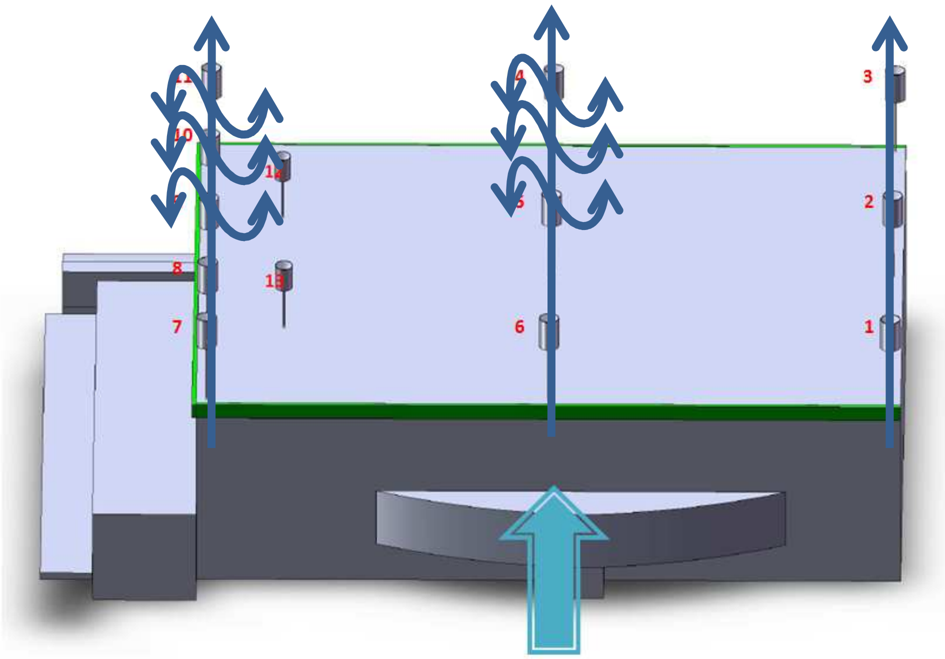


Figure 61. Draw of the turbulences

The following photo shows the model at the North East position. The light seen is lighting the back of the building. It can be seen than the flow is different than for the middle of the building (i.e. photo South West). On this picture, the course of the wind is larger and more dispersed.

It can be also remarked than the gap observed before is not present here. That can explain why the point number one do not presents better result than the points number 2 and 3. There is not the factor of concentration like before.

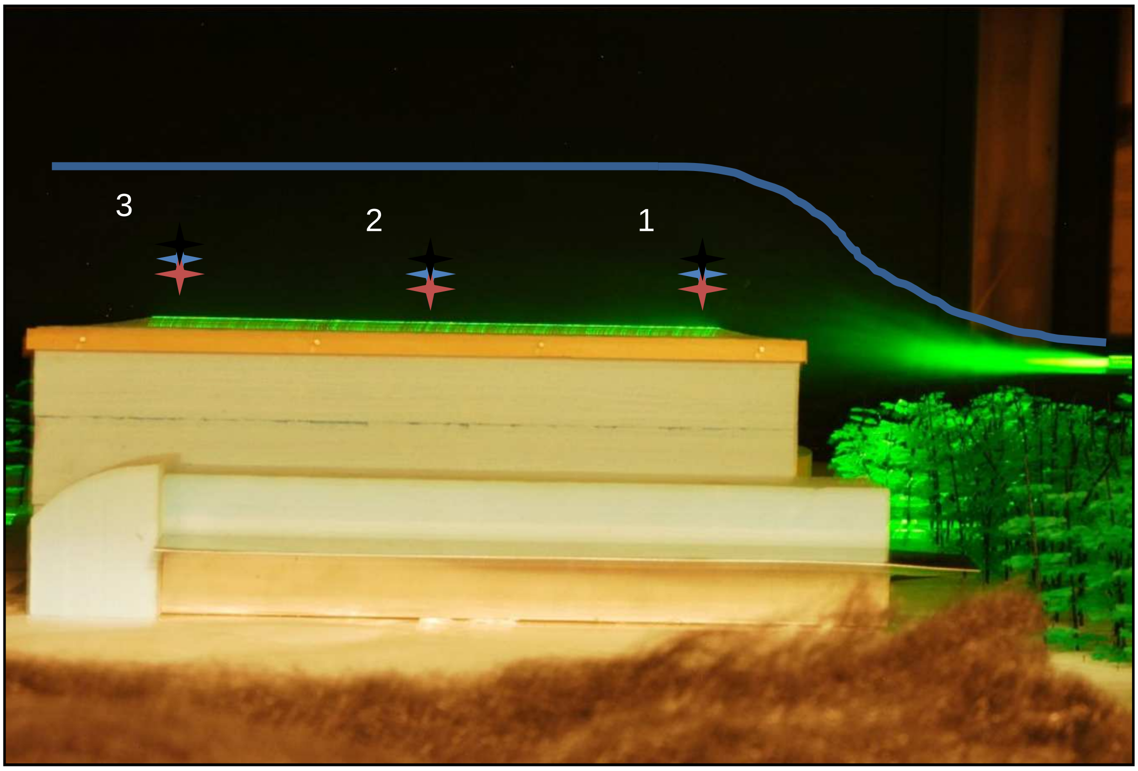


Figure 62. Smoke Photo

North West

We can now take a look of the back of the building with the North West direction.

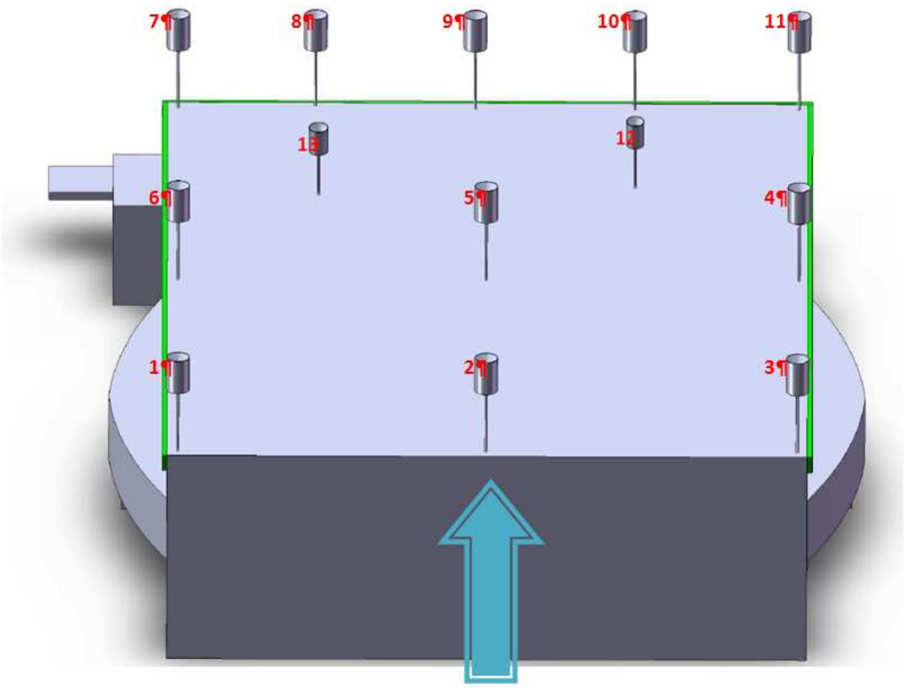
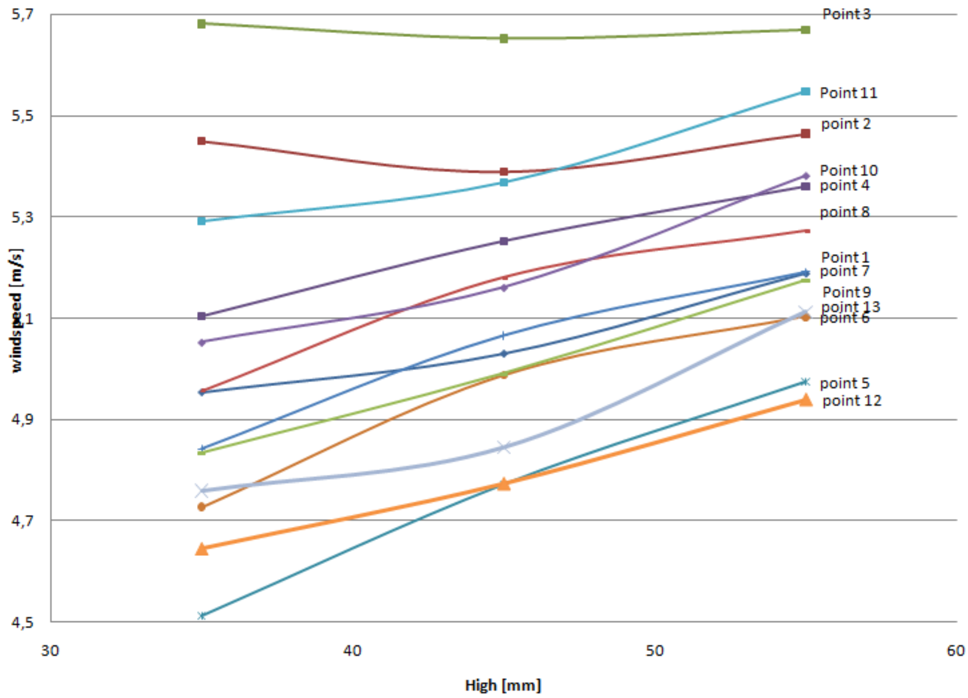
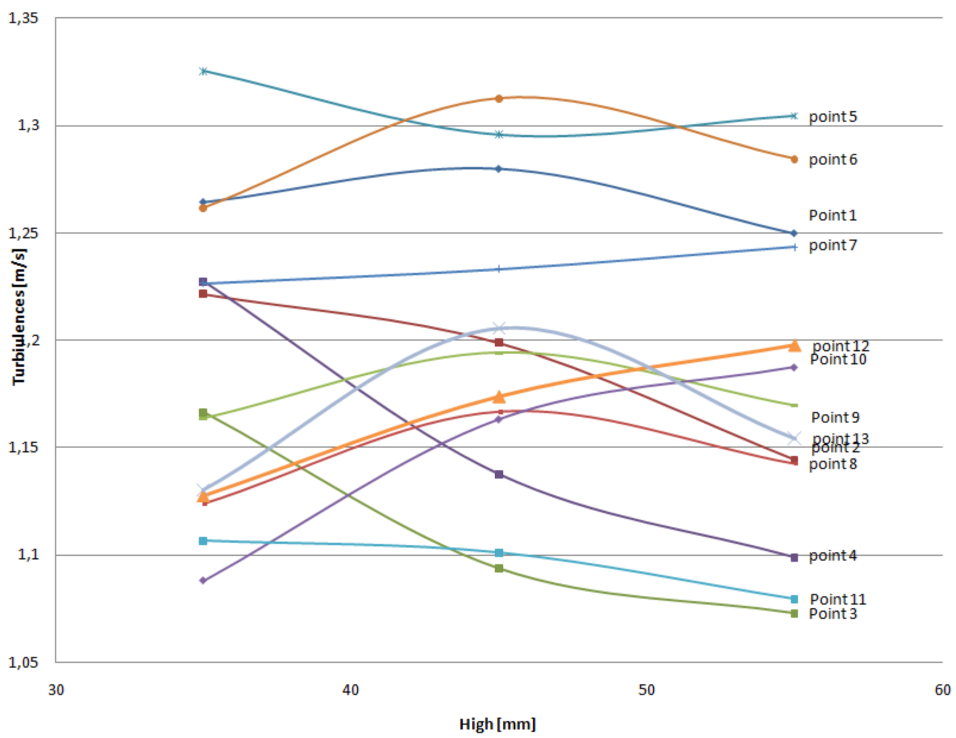


Figure 63. Model at the North West



Graph 17. Windspeed at the North West



Graph 18. Turbulences at the North West

On this direction, it can be seen than the point number 5, 9, 12 and 13 present a lower velocity than the other point. In the same way they have a higher amount of turbulences. All these points are situated on the middle of the roof. Once again we can guess than the turbulences are higher on this position of the roof.

Also the points 2 and 3 situated in the back of the building do not have so much turbulence. This can be explained by the fact than the wind is blowing directly on them on this direction.

In another way, the points situated on the side of the building (point 4, 11) do not present a really large amount of turbulences. Here the flow repartition is a bit more complex.

A scheme of the flow over the building can help to appreciate the understanding of the reparation of the turbulences. This repartition is a guess. Unfortunately, no laser picture can confirm the following assumption.

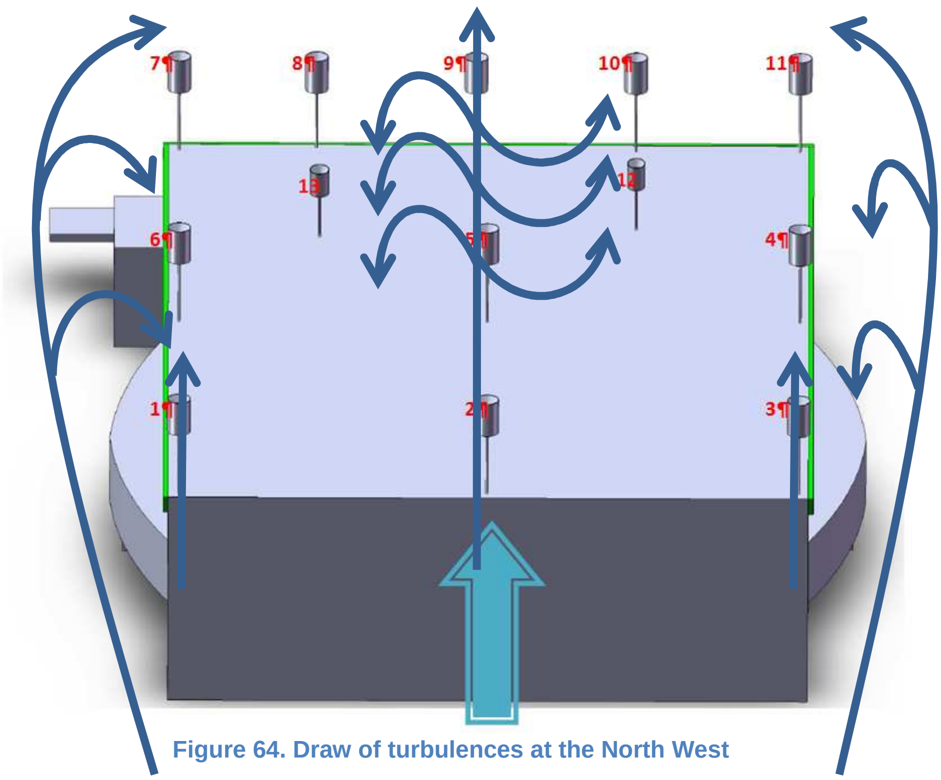


Figure 64. Draw of turbulences at the North West

South East

The following direction shows the main entrance of the building. Even if the wind is blowing only 5 % of the time in this direction, it is really interesting to study it because of marketing reason.

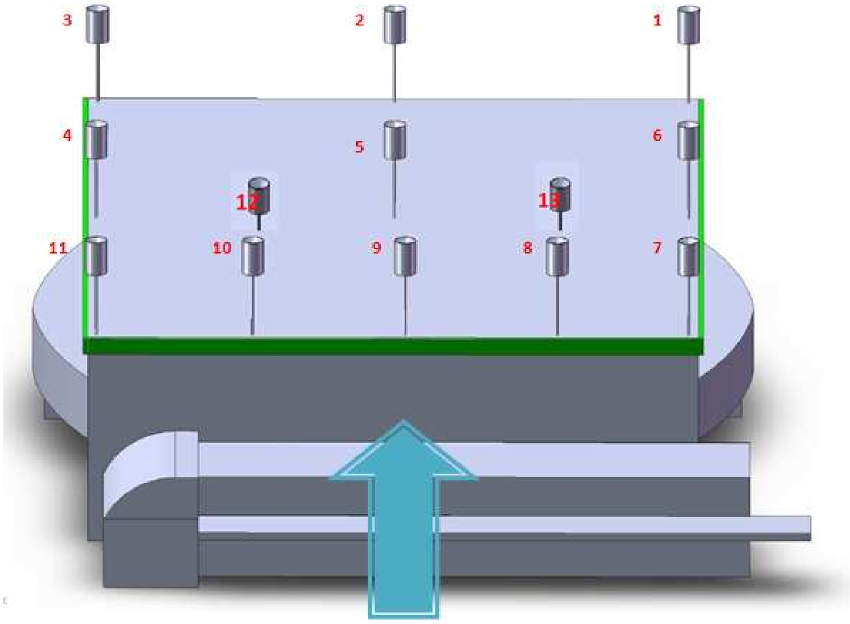
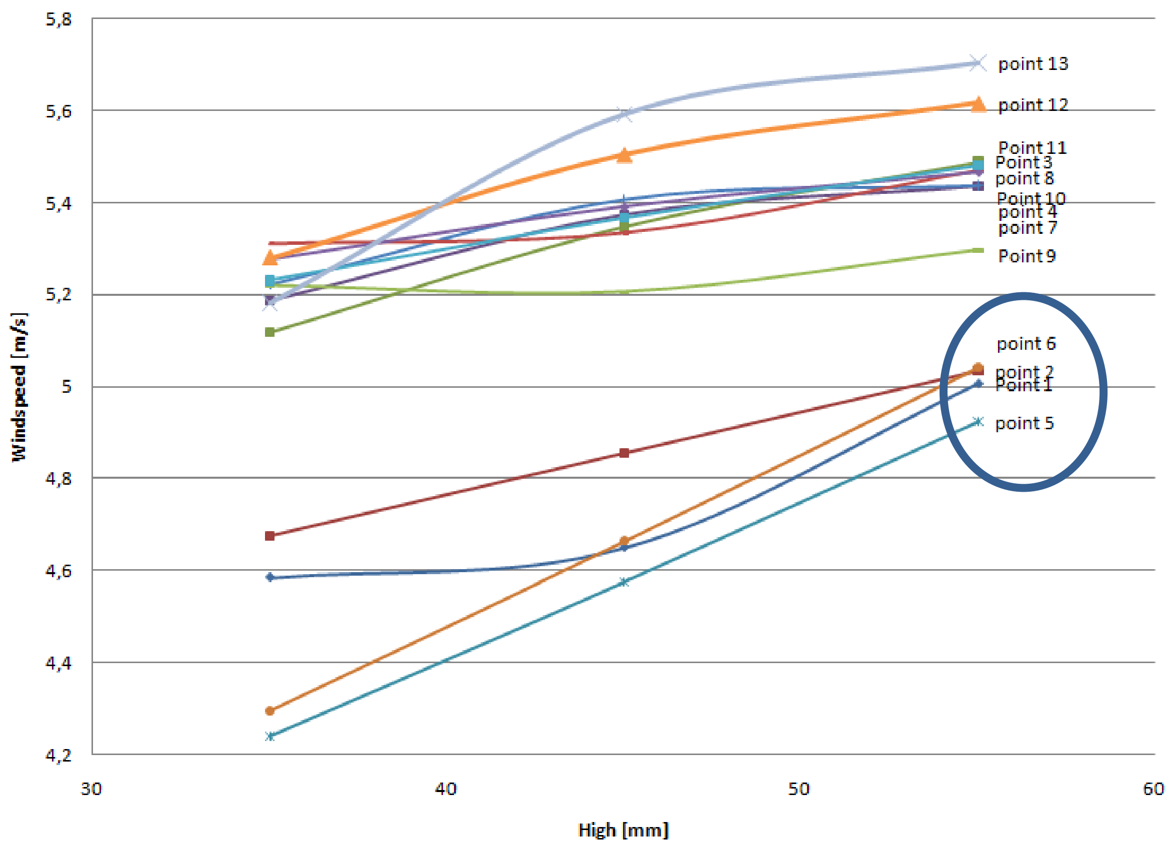
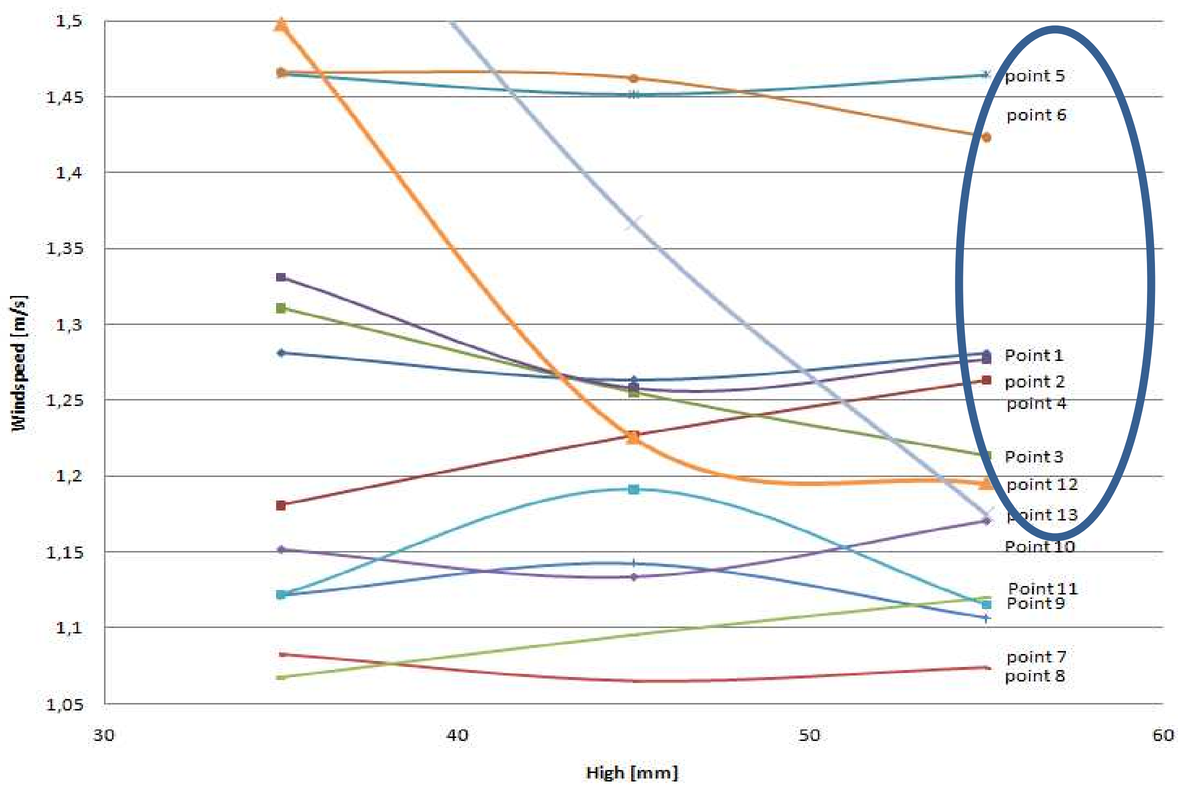


Figure 65. Model at the South East



Graph 19. Windspeed at the South East



Graph 20. Turbulences at the South East

As it can be seen, the points 1, 6, 2, 5, 4 and 3 have the highest turbulences. All these points are situated in the middle and at the back of the building. Also, the points 11, 10, 9, 8 and 7 present low turbulences and a good velocity. These points are in the side of the main entrance. The wind is blowing directly on them.

It is really interesting to see that the point number 12 and 13 have the highest velocity. However they have a medium amount of turbulences compare to the other points.

All these information are treated into the following laser photo.

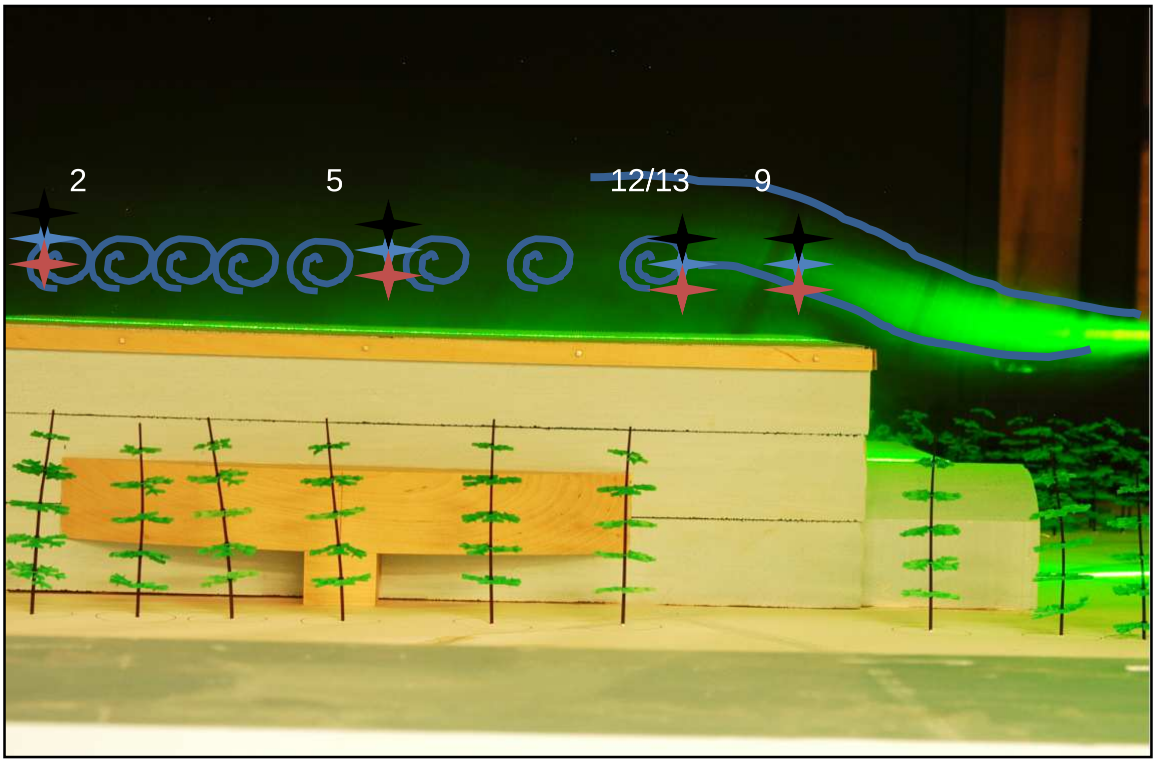


Figure 66. Smoke picture at the South East

The light sheet is lighting the middle of the building. Thus, the points 9, 5 and 2 can be analysed. It can be also assume than the point 12 and 13 can be seen. As the first laser photo, a gap is present. This gap is the result of a concentration of the flow. This factor of concentration will increase the velocity of the point number 9, 12 and 13. However, the farther the point is from the blowing side, the higher are the turbulences. That is why the turbulences of the points 12 and 13 are higher than the turbulence at 9. Also the turbulences at 5 and 2 are higher than at 12 and 13.

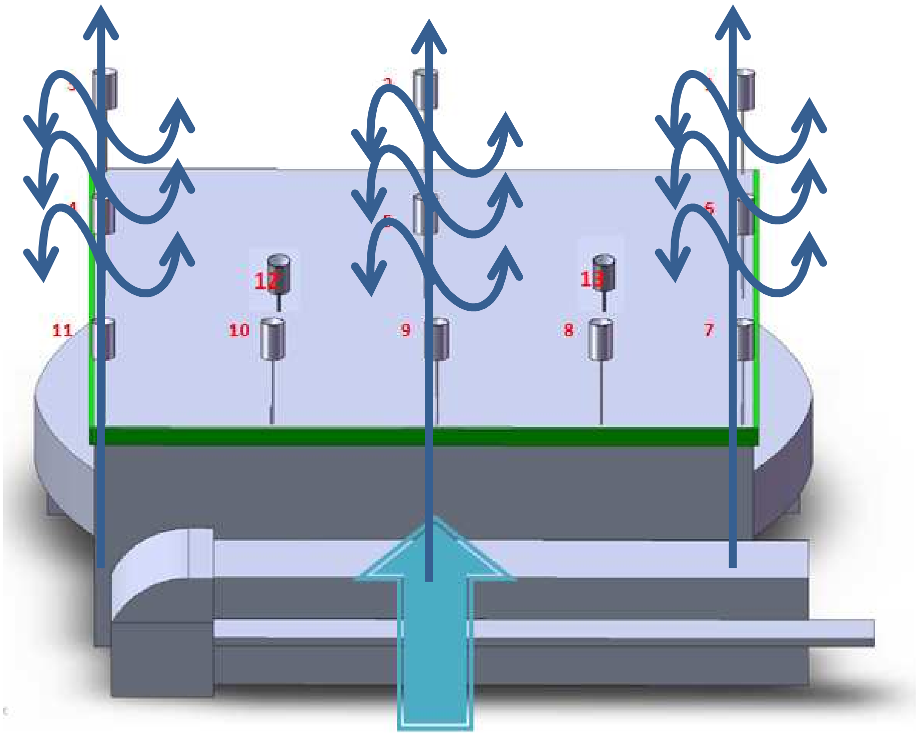


Figure 67. Draw of the turbulences at the South East

North

The building is now in the North direction. The design of the wind will change due to the different position of the building. For the four next directions, the wind is blowing at the corners of the roof.

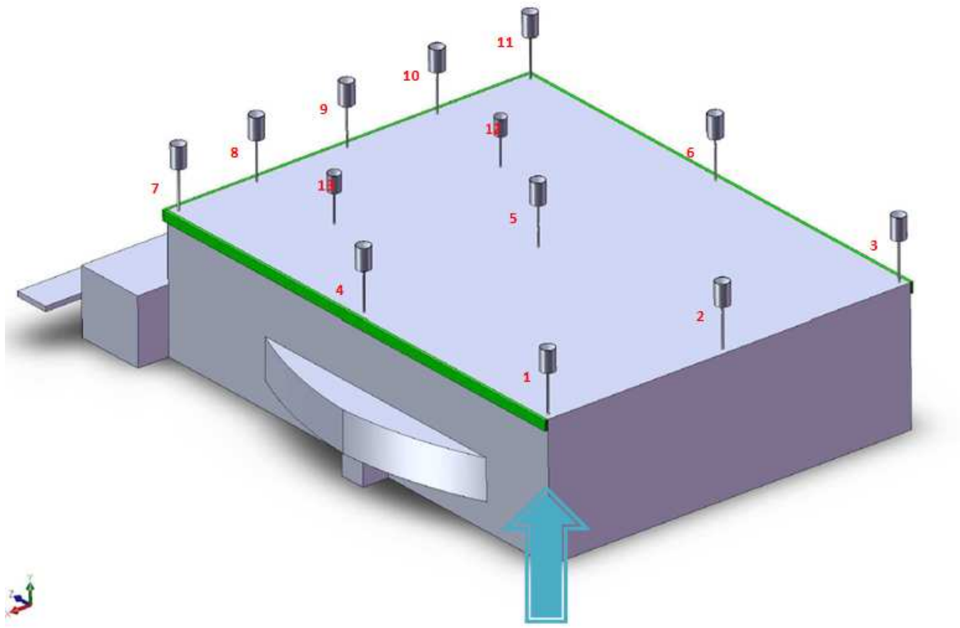
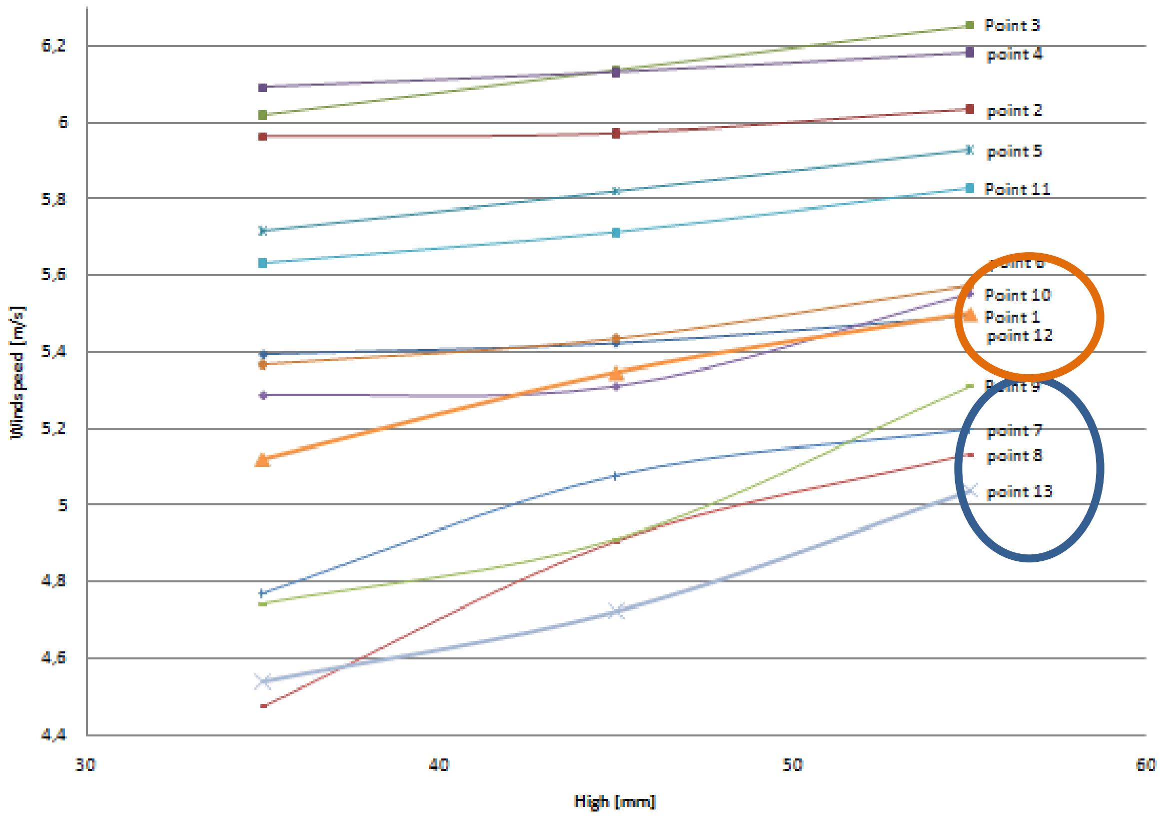
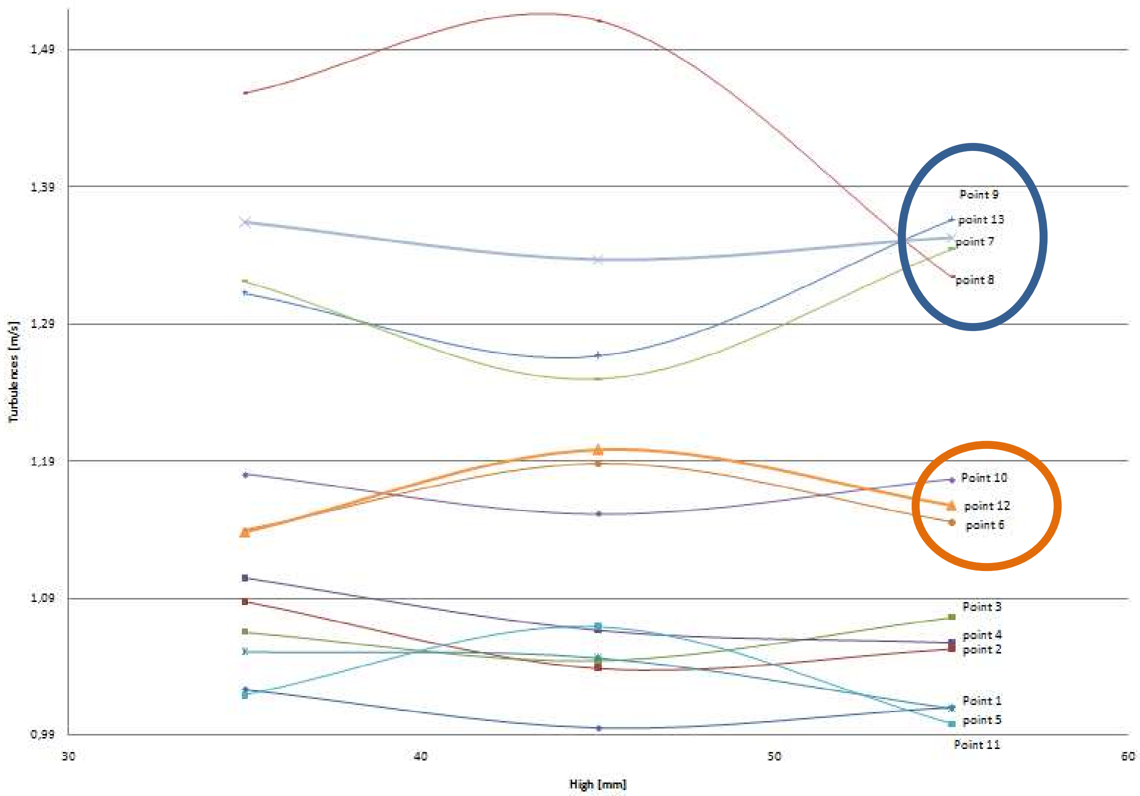


Figure 68. Model at the North



Graph 21. Windspeed at the North



Graph 22. Turbulences at the North

The first comment is that the points 2, 3 and 4 present good results. All these point received directly the wind. However, the point number 1 has a lot of turbulences. This point is situated directly on the corner.

