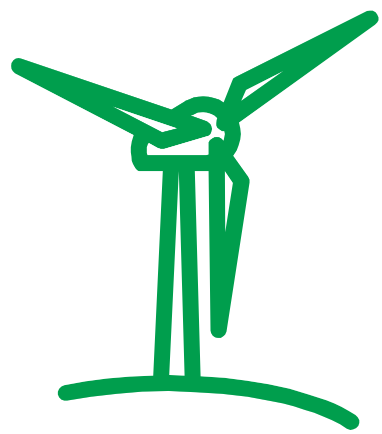
FAKULTEIT INGENIEURSWESE
FACULTY OF ENGINEERING

Feasibility Study for Wind Power at SAB Newlands



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1. ABSTRACT

This paper describes a MEng thesis project for a MEng in Renewable Energy Systems program at the Centre for Renewable Energy Studies at the University of Stellenbosch, South Africa. The aim of this paper was to offer to SAB (South African Breweries), in Cape Town, a feasibility study for the possibilities of the usage of wind energy on site.

The small scale wind power technology has a long history and has been in South Africa for more than a hundred years in the form of water pump wind mills. All wind mills have an absolute maximum power output defined by the Betz limit. The choice of a wind turbine depends not only on this, but also on the wind speed distribution, the power curve, the location and financing. The small scale turbines have many different design which are predominantly grouped in horizontal axis (HAWT) and vertical axis (VAWT) machines.

The choice of turbine for SAB depends on the available wind energy, the available budget, the available space and the application. The aim of the measurements on site was threefold; find a correlation with existing weather stations in the area like at Cape Town International Airport, propose a turbine for SAB's budget and research the possibility for installing the turbine on one of the buildings. This is also known as building integrated wind turbines.

Wind speeds can increase over buildings due to venturi effects and it could therefore be viable to locate these acceleration zones and install a turbine there. The data analysis shows that the wind above the brewery is very well correlated with the wind at the airport. We can therefore use the average speed values of this station to predict average power production. This leads to the proposal of a 1kW or 3kW turbine from a South African manufacturer: Kestrel. Building integration is however not a good idea. The wind is too turbulent and can therefore not be used. This is mainly caused by the fact that the surroundings of the brewery are too high and irregularly shaped. This makes it difficult for the wind to "lower" in between the buildings and accelerate.

The wind turbine for SAB is proposed to be installed on the highest point of the roof and based on the neighbouring average wind speed values. The wind turbine should be connected directly to the brewery's grid with an inverter and would then solely function as an energy saver. Another important aspect is the promotional value in the energy efficiency strategy of SAB.

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2. INTRODUCTION

Cape Town has a reputation of a very windy city. It is therefore logical to investigate the potential of this wind power for harvesting it in the form of electric power by use of wind turbines. The dominating winds in the region are the infamous south eastern wind and the north western wind. These are seasonal and are responsible for the reputation of Cape Town as a good wind sports site.

Since several years, the effects of climate change have been increasing and the general interest in renewable energy technologies has been growing steadily. Wind energy in particular seems to be the fastest growing energy technology at the moment. European countries like Germany are aiming at a penetration level of 20% and higher. The main objective there is to use wind energy as a fuel saver and for replacing a percentage of conventional energy technology.

In South Africa, the interest in wind energy is not less than elsewhere although the legislative mechanisms are lagging behind. Many private investors like companies and households don't wish to wait for this and are prepared to take the initiative to invest in wind energy. However, the knowledge of wind turbines is still quite low. SAB is one of the companies that would like to invest in wind turbines to be placed on the premises of its factories. The question arises then where to place the turbine, which system to choose and how big it should be. The purpose of this report is to answer these questions.

The first half of this report includes a history, summary and description of existing technologies, types and more.

The second half comprises a feasibility study for SAB Cape Town. The site was surveyed by measuring the wind speeds and directions with two measuring devices. Based on that and other limitations, a list of recommendations will be made in order to provide a clear conclusion to SAB.

3. THEORY AND BACKGROUND

Introduction

The theory and background described in this chapter contains a general overview of wind energy systems. First the history of wind energy and turbines is briefly described. After that, the topic of wind energy is described by starting from the definition of wind energy and its limitation by the Betz law. The latter influences directly the power curve and performance of a wind turbine. Then, the variability of wind energy is discussed because this is probably the most important topic to understand. The next paragraphs discuss how to calculate the annual energy production (AEP) of wind turbines and the related capacity factor and capacity credit. The main objective of wind turbines is electricity generation and we have added a paragraph regarding this subject which touches on electricity and generators.

History

Throughout the human history the wind has been used to power sailboats and sail ships and to ventilate buildings or houses. The applications where wind power is used to generate mechanical power or shaft power are relatively young. As early as the 17th century BC, in Babylon, there are traces of the use of wind mills to power irrigation systems. The oldest practical wind mills have been found in Afghanistan dating back to the 7th century. These were vertical-axis windmills, which had long vertical drive shafts with rectangular blades. The materials used were wood, reed matting, cloth and limestone. These windmills were used to grind corn and draw up water. Horizontal-axis windmills were later used extensively in North-western Europe and Greece to grind flour. The most famous are found in The Netherlands which date back to the 1180s.