The point 5 and 11, present also good result, the photo can help to explain this.

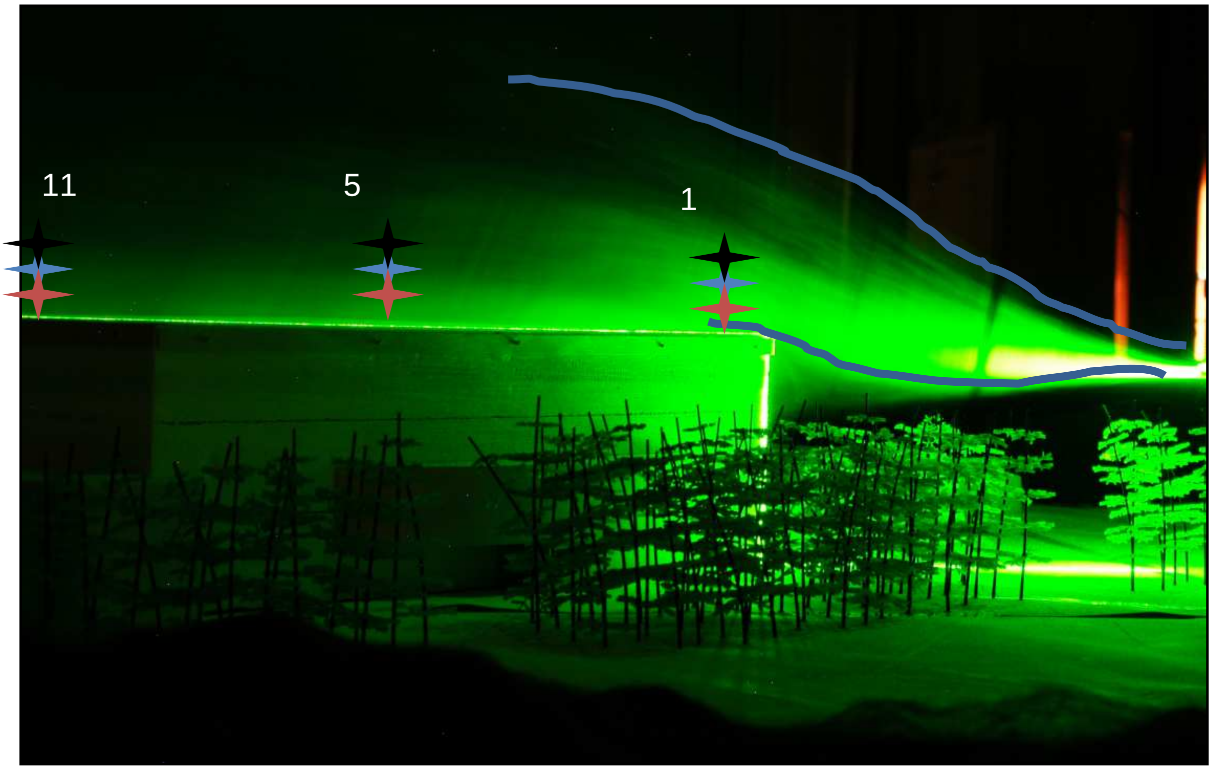


Figure 69. Smoke Photo at the North

The above photo has been taken with the laser sheet in the corner of the building. The point 1, 5 and 11 are concerned. On the graphs, the points 5 and 11 have good velocity and low turbulences. This can be explained by the fact that there is no gap and no factor of concentration when the wind blows on a corner. It can be seen than the flow is really linear. However it is difficult to explain why the point number 1, on the corner has high turbulences. This fact will be explained later.

Here the points 9, 13, 7 and 8 (blue circle) present a high turbulences and a low velocity. In the same way the points 10, 12 and 6 (orange circle) presents the same characteristics. Another laser photo can help to understand this. The laser is now lighting the points 2 and 6. The following model helps to see the laser sheet.

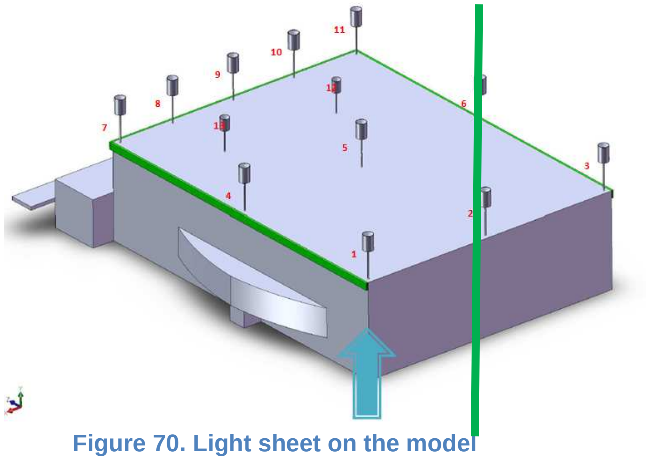


Figure 70. Light sheet on the model

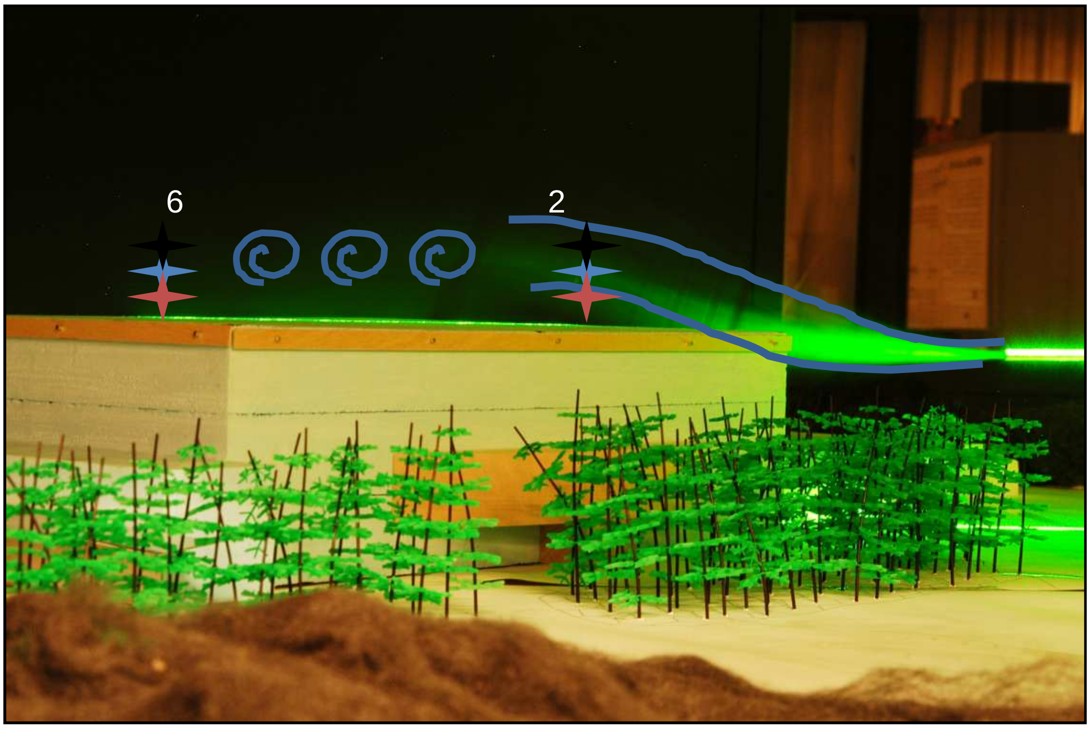


Figure 71. Smoke photo at the North

As we can see, when the wind is blowing in the middle of one wall, the gap present for the other directions appears. This leads to a creation of turbulences behind the gap. Thus, the point 6 has high turbulences and low velocity.

The turbulence design on the north direction is resumed on the following scheme.

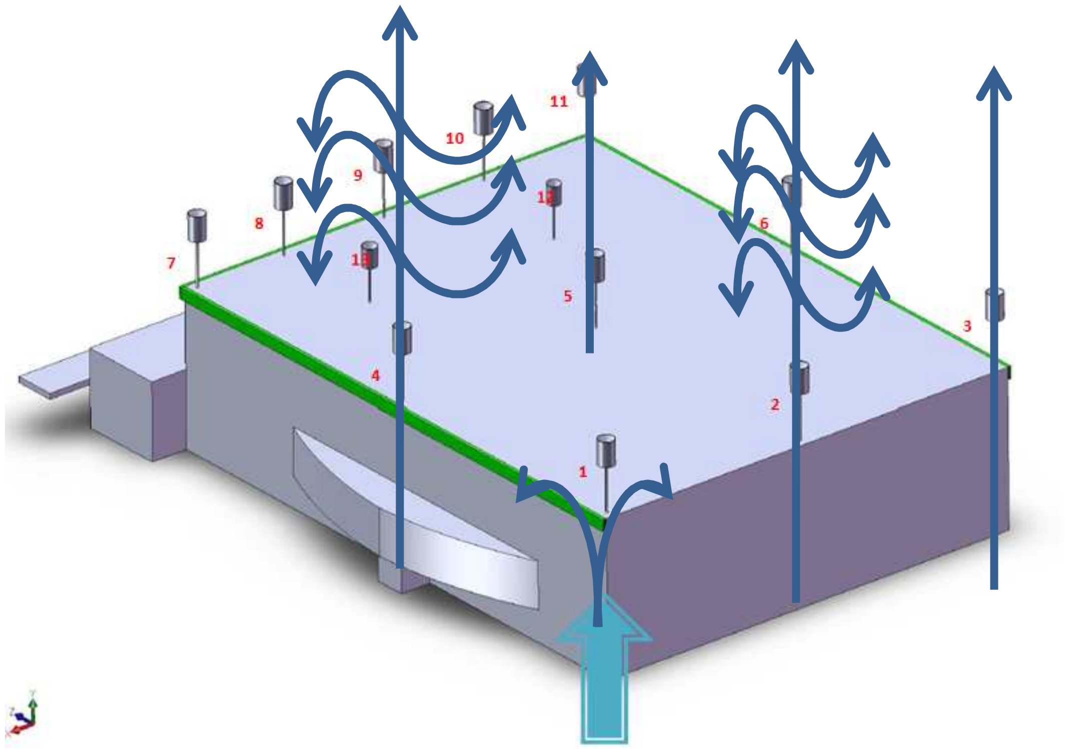


Figure 72. Draw of the turbulences at the North

South

The South direction is the second most important.

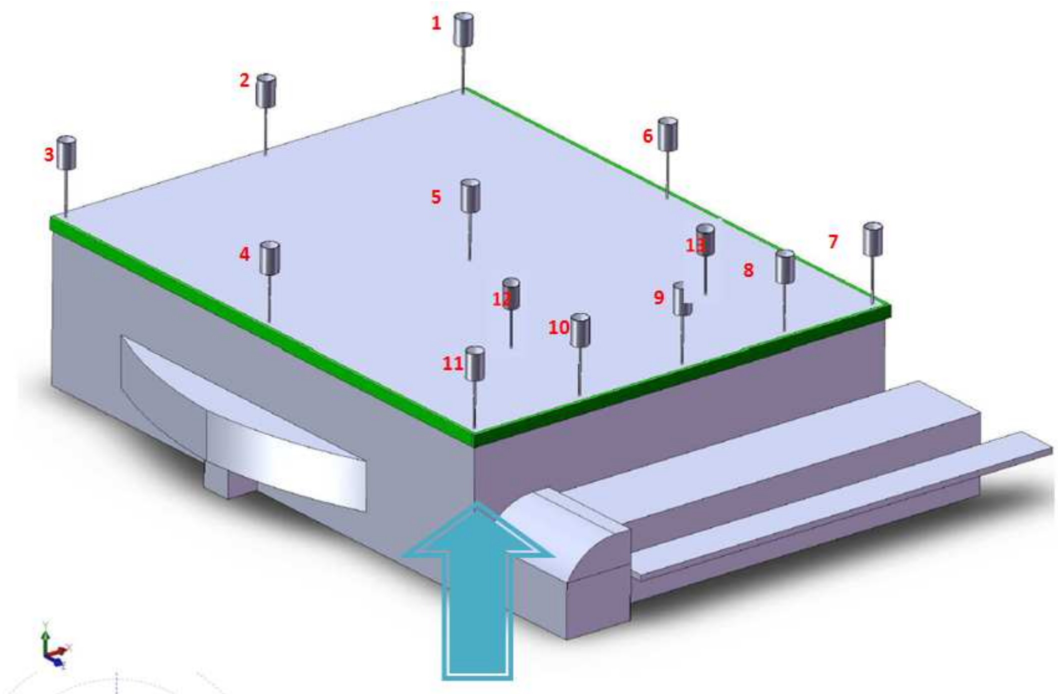
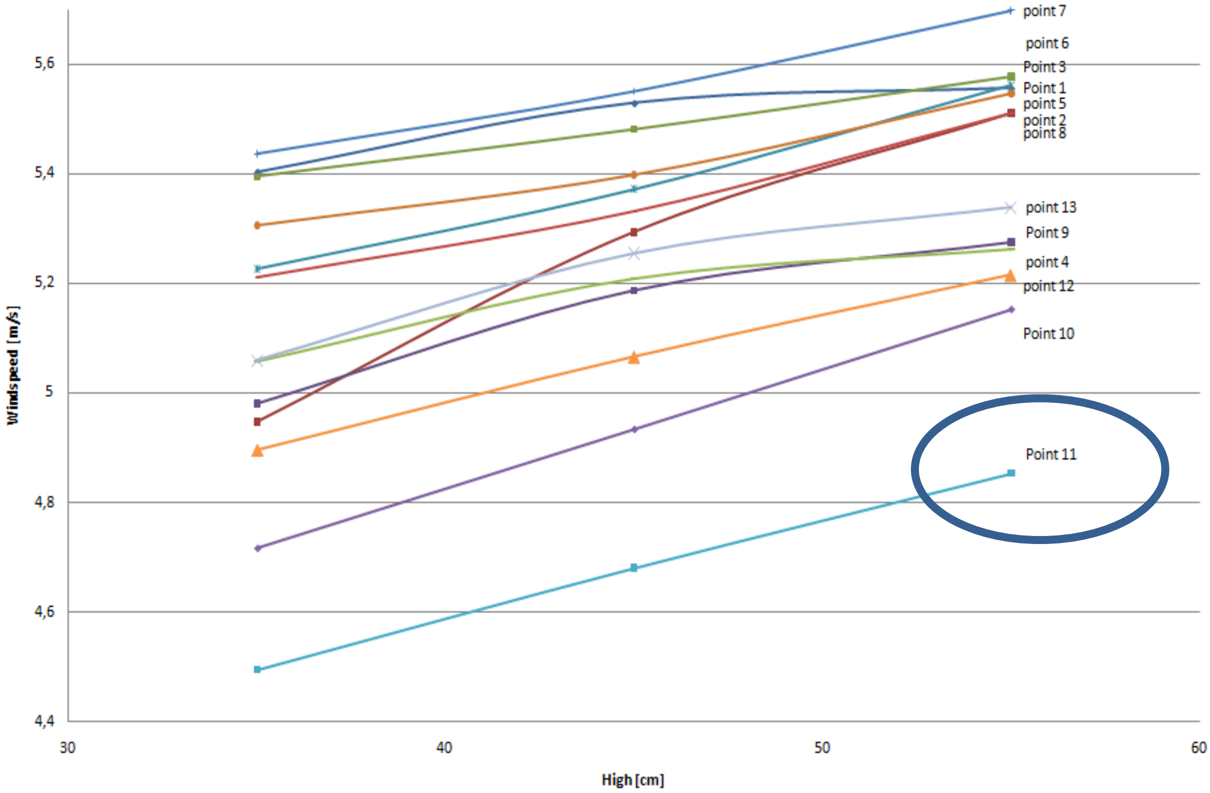
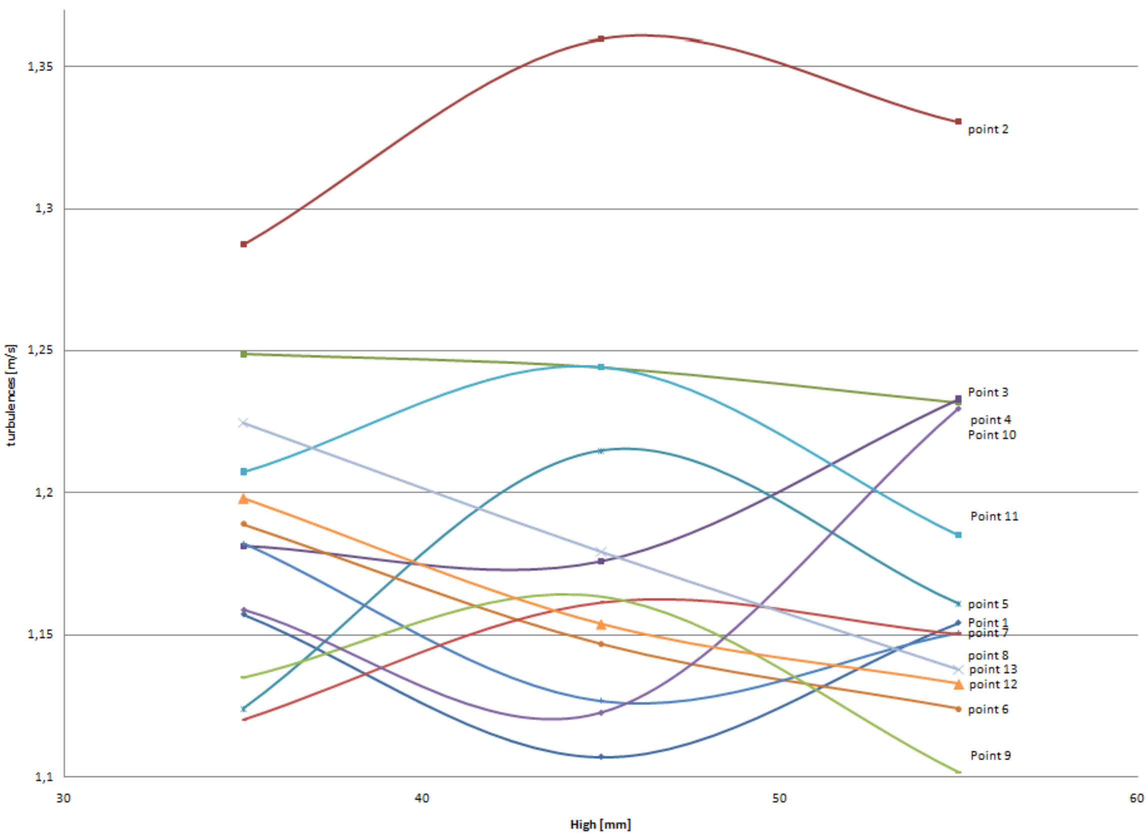


Figure 73. Model at the South



Graph 23. Windspeed at the South



Graph 24. Turbulences at the South

First, the highest velocity is at the point 7 with 5.6 m/s for 39 meters height. However, the previous directions the maximum velocity was approximately 6.2 m/s. It can be conclude than the direction is not the best. This can be due to the entrance. In effect, tree different structure can influence the wind flow. The first roof situated 10 meters under the main one. There is also fan shop and the second roof.

It can also be seen that the point number 11, situated on the corner presents really bad result, the same thing than for the previous direction. The following model shows the turbulences for the South direction. Tree main outcomes can be done. The first is that a lot of turbulences affect the corner where the wind is blowing. The second is that there are turbulences when the wind blows at the middle of the wall. Then we can say that the two others extremity (points 3 and 7/8) are not affected by turbulences and present a good velocity.

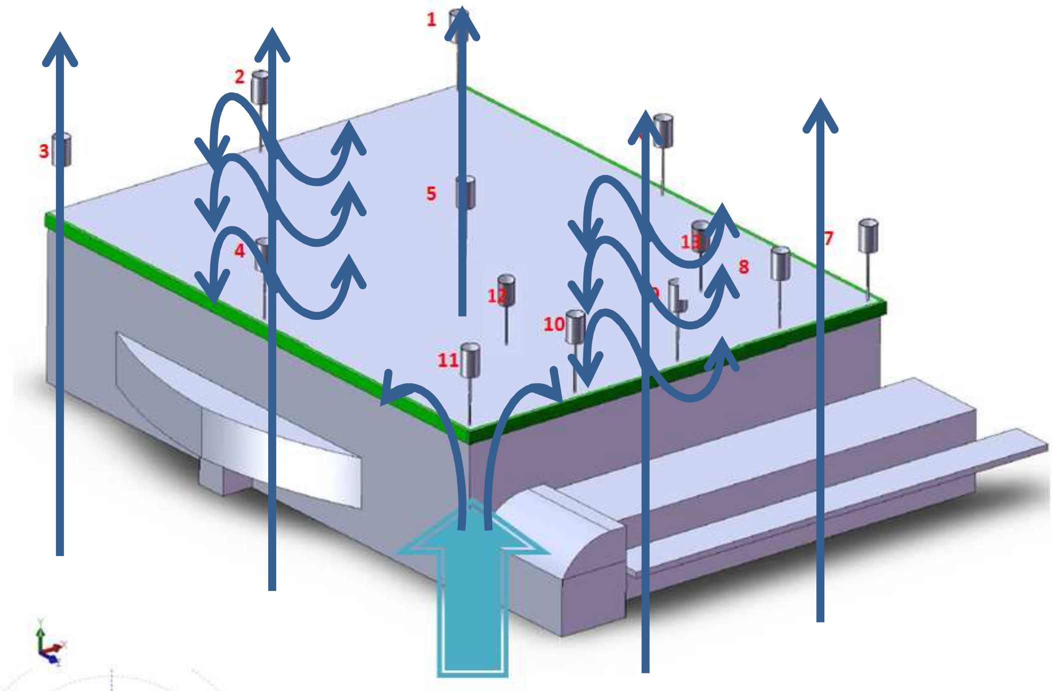


Figure 74. Draw of the turbulences at the South

The following photo shows the complex flow at the corner of the building.

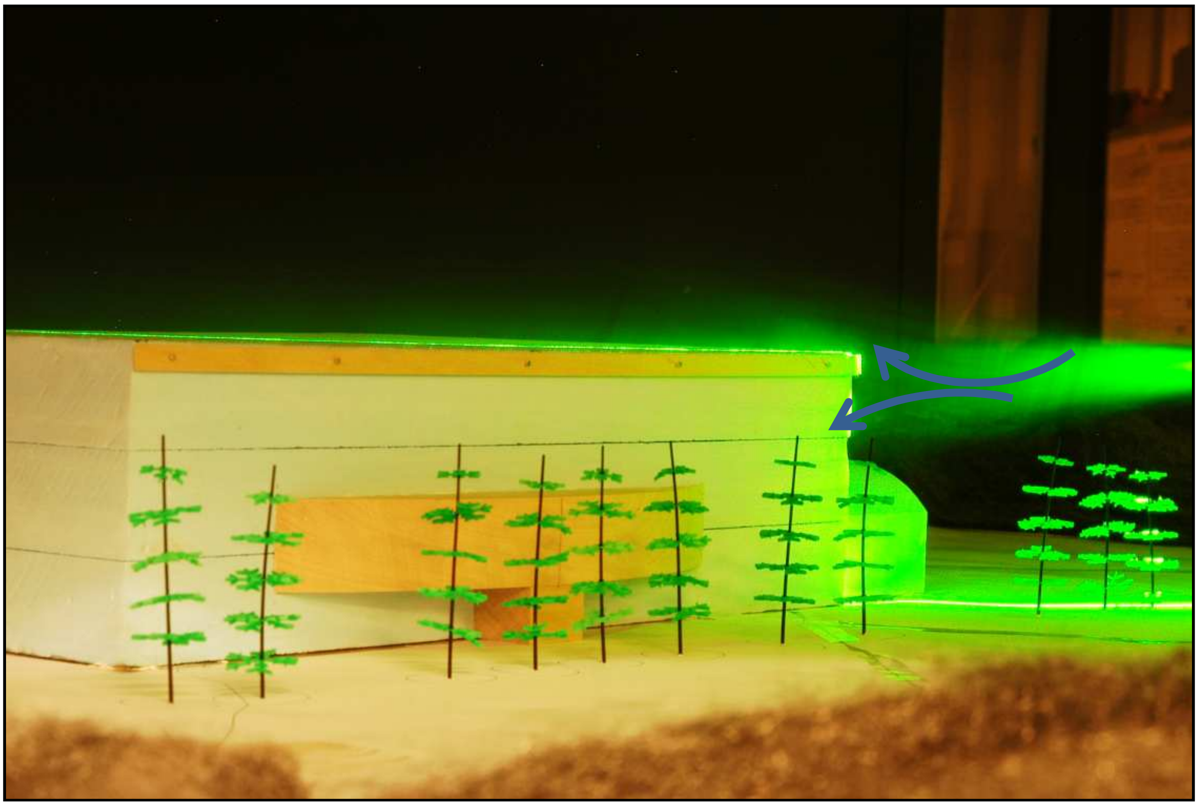


Figure 75. Repartition of the flow at the corner

West

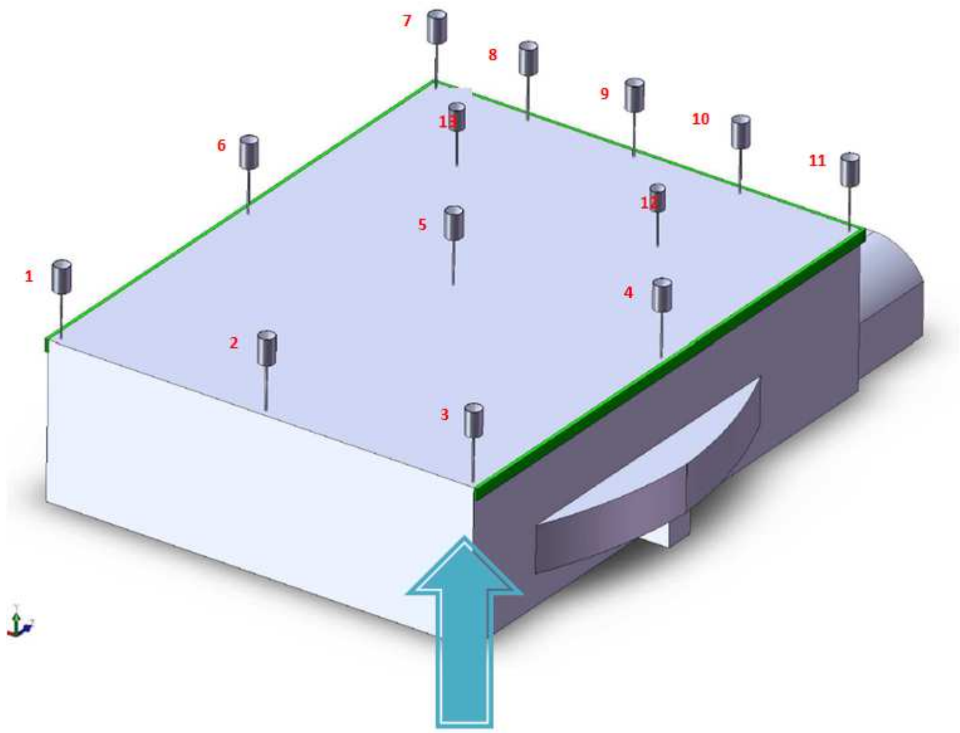
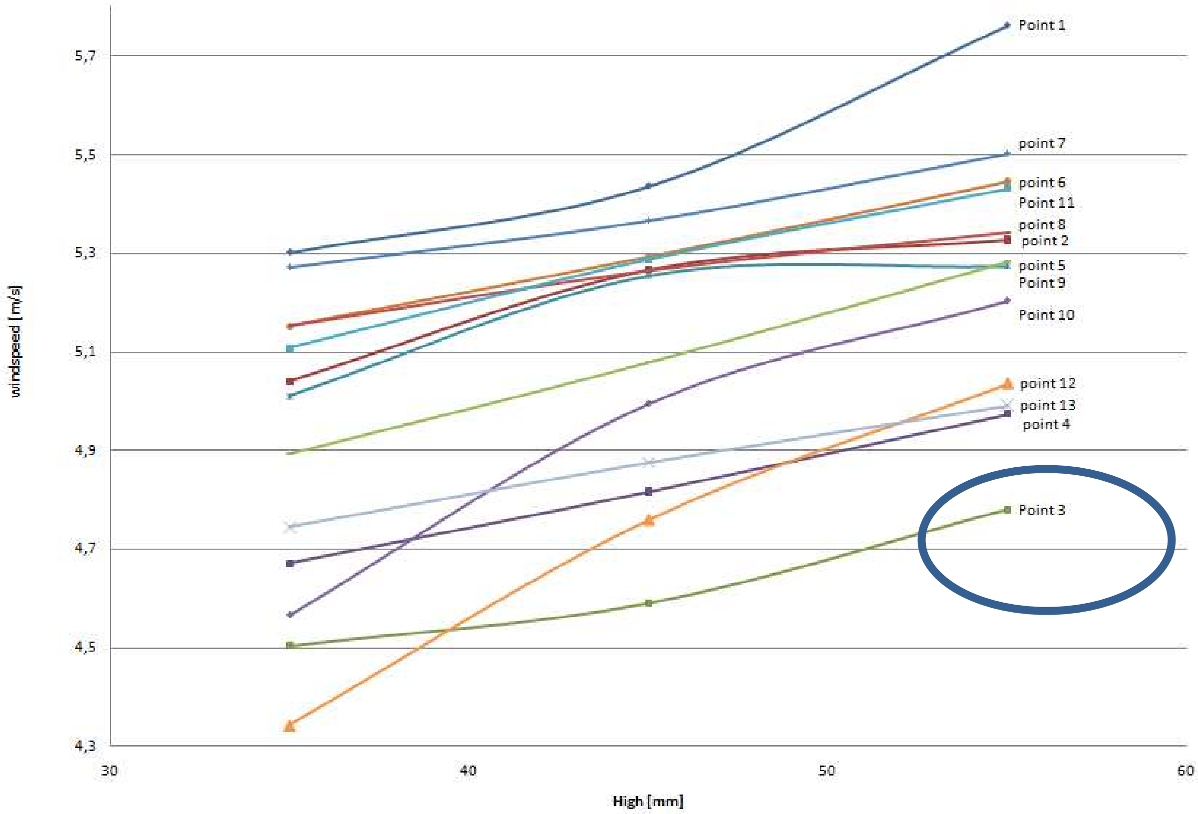
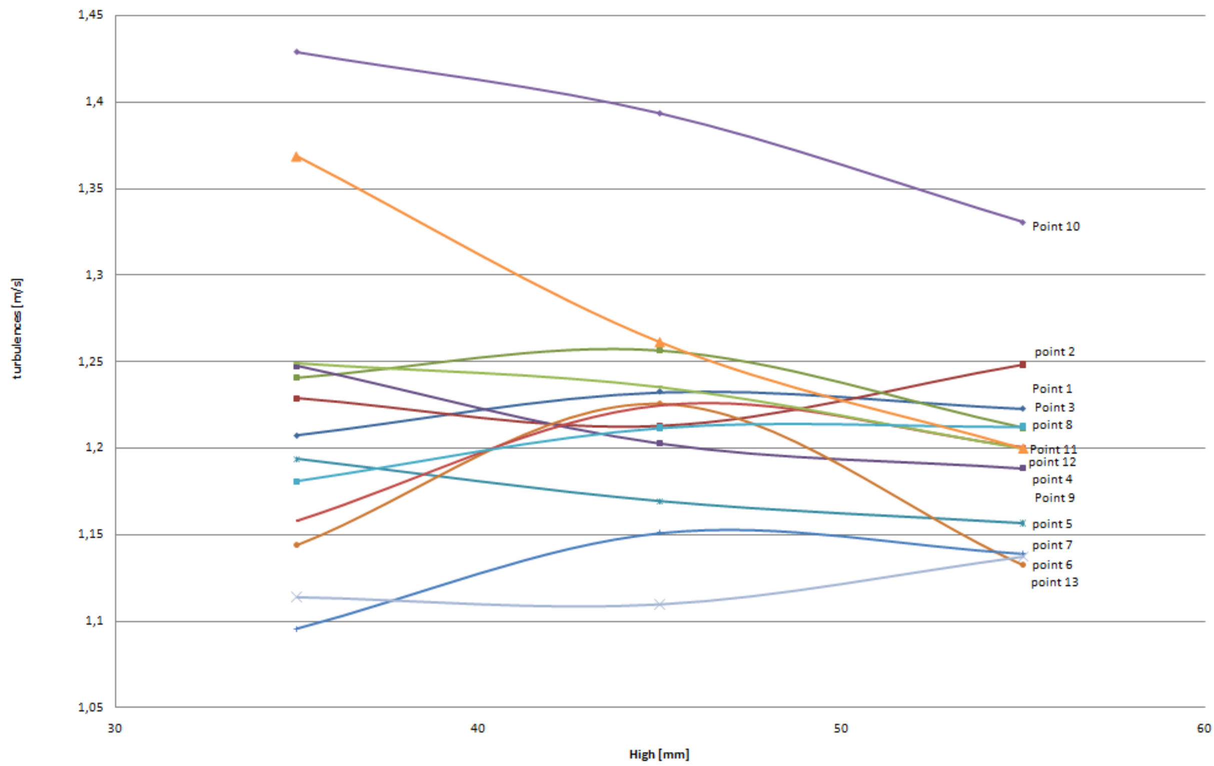


Figure 76. Model at the West direction



Graph 25. Windspeed at the West



Graph 26. Turbulences at the West direction

As the following model shows, the shape of the wind over the roof at the West direction is really similar than for the South direction. The point number 3 has a lot of turbulences, the points 4, 12, 10, 9 and 4 all situated at the middle of the walls as well.

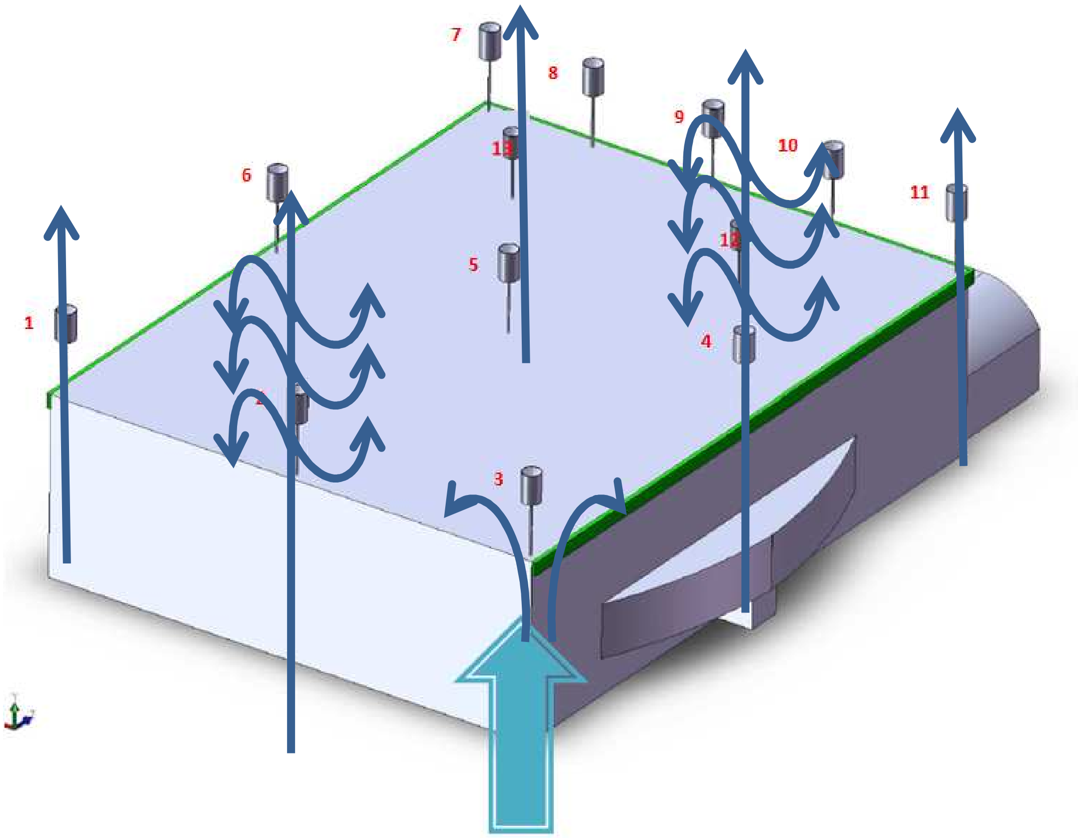


Figure 77. Draw of the turbulences at the West direction

East

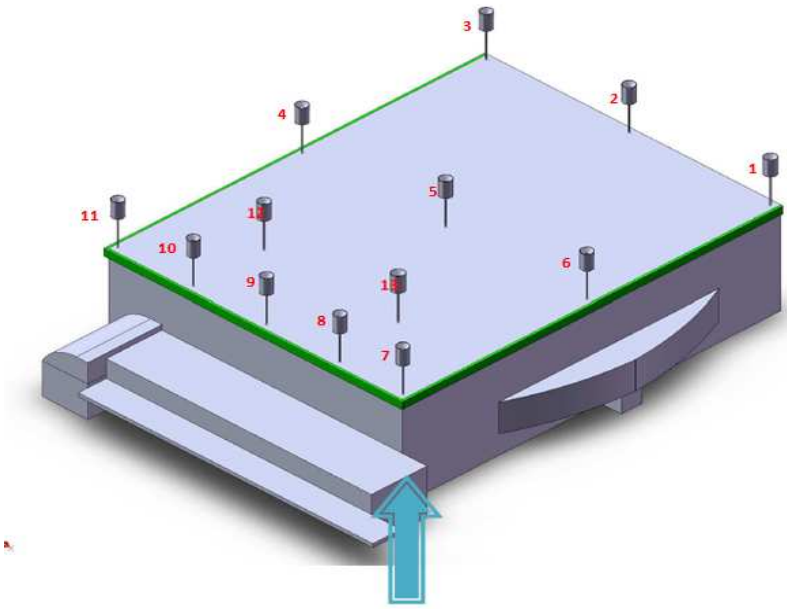
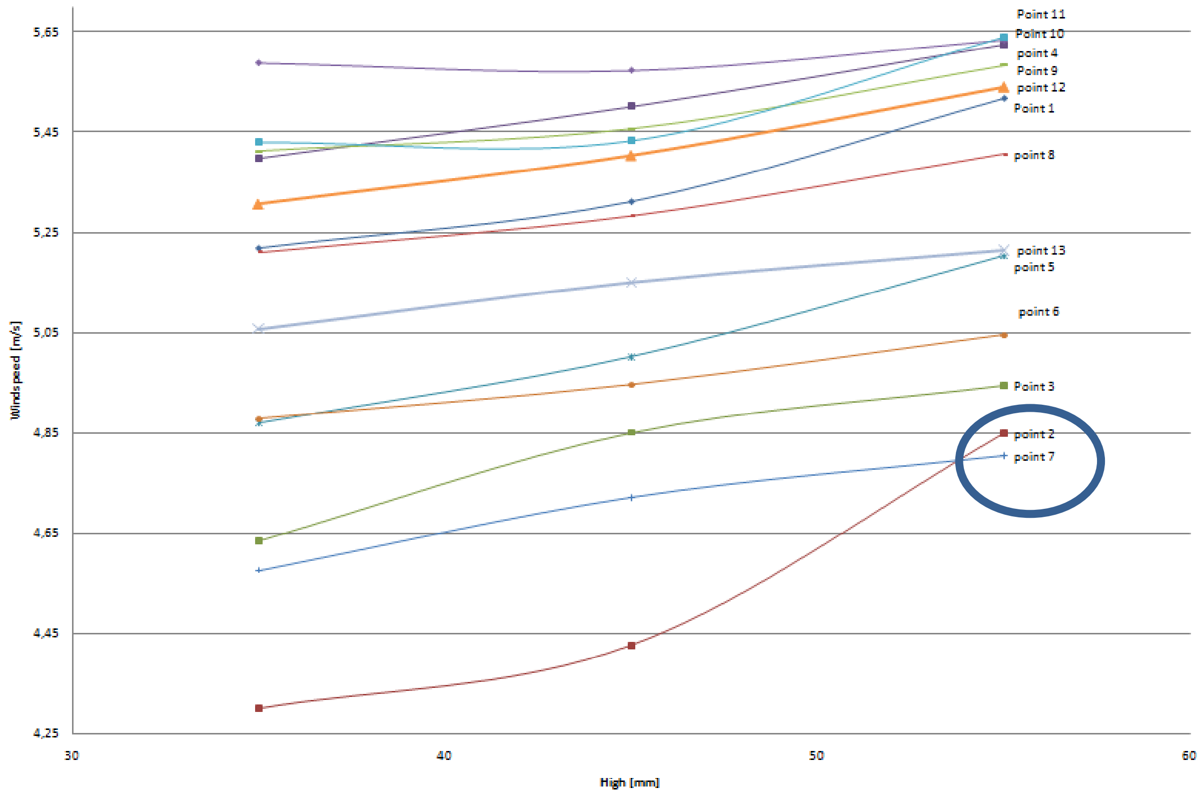
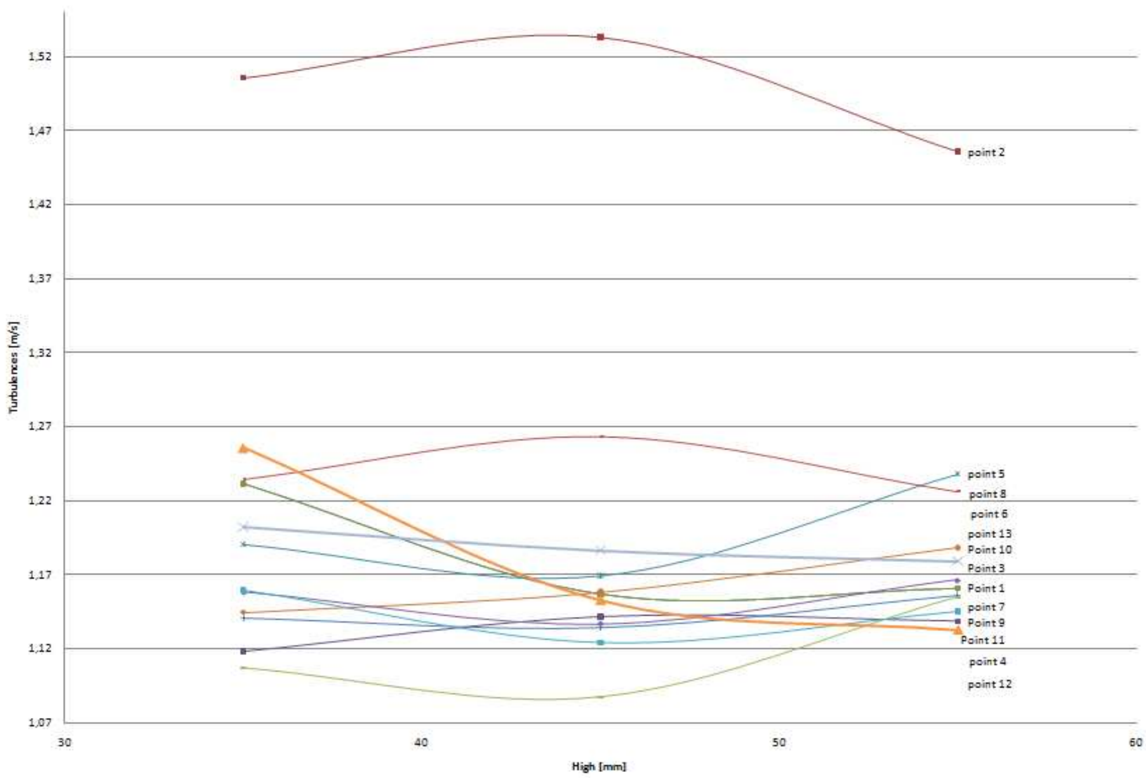


Figure 78. Model at the East direction



Graph 27. Windspeed at the East direction



Graph 28. Turbulences at the East direction

Once again, the point on the corner is really affected by turbulences. The other conclusion are similar than the tree previous direction. On this direction, the different parts of the roof of the main entrance do not affect the points 11, 10 and 9.

The point number 3 has not the same similarities. On this direction, the velocity is not so high.

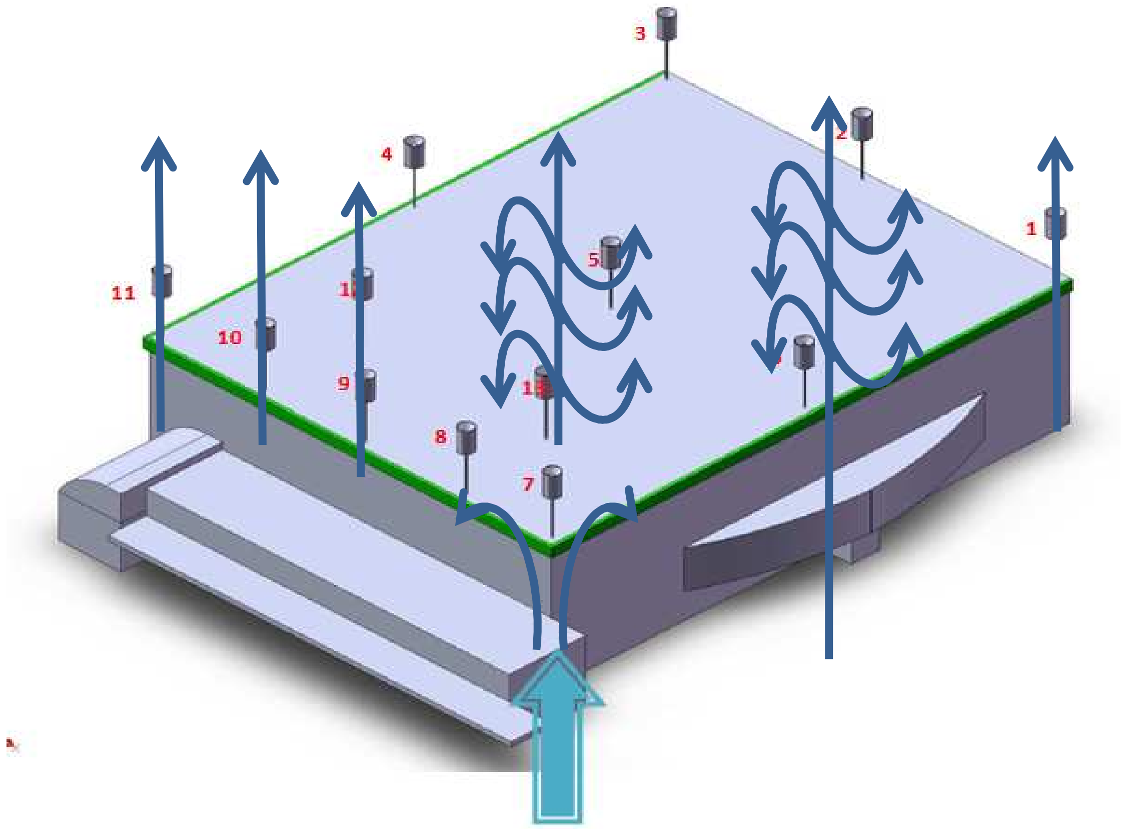


Figure 79. Draw of the turbulences at the East direction

The following photo shows the how the flow is for the points 9 and 12. It can be observed that the wind is not turbulent.

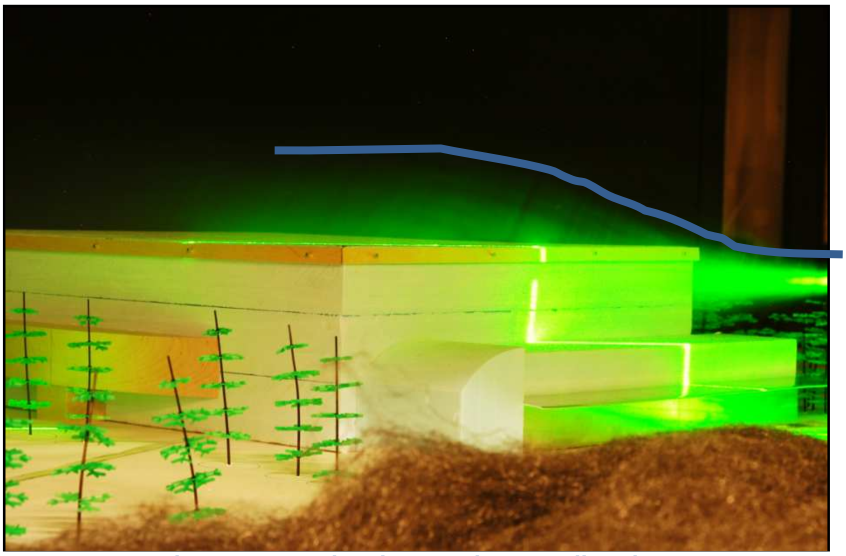


Figure 80. Smoke photo at the East direction

Witch high of mast will permits to produce more energy?

As the table 24 shows, as higher the turbine is installed, higher energy is gotten. This is the energy average for one year:

	7m	9m	11m
Point 1	2199.2	2297.2	2431.2
Point 2	2217.2	2383.4	2564
Point 3	2381.4	2491.6	2585.6
Point 4	2296.4	2391	2478.2
Point 5	1820.78	2059.6	2282.4
Point 6	1909.82	2038.8	2200.2
Point 7	2223	2165.4	2350.4
Point 8	1966.46	2179.8	2321.4
Point 9	1949.68	2107.6	2314.8
Point 10	2087.2	2218	2413.2
Point 11	2220.8	2312.8	2432.8
Point 12	2622.6	2835	3059.8
Point 13	2385.2	2605.6	2792.8

Table 24. Energy average for one year

If the only thing is taken into account is the energy output, it is clear, the highest mast is the most suitable. But it would be not accurate because there are a lot of factors besides the output.

Firstly, it should be include the factor “price” and how profitable it would for each high.

High of the mast (m.)	Price of the mast (SEK)	Total price (SEK)
5.5	19522	204637
7	20378	205493
8	*26289*	211404
9	No provided	
11	*31500*	216615
13	29167	214282

Table 25. Cost of the installation for the different heights.

The differences are not so large in the output for the different highs, as well the price doesn’t change so much. So the paybacks for all of combinations are quite similar and it would take around one hundred years.

And finally, the last factor taken into account should be a deep study of the weigh and loads resultant from the different settings (different high masts). This point is not really studied in detail, but some conclusions were obtained after consulting Kjell Westberg and studying the structure, and the internal trusses should be studied after this project like the optimum place to install the turbines.

Is the centre of the roof the best location to install a turbine, and if so, at what height?

The centre of the roof (Point 5) was thought to be the best place to install the turbines because low turbulences were expected.
On a contrary way, after the calculation of the concentration factors, it was clear that it was not a good place, actually for 11 meters tower it's the second worst position as is showed in the table Table 8 or in the graph 7, graph 8 and graph 9.

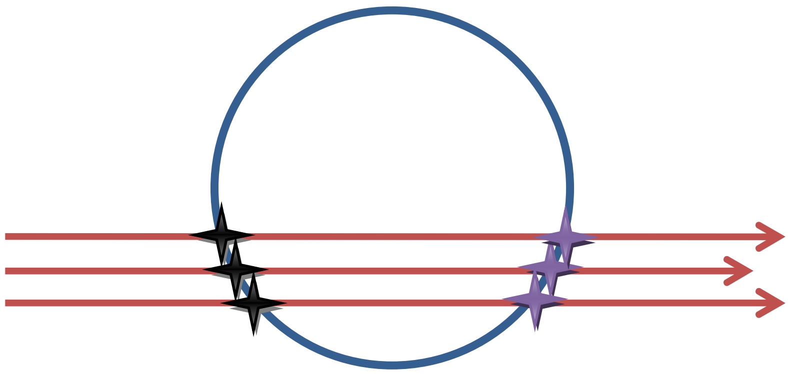
Installation

As it was written several times, a better study of this point should be carried out.

Focusing on the front side of the Läkerol, the second truss is the optimum place to install them because the load capacity of the first one is almost totally used. Furthermore, the energy obtain in the points 12 and 13 are the highest ones.

Betz' Law Calculations

After doing the calculations, it was conclude that this law is not able to used in a vertical-axe turbine. In our opinion, it is due to the flow hit the blades twice instead only once as is possible to see in the picture:



The red lines represent the air flow, the blue circle the turbine and the black and purple starts, the first and the second time the flow hits the blades.

Furthermore some more coefficients should be taken into account:

$$C_L = \frac{F_L}{1/2\ \rho A W^2}\ ;\ C_D = \frac{D}{1/2\ \rho A W^2}\ ;\ C_T = \frac{T}{1/2\ \rho A U^2}\ ;\ C_N = \frac{N}{1/2\ \rho A U^2}$$

Where $W = U\sqrt{1 + 2\lambda\cos\theta + \lambda^2}$, $\alpha = \tan^{-1}\left(\frac{\sin\theta}{\cos\theta + \lambda}\right)$ and $\lambda = \frac{\omega R}{U}$ is the tip speed ratio parameter.

The conclusion is that is not possible to apply directly Betz' Law for our turbine.

Conclusion

The wind investigation presented on this report presents some incertitude. In effect, the left of tools and time leaded to guess that the wind data from Valbo was suitable for the Läkerol Arena. However, the good result of the wind profile calculated at the wind tunnel and the extrapolation of the data for three different heights are improving the assurance of our results.

The utilization of the wind tunnel of the University permitted to pick up thirteen different positions on the roof of the Läkerol Arena model at the scale 1:200. The wind tunnel investigation has been done for thirteen points, at three different heights and for the eight direction of the wind rose; whether 312 positions. These measurements gave the velocity of the points and the turbulences.

These data, in accordance with the power curve of the Vertical Axe Wind Turbine permitted to know the maximum power possible to get. Also, it has been possible to understand which point would be the better place. Fortunately, the maximum output is situated for the points 12 and 13 on the model, points chosen since the beginning for marketing reasons. It should be possible to get proximally 6000 kWh per year. These two points are the result of a load investigation. However, so further study should be made to be sure of our result and to know exactly how to install them on the roof.

Also, it has been possible to know how the wind is blowing on the roof of the Läkerol Arena. When the flow is perpendicular at the building, a concentration factor appears with a gap under it. However, behind this concentration emerge turbulences which affect the velocity of other points. Then, when the wind is blowing in front of a corner, the design is more complex. The point on the corner has a low velocity because the flow is splitting in two parts. Turbulences appear and in some case affect the points around.

Other horizontal axe turbines have been tested, some of them could permit to have a larger amount of energy, however the esthetical aspect of the building and the energy needed to rotate the turbine have to be taking to account.

All the aspects of this study permits to understand and visualize how the wind is blowing over the roof of the Läkerol Arena. Hopefully it will permit the installation of the two vertical axe wind turbines. Despite the output is lower, the design of the building will be better. Moreover, the installation of wind turbine on a hockey arena is a good symbol for Sweden.

This study could be developed with a CFD simulation to appreciate better the flow over the roof. Moreover, some other study has to be done to assure the good installation of the turbines.

References

Betz' Law

- Betz, A. (1966) *Introduction to the Theory of Flow Machines.* (D. G. Randall, Trans.) Oxford: Pergamon Press

Warwick Microwind Trial project

- All the information used from this project was taken from the official web site: www.warwickwindtrials.org.uk/ www.reuk.co.uk

Gävle Energi AB

The website of the company: www.gavleenergi.se

Urban Green Energy

In this website all the information about the turbine and the company can be found, as well, an email address is able: www.urbangreenenergy.com

Other Turbine Information

- Ampair 6000: www.ampair.com
- AV-7: www.aventa.ch
- Bornay 6000 and Bornay 3000: www.bornay.com

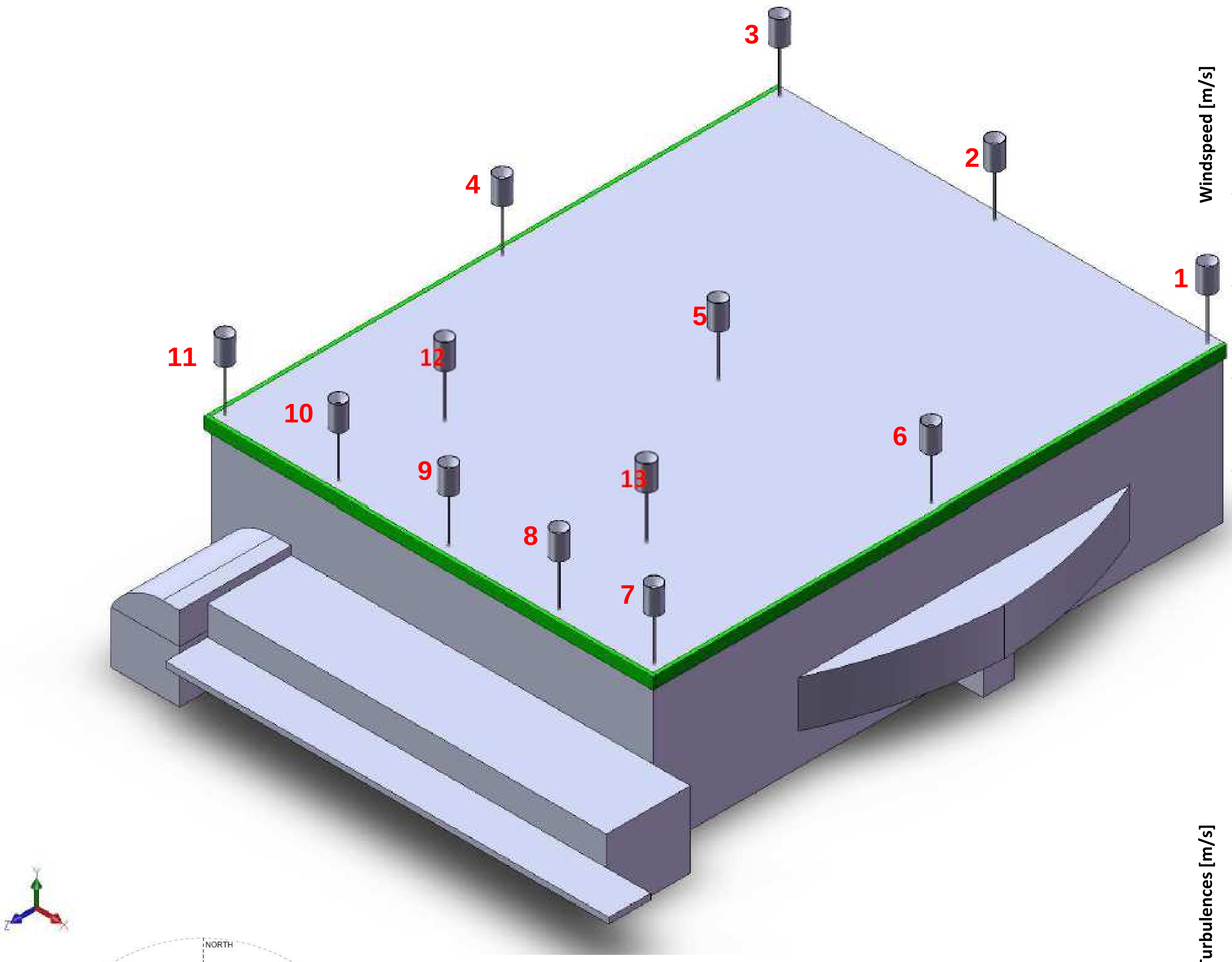
Wind Data

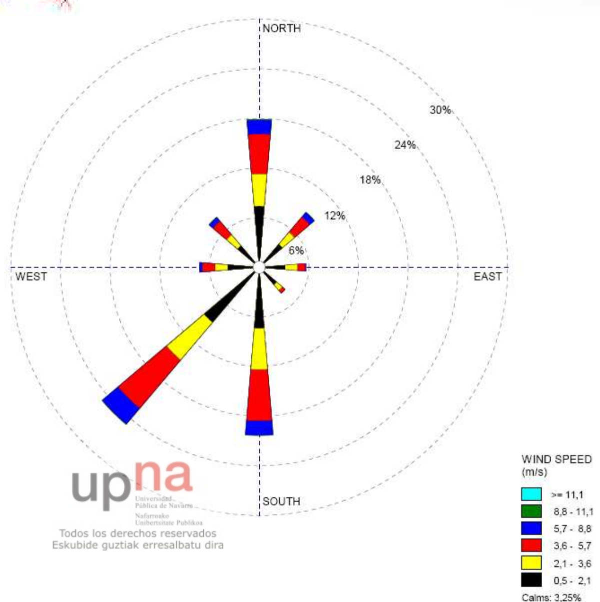
The hourly wind data was obtained from the Sveriges meteorologiska och hydrologiska institu (SMHI): www.smhi.se

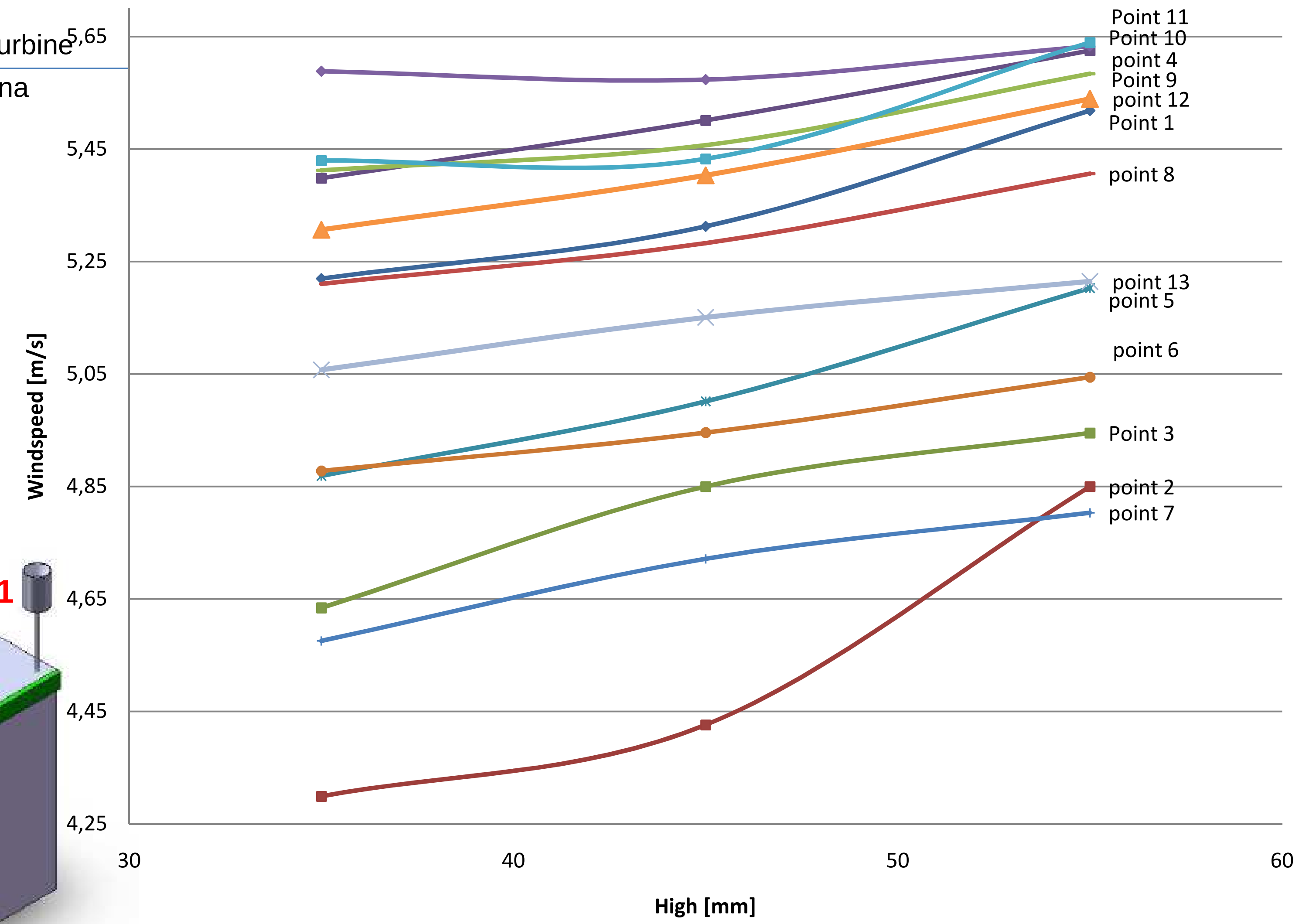
Appendices

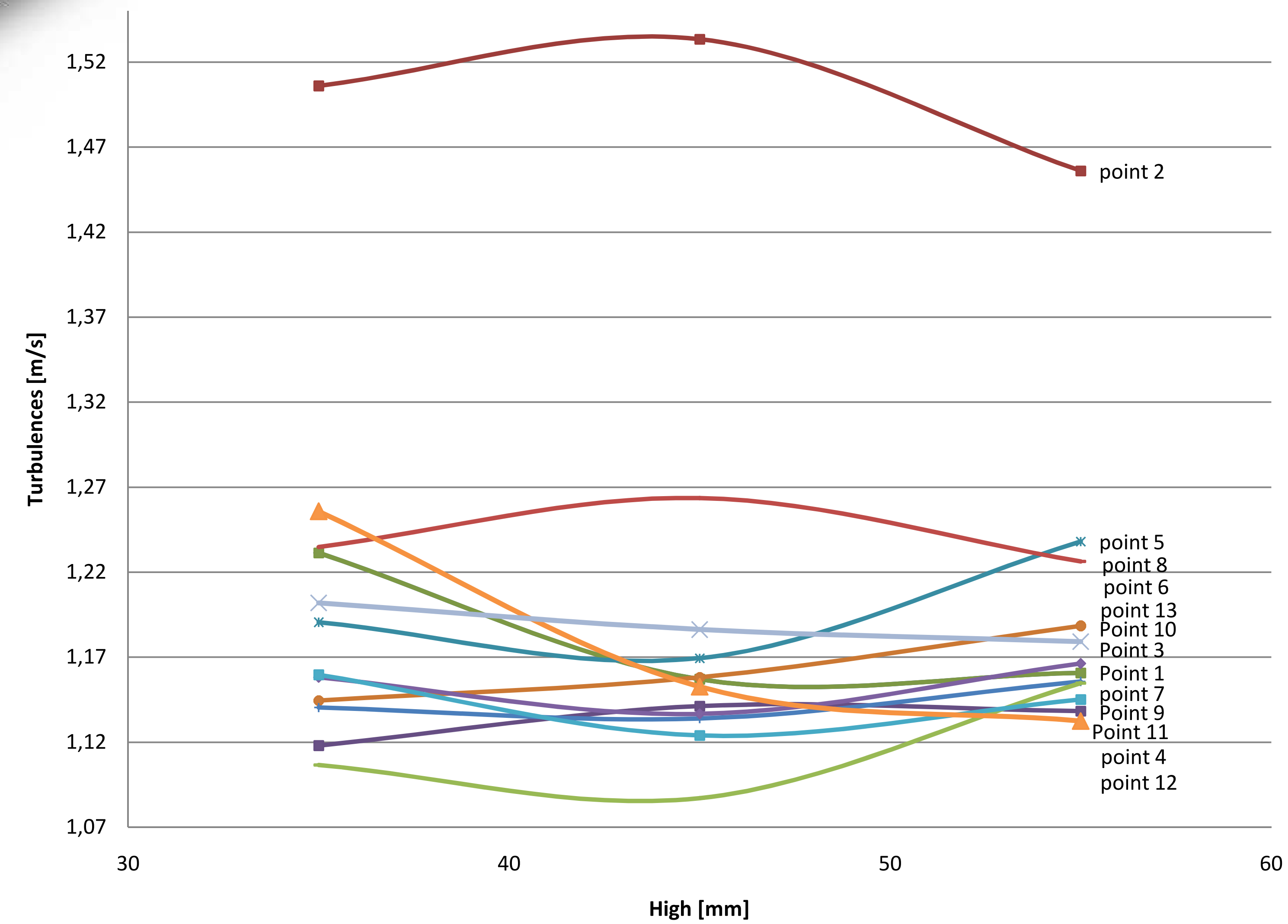
Appendix A: Model 3D of the Läkerol Arena and results of the wind tunnel investigation

Wind tunnel data analysis (EAST)