During the 1800s there was a major boom in the development and distribution of the well known multi-bladed turbine which was mounted on a wooden structure. These were used by farms and railroads to pump ground water used for irrigation, cattle and steam locomotives and were rapidly distributed all over the world.

The first modern wind turbines were built in the early 1980s, and have been subject to increasingly efficient design.

Wind Energy

Wind is generated by atmospheric pressure differences. The solar energy that falls upon the earth warms the surface by radiation. The surface warms up and transmits a large part of the heat back to the air by convection and this causes the air to rise in the warmer regions near the equator. This mechanism causes the major wind systems that govern global wind patterns. They are quite well understood, but on the more local level there are many parameters still unknown. Most of the energy stored in these wind movements can be found at high altitudes where continuous wind speeds of over 160 km/h occur. Eventually, the wind energy is converted back through friction into diffuse heat throughout the earth's surface and the atmosphere. A good example of local wind patterns occurs in high altitude mountain ranges like the Alps in Europe. Here, aside from the meteorological wind, there is also a wind force generated by the difference in temperature of the mountain flanks and valleys. This wind is also known as a valley breeze. Another example of local wind force is the acceleration of wind between buildings in built-up areas in cities or between funnel shaped hills.

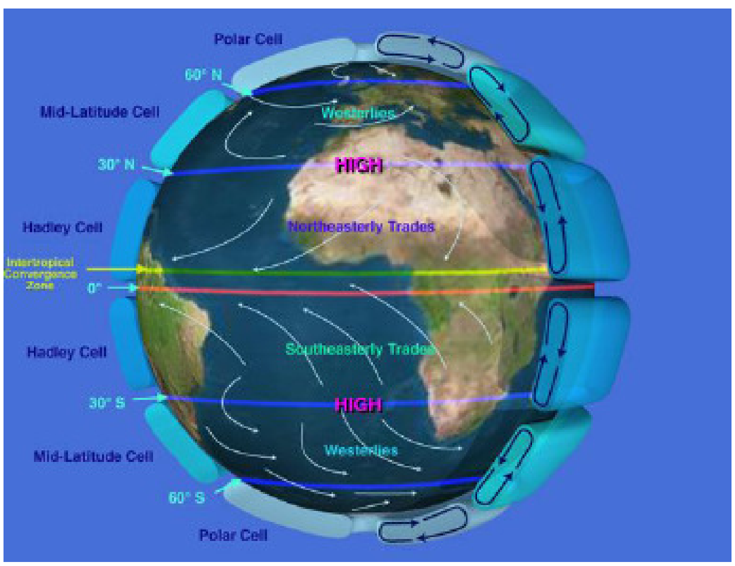

Figure 1: Global wind systems; trade winds
(**http://ww2010.atmos.uiuc.edu**)

The total wind power that is present in the earth's atmosphere is estimated to be considerably more that the present total human power usage. Of this total power, it is estimated that about 72 TW can be commercially exploited compared to the 15 TW average global power consumption. This number is incentive enough to allow investments and research to continue.

Betz Law

The Betz law allows us to calculate the maximum energy that can be converted by a wind turbine. It was developed in 1919 by German physicist Albert Betz (Jackson, 2009).

The essence of the Betz law the power extracted from the wind by the rotor is proportional to the product of the wind speed times the pressure drop across the rotor.

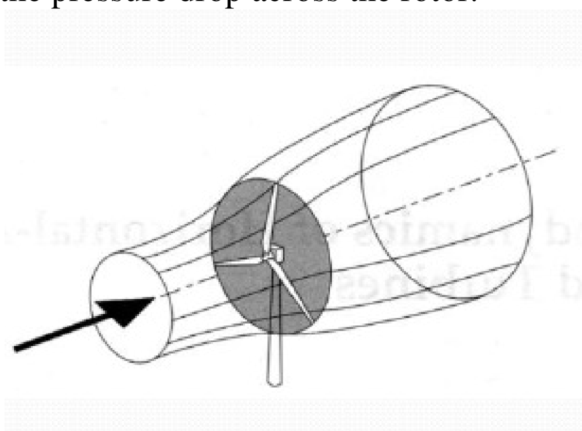

Figure 2: A rotor in a wind stream (Jackson, 2009)

If the rotor has a higher flow resistance, the pressure drop is increased, but less flow goes through the disc and more goes around it. The Betz law shows that there is a maximum efficiency for the extraction of power which is at 59.3%. See Appendix A for a derivation of the Betz law.

Based on the law, it is common practice to say that a turbine can't capture more than 59.3 % of the kinetic energy in wind.