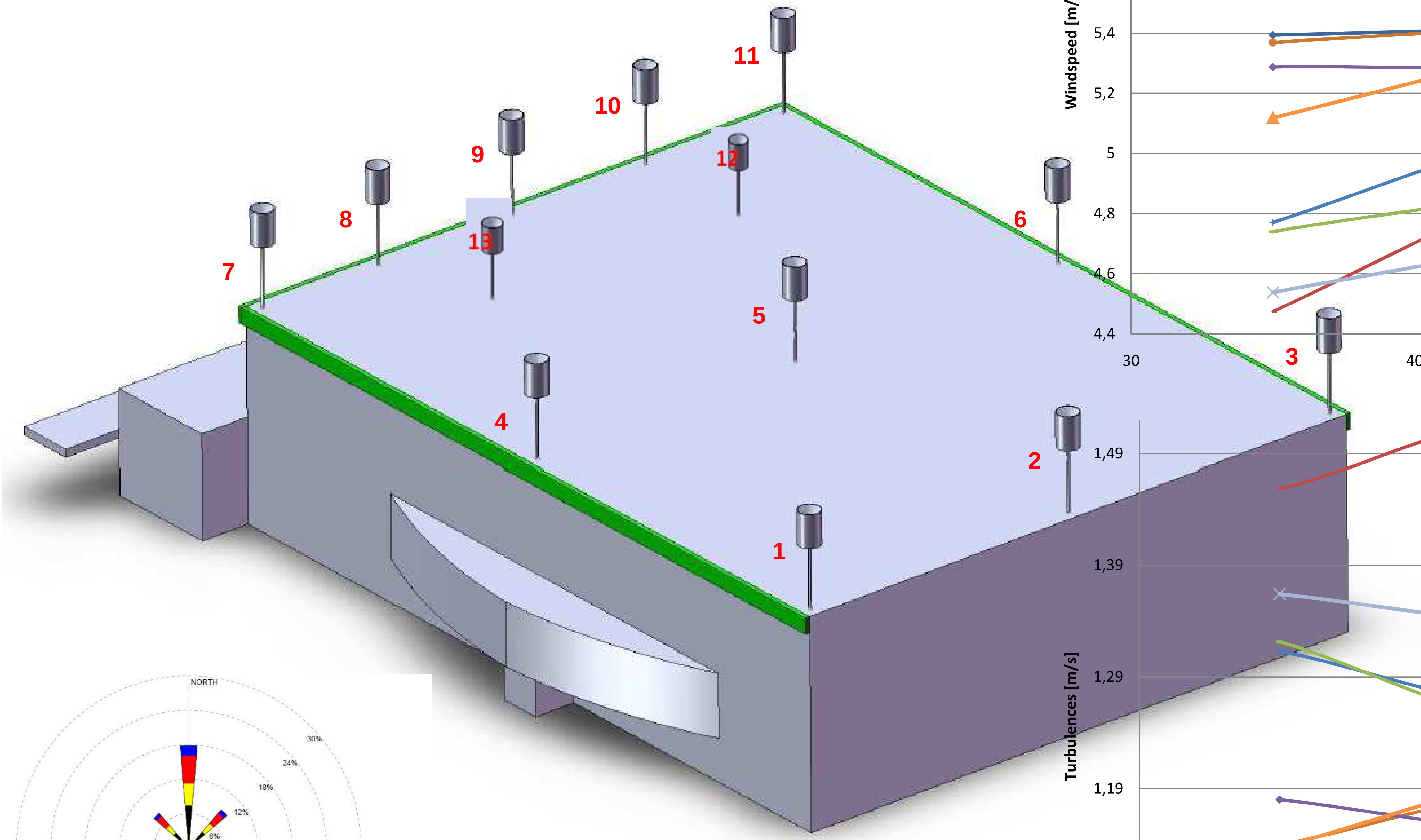


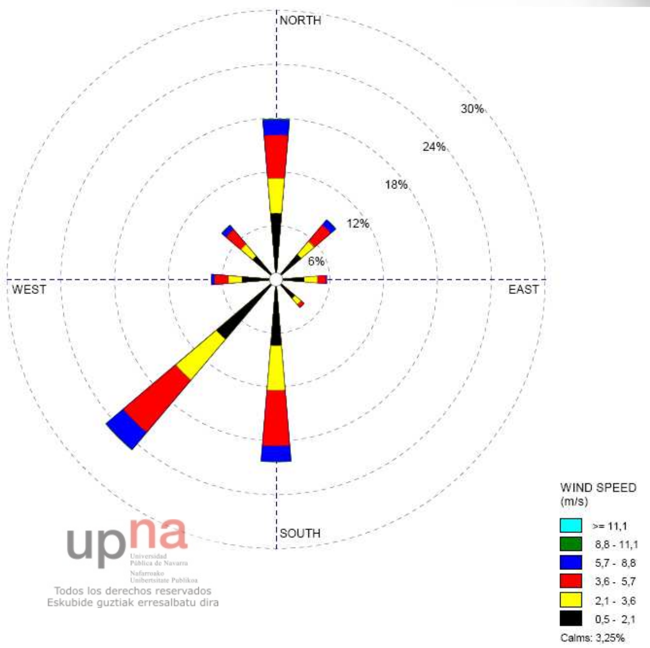


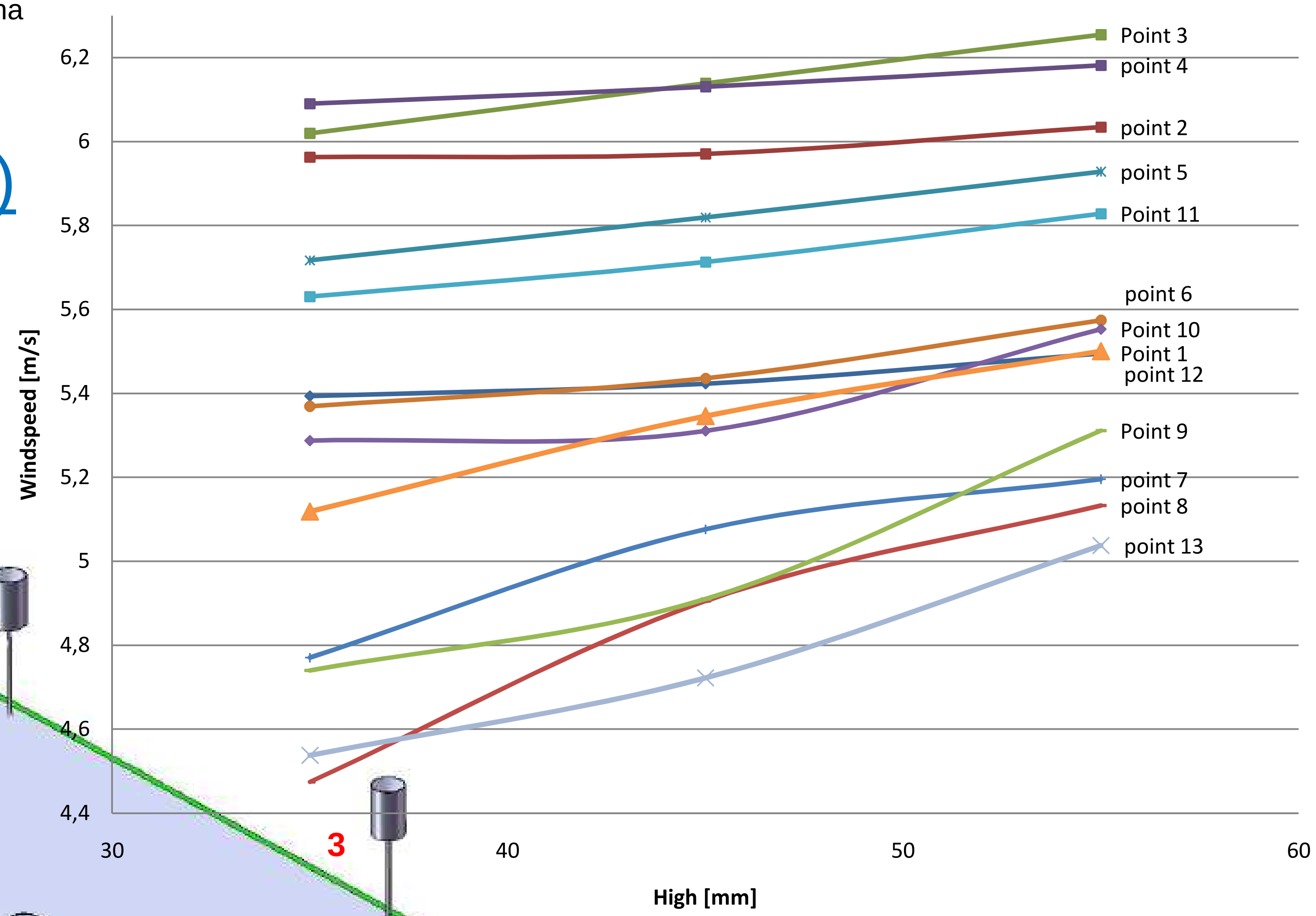


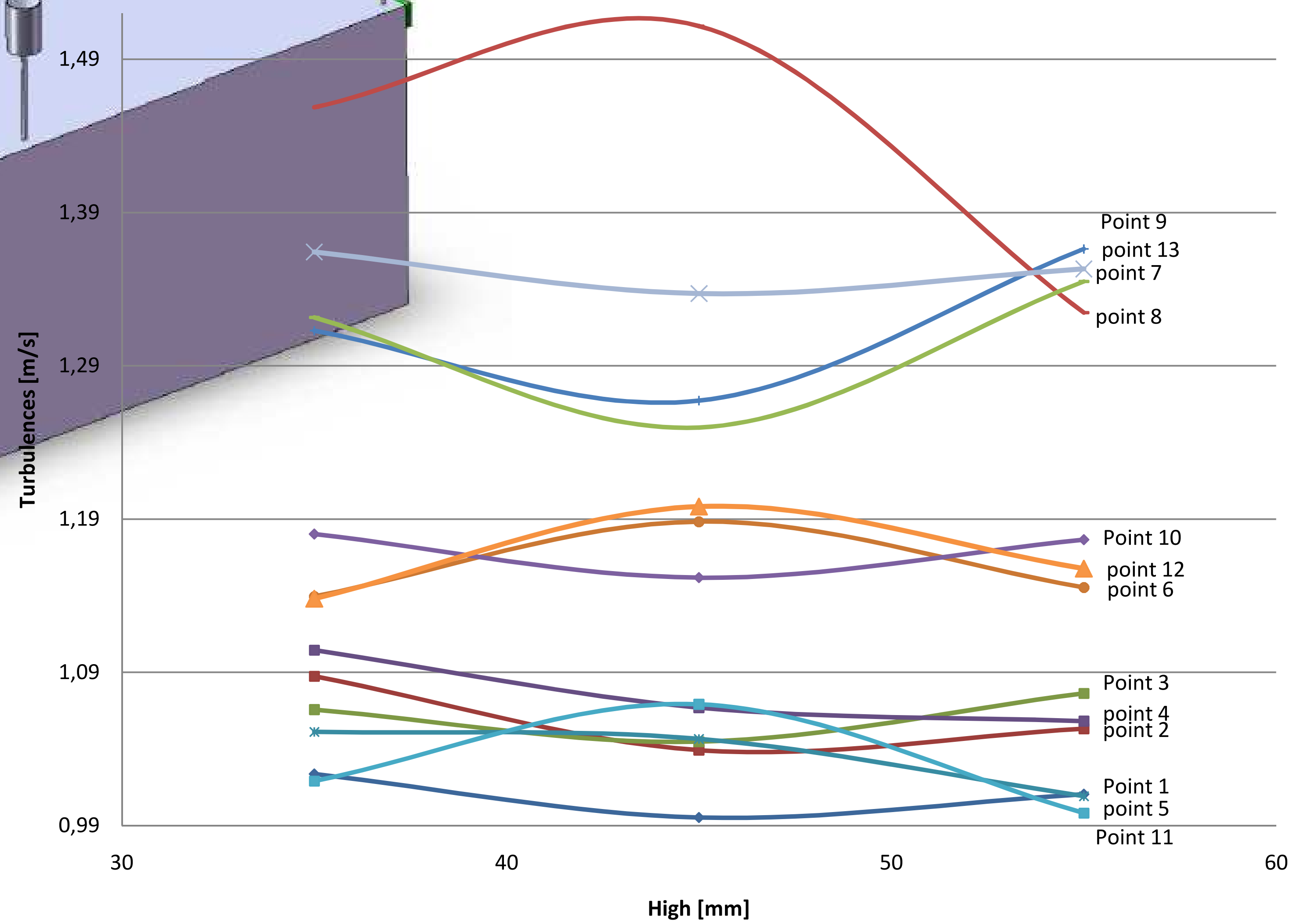
Wind tunnel data analysis (NORTH)

Velocity (m/s) & turbulence (m/s) in the north face of the building

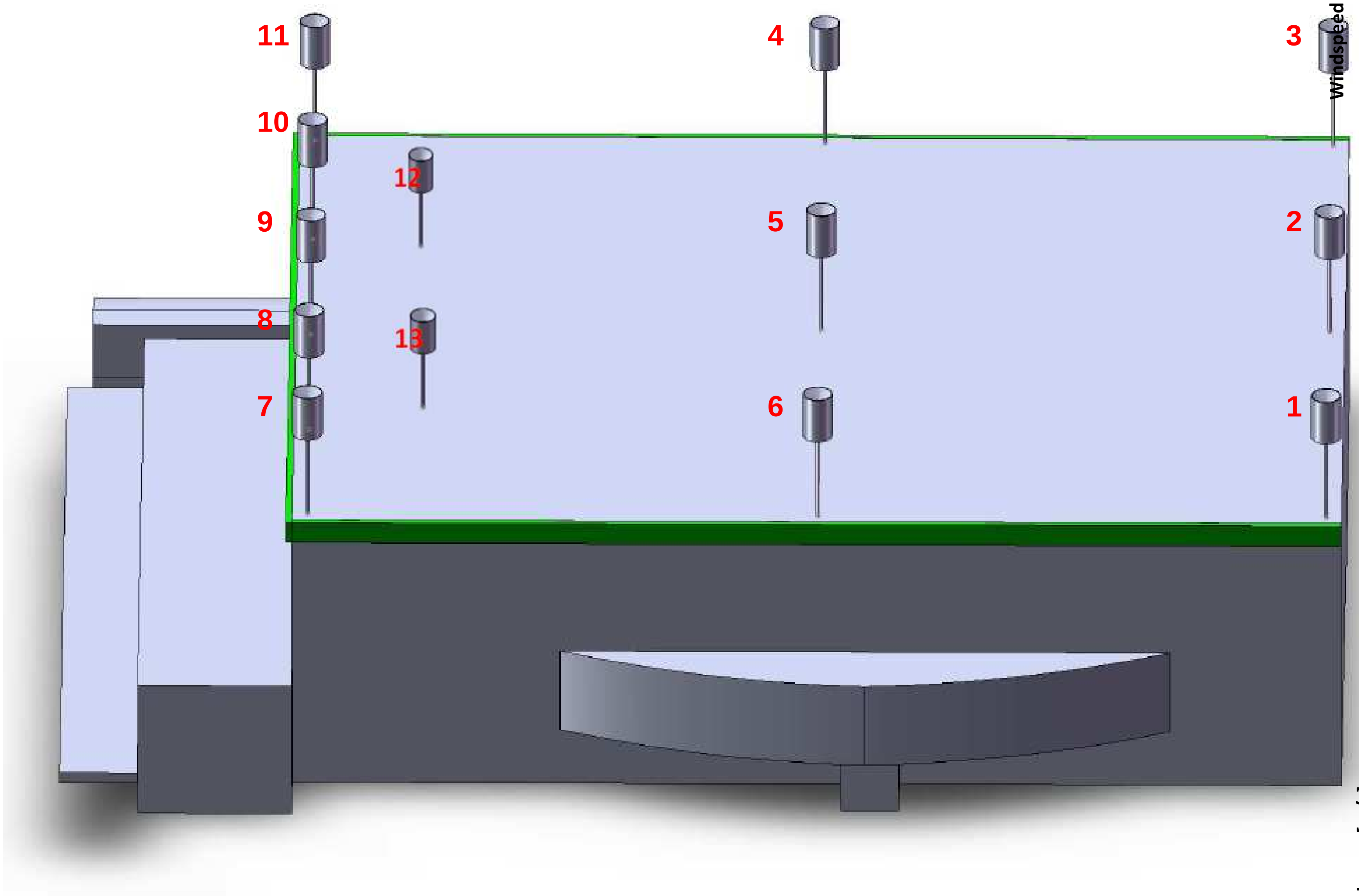


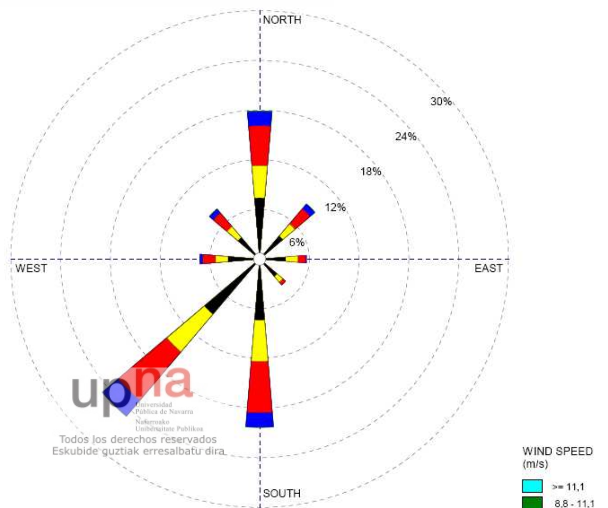


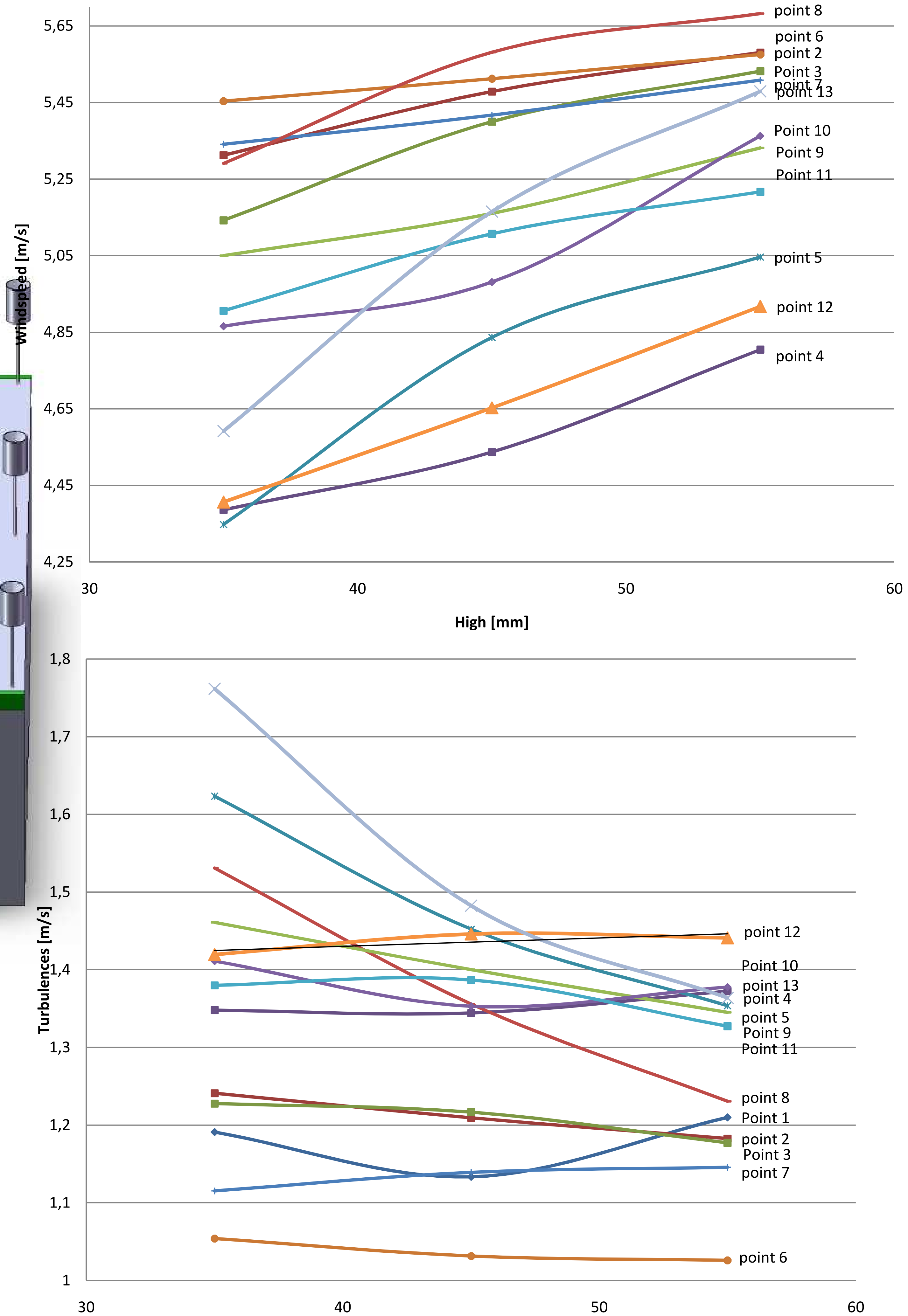




Wind tunnel data analysis (NORTH EAST)

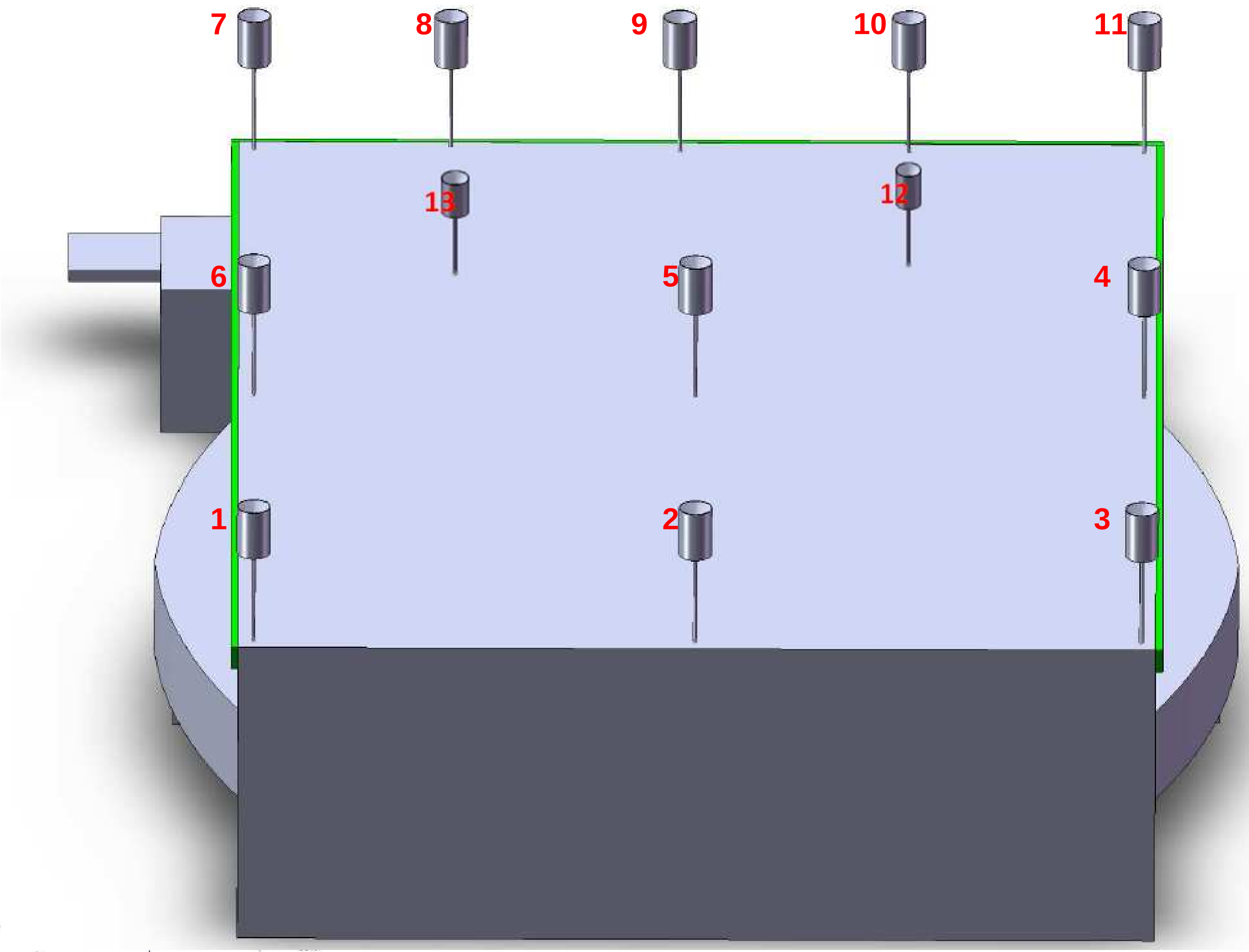


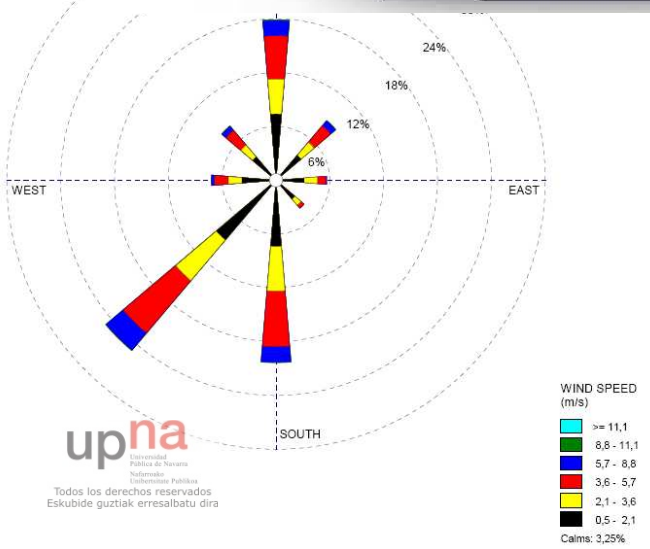


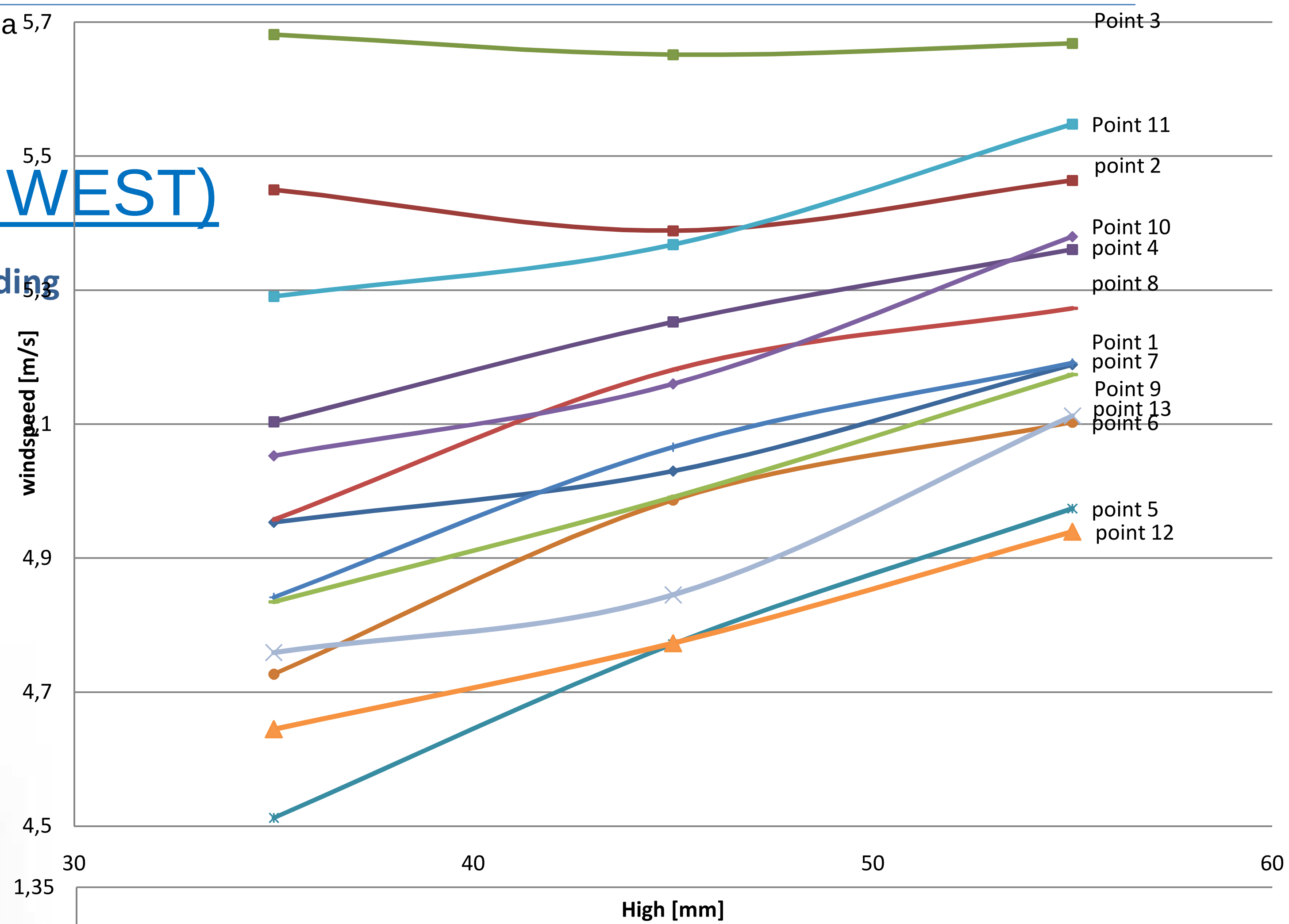


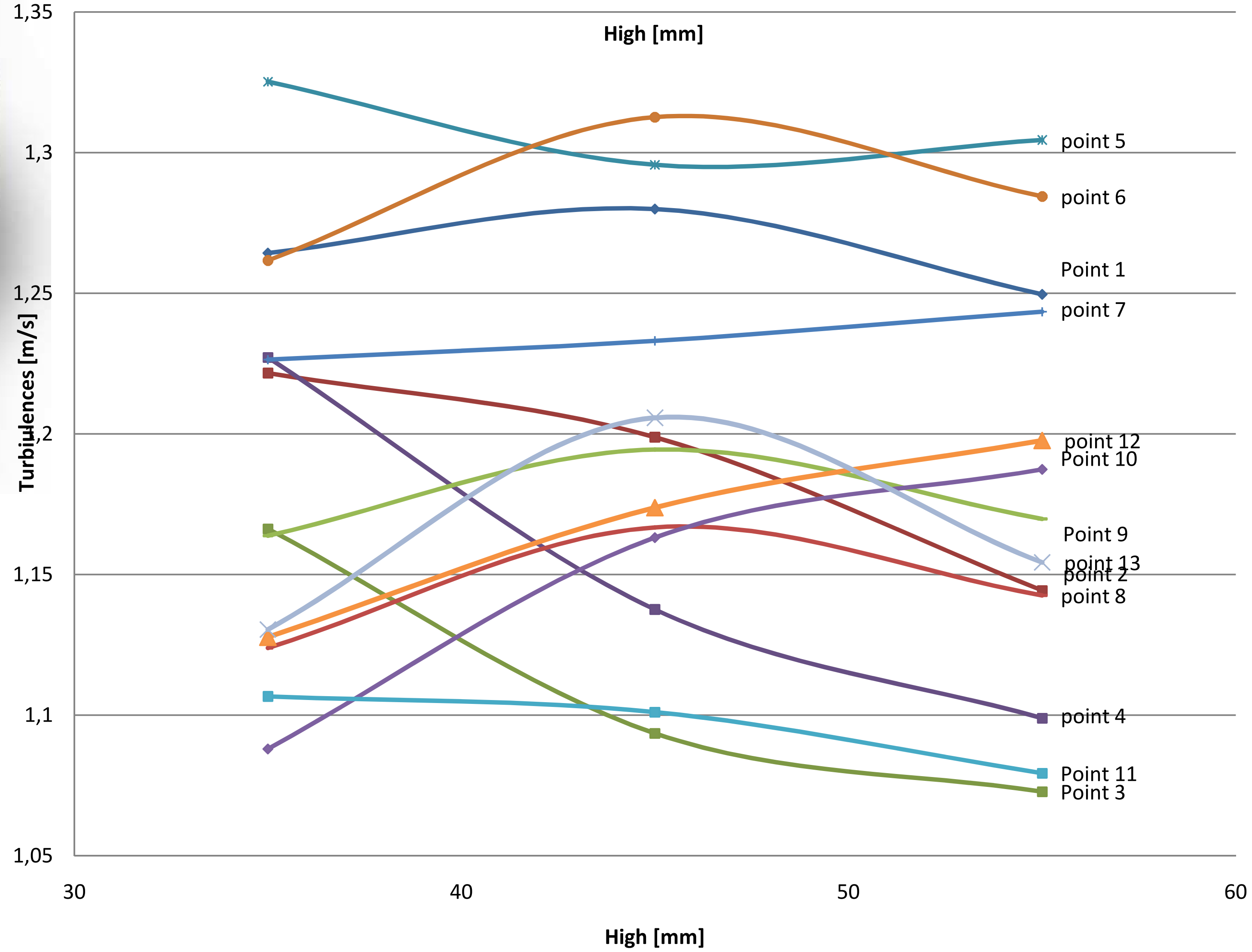
Wind tunnel data analysis (NORTH WEST)

Velocity (m/s) & turbulence (m/s) in the north west face of the building



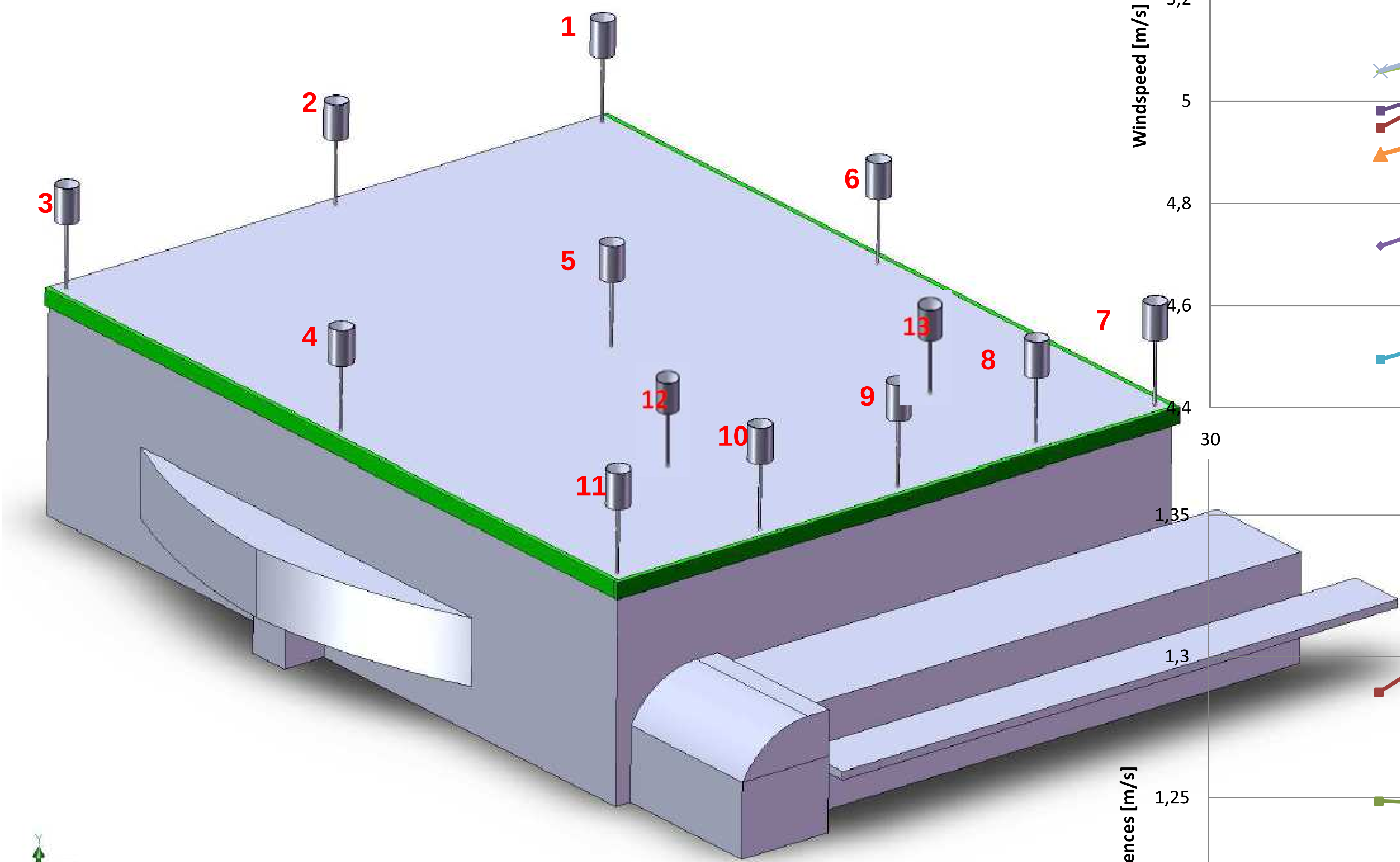


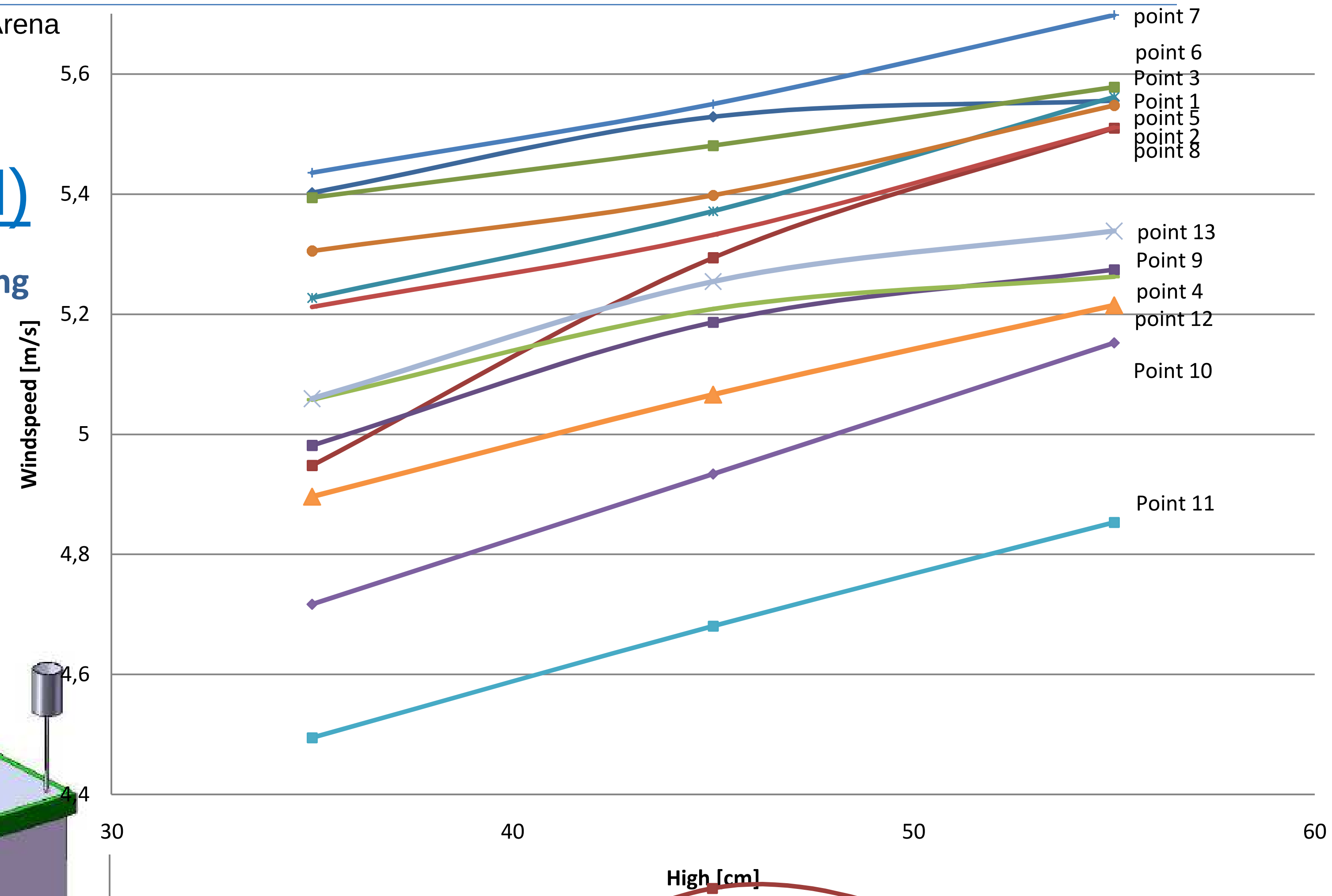


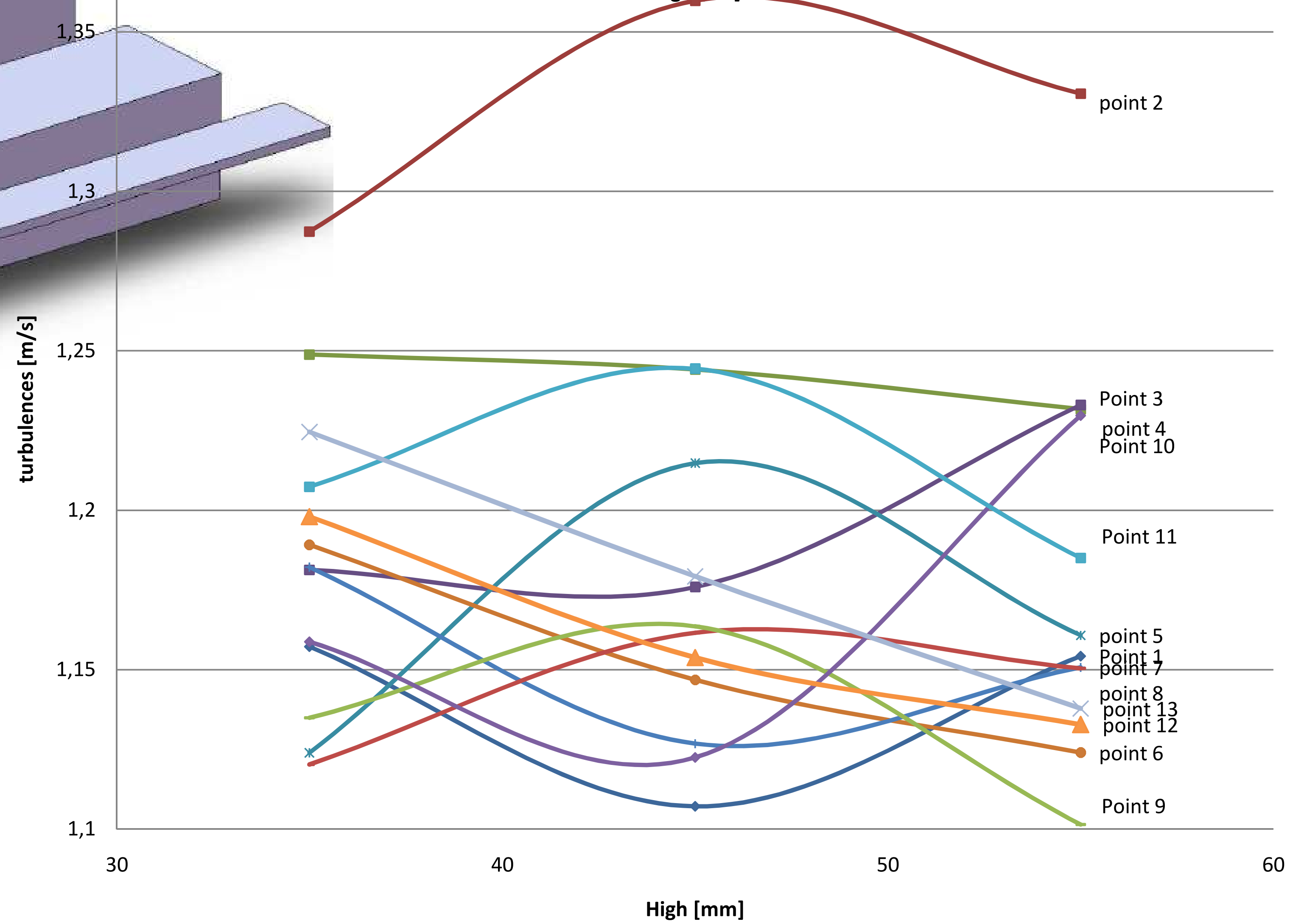


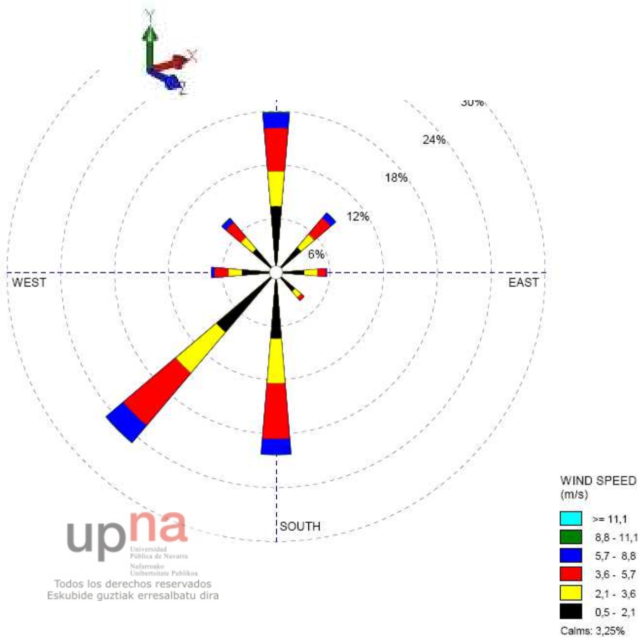
Wind tunnel data analysis (SOUTH)

Velocity (m/s) & turbulence (m/s) in the south face of the building



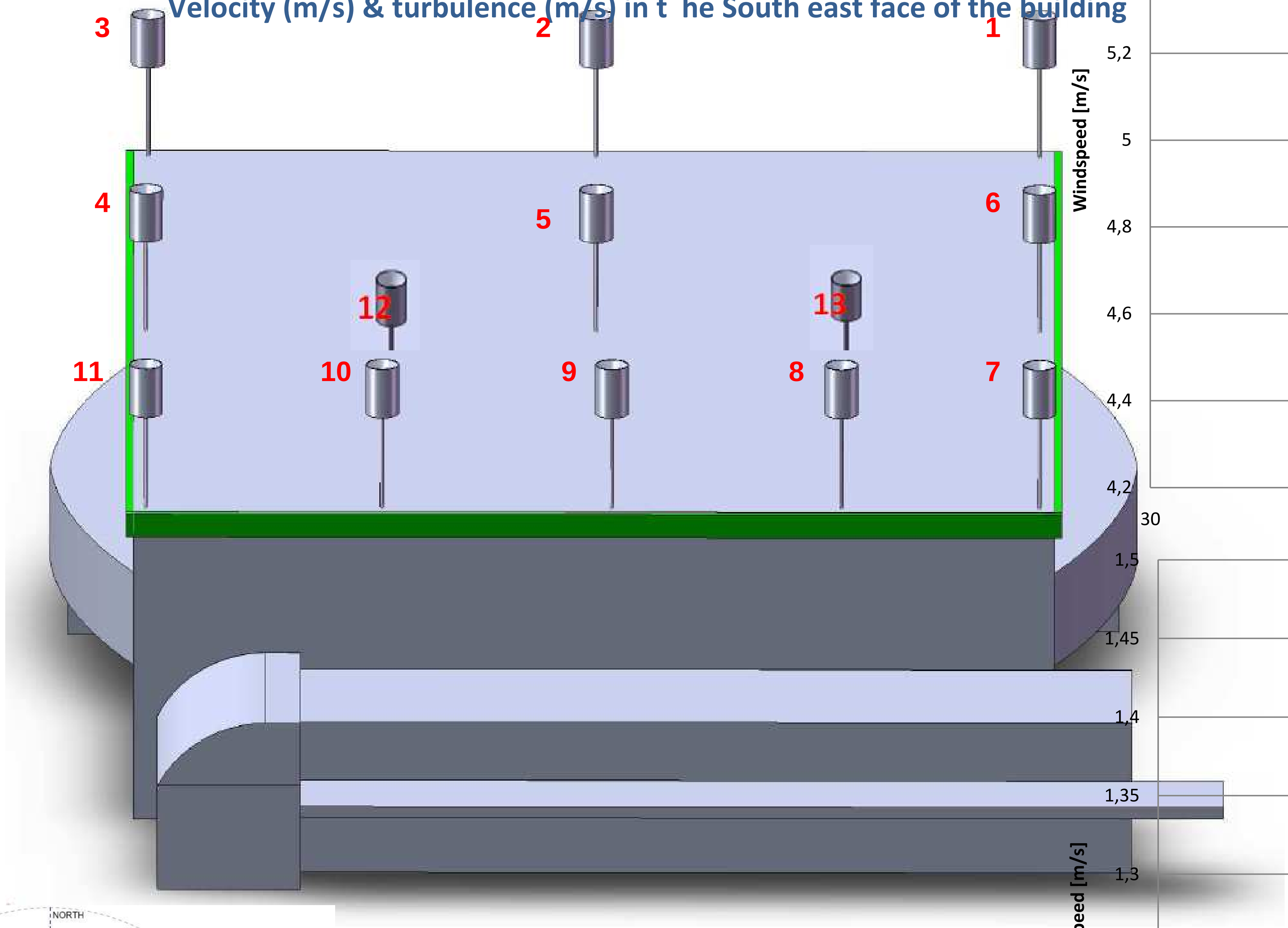


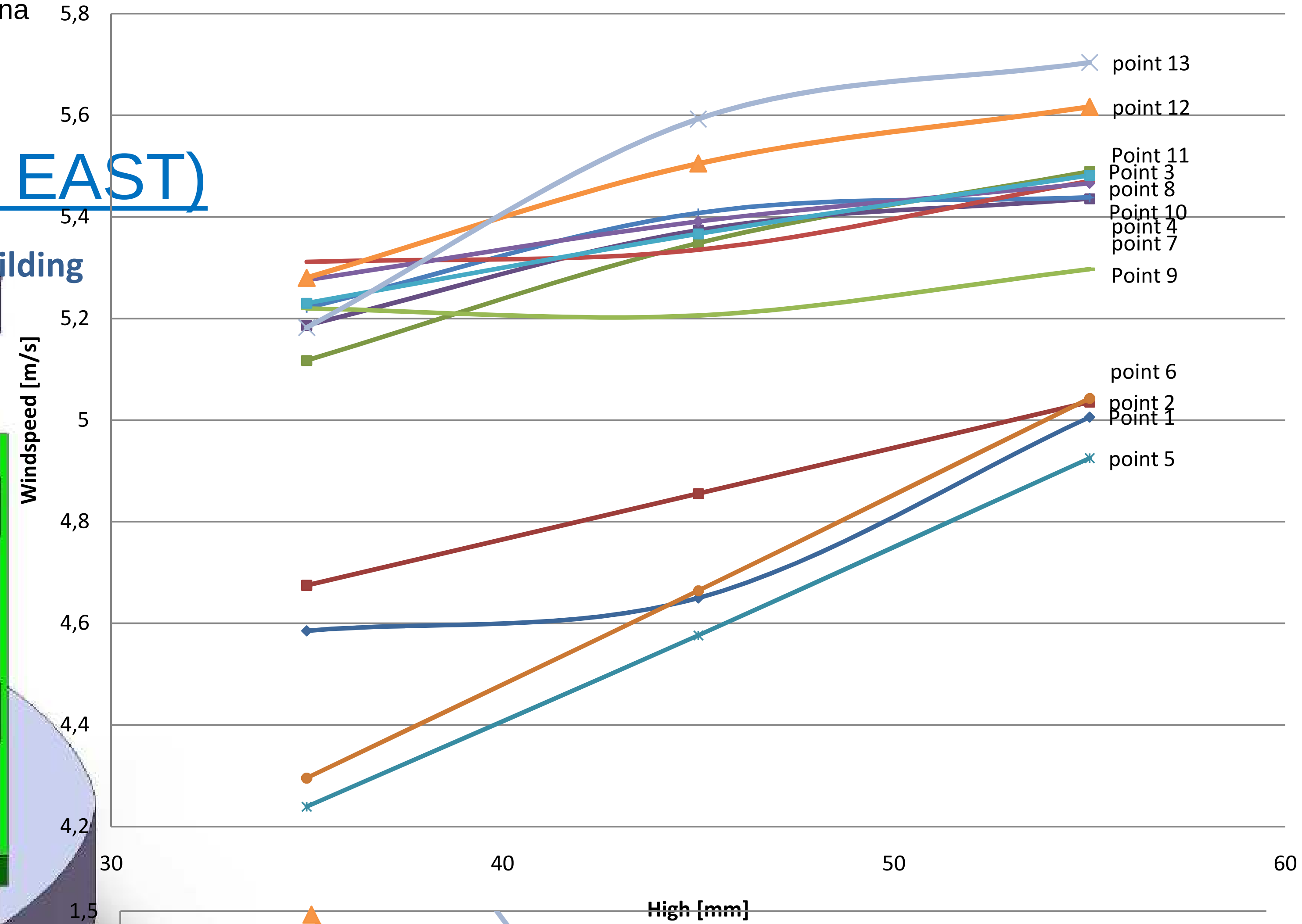


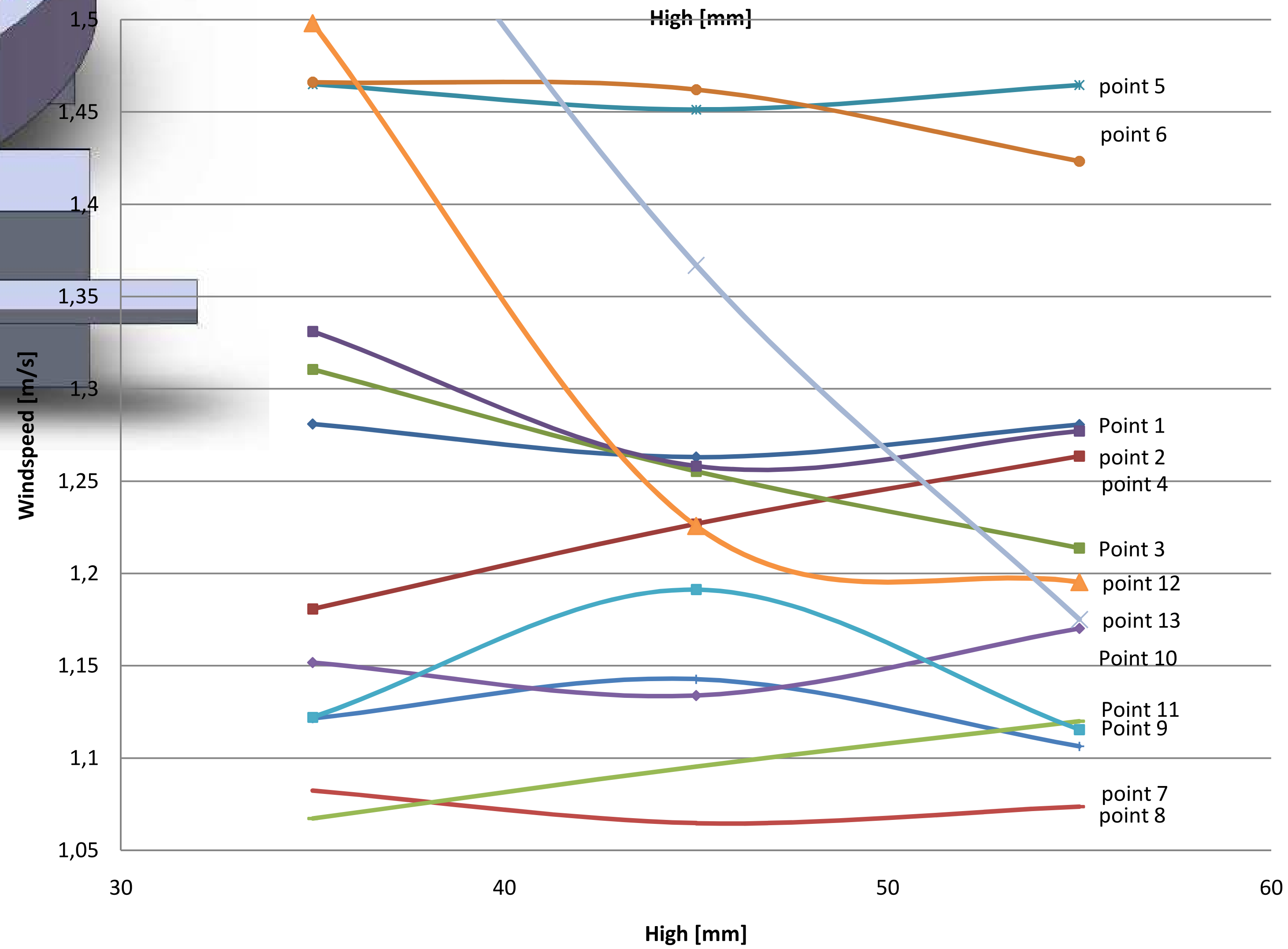


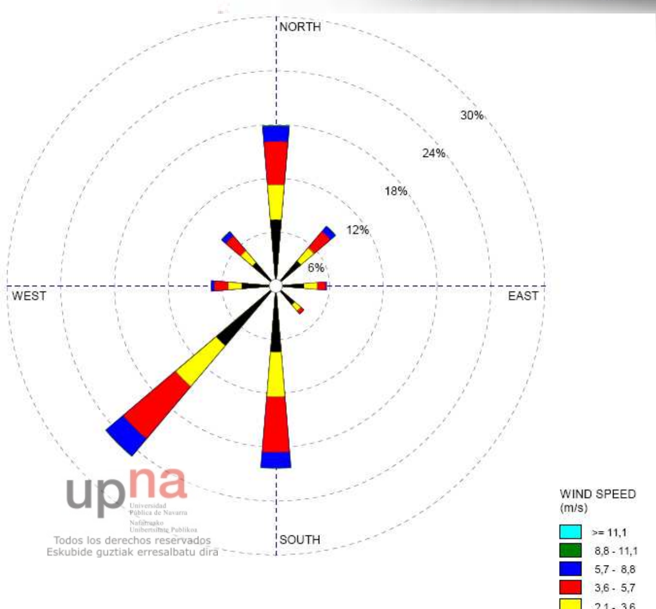
Wind tunnel data analysis (SOUTH EAST)

Velocity (m/s) & turbulence (m/s) in t he South east face of the building



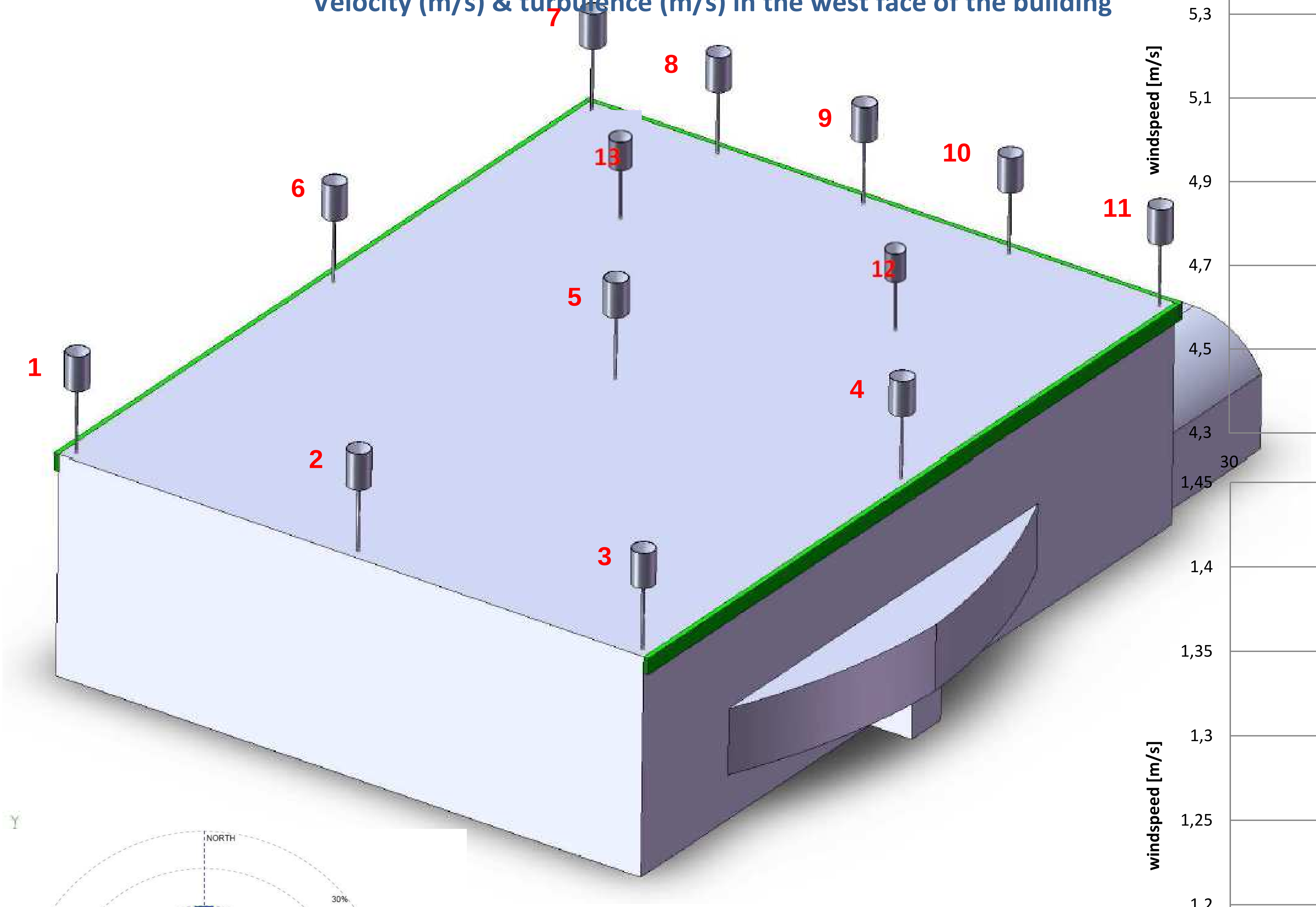


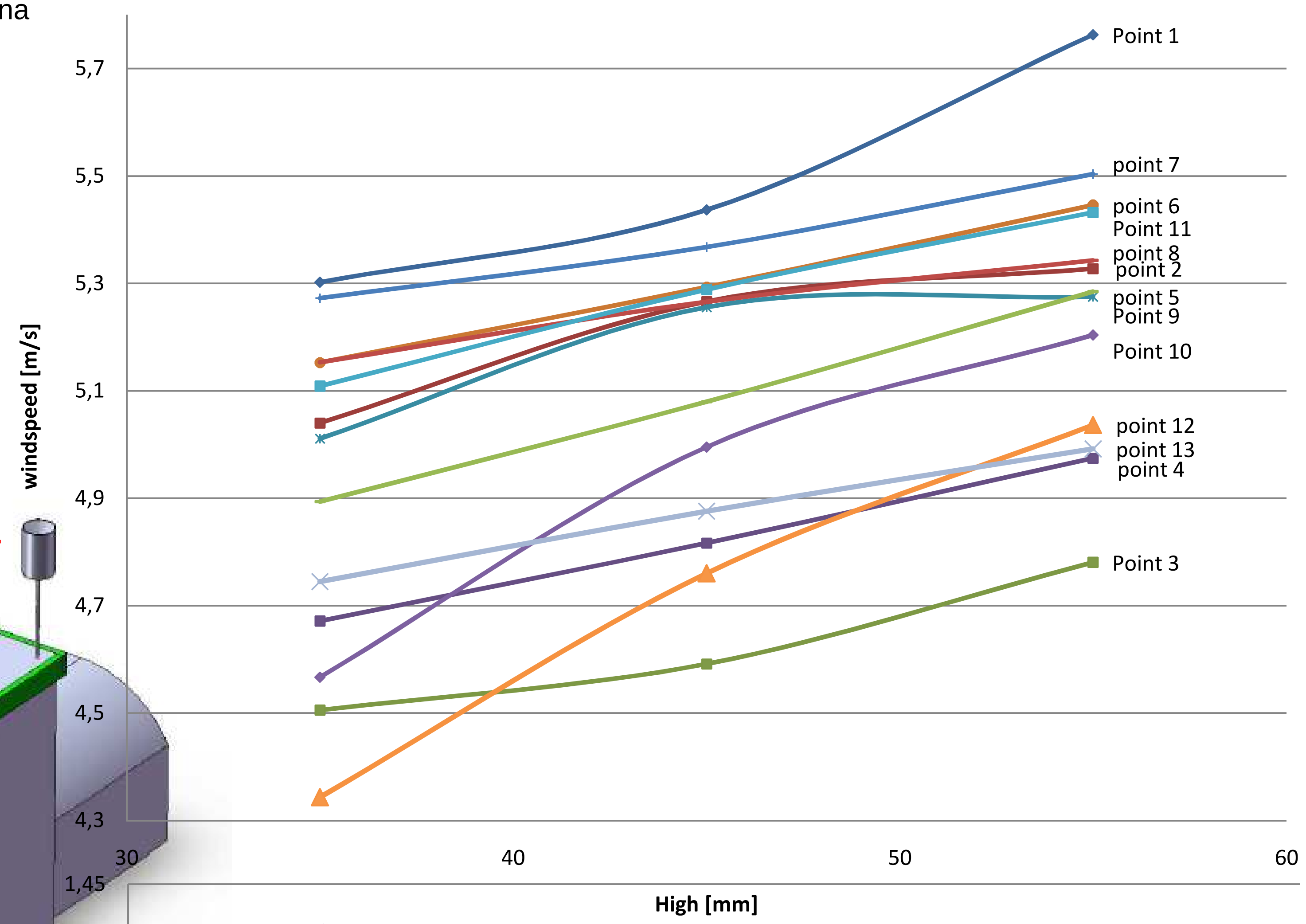


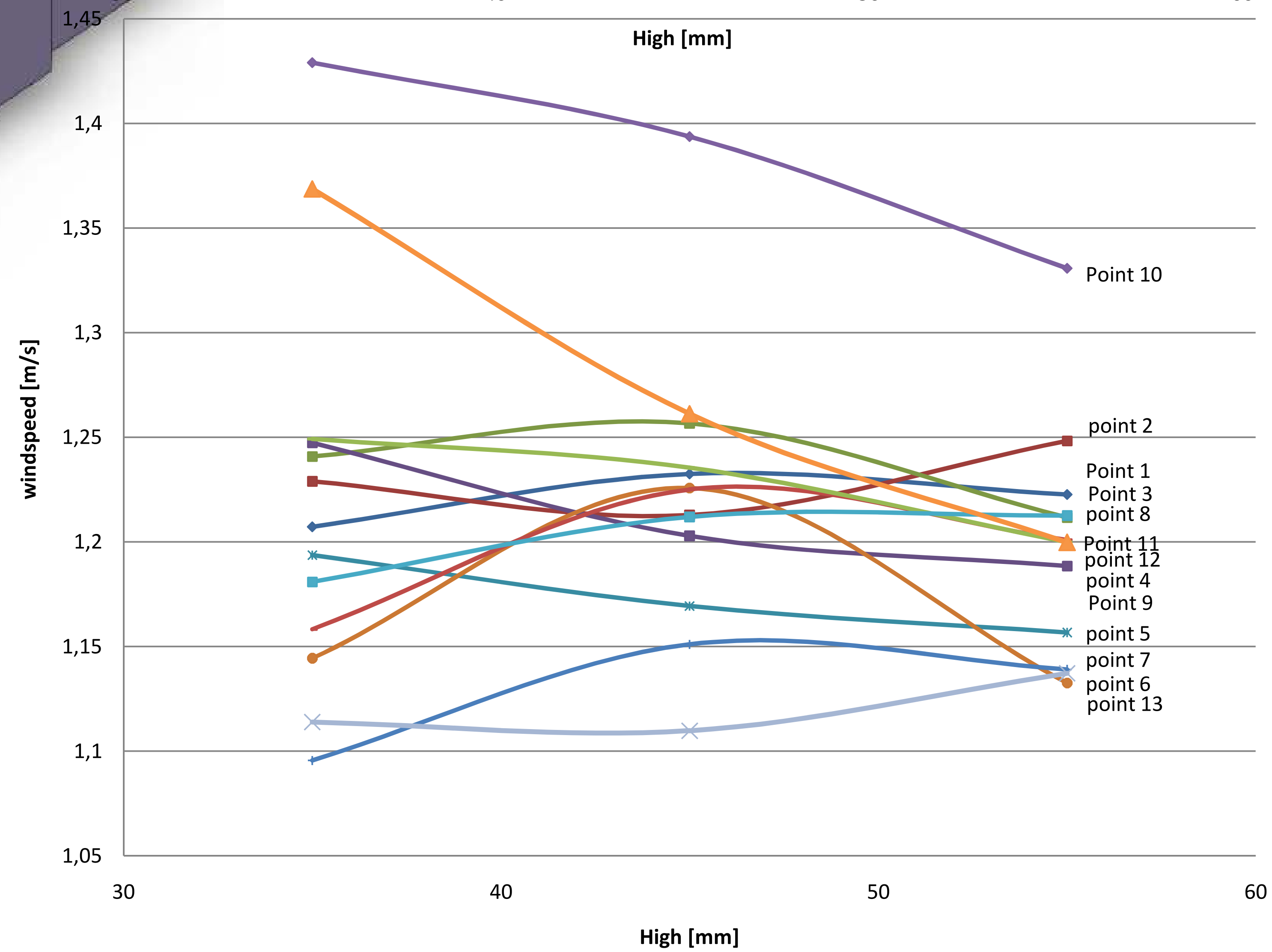


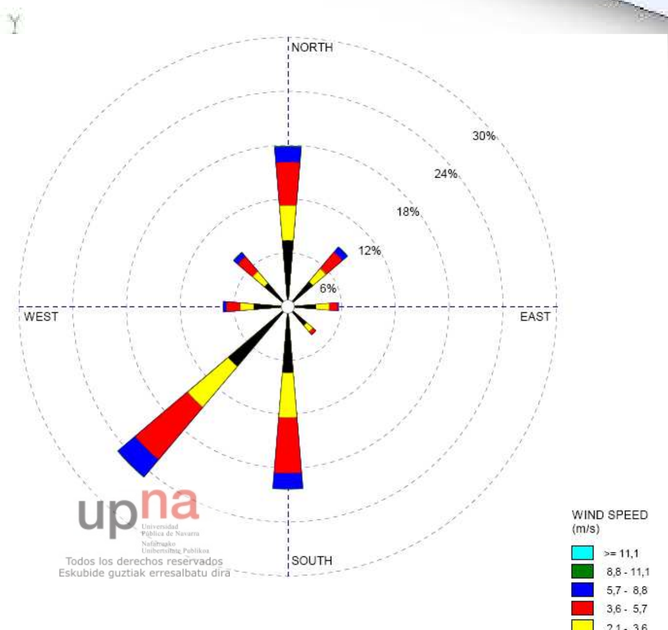
Wind tunnel data analysis (West)