Because some modern wind turbines approach this potential maximum efficiency, once practical engineering obstacles are considered, the Betz law shows a limiting factor for this form of renewable energy. Engineering constraints, energy storage limitations and transmission losses cause for even the best modern turbines to operate at efficiencies substantially below the Betz limit.

The Power Curve of a Wind Turbine

The power curve of a wind turbine is a graph that indicates how large the electrical power output will be for the turbine at different wind speeds. Usually, wind turbines are designed to start generating at wind speeds somewhere around 3 to 5 metres per second. This is called the cut-in wind speed. The wind turbine will be programmed or designed to stop at high wind speeds in order to avoid damaging the turbine or its surroundings. This speed is called the cut-out wind speed. In Figure 3 this speed is 10, 5 m/s.

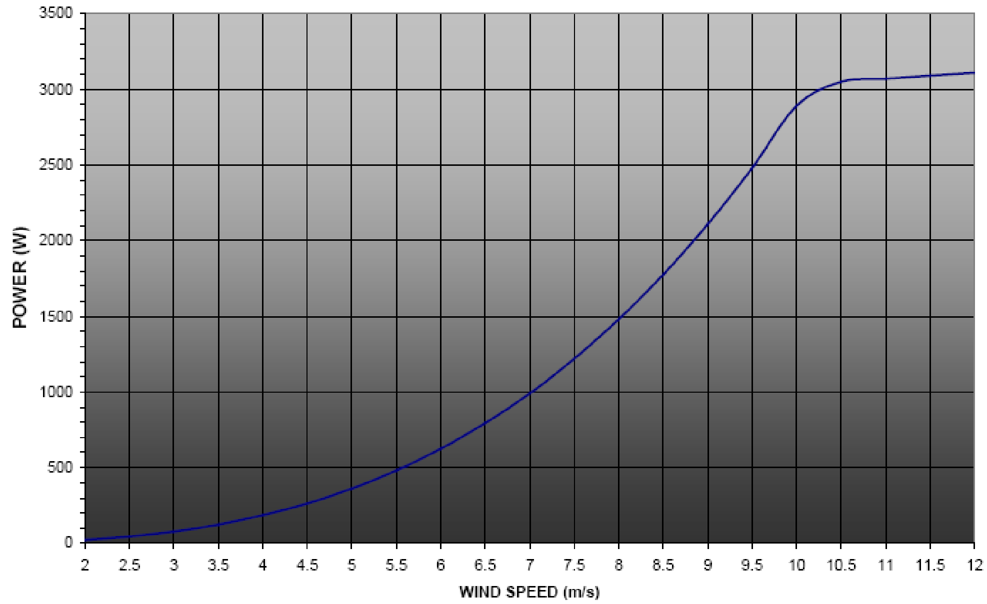

Figure 3: Example of a power curve (Kestrel Wind)

The Variability of Wind

Wind Speed Distribution

The limitation stated by the Betz law is not the only factor that counters the easy implementation of wind turbines. Another important one is the non-consistency of wind speed regardless of location. Common practice these days is to measure wind speeds continuously and map these data on graphs and analyze these statistically with the Weibull distribution formulas. These give us a good graphical representation of the behaviour of the wind at a certain location. An example is given underneath.

Figure 4 shows two Weibull curves with the same mean wind speed, but different shape factors. When the shape factor is 2, the distribution is called a Raleigh distribution.

This wind speed distribution is a very accurate display of the shortcoming of wind energy: the energy is not reliably available when needed and not constant. Unlike fossil fuel plants which can run 24 hrs regardless of weather conditions.