Velocity (m/s) & turbulence (m/s) in the west face of the building



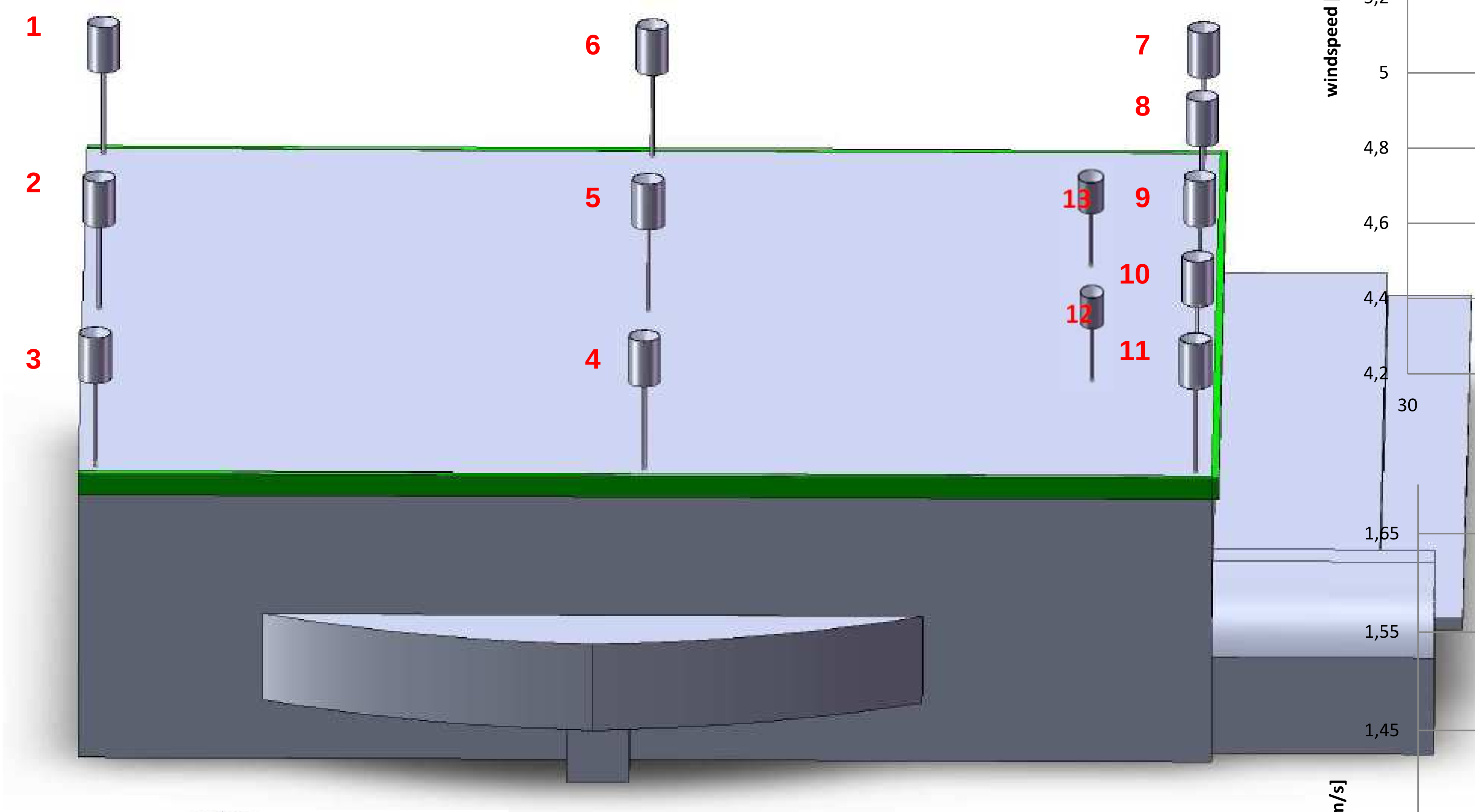


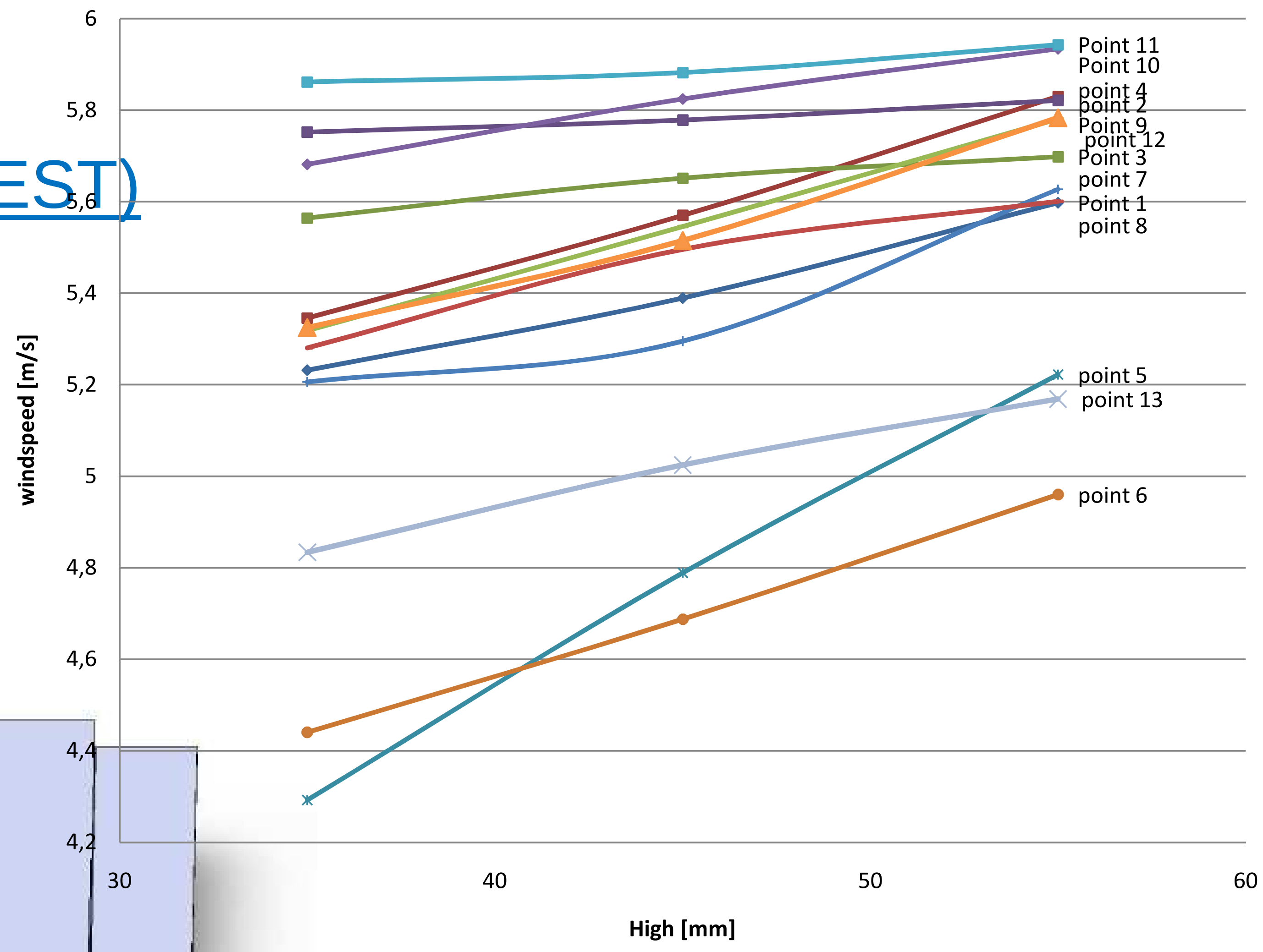


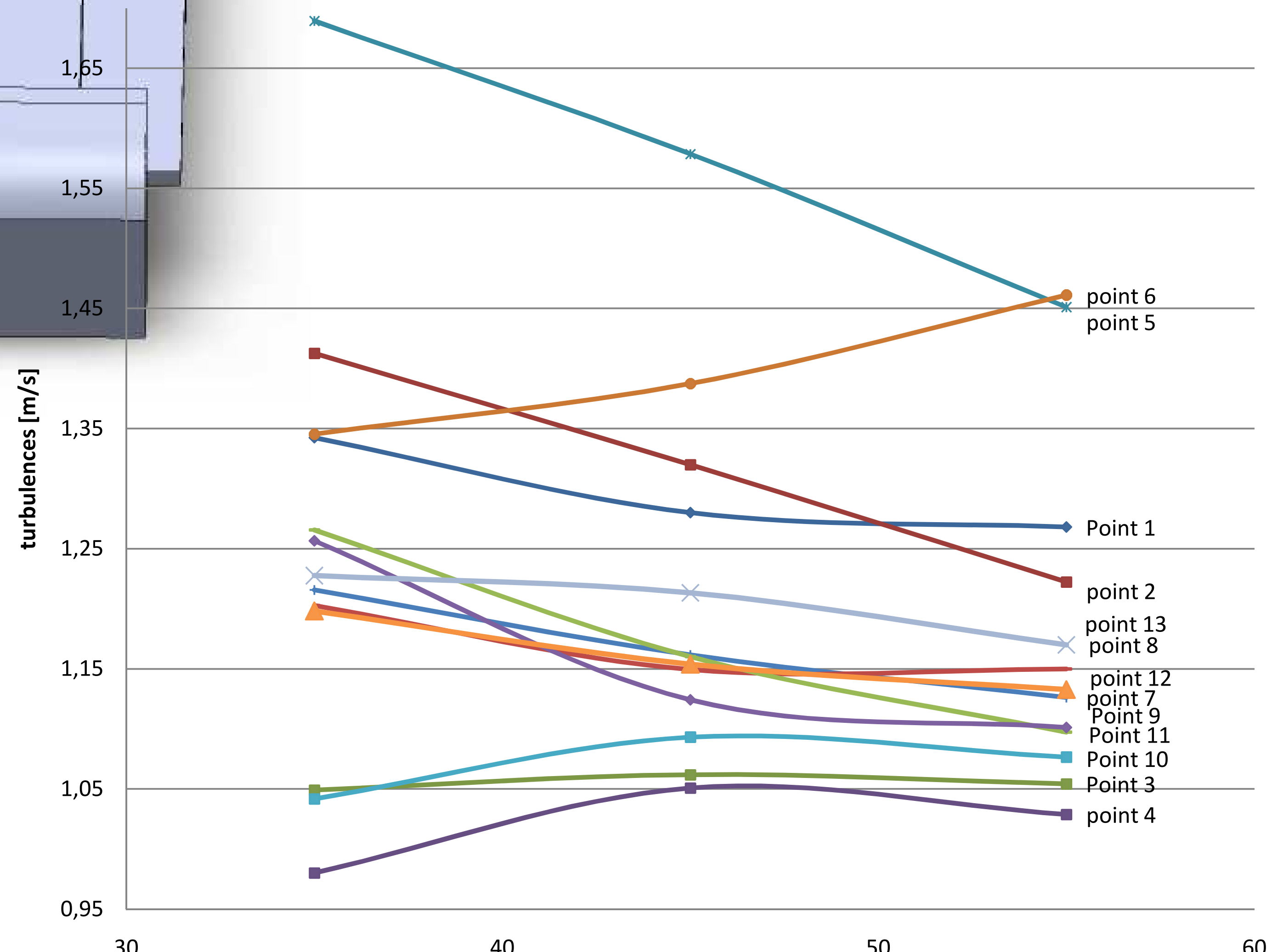


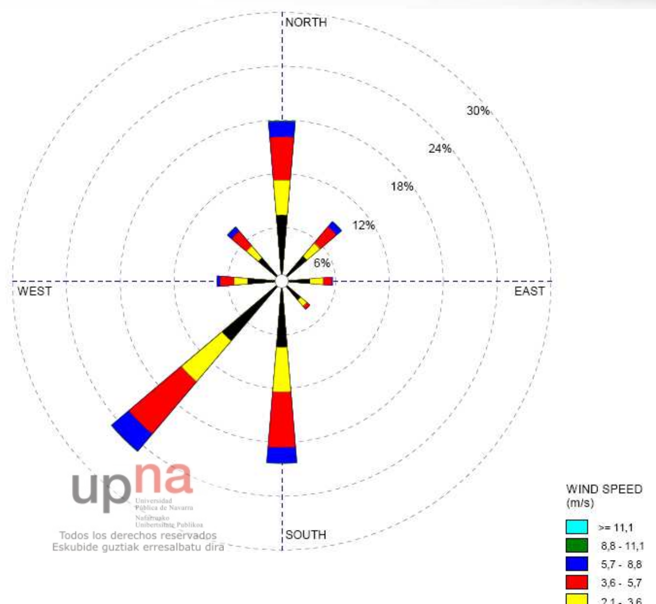
Wind tunnel data analysis (SOUTH WEST)

Velocity (m/s) & turbulence (m/s) in the south west face of the building

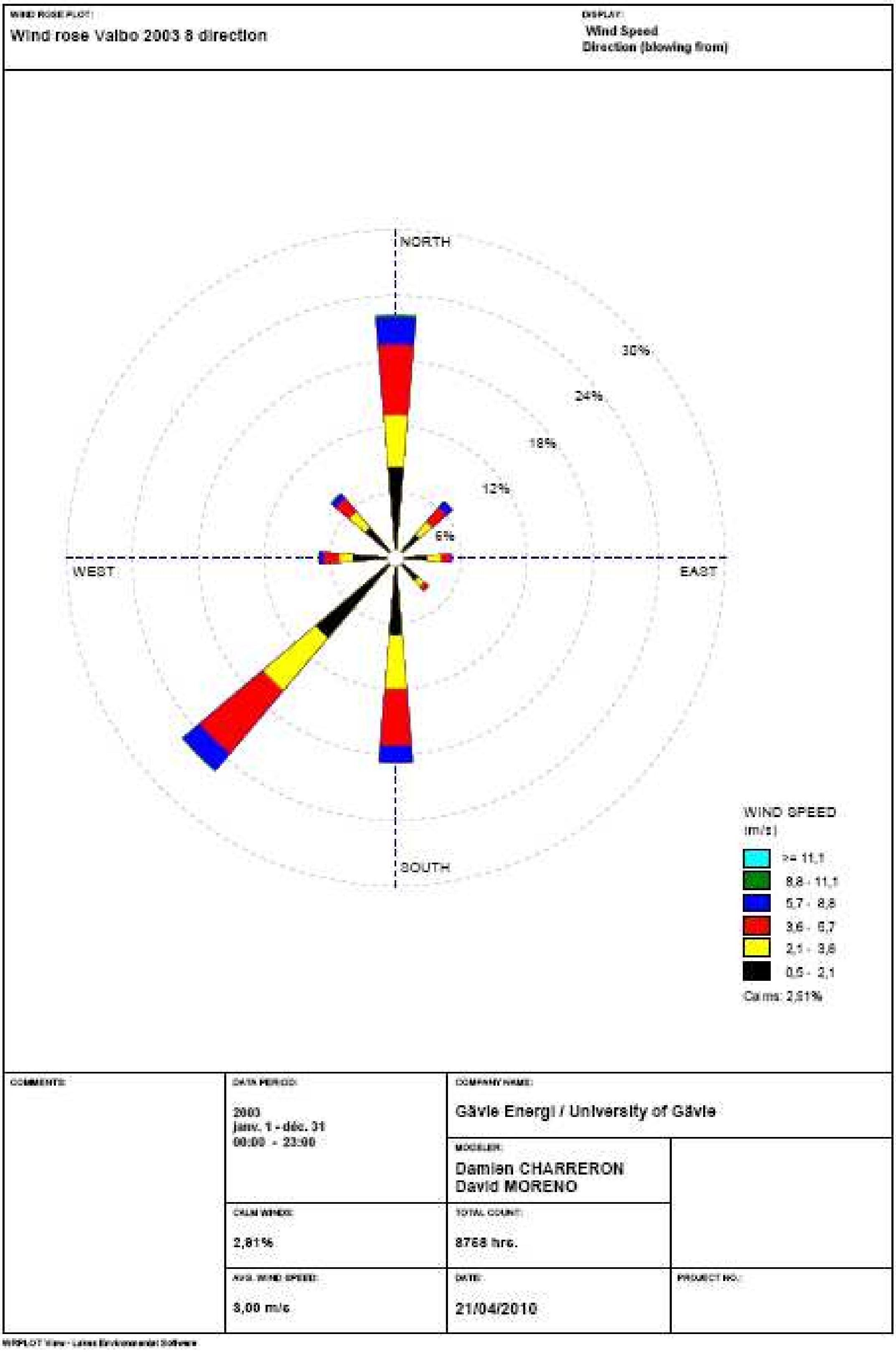






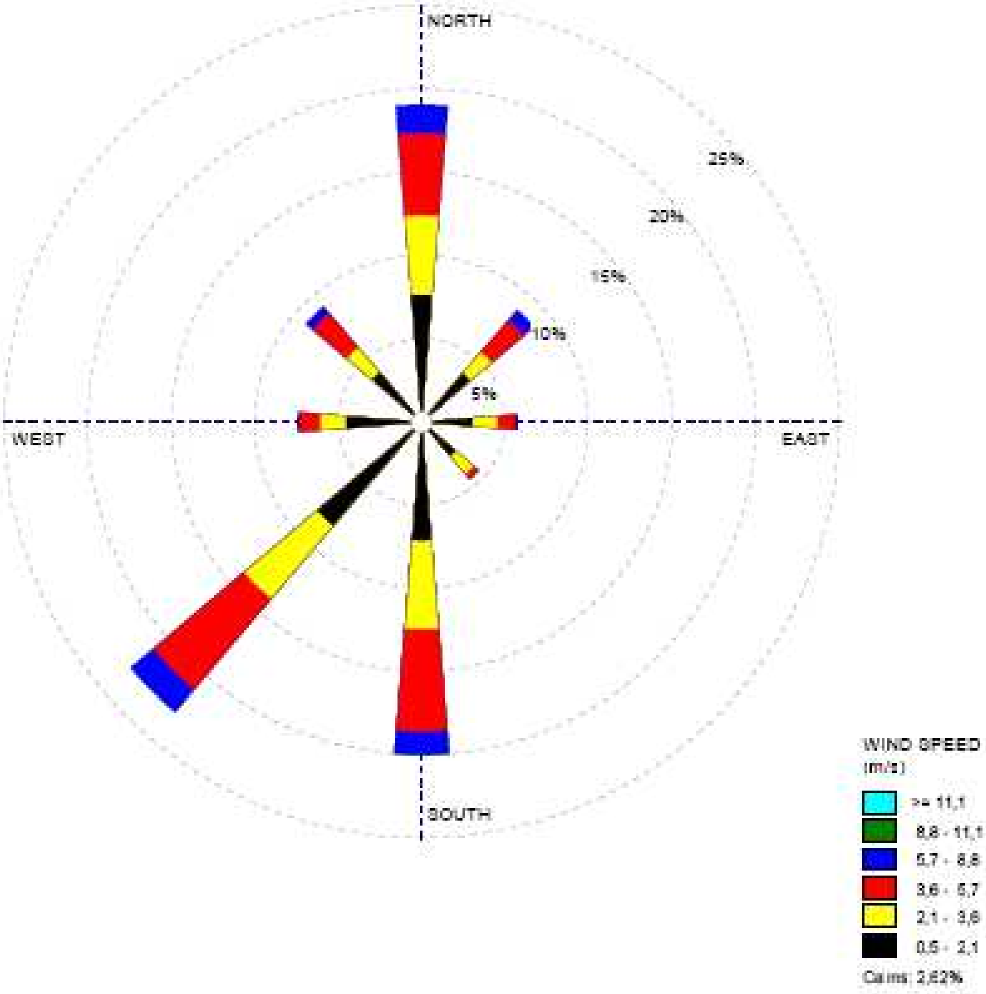


Appendix B: Wind rose over Gävle



WIND ROSE PLOT:
Wind rose Valbo 2004 8 direction

DISPLAY:
Wind Speed
Direction (blowing from)

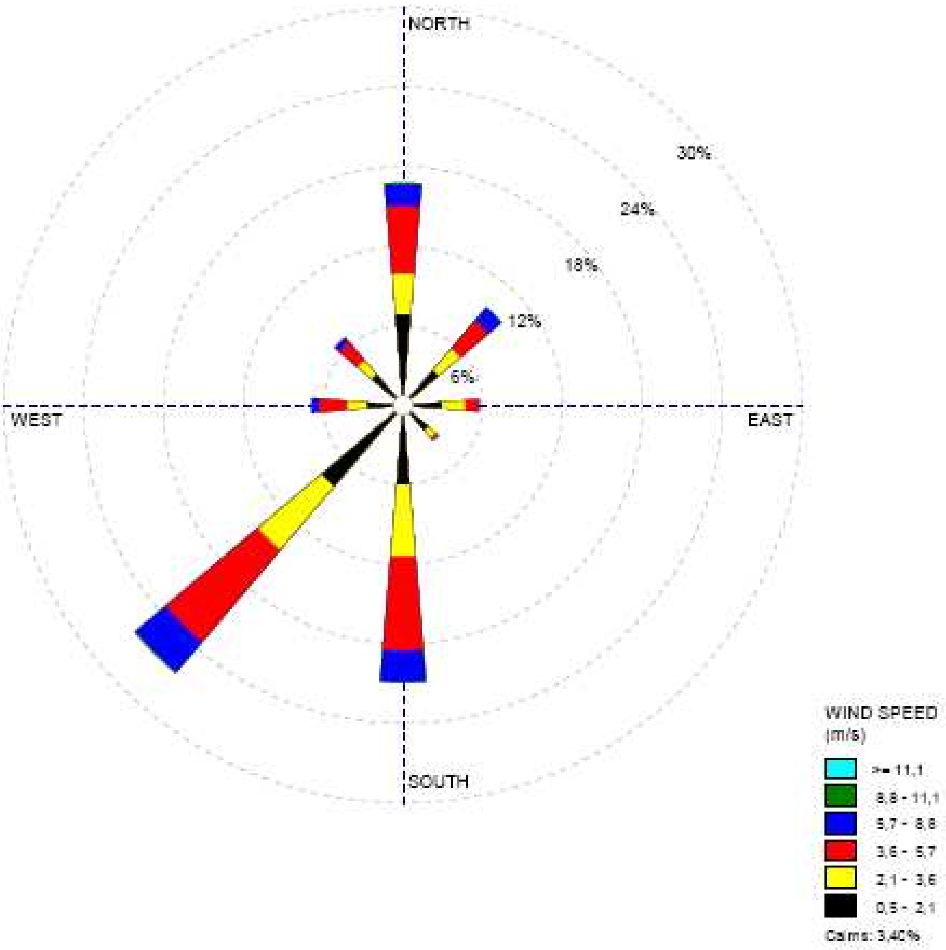


COMMENTS:	DATA PERIOD: 2004 janv. 1 - déc. 31 00:00 - 23:00	COMPANY NAME: Gävle Energi / University of Gävle	
		MODELER: Damien CHARRERON David MORENO	
	CALM WINDS: 2,62%	TOTAL COUNT: 8783 hrs.	
	AVG. WIND SPEED: 2,82 m/s	DATE: 21/04/2010	PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Wind rose Valbo 2005 8 direction

DISPLAY:
Wind Speed
Direction (blowing from)

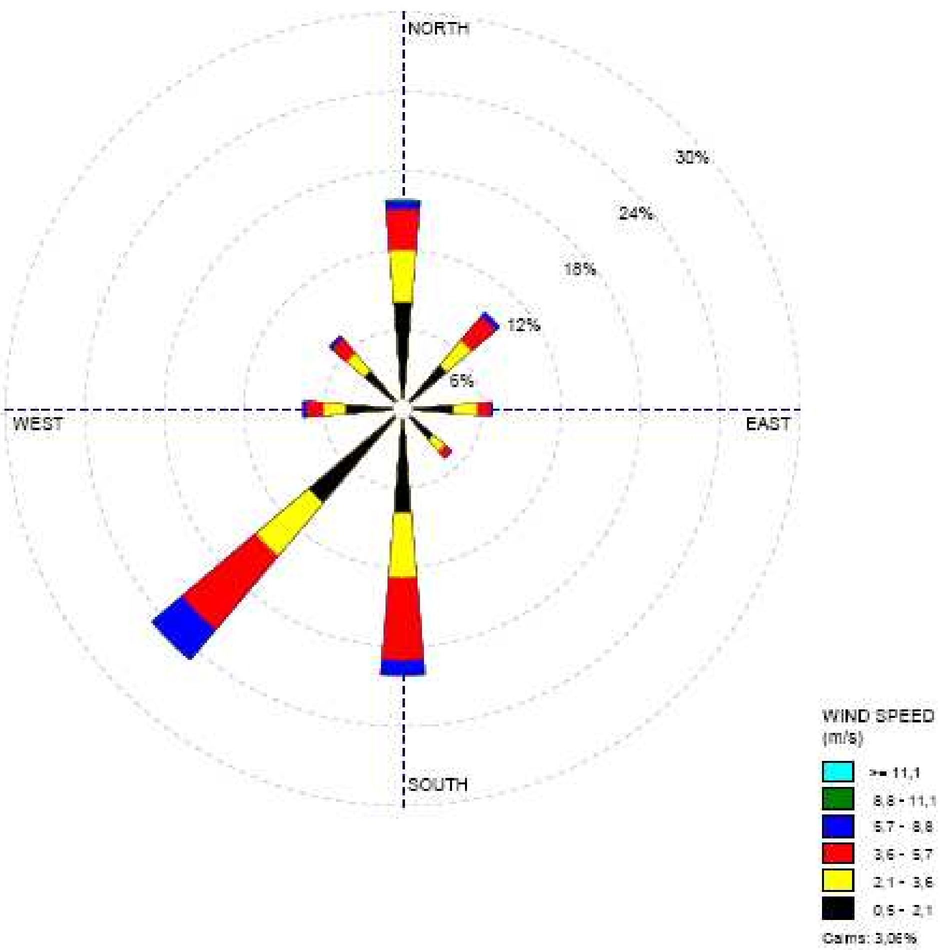


COMMENTS:	DATA PERIOD:	COMPANY NAME:	
	2005 Janv. 1 - déc. 31 00:00 - 23:00	Gävle Energi / University of Gävle	
		MODELER: Damien CHARRERON David MORENO	
	CALM WINDS: 3,40%	TOTAL COUNT: 8759 hrs.	
	AVG. WIND SPEED: 3,15 m/s	DATE: 21/04/2010	PROJECT NO.:

WRPLOT View - Lakes Environmental Software

WIND ROSE PLOT:
Wind rose Valbo 2006 8 direction

DISPLAY:
Wind Speed
Direction (blowing from)

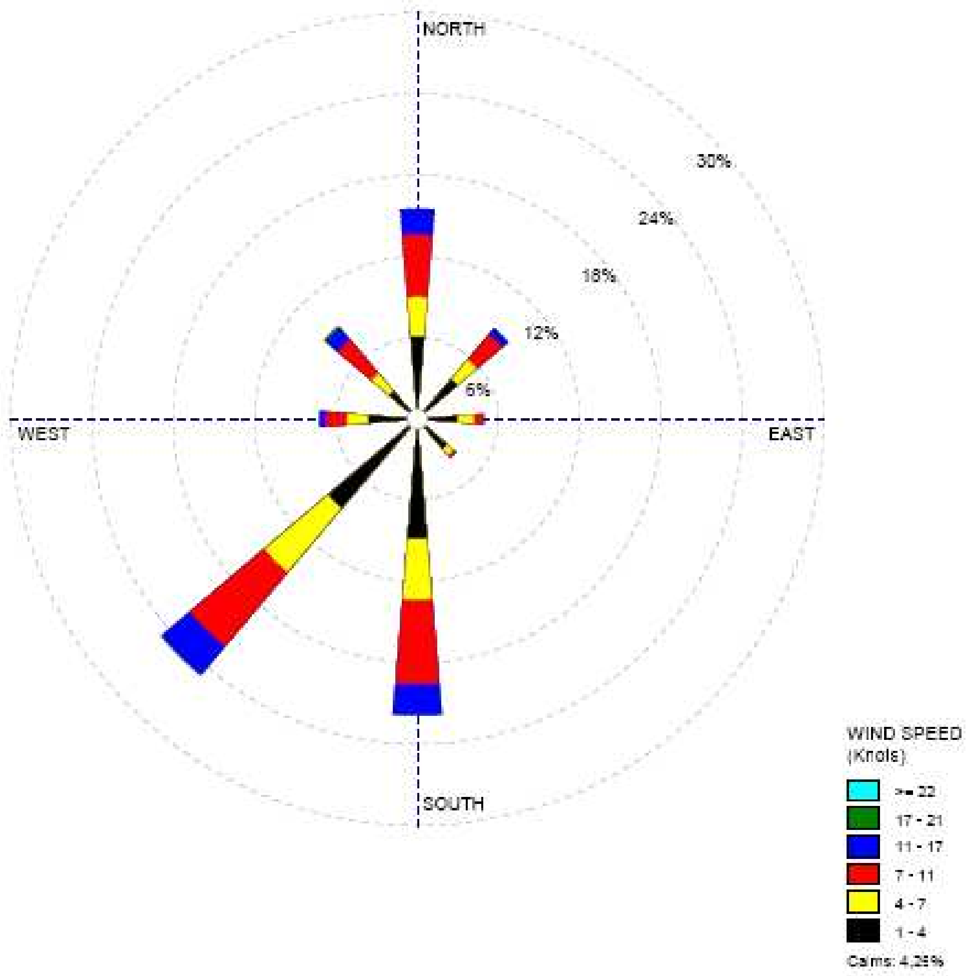


COMMENTS:	DATA PERIOD: 2008 Janv. 1 - déc. 31 00:00 - 23:00	COMPANY NAME: Gävle Energi / University of Gävle	
		MODELER: Damien CHARRERON David MORENO	
	CALM WINDS: 3,06%	TOTAL COUNT: 8759 hrs.	
	AVG. WIND SPEED: 2,82 m/s	DATE: 21/04/2010	PROJECT NO.:

WRPLOT View - Lakes Environmental Software

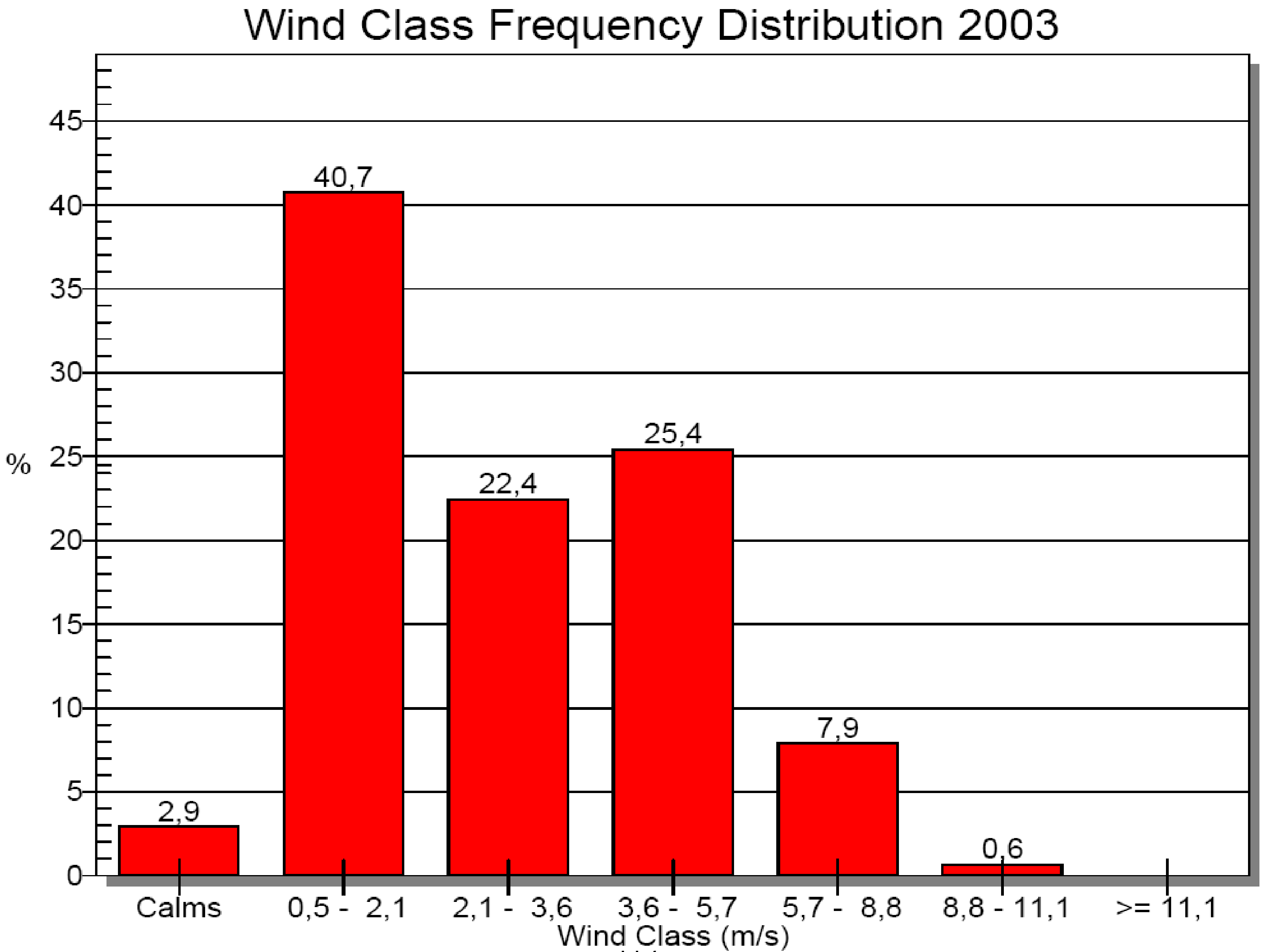
WIND ROSE PLOT:
Wind rose Valbo 2007 8 direction

DISPLAY:
Wind Speed
Direction (blowing from)