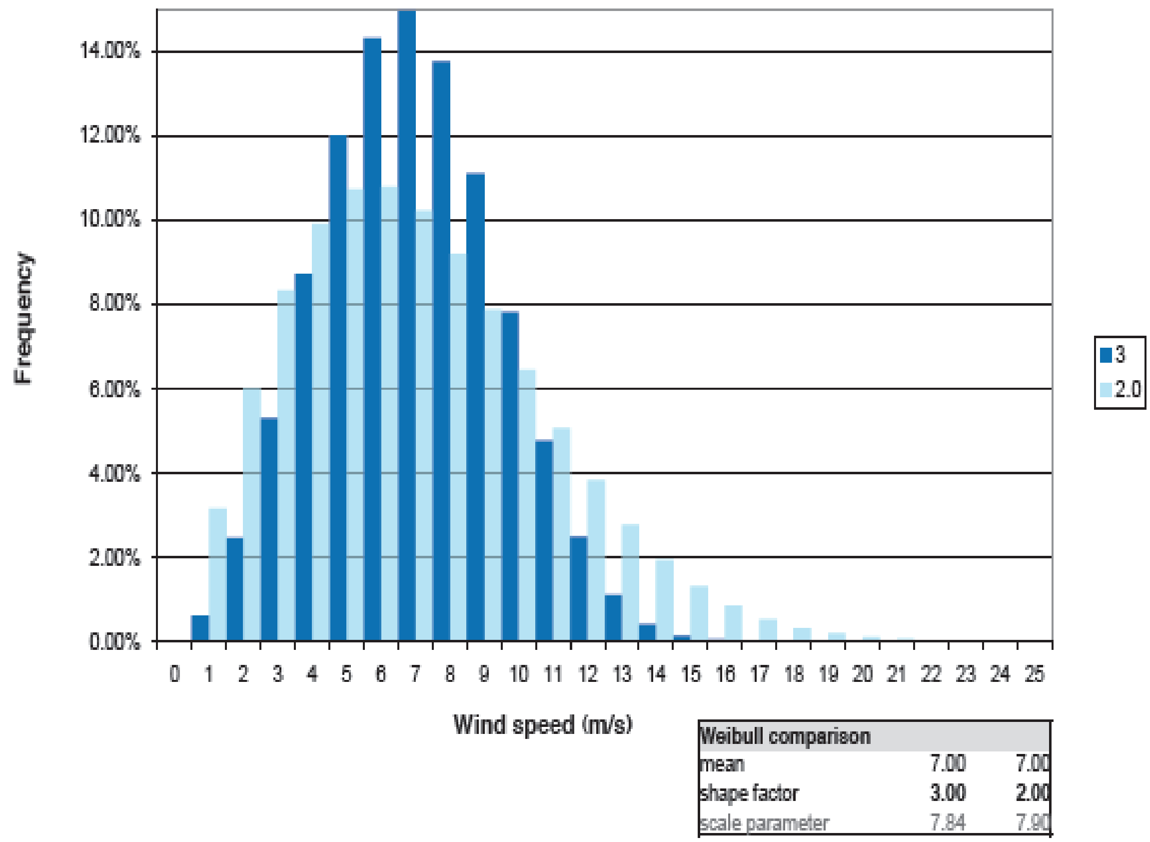

Figure 4: Two Weibull curves with different shape factors but same mean wind speed. (Jackson, 2009)

Variation over long periods

The effects of day and night, of seasonal differences and annual variation trends are all visible when wind speeds are plotted versus a time scale. The wind speed at a certain location can differ between night and day for instance when a daily sea breeze exists.

When data of many years is available, one can also detect trends over the years. In Europe, the wind has been monitored for more than a hundred years which has enabled to find certain trends. One can for example find that the average annual wind speed differs with a standard mean deviation of 6% between the years.

Local obstructions and wind shear

Wind is air in motion. The air behaves like a fluid and its flow path is not only defined by a pressure difference and a flow rate, but also by the obstructions it meets. When air flows over or around an obstruction, there is always a certain amount of turbulence in the vicinity of this obstruction. The turbulence depends on the wind speed and can affect a wind turbine performance negatively. This can be understood from the fact that the force on the blades is a result of a smooth well ordered laminar flow over them. The lift that is generated by the blade results in a displacement or rotation of the rotor. When the incoming airflow is turbulent, the flow around the blade is disturbed and this causes a 'stall' of the blade resulting in very little to no lift force. There are two ways to stall a blade. One is to increase the angle of attack α (Fig 7) too much and the second one is to vary α too fast and irregularly which is the case with turbulent flow.

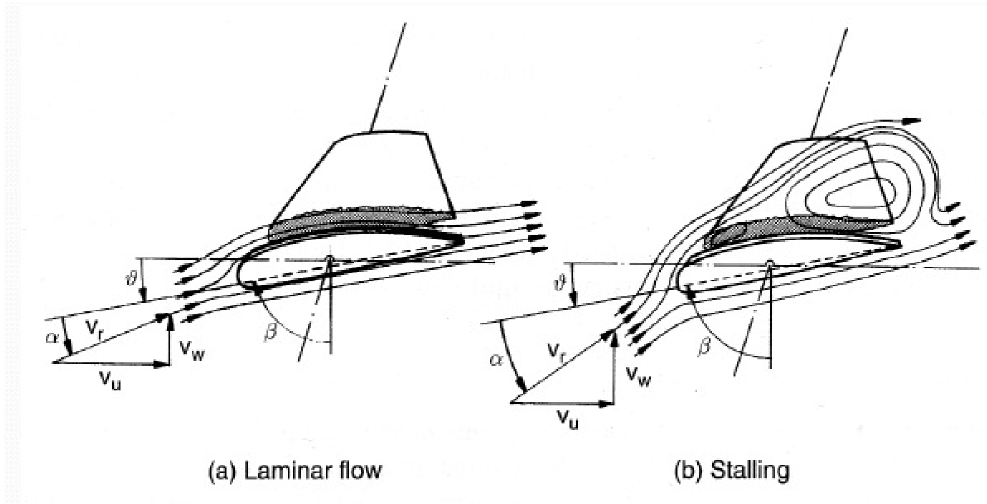

Figure 5: Laminar flow and stalling due to turbulence (Jackson, 2009)

The positioning of a wind turbine will be heavily influenced by its surrounding characteristics as is shown in the next figure. The reader can understand that the placement of a turbine in an open field is much different from the placement in a built up area where the turbulences are very difficult to predict.

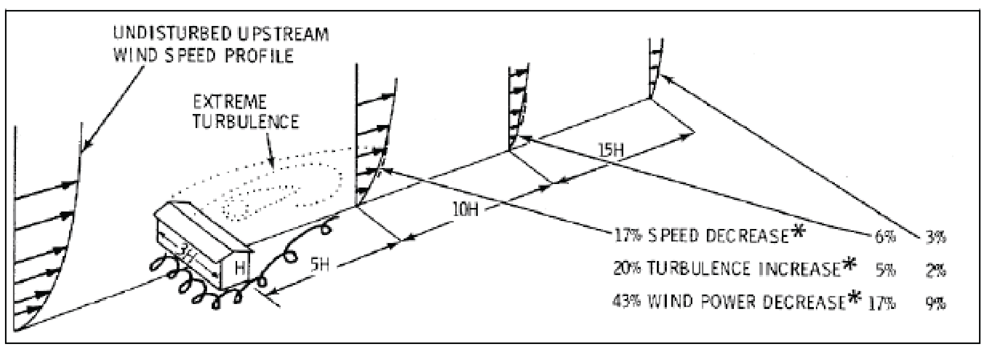

Figure 6: turbulence effect due to building (Jackson, 2009)

Another variation due to obstructions is the variation of the wind speed between the ground level and higher up in the air. At any location, a shear profile can be measured which shows the effect of the ground on the wind speed. Like any normal fluid, air is sensitive to the roughness of its surroundings. This roughness creates a shear effect depending on its speed and viscosity. When measurements are made at a location, the best thing to do is to measure the wind shear profile by using wind vanes at different heights. This profile tends to be an exponential function with following relationship:

$$\frac{U(z_2)}{U(z_1)} = \left(\frac{z_2}{z_1}\right)^{\alpha}$$

Where the velocities $U_{(x)}$ are related to the heights z_x. (See Fig 7)