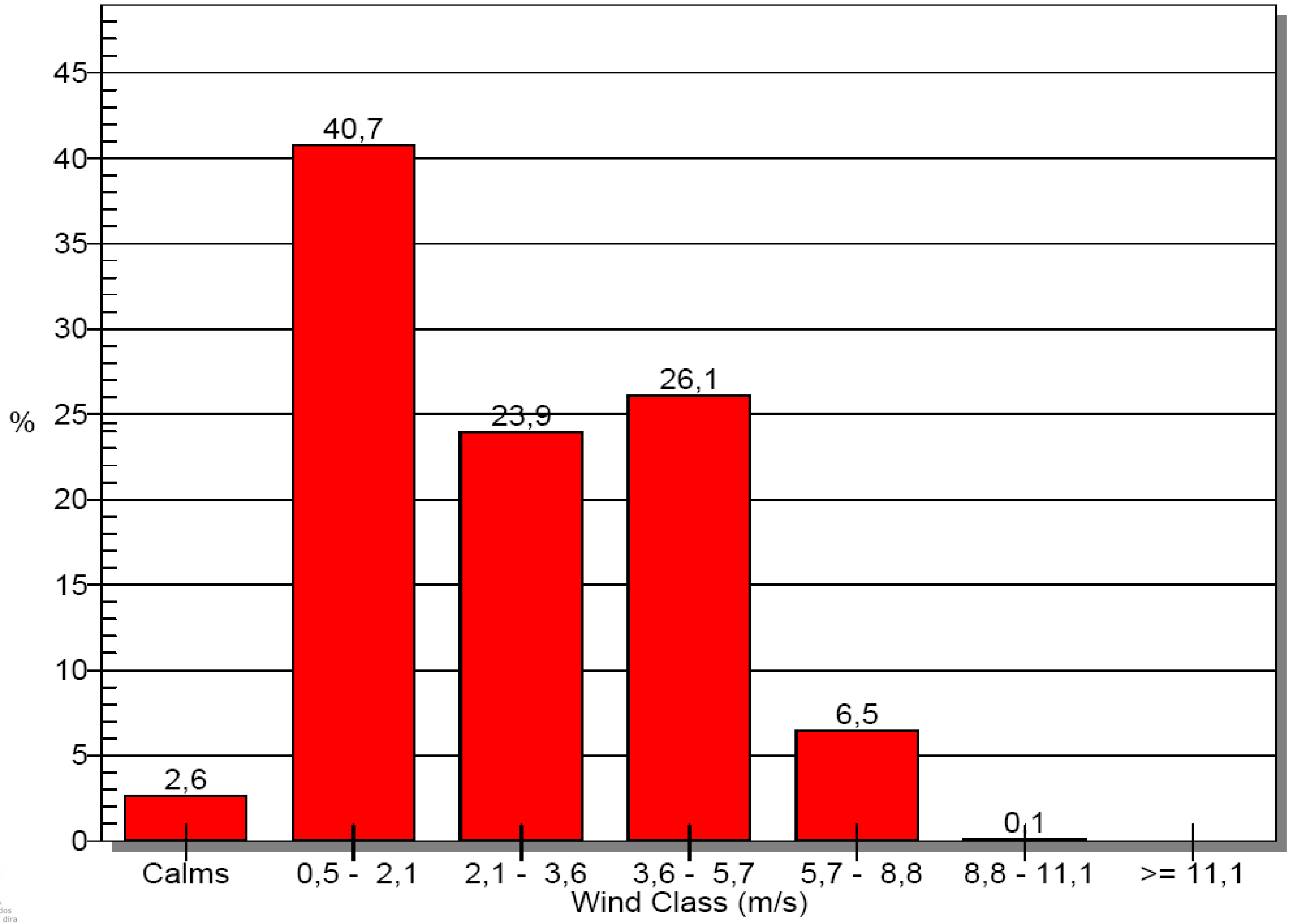


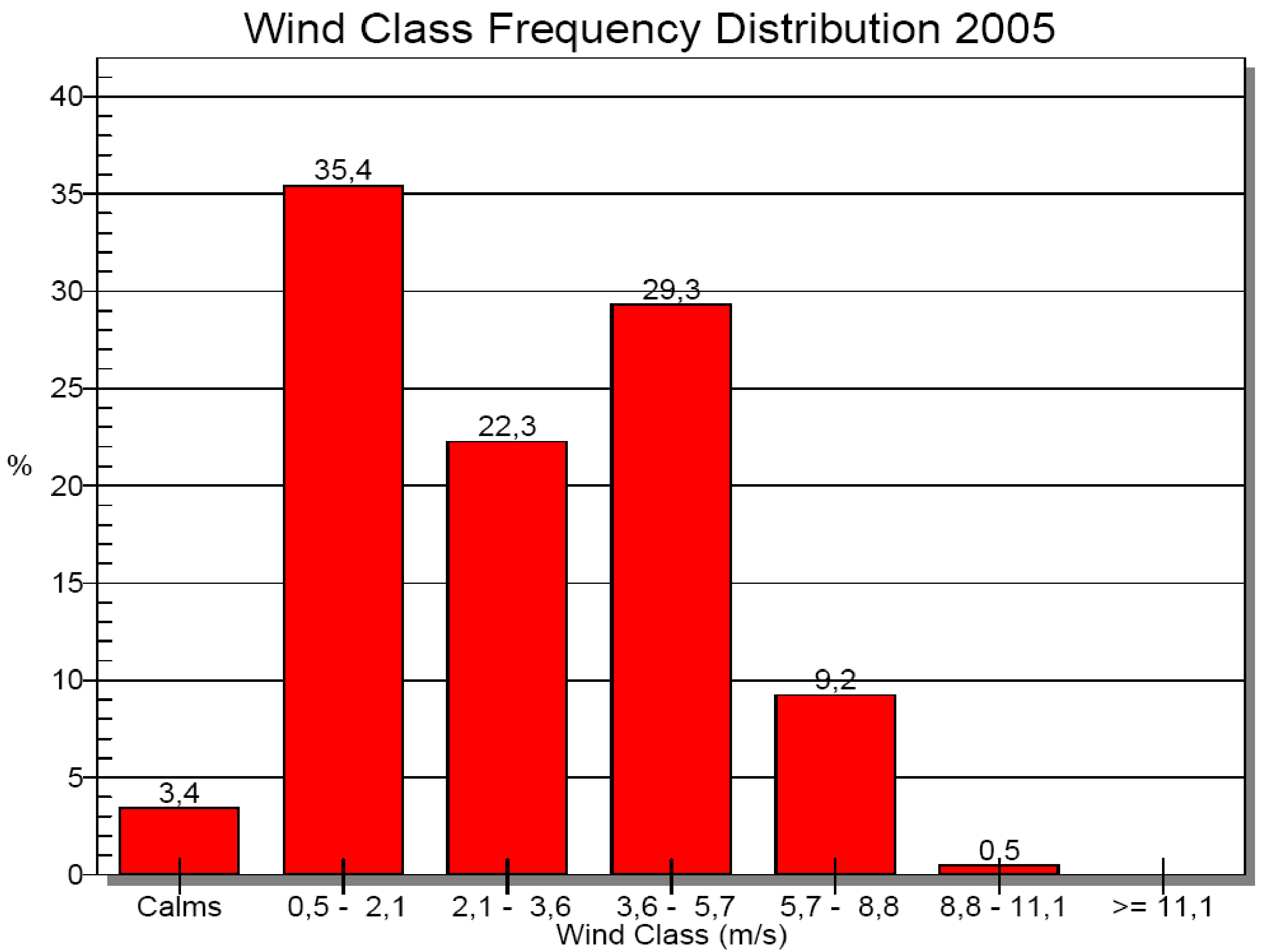
COMMENTS:	DATA PERIOD: 2007 Janv. 1 - déc. 31 00:00 - 23:00	COMPANY NAME: Gävle Energi / University of Gävle	
		MODELER: Damien CHARRERON David MORENO	
	CALM WINDS: 4,25%	TOTAL COUNT: 8736 hrs.	
	AVG. WIND SPEED: 5,87 Knots	DATE: 21/04/2010	PROJECT NO.:

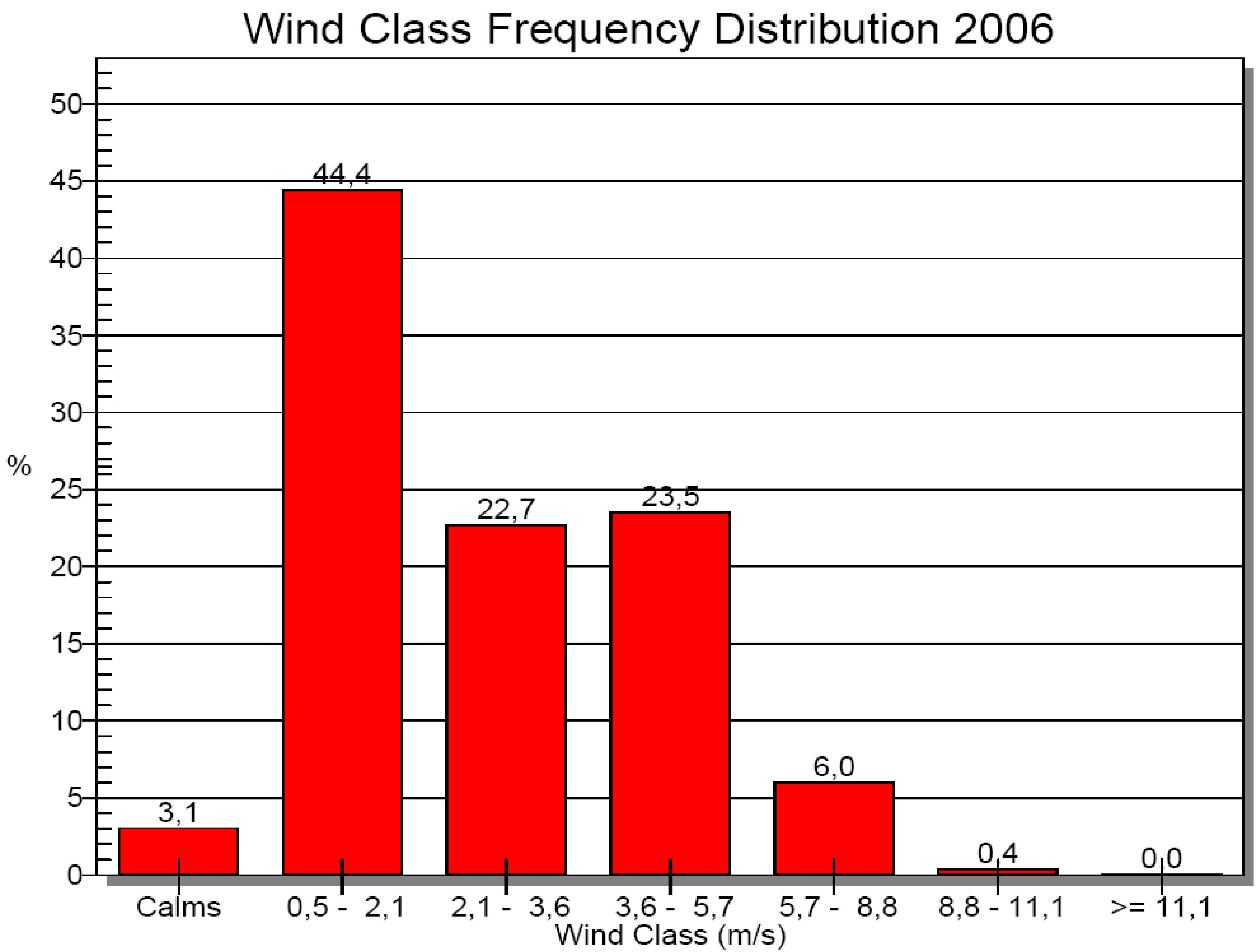
Appendix C: Wind class distribution

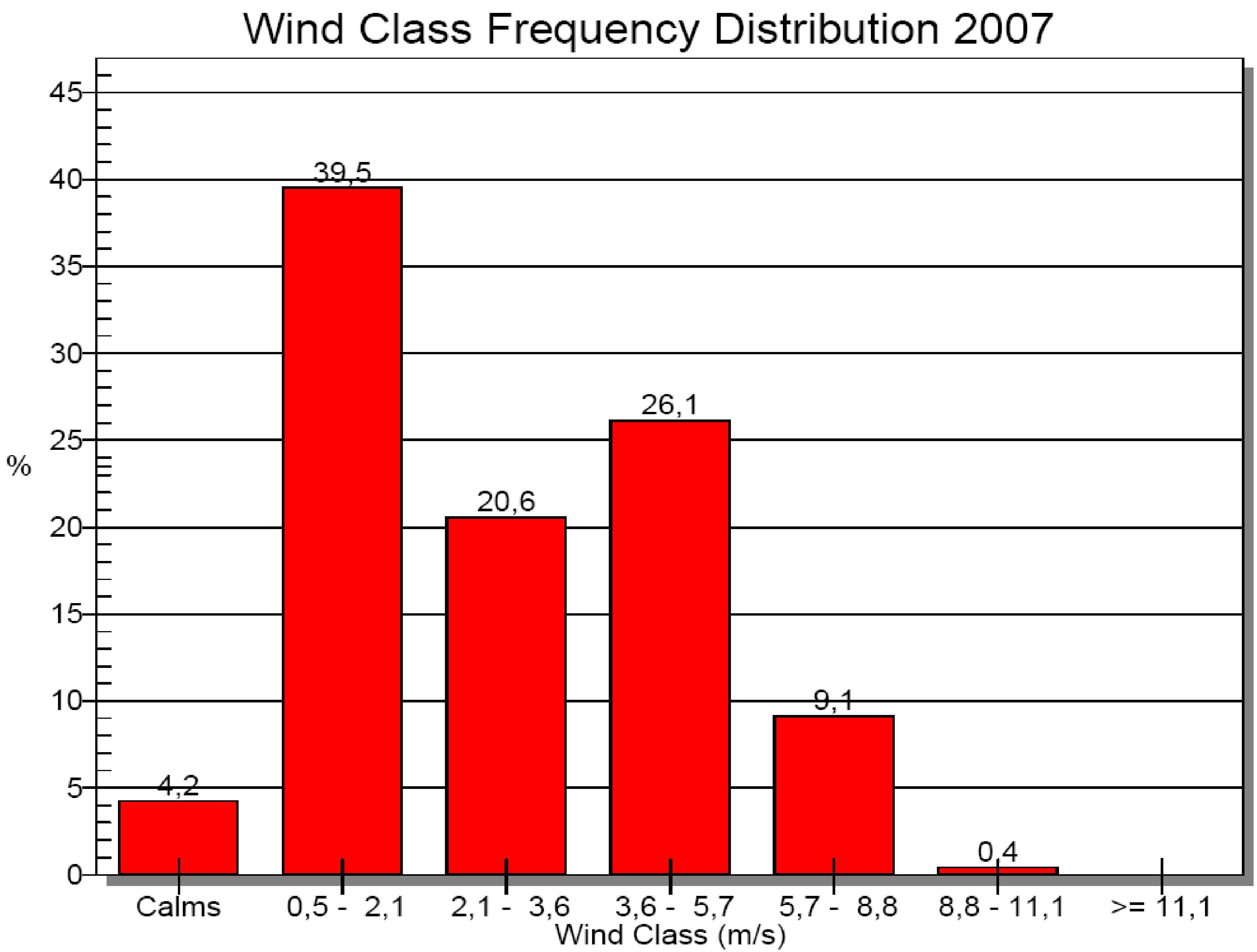

Wind Class Frequency Distribution 2003
%
45
40
35
30
25
20
15
10
5
0
2,9
40,7
22,4
25,4
7,9
0,6
Calms
0,5 - 2,1
2,1 - 3,6
3,6 - 5,7
5,7 - 8,8
8,8 - 11,1
>= 11,1
Wind Class (m/s)

Wind Class Frequency Distribution 2004




Wind Class Frequency Distribution 2005
%
40
35
30
25
20
15
10
5
0
35,4
29,3
22,3
9,2
3,4
0,5
Calms
0,5 - 2,1
2,1 - 3,6
3,6 - 5,7
5,7 - 8,8
8,8 - 11,1
>= 11,1
Wind Class (m/s)


Wind Class Frequency Distribution 2006
%
50
45
40
35
30
25
20
15
10
5
0
3,1
44,4
22,7
23,5
6,0
0,4
0,0
Calms
0,5 - 2,1
2,1 - 3,6
3,6 - 5,7
5,7 - 8,8
8,8 - 11,1
>= 11,1
Wind Class (m/s)


Wind Class Frequency Distribution 2007
%
45
40
35
30
25
20
15
10
5
0
39,5
26,1
20,6
9,1
4,2
0,4
Calms
0,5 - 2,1
2,1 - 3,6
3,6 - 5,7
5,7 - 8,8
8,8 - 11,1
>= 11,1
Wind Class (m/s)

Appendix D. Calculation of the maximum output

Wind coefficients from the wind tunnel

Point 1

North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	5.393548	1.023684	18.979782	0.904956862
	45	5.422944	0.995244	18.352458	0.899077842
	55	5.495479	1.010526	18.388306	0.900844687
North-East					
	35	5.764878	1.191044	20.660344	0.967260495
	45	5.783962	1.133334	19.594419	0.958931546
	55	5.833877	1.209877	20.738812	0.956316474
East					
	35	5.219686	1.231414	23.591717	0.875785413
	45	5.312307	1.157038	21.780323	0.880735172
	55	5.518417	1.160875	21.036371	0.904604792
South-East					
	35	4.585019	1.280947	27.937672	0.769297762
	45	4.650033	1.263039	27.161926	0.770935794
	55	5.005977	1.280672	25.582862	0.820603224
South					
	35	5.402107	1.157181	21.420913	0.906392935
	45	5.528579	1.107127	20.025529	0.916591224
	55	5.55548	1.154234	20.776493	0.910680332
South-West					
	35	5.2317	1.342409	25.659134	0.877801183
	45	5.38918	1.279934	23.750069	0.893480059
	55	5.597732	1.267989	22.651835	0.917606478
West					
	35	5.302068	1.207242	22.769271	0.889607883
	45	5.436718	1.232549	22.67082	0.901361454
	55	5.762498	1.222747	21.21905	0.944615694
North-West					
	35	4.95329	1.264354	25.525543	0.83108814
	45	5.029981	1.280002	25.447458	0.83392793
	55	5.188769	1.249642	24.083597	0.850567346

Point 2

North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	5.963041	1.087477	18.236952	1.00050929
	45	5.970415	1.03916	17.405163	0.98984386
	55	6.034625	1.053098	17.450927	0.98922403
North-East					
	35	5.312203	1.241017	23.361629	0.89130839
	45	5.478854	1.209349	22.07303	0.90834724
	55	5.580849	1.182608	21.190463	0.91483894
East					
	35	4.299403	1.505887	35.025488	0.72137566
	45	4.426277	1.533472	34.644734	0.73383896
	55	4.849938	1.455991	30.020818	0.79502458
South-East					
	35	4.674451	1.180703	25.258639	0.78430312
	45	4.855349	1.226955	25.270171	0.80497543
	55	5.035776	1.263514	25.09074	0.82548802
South					
	35	4.947687	1.287429	26.020823	0.83014804
	45	5.293721	1.359782	25.686701	0.87765377
	55	5.509869	1.330686	24.150948	0.90320356
South-West					
	35	5.34586	1.412737	26.426748	0.89695553
	45	5.570063	1.320021	23.698488	0.92346892
	55	5.830683	1.22241	20.965117	0.9557929
West					
	35	5.039947	1.228931	24.383805	0.84562789
	45	5.266118	1.212808	23.030391	0.87307743
	55	5.32747	1.248344	23.432208	0.87330386
North-West					
	35	5.449929	1.221608	22.415126	0.91441675
	45	5.388849	1.198808	22.24608	0.89342518
	55	5.463966	1.144329	20.943194	0.89567893

Point 3

North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	6.019383	1.065566	17.702247	1.00996264
	45	6.138611	1.044757	17.019431	1.01772932
	55	6.254366	1.076266	17.208244	1.025245
North-East					
	35	5.142098	1.227632	23.874137	0.8627673
	45	5.399836	1.216559	22.529558	0.89524673
	55	5.531678	1.177031	21.278008	0.9067786
East					
	35	4.633923	1.14018	24.60506	0.77750312
	45	4.850121	1.19119	24.560012	0.80410868
	55	4.945218	1.186972	24.002425	0.81064332
South-East					
	35	5.11739	1.310586	25.610435	0.85862167
	45	5.348477	1.255277	23.469803	0.88673185
	55	5.489307	1.213708	22.110399	0.89983294
South					
	35	5.394069	1.248872	23.152687	0.90504428
	45	5.480883	1.244127	22.699387	0.90868363
	55	5.578087	1.231753	22.081997	0.91438618
South-West					
	35	5.564691	1.04909	18.852627	0.9336721
	45	5.651908	1.061886	18.788096	0.93703812
	55	5.69855	1.054249	18.500311	0.93413304
West					
	35	4.505147	1.240917	27.544429	0.75589643
	45	4.591428	1.256726	27.371129	0.76121958
	55	4.780452	1.211754	25.348115	0.78363411
North-West					
	35	5.681414	1.166284	20.528059	0.95325648
	45	5.651621	1.09357	19.349661	0.93699054
	55	5.668624	1.072774	18.924767	0.92922743

Point 4

North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	6.09058	1.104468	18.134043	1.02190843
	45	6.130381	1.066934	17.404044	1.01636486
	55	6.181924	1.058048	17.115196	1.01336997
North-East					
	35	4.386503	1.347866	30.727573	0.73598974
	45	4.537334	1.34425	29.626433	0.75225126
	55	4.804398	1.372246	28.562289	0.78755945
East					
	35	5.398291	1.11796	20.709511	0.90575267
	45	5.501149	1.141295	20.74648	0.91204356
	55	5.624959	1.13838	20.238017	0.92206966
South-East					
	35	5.186514	1.331037	25.66342	0.87021965
	45	5.373838	1.25822	23.413806	0.89093649
	55	5.435939	1.277077	23.493222	0.89108461
South					
	35	4.981216	1.181314	23.715373	0.83577371
	45	5.186718	1.175912	22.671592	0.85991359
	55	5.274037	1.232962	23.377955	0.86454488
South-West					
	35	5.752065	0.98014	17.039794	0.96511066
	45	5.778205	1.050764	18.184962	0.95797708
	55	5.821251	1.028728	17.671949	0.95424676
West					
	35	4.671108	1.247394	26.70446	0.78374221
	45	4.816763	1.202893	24.973049	0.79857821
	55	4.974562	1.188567	23.892899	0.81545353
North-West					
	35	5.103279	1.227254	24.048342	0.85625406
	45	5.252465	1.137551	21.657461	0.87081388
	55	5.360746	1.098903	20.499075	0.87875862

Point 5

North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	5.717251	1.051136	18.385346	0.95926939
	45	5.819422	1.046591	17.984445	0.96481051
	55	5.928148	1.009188	17.023668	0.97176982
North-East					
	35	4.348116	1.623272	37.332775	0.72954897
	45	4.836558	1.452349	30.028559	0.80186005
	55	5.046722	1.353687	26.823106	0.82728234
East					
	35	4.868898	1.190529	24.451707	0.81692842
	45	5.001118	1.169484	23.384452	0.82914269
	55	5.202592	1.23806	23.796984	0.85283328
South-East					
	35	4.23923	1.465085	34.560162	0.71127953
	45	4.576298	1.45133	31.71406	0.75871116
	55	4.92497	1.464523	29.736694	0.80732418
South					
	35	5.226927	1.12391	21.50231	0.87700035
	45	5.37172	1.214764	22.614062	0.89058534
	55	5.56185	1.16079	20.8706	0.91172453
South-West					
	35	4.291987	1.689417	39.362108	0.72013137
	45	4.788575	1.578629	32.966568	0.79390488
	55	5.221995	1.451024	27.786774	0.85601391
West					
	35	5.010915	1.193779	23.823566	0.84075676
	45	5.255377	1.16941	22.251694	0.87129666
	55	5.274995	1.156698	21.927939	0.86470192
North-West					
	35	4.512045	1.325301	29.372522	0.75705381
	45	4.771672	1.295713	27.154281	0.7911025
	55	4.974275	1.304492	26.224763	0.81540648

Point 6

North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	5.369058	1.139506	21.223577	0.90084781
	45	5.436122	1.188279	21.858944	0.90126264
	55	5.574038	1.145335	20.547675	0.91372245
North-East					
	35	5.453937	1.05391	19.323842	0.91508924
	45	5.512027	1.031416	18.712091	0.91384704
	55	5.575514	1.025978	18.401494	0.9139644
East					
	35	4.877744	1.144576	23.465284	0.81841265
	45	4.945565	1.158277	23.420527	0.81993248
	55	5.044687	1.188413	23.557708	0.82694875
South-East					
	35	4.295499	1.466053	34.129987	0.72072063
	45	4.664195	1.462142	31.348225	0.77328373
	55	5.042925	1.423305	28.2238	0.82665991
South					
	35	5.305039	1.189132	22.415147	0.89010637
	45	5.39797	1.146855	21.246046	0.89493737
	55	5.547354	1.123981	20.261568	0.90934828
South-West					
	35	4.440087	1.3454	30.301198	0.74498034
	45	4.68765	1.38753	29.599698	0.77717237
	55	4.959838	1.461007	29.456757	0.8130399
West					
	35	5.152663	1.144384	22.209563	0.86453995
	45	5.292979	1.225876	23.160415	0.87753075
	55	5.445534	1.132621	20.799087	0.89265747
North-West					
	35	4.727043	1.261625	26.689519	0.79312727
	45	4.986951	1.312655	26.321795	0.82679392
	55	5.102943	1.284491	25.171568	0.83649835

Point 7

North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	4.770708	1.312863	27.519243	0.80045361
	45	5.076615	1.267167	24.960873	0.84165945
	55	5.195324	1.366285	26.298357	0.85164187
North-East					
	35	5.340908	1.115223	20.880786	0.89612466
	45	5.417168	1.139186	21.029182	0.89812023
	55	5.508422	1.14555	20.796329	0.90296636
East					
	35	4.575847	1.140488	24.924097	0.76775884
	45	4.721458	1.134025	24.018539	0.78277745
	55	4.80356	1.155693	24.059093	0.78742208
South-East					
	35	5.220719	1.121435	21.480463	0.87595874
	45	5.407676	1.142741	21.131827	0.89654654
	55	5.438225	1.10633	20.343578	0.89145934
South					
	35	5.435347	1.182146	21.749226	0.91197011
	45	5.550044	1.126837	20.303216	0.92014994
	55	5.69797	1.150768	20.196099	0.93403796
South-West					
	35	5.205986	1.21567	23.351386	0.87348676
	45	5.295031	1.161594	21.93744	0.87787096
	55	5.627498	1.126189	20.012258	0.92248586
West					
	35	5.272355	1.095584	20.779786	0.88462249
	45	5.367361	1.151105	21.446381	0.88986266
	55	5.503053	1.138999	20.697589	0.90208625
North-West					
	35	4.841405	1.226476	25.33306	0.81231551
	45	5.065919	1.233062	24.340344	0.83988614
	55	5.191446	1.243489	23.95265	0.85100617

Point 8

North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	4.474695	1.458508	32.59459	0.75078704
	45	4.9056	1.511524	30.812216	0.81330662
	55	5.132845	1.324547	25.805324	0.84140002
North-East					
	35	5.290974	1.530945	28.935037	0.88774648
	45	5.581489	1.355869	24.292253	0.92536325
	55	5.682239	1.230547	21.656024	0.93145926
East					
	35	5.210389	1.234737	23.697607	0.87422552
	45	5.282796	1.263669	23.920458	0.8758425
	55	5.40624	1.226357	22.684095	0.88621621
South-East					
	35	5.311646	1.082344	20.376802	0.89121493
	45	5.33542	1.064741	19.956083	0.88456711
	55	5.470849	1.073671	19.625305	0.89680722
South					
	35	5.211758	1.120285	21.495343	0.87445521
	45	5.33216	1.161539	21.783657	0.88402663
	55	5.510875	1.150439	20.875798	0.90336847
South-West					
	35	5.280207	1.202765	22.778748	0.88593993
	45	5.495584	1.149396	20.914904	0.91112093
	55	5.601193	1.149809	20.527926	0.91817382
West					
	35	5.152829	1.158301	22.478927	0.86456781
	45	5.265518	1.225071	23.265925	0.87297795
	55	5.34296	1.20092	22.476673	0.87584306
North-West					
	35	4.957181	1.123914	22.672434	0.83174099
	45	5.181182	1.166775	22.519483	0.85899577
	55	5.272789	1.142569	21.669161	0.8643403

Point 9

North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	4.740298	1.321459	27.87712	0.79535126
	45	4.910142	1.249685	25.451087	0.81405965
	55	5.311417	1.344929	25.321468	0.87067238
North-East					
	35	5.050305	1.460755	28.9241	0.84736581
	45	5.160402	1.40017	27.132964	0.85555062
	55	5.331681	1.344978	25.226153	0.87399415
East					
	35	5.412477	1.106717	20.447509	0.90813287
	45	5.457053	1.087192	19.922694	0.90473282
	55	5.583904	1.154761	20.68017	0.91533973
South-East					
	35	5.219572	1.067302	20.448074	0.87576629
	45	5.205928	1.095342	21.040288	0.86309844
	55	5.296988	1.119929	21.142753	0.86830711
South					
	35	5.057686	1.13494	22.439898	0.84860423
	45	5.208726	1.163598	22.339396	0.86356233
	55	5.262451	1.101445	20.930257	0.86264564
South-West					
	35	5.31824	1.265594	23.797234	0.8923213
	45	5.545531	1.160178	20.92095	0.91940172
	55	5.780771	1.097325	18.982338	0.94761109
West					
	35	4.893718	1.249263	25.527896	0.82109285
	45	5.0797	1.235519	24.322673	0.84217092
	55	5.284683	1.199944	22.706071	0.86629002
North-West					
	35	4.834562	1.163848	24.073492	0.81116735
	45	4.990938	1.194461	23.932585	0.82745493
	55	5.173921	1.169789	22.609339	0.84813339

Point 10

North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	5.287638	1.180172	22.319455	0.88718674
	45	5.310592	1.151737	21.687535	0.88045084
	55	5.553242	1.1765	21.185826	0.91031347
North-East					
	35	4.865776	1.41118	29.002159	0.8164046
	45	4.98092	1.353018	27.164023	0.82579403
	55	5.362875	1.377672	25.689057	0.87910762
East					
	35	5.588265	1.158167	20.724978	0.93762747
	45	5.573428	1.136682	20.394658	0.92402681
	55	5.633045	1.166312	20.704816	0.92339515
South-East					
	35	5.275714	1.151661	21.82949	0.88518608
	45	5.390953	1.133926	21.033877	0.89377401
	55	5.466278	1.170215	21.407894	0.89605792
South					
	35	4.716546	1.158779	24.568394	0.79136603
	45	4.933569	1.122487	22.752018	0.81794364
	55	5.15237	1.22972	23.867072	0.84460065
South-West					
	35	5.681579	1.256568	22.116536	0.95328417
	45	5.824629	1.124255	19.301751	0.96567379
	55	5.934518	1.10127	18.55702	0.97281402
West					
	35	4.566742	1.429135	31.29442	0.76623115
	45	4.995245	1.393745	27.901443	0.828169
	55	5.203964	1.330821	25.573207	0.85305818
North-West					
	35	5.052618	1.087985	21.533087	0.8477539
	45	5.160181	1.163103	22.539971	0.85551398
	55	5.379904	1.187347	22.070032	0.88189909

Point 11

North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	5.631042	1.01914	18.098602	0.94480481
	45	5.713124	1.069061	18.712364	0.94718721
	55	5.828198	0.998161	17.126405	0.95538555
North-East					
	35	4.906107	1.380045	28.129131	0.82317154
	45	5.106957	1.386804	27.155199	0.84668989
	55	5.216529	1.327154	25.441315	0.85511789
East					
	35	5.429666	1.159644	21.357547	0.91101692
	45	5.432527	1.124038	20.690888	0.90066662
	55	5.639525	1.145186	20.306417	0.92445738
South-East					
	35	5.230382	1.122116	21.4538	0.87758004
	45	5.366929	1.19126	22.196297	0.88979103
	55	5.481649	1.115307	20.346201	0.89857761
South					
	35	4.494785	1.2074	26.862254	0.75415784
	45	4.680758	1.244385	26.585117	0.77602974
	55	4.8534	1.185058	24.417063	0.79559209
South-West					
	35	5.86194	1.041743	17.771295	0.98354605
	45	5.882256	1.093056	18.582267	0.97522785
	55	5.943449	1.076384	18.110432	0.97427803
West					
	35	5.108453	1.180921	23.11701	0.85712218
	45	5.288482	1.211898	22.915797	0.87678519
	55	5.432082	1.212576	22.322485	0.89045235
North-West					
	35	5.290755	1.10661	20.915912	0.88770973
	45	5.36785	1.10107	20.512304	0.88994373
	55	5.548154	1.079331	19.453875	0.90947942

Point 12

North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	5.118724	1.138078	22.233626	0.98437
	45	5.346147	1.19812	22.410912	1.00870698
	55	5.500793	1.157695	21.045967	1.01866537
North-East					
	35	4.406747	1.419527	32.212582	0.84745135
	45	4.652677	1.445973	31.078306	0.87786358
	55	4.917228	1.440981	29.304736	0.91059778
East					
	35	5.306655	1.255752	23.663718	1.02051058
	45	5.403318	1.152653	21.332323	1.01949396
	55	5.539119	1.132488	20.445273	1.02576278
South-East					
	35	5.280106	1.497959	28.36986	1.015405
	45	5.504868	1.225593	22.263806	1.03865434
	55	5.616556	1.195274	21.281259	1.04010296
South					
	35	4.896151	1.198019	24.468579	0.9415675
	45	5.06599	1.153805	22.775508	0.95584717
	55	5.21481	1.132769	21.72215	0.96570556
South-West					
	35	5.324534	1.467903	27.568669	1.02394885
	45	5.514904	1.262009	22.883603	1.04054792
	55	5.78376	1.223171	21.148375	1.07106667
West					
	35	4.342988	1.368805	31.517595	0.83519
	45	4.75985	1.26133	26.4993645	0.89808491
	55	5.036227	1.199737	23.822134	0.93263463
North-West					
	35	4.644309	1.127655	24.28035	0.89313635
	45	4.773116	1.173797	24.591847	0.90058792
	55	4.939416	1.197698	24.24776	0.91470667

Point 13

North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	4.537782	1.364265	30.064578	0.87265038
	45	4.722655	1.337053	28.311476	0.89106698
	55	5.037795	1.353149	26.859943	0.932925
North-East					
	35	4.591913	1.761771	38.366824	0.88306019
	45	5.16525	1.482427	28.700002	0.97457547
	55	5.479451	1.363644	24.886512	1.01471315
East					
	35	5.057449	1.201946	23.765859	0.97258635
	45	5.150753	1.186279	23.031174	0.97184019
	55	5.214622	1.179184	22.613036	0.96567074
South-East					
	35	5.182361	1.634074	31.531451	0.99660788
	45	5.592771	1.36689	24.440295	1.05523981
	55	5.704096	1.175025	20.599666	1.05631407
South					
	35	5.059242	1.224547	24.204153	0.97293115
	45	5.254271	1.179254	22.443728	0.99137189
	55	5.338398	1.137797	21.313461	0.98859222
South-West					
	35	4.833954	1.227633	25.396043	0.92960654
	45	5.024494	1.213365	24.148988	0.94801774
	55	5.168813	1.170055	22.636825	0.95718759
West					
	35	4.744859	1.113908	23.476111	0.91247288
	45	4.875721	1.109782	22.761385	0.91994736
	55	4.991663	1.137211	22.782198	0.92438204
North-West					
	35	4.759117	1.130439	23.753121	0.91521481
	45	4.845063	1.205752	24.8862	0.91416283
	55	5.112408	1.154357	22.579508	0.94674222

Appendix E. Data Treatment

Excel file with the wind information for Valbo for a high of 10 meters. The whole table can be found in the file “Wind statistics Valbo_met_2003_2009 37m extrapolation”.

Example with the first forth hours:

Date	Hour	Direccction (Degree)	Wind Speed (m/s)
01/01/2003	100	260.7	1.99
01/01/2003	200	249.8	2.08
01/01/2003	300	231.2	1.87
01/01/2003	400	237.8	0.87
…	…	…	…
All the data hour by hour during 5 years. In total 43800 rows.			

The useful part of the table is the direction and the wind speed. Furthermore the direction is approximated 10 by 10, getting a new table:

Direccction (Degree)	Wind Speed (m/s)
260	1.99
250	2.08
230	1.87
240	0.87
…	…
All the data hour by hour during 5 years. In total 43800 rows.	

With this table, using the direction and speed columns, a new table “Output Energy 5-Years 35” for each point and high is gotten applying the coefficients:

Wind Direction		Wind Velocity	Point 1	Point 2	Point 3	…	Point 11	Point 12	Point 13
260	West	2	1.779	1.691	1.512	…	1.714	1.670	1.825
250	West	2	1.779	1.691	1.512	…	1.714	1.670	1.825
230	South_West	1.9	1.668	1.704	1.774	…	1.869	1.946	1.766
240	South_West	0.9	0.790	0.807	0.840	…	0.885	0.922	0.837
…	…	…	…	…	…	…	…	…	…

For the cardinal-points column the next EXCEL formula is used:

```
=SI(O(Y($E2>='W. Rose'!$B$2;$E2<=360);Y($E2<='W.
Rose'!$C$2;$E2>=0));"North";SI(Y($E2>='W. Rose'!$B$3;$E2<='W.
Rose'!$C$3);"North_East";SI(Y($E2>='W. Rose'!$B$4;$E2<='W.
Rose'!$C$4);"East";SI(Y($E2>='W. Rose'!$B$5;$E2<='W.
Rose'!$C$5);"South_East";SI(Y($E2>='W. Rose'!$B$6;$E2<='W.
Rose'!$C$6);"South";SI(Y($E2>='W. Rose'!$B$7;$E2<='W.
Rose'!$C$7);"South_West";SI(Y($E2>='W. Rose'!$B$8;$E2<='W.
Rose'!$C$8);"West";SI(Y($E2>='W. Rose'!$B$9;$E2<='W.
Rose'!$C$9);"North_West";"None"))))))))
```

Where, ‘W.Rose’ is the name of the next sheet, with the next table:

Directions	Bottom	Top	0.5-2.1	2.1-3.6	3.6-5.7	5.7-8.8	8.8-11.1	>=11.1	Total
North	337.5	22.5	0.07386	0.03879	0.04822	0.01655	0.00123	0.00005	0.1787
North-East	22.5	67.5	0.03642	0.01927	0.02386	0.00737	0.00048	0	0.0874
East	67.5	112.5	0.03126	0.01477	0.00929	0.00146	0	0	0.05678
South-East	112.5	157.5	0.02738	0.00929	0.00422	0.00039	0	0	0.04128
South	157.5	202.5	0.07345	0.04984	0.06187	0.01735	0.00053	0	0.20304
South-West	202.5	247.5	0.0871	0.05941	0.07644	0.02477	0.00078	0	0.2485
West	247.5	292.5	0.03804	0.01509	0.01525	0.00365	0.00014	0	0.07217
North-West	292.5	337.5	0.03409	0.01731	0.02169	0.0058	0.00078	0	0.07967
Sub-Total			0.4016	0.22377	0.26084	0.07734	0.00394	0.00005	0.96754
Calms									0.03246

For the Point 1 column the next EXCEL formula is used:

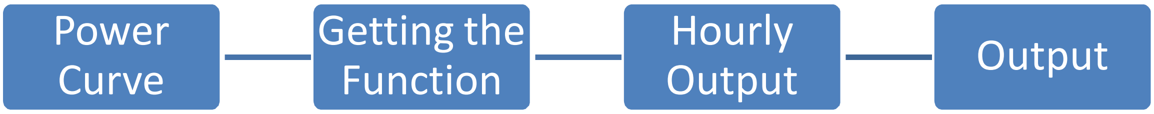
```
=SI(O(Y($E2>='W. Rose'!$B$2;$E2<=360);Y($E2<='W.
Rose'!$C$2;$E2>=0));$G2*'1'!$F$2;SI(Y($E2>='W. Rose'!$B$3;$E2<='W.
Rose'!$C$3);$G2*'1'!$F$6;SI(Y($E2>='W. Rose'!$B$4;$E2<='W.
Rose'!$C$4);$G2*'1'!$F$10;SI(Y($E2>='W. Rose'!$B$5;$E2<='W.
Rose'!$C$5);$G2*'1'!$F$14;SI(Y($E2>='W. Rose'!$B$6;$E2<='W.
Rose'!$C$6);$G2*'1'!$F$18;SI(Y($E2>='W. Rose'!$B$7;$E2<='W.
Rose'!$C$7);$G2*'1'!$F$22;SI(Y($E2>='W. Rose'!$B$8;$E2<='W.
Rose'!$C$8);$G2*'1'!$F$26;SI(Y($E2>='W. Rose'!$B$9;$E2<='W.
Rose'!$C$9);$G2*'1'!$F$30;"None"))))))))
```

Where, '1' is the name of the next sheet, with the next table:

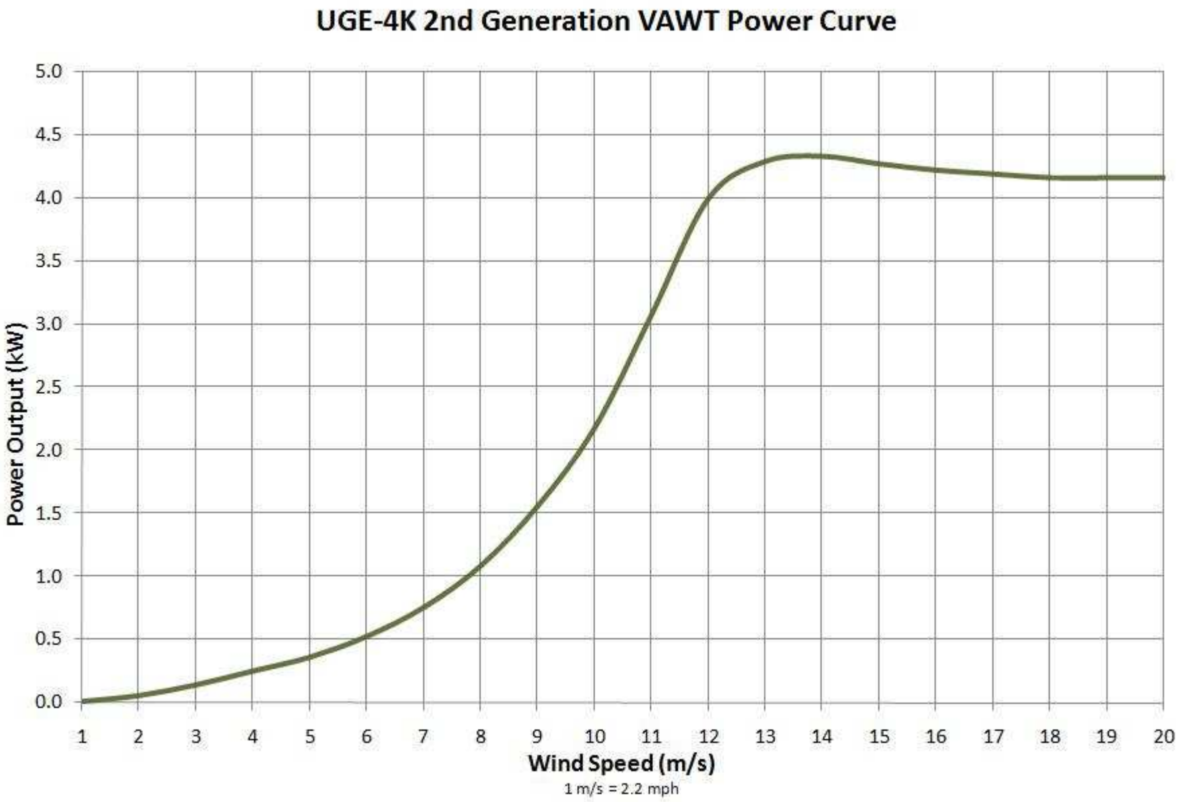
North	Altitud	Speed [m/s]	Turb. [m/s]	Turb. Rel. [%]	Coef. Conc.
	35	5.393548	1.023684	18.979782	0.904956862
	45	5.422944	0.995244	18.352458	0.899077842
	55	5.495479	1.010526	18.388306	0.900844687
North-East					
	35	5.764878	1.191044	20.660344	0.967260495
	45	5.783962	1.133334	19.594419	0.958931546
	55	5.833877	1.209877	20.738812	0.956316474
East					
	35	5.219686	1.231414	23.591717	0.875785413
	45	5.312307	1.157038	21.780323	0.880735172
	55	5.518417	1.160875	21.036371	0.904604792
South-East					
	35	4.585019	1.280947	27.937672	0.769297762
	45	4.650033	1.263039	27.161926	0.770935794
	55	5.005977	1.280672	25.582862	0.820603224
South					
	35	5.402107	1.157181	21.420913	0.906392935
	45	5.528579	1.107127	20.025529	0.916591224
	55	5.55548	1.154234	20.776493	0.910680332
South-West					
	35	5.2317	1.342409	25.659134	0.877801183
	45	5.38918	1.279934	23.750069	0.893480059
	55	5.597732	1.267989	22.651835	0.917606478
West					
	35	5.302068	1.207242	22.769271	0.889607883
	45	5.436718	1.232549	22.67082	0.901361454
	55	5.762498	1.222747	21.21905	0.944615694
North-West					
	35	4.95329	1.264354	25.525543	0.83108814
	45	5.029981	1.280002	25.447458	0.83392793
	55	5.188769	1.249642	24.083597	0.850567346

This example is for Point 1 in a high of 35mm. in the model (mast of 7 meters in the reality).

Output



The curve gotten from the Urban green Energy website.



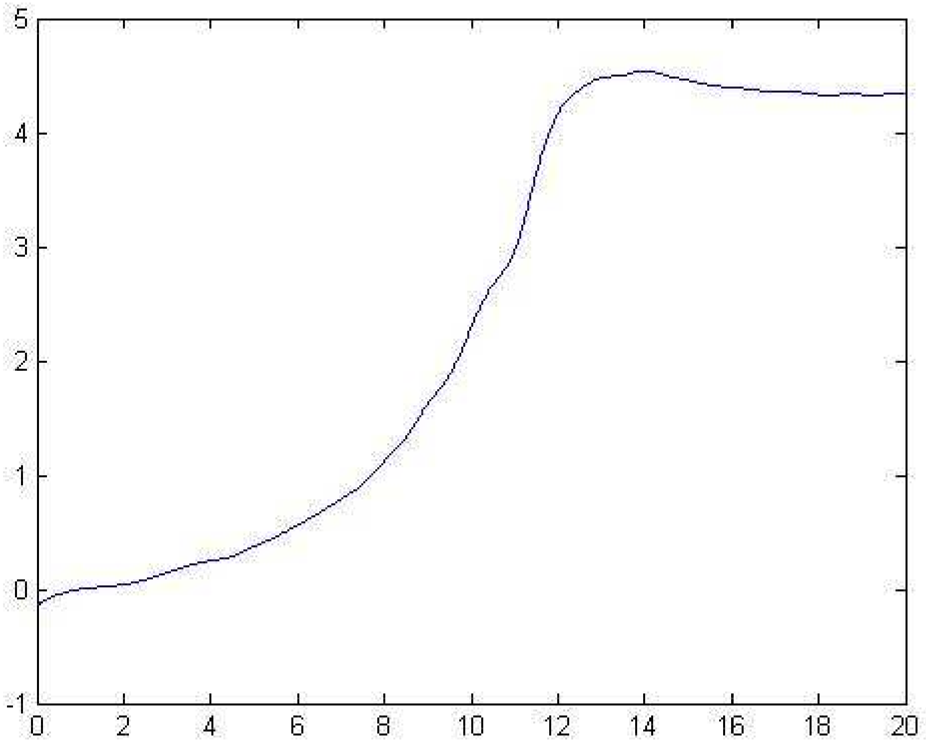
Points taken by hand from the curve.

Wind Speed	Power output
1	0
1.5	0.020833333
2	0.041666667
2.5	0.083333333
3	0.145833333
3.5	0.208333333
4	0.25
4.5	0.291666667
5	0.375
5.5	0.458333333
6	0.5625
6.5	0.666666667
7	0.791666667
7.5	0.916666667
8	1.125
8.5	1.333333333
9	1.625
9.5	1.875
10	2.291666667
10.5	2.666666667
11	2.958333333
11.5	3.645833333
12	4.166666667
12.5	4.375
13	4.479166667
13.5	4.5
14	4.541666667
14.5	4.5
15	4.458333333
15.5	4.416666667
16	4.395833333
16.5	4.375
17	4.354166667
17.5	4.354166667
18	4.333333333
18.5	4.333333333
19	4.333333333
19.5	4.333333333
20	4.333333333

The Matlab file GraphUGE.m gives the calculation of the output using “spline” command:

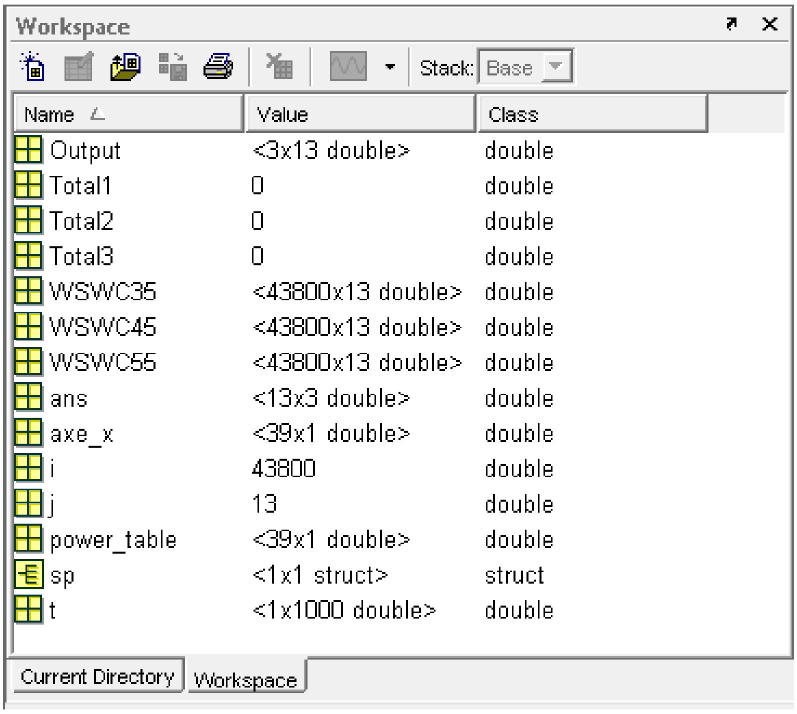
```
%Fitting the curve using the command "spline"
axe_x=[1:0.5:20]';
sp=spline(axe_x,power_table)
t=linspace(0,20,1000);
plot(t,ppval(sp,t))

%Program
   Total1=0;
   Total2=0;
   Total3=0;
for j=1:13
   for i=1:43800
   Total1= ppval(sp,WSWC35(i,j))+Total1;
   Total2= ppval(sp,WSWC45(i,j))+Total2;
   Total3= ppval(sp,WSWC55(i,j))+Total3;
   end
   Output(1,j)=Total1;
   Output(2,j)=Total2;
   Output(3,j)=Total3;
   Total1=0;
   Total2=0;
   Total3=0;
end
Output
```

With the first part of the program (%Fitting the curve using the command "spline") the curve is found:



With the second part (%Program), the output is calculated for the 13 points and the 3 high.

Working space necessary for the program:



Name	Value	Class
Output	<3x13 double>	double
Total1	0	double
Total2	0	double
Total3	0	double
WSWC35	<43800x13 double>	double
WSWC45	<43800x13 double>	double
WSWC55	<43800x13 double>	double
ans	<13x3 double>	double
axe_x	<39x1 double>	double
i	43800	double
j	13	double
power_table	<39x1 double>	double
sp	<1x1 struct>	struct
t	<1x1000 double>	double

Output: Is the result, a matrix 3x13 (Highs x Number of points)
Total1, Total2 and Total3: Are accumulators for the different highs (7m., 9m. and 11m.)
WSWC35, WSWC45 and WSWC55: Are the tables obtained in part "Data Treatment".
i and j: The variables to run the counter.
sp: The function obtained with me method "spline".

The Output table "Output":

	7m	9m	11m
Point 1	10996	11486	12156
Point 2	11086	11917	12820
Point 3	11907	12458	12928
Point 4	11482	11955	12391
Point 5	9103.9	10298	11412
Point 6	9549.1	10194	11001
Point 7	11115	10827	11752
Point 8	9832.3	10899	11607
Point 9	9748.4	10538	11574
Point 10	10436	11090	12066
Point 11	11104	11564	12164
Point 12	13113	14175	15299
Point 13	11926	13028	13964

Appendix F. Other Turbines

Ampair 6000

This information comes from the official web site of the manufacturer: www.ampair.com

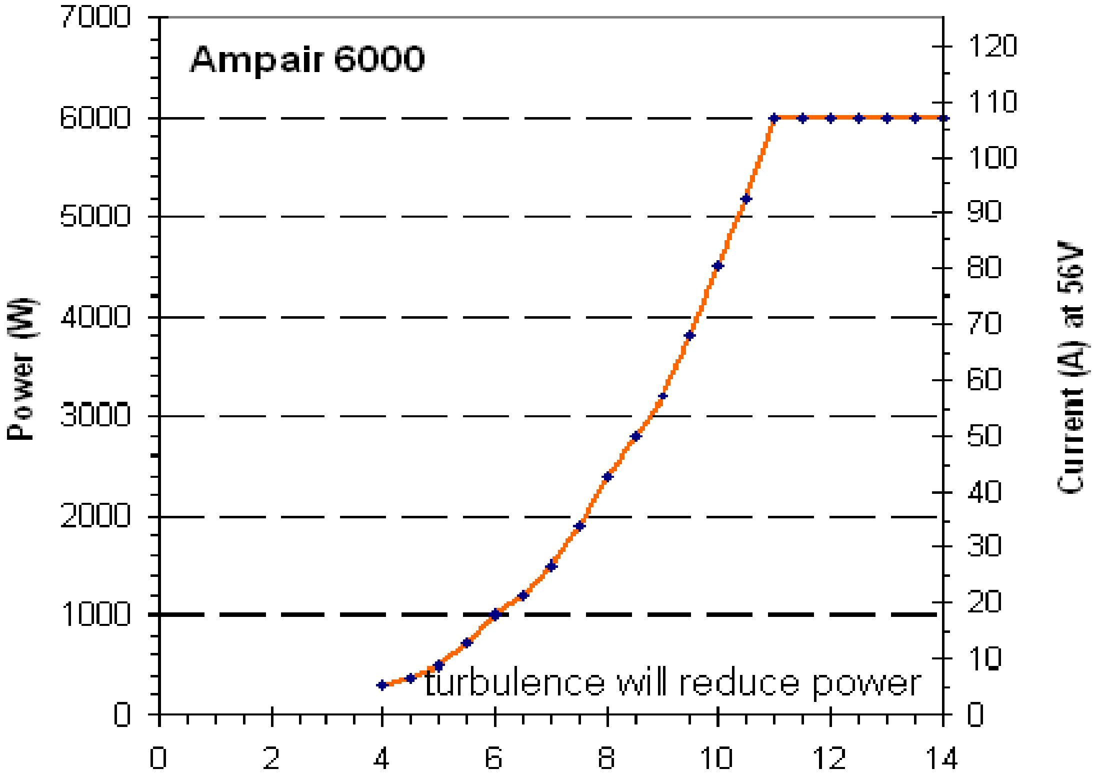
Table of Output [kwh] for 5 years:

	7m	9m	11m
Point 1	16300	17257	18540
Point 2	16503	18125	19891
Point 3	18115	19175	20083
Point 4	17273	18181	19022
Point 5	12680	14944	17108
Point 6	13522	14734	16277
Point 7	16569	15988	17808
Point 8	14072	16113	17479
Point 9	13895	15429	17432
Point 10	15226	16487	18385
Point 11	16529	17405	18558
Point 12	20457	22549	24733
Point 13	18102	20252	22061

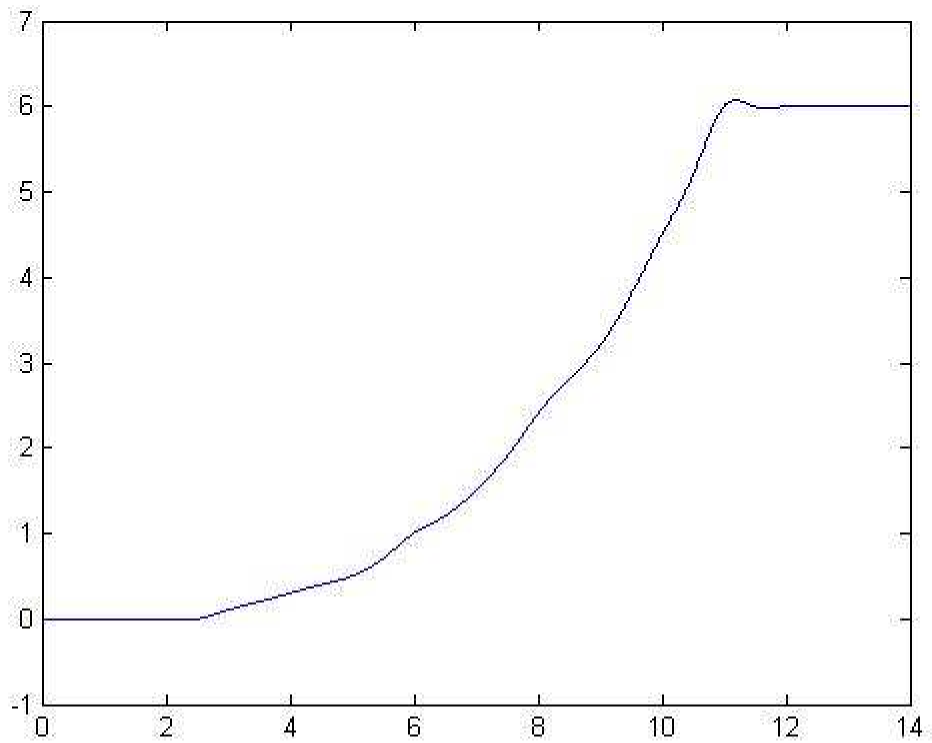
Table of the Differences:

	7m	9m	11m
Point 1	148.2	150.2	152.5
Point 2	148.9	152.1	155.2
Point 3	152.1	153.9	155.3
Point 4	150.4	152.1	153.5
Point 5	139.3	145.1	149.9
Point 6	141.6	144.5	148.0
Point 7	149.1	147.7	151.5
Point 8	143.1	147.8	150.6
Point 9	142.5	146.4	150.6
Point 10	145.9	148.7	152.4
Point 11	148.9	150.5	152.6
Point 12	156.0	159.1	161.7
Point 13	151.8	155.4	158.0

Power Graph from the manufacturer



Power Graph from Matlab



AV-7

This information comes from the official web site of the manufacturer: www.aventa.ch

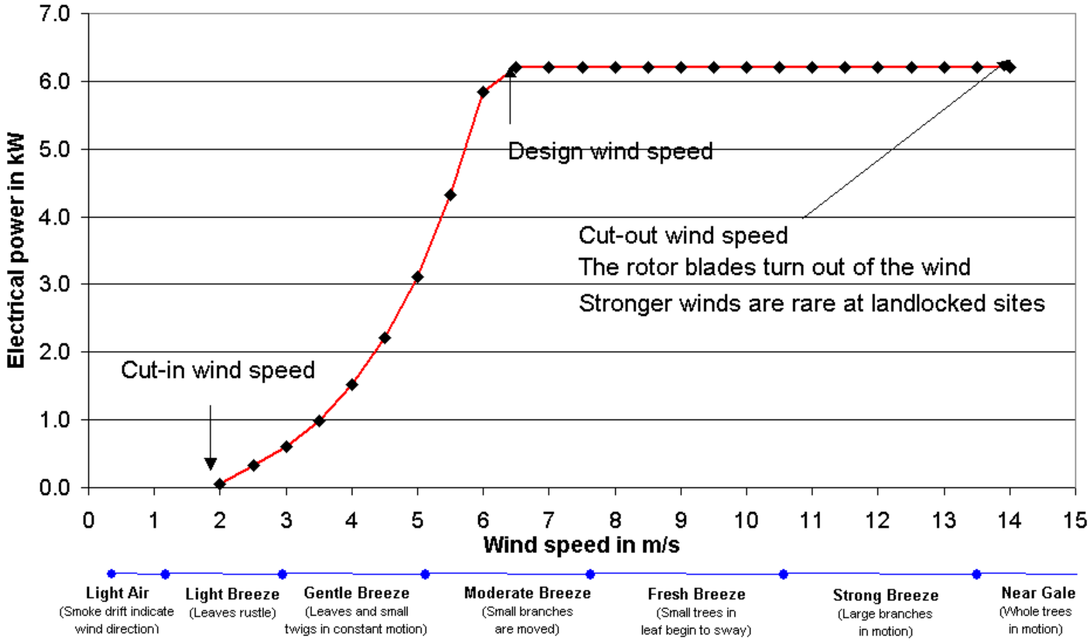
Table of Output [kwh] for 5 years:

	7m	9m	11m
Point 1	73637	76593	80448
Point 2	73096	78303	83308
Point 3	78007	81049	83559
Point 4	74851	77929	80579
Point 5	60098	68616	75744
Point 6	63788	68246	73456
Point 7	74509	72870	78164
Point 8	66590	73236	77425
Point 9	66126	71044	77033
Point 10	69475	73659	79444
Point 11	72657	75713	79353
Point 12	85166	90618	95744
Point 13	79594	85556	90233

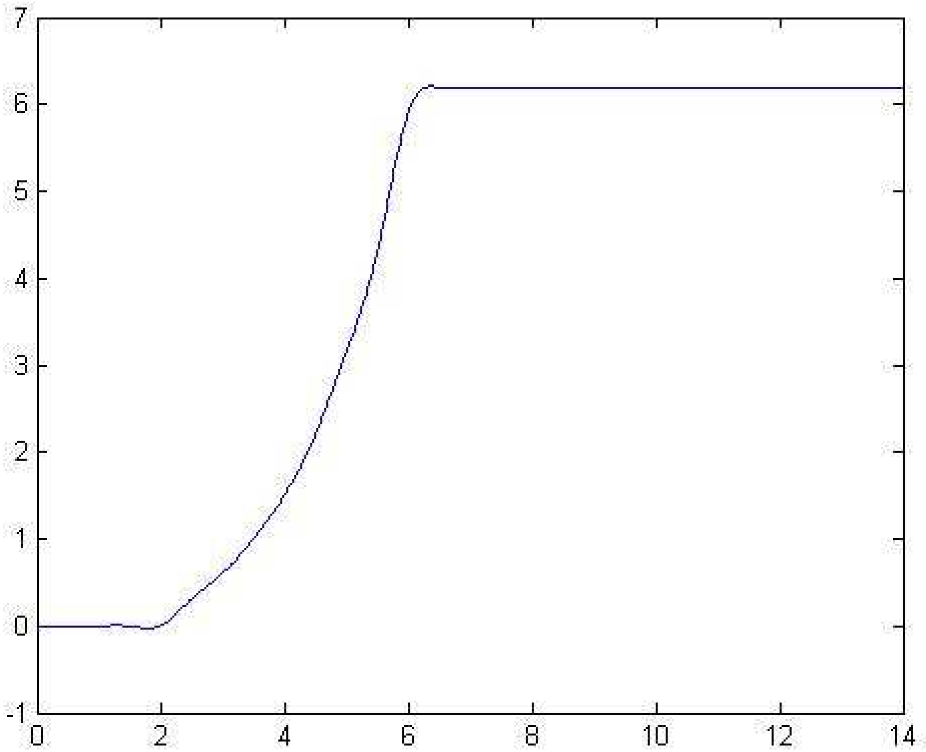
Table of the differences:

	7m	9m	11m
Point 1	669.7	666.8	661.8
Point 2	659.4	657.1	649.8
Point 3	655.1	650.6	646.3
Point 4	651.9	651.9	650.3
Point 5	660.1	666.3	663.7
Point 6	668.0	669.5	667.7
Point 7	670.3	673.0	665.1
Point 8	677.3	672.0	667.1
Point 9	678.3	674.2	665.6
Point 10	665.7	664.2	658.4
Point 11	654.3	654.7	652.4
Point 12	649.5	639.3	625.8
Point 13	667.4	656.7	646.2

Power Graph from the manufacturer



Power Graph from Matlab



Bornay 3000

This information comes from the official web site of the manufacturer: www.bornay.com

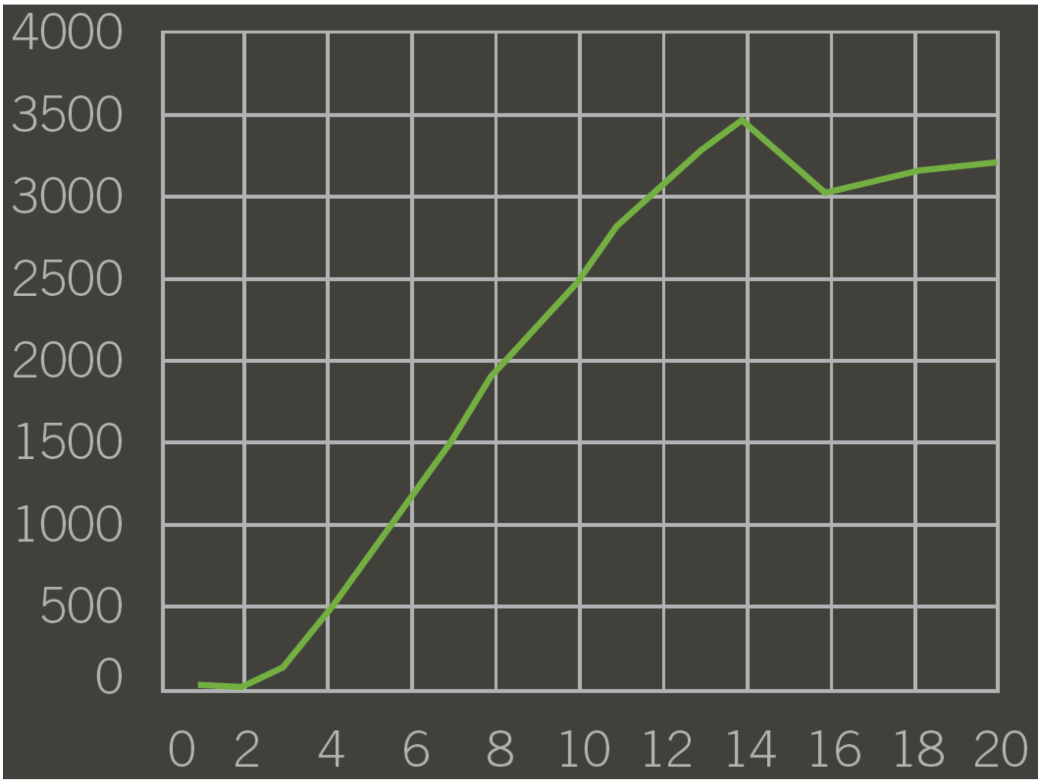
Table of Output [kwh] for 5 years:

	7m	9m	11m
Point 1	18822	19623	20689
Point 2	18794	20184	21598
Point 3	20141	20999	21715
Point 4	19373	20179	20891
Point 5	15436	17577	19452
Point 6	16305	17437	18798
Point 7	19047	18589	20057
Point 8	16936	18695	19839
Point 9	16805	18115	19762
Point 10	17813	18907	20475
Point 11	18770	19555	20529
Point 12	22109	23687	25247
Point 13	20404	22093	23463

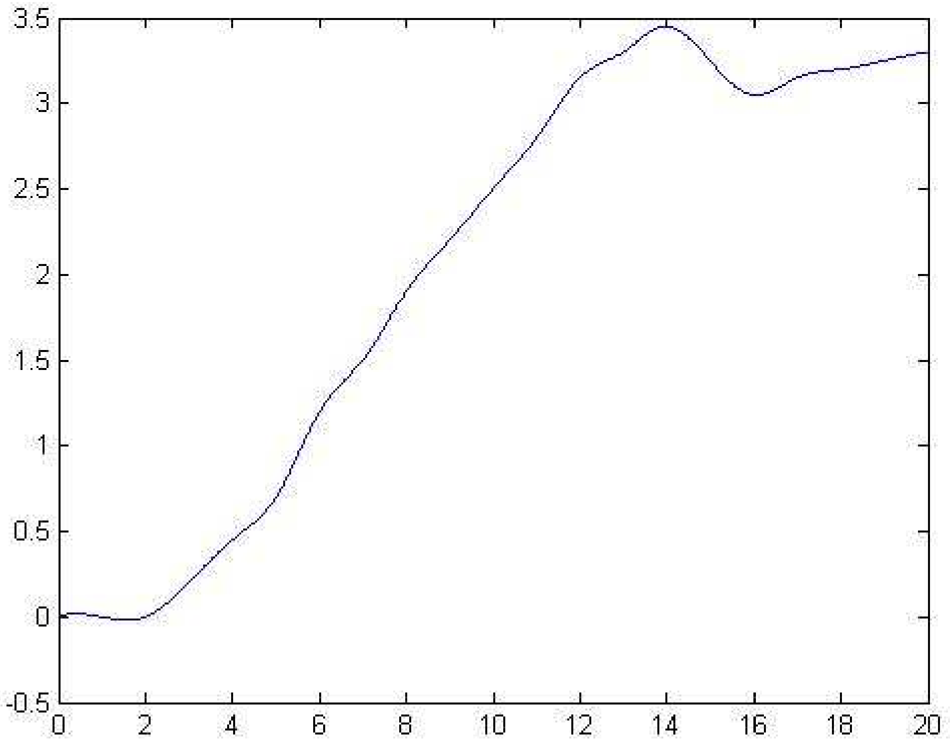
Table of the differences

	7m	9m	11m
Point 1	171.2	170.8	170.2
Point 2	169.5	169.4	168.5
Point 3	169.2	168.6	168.0
Point 4	168.7	168.8	168.6
Point 5	169.6	170.7	170.5
Point 6	170.7	171.1	170.9
Point 7	171.4	171.7	170.7
Point 8	172.2	171.5	170.9
Point 9	172.4	171.9	170.7
Point 10	170.7	170.5	169.7
Point 11	169.0	169.1	168.8
Point 12	168.6	167.1	165.0
Point 13	171.1	169.6	168.0

Power Graph from the manufacturer



Power Graph from Matlab



Bornay 6000

This information comes from the official web site of the manufacturer: www.bornay.com

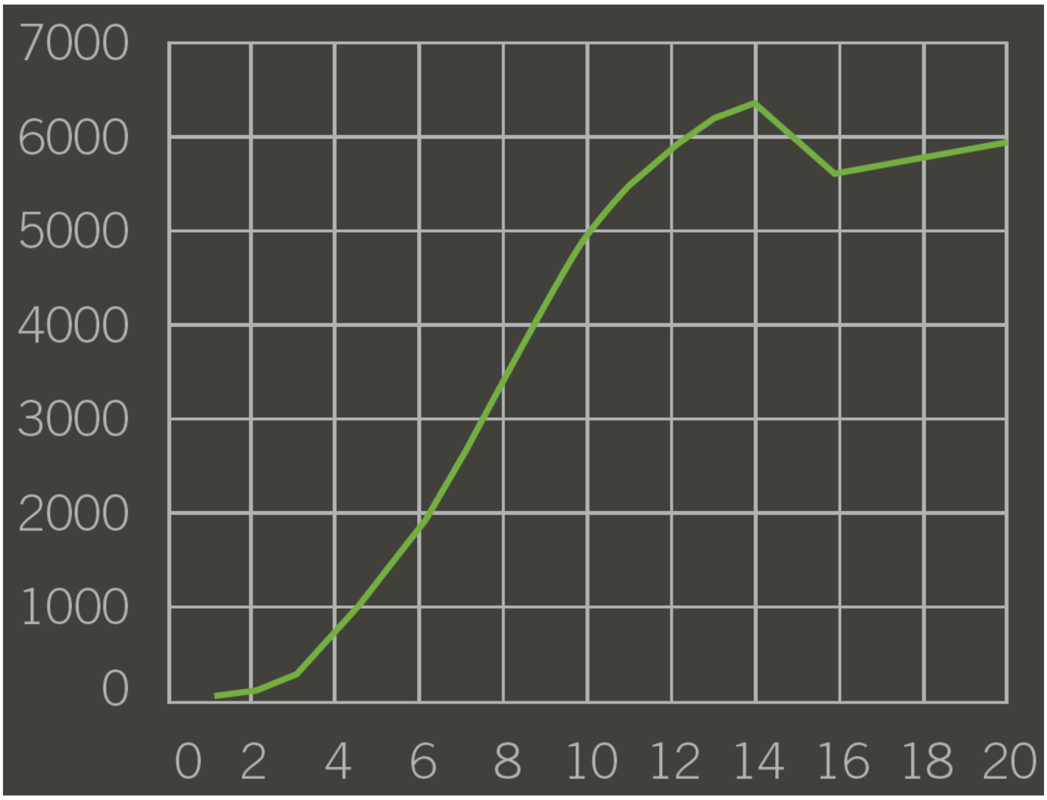
Table of Output [kwh] for 5 years:

	7m	9m	11m
Point 1	30667	32094	33989
Point 2	30667	33132	35664
Point 3	33070	34603	35890
Point 4	31761	33173	34428
Point 5	24810	28493	31801
Point 6	26269	28219	30605
Point 7	31069	30239	32867
Point 8	27366	30449	32471
Point 9	27119	29431	32345
Point 10	28930	30852	33627
Point 11	30659	32026	33746
Point 12	36568	39409	42248
Point 13	33451	36480	38952

Table of the differences

	7m	9m	11m
Point 1	278.9	279.4	279.6
Point 2	276.6	278.0	278.2
Point 3	277.7	277.8	277.6
Point 4	276.6	277.5	277.8
Point 5	272.5	276.7	278.7
Point 6	275.1	276.8	278.2
Point 7	279.5	279.3	279.7
Point 8	278.3	279.4	279.8
Point 9	278.2	279.3	279.5
Point 10	277.2	278.2	278.7
Point 11	276.1	276.9	277.4
Point 12	278.9	278.0	276.1
Point 13	280.5	280.0	278.9

Power Graph from the manufacturer



Power Graph from Matlab