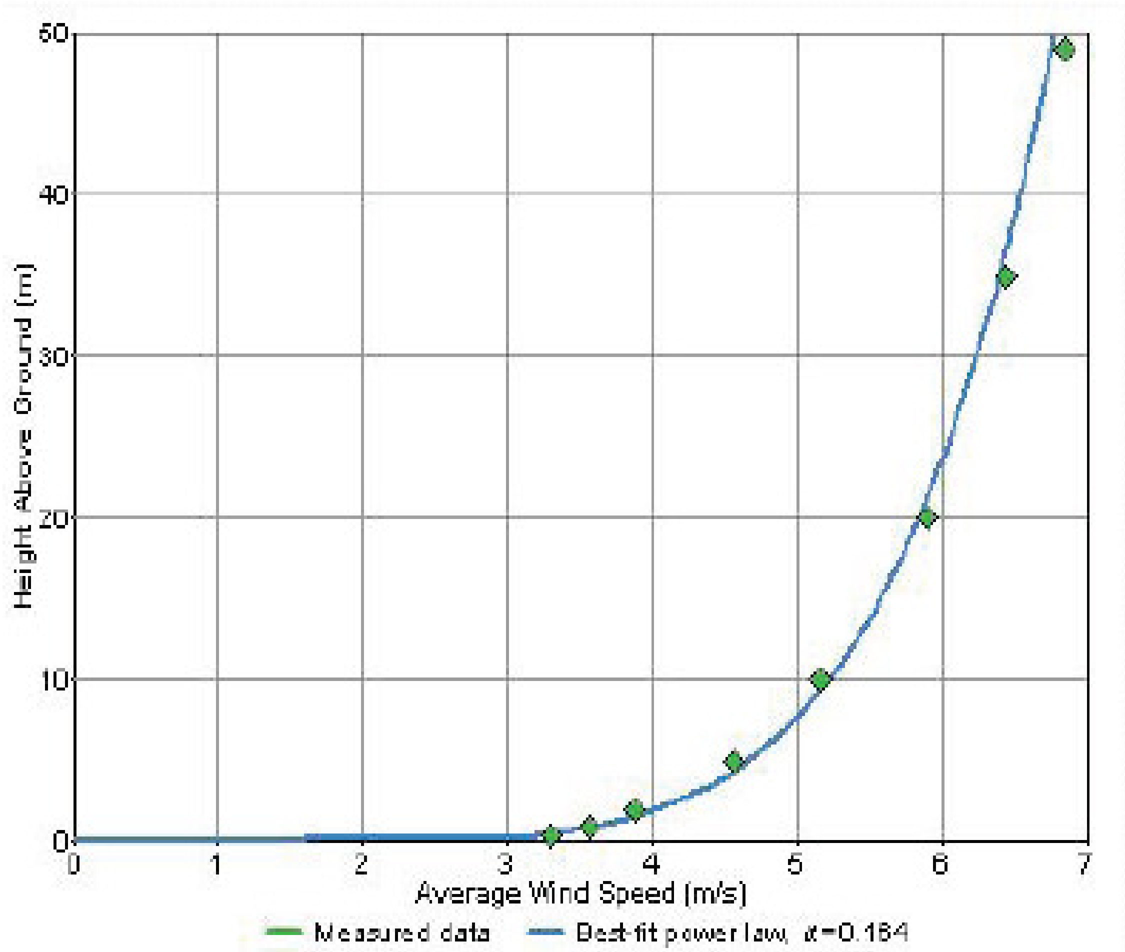

Figure 7: wind shear profile (Jackson, 2009)

It is clear that the wind speeds are generally higher at greater elevation from the surface where the measurement was taken. This is why commercial wind farms reach for higher wind speeds by using higher turbines. There is of course a maximum to this which is a balance between cost and benefit.

Wind Maps

The effects of geography and pressure zones and the previously mentioned disturbances cause an average variability between regions. This is easily shown in the next figures which are wind maps for South Africa. These windmaps show the average wind speeds in all the areas in South Africa. Although this should not be the only decisive indicator for the choice of a wind farm location, this certainly indicates where the best regions will be found. These windmaps show for example that the coastal regions of the Western Cape have a higher mean annual wind speed than the more inland regions of for example the Northern Cape. (Fig 8 and 9)

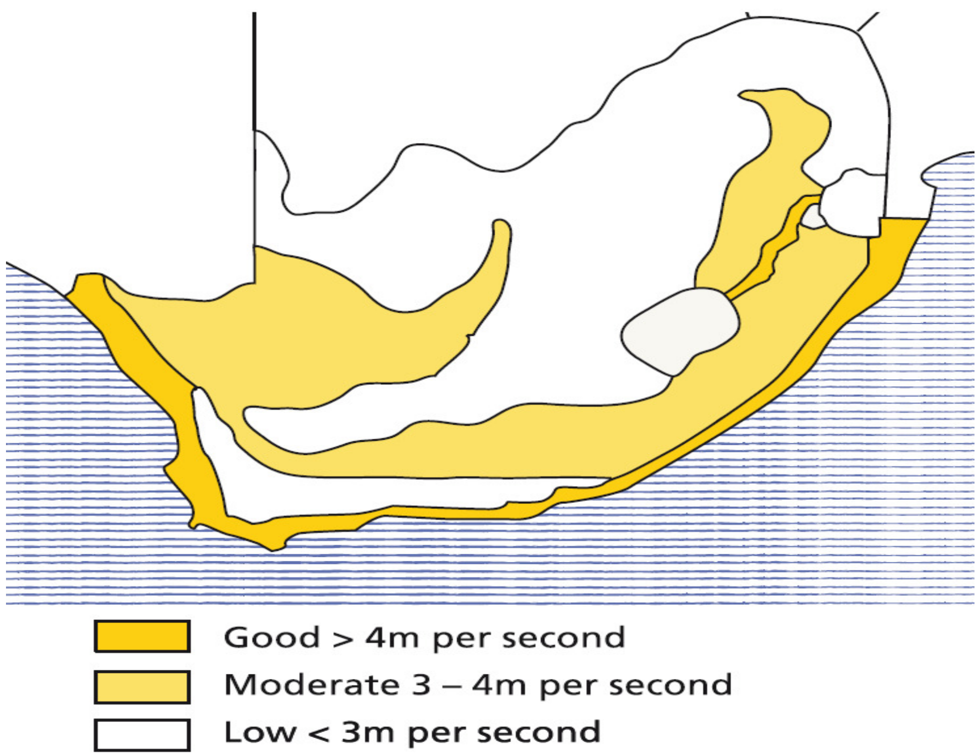

Figure 8: wind speed variation with region (DME)

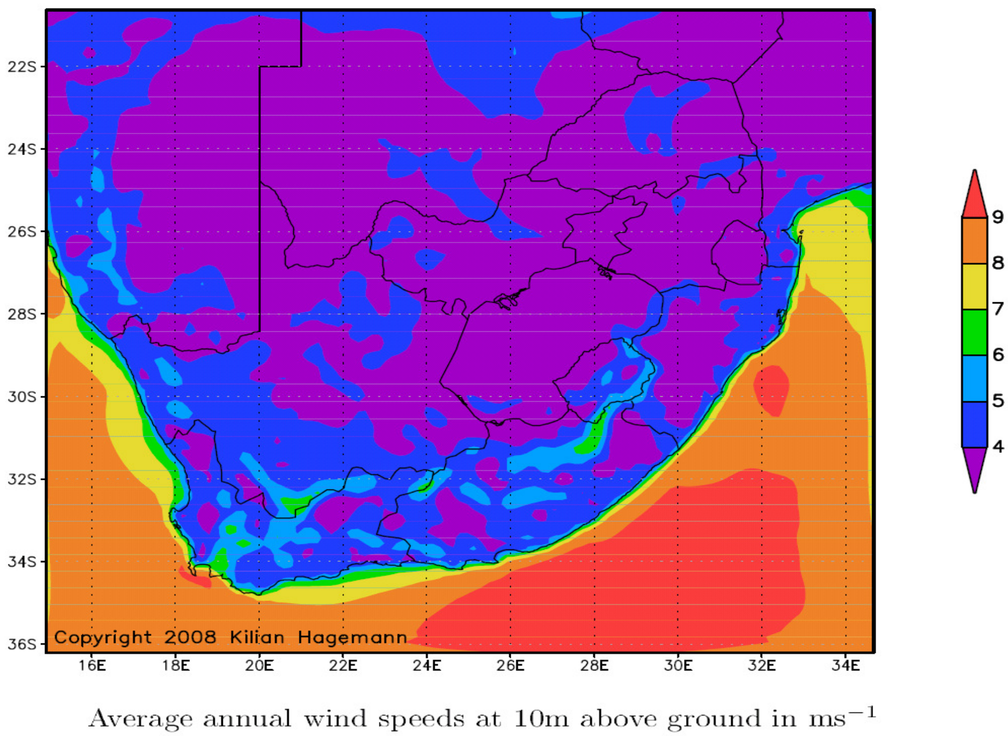

Figure 9: Another wind map (Hageman, 2008)

Annual Energy Production

The total maximum energy that a wind turbine can produce in a year is calculated by multiplying the nominal capacity by the number of hours in a year. The total annual energy production (AEP) of a wind turbine is never as high because of the varying wind speed.

The easiest way to explain how to find the AEP is by using the following graphs:

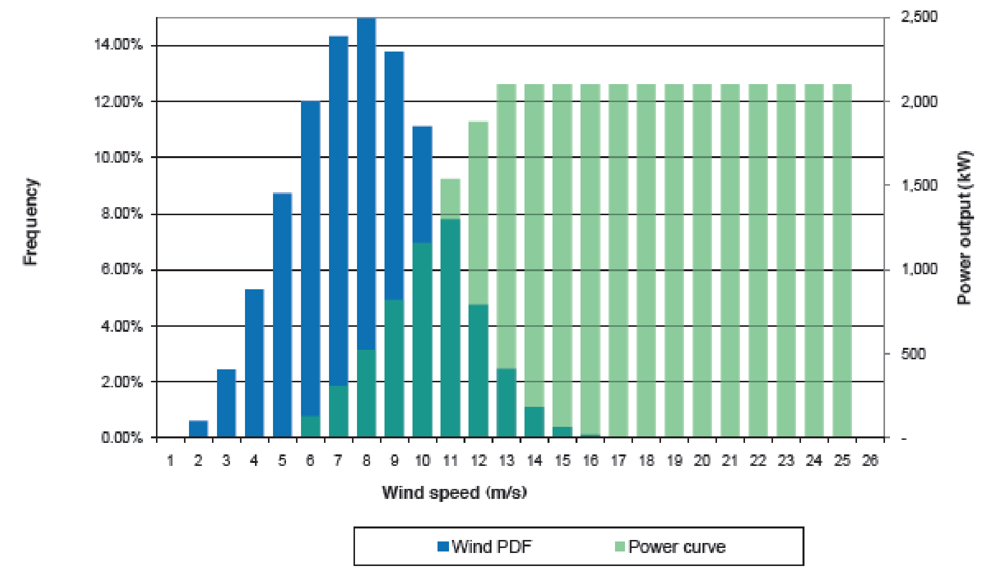

Figure 10: wind speed distribution vs. power curve (Jackson, 2009)

Figure 10 shows the effect of the available power from a certain wind speed distribution in combination with a certain turbine's power curve. When overlapping these, one can see the available power underneath the intersection of the curves for each wind speed window.

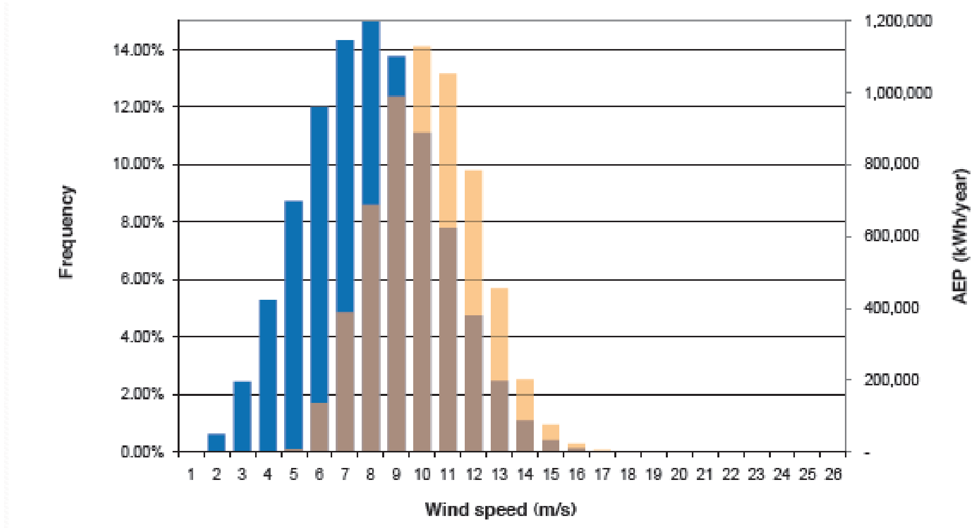

Figure 11: wind speed, power and AEP (Jackson, 2009)

This available power is then used to calculate the AEP for each window which results in a graph like figure 11. The total AEP is then the sum of each speed window's AEP.

- For each wind speed bin (u) a certain number of hours per year occur t_u [h]
- The turbine puts out power for that bin P_u according to the power curve. P_u [W]
- Energy captured in that bin is the number of hours times

$$Eu = P_u \times t_u \text{ [WH]} \quad (1)$$

- Total energy captured is sum of all bins

$$AEP = \Sigma E_u \text{ [WH]} \quad (2)$$

Capacity factor

The ratio of actual productivity in a year to the theoretical maximum is called the capacity factor. Typical capacity factors are 20–40%, with values at the upper end of the range in particularly favourable sites.

For example: a 1MW turbine with a capacity factor of 35% will not produce 8,760 MWh in a year (1 × 24 × 365), but only 1 × 0.35 × 24 × 365 = 3,066 MWh, averaging to 0.35 MW.

$$CF = \frac{AEP}{24 * days\ in\ month * P_{rated}} \quad (3)$$

In comparison, the capacity factors of conventional plants can be as high as 90% if they are used to provide base load. Some expensive plants that run on natural gas are mostly used for peak load production and therefore have capacity factors of around 5 to 25 %.

Capacity Credit

Due to the intermittency of wind energy, the grid will never be supplied with wind power only. That is the reason why wind energy is mostly seen as a conventional fuel saver and a greenhouse gas reducer. However, there is always a certain amount of conventional capacity that can be displaced by wind and this is expressed as a percentage of the installed wind capacity.

$$Capacity\ Credit = \frac{Displaceable\ Conventional\ Capacity[MW]}{Installed\ Wind\ Capacity[MW]} \qquad (4)$$

This capacity credit can also be expressed in GW capacity, meaning the exact displaceable capacity. This so-called shortcoming of wind power is often used as an argument to say that for each wind farm, one needs to build as much conventional capacity. This statement has been found incorrect by recent studies. In the UK for example, history suggests that the capacity credit should be about 30% at low wind penetrations. (Marsh, 2009)

At low penetration this capacity credit is usually equal to the capacity credit. (Jackson, 2009) At higher penetration, this relation is not correct and the capacity credit follows a square root curve like in following figure:

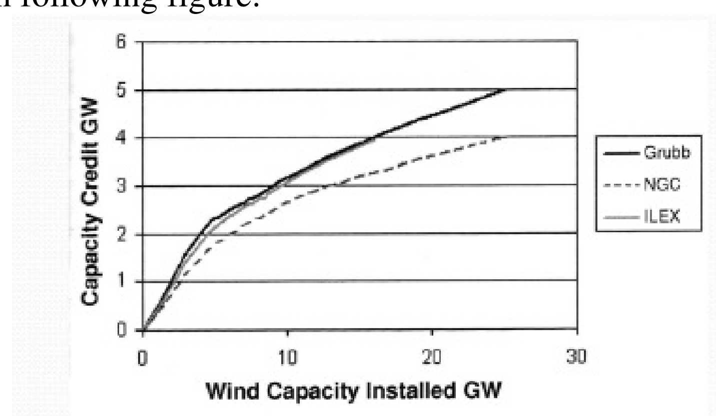

Figure 12: wind capacity in the UK related to the national grid (Boyle, 2007)

Electricity Generation

Wind turbines can generate mechanical power which can either be used directly in pumping applications or for running a generator to create electric power. Wind turbines that feed the national grid are usually grouped in a wind farm and generate electrical power of several kVolts and are connected to the grid through a transmission system. The small scale wind turbines that are discussed further in this report operate at a much lower voltage of around 12 to 200 V. On large wind turbines (above 100-150 kW) the voltage generated by the turbine is usually 690 V three-phase alternating. Turbines usually produce alternating current or AC since they are mostly directly coupled to the generator. With the small turbines this is not always the case as will be seen later.

Following paragraphs are a summary of the theory of electricity generation since it is important for understanding the basic characteristics of wind turbines.

Voltage

A voltage is the same as a potential difference between two ends of any electrical circuit or conducting material. The voltage is like the driving force for the current and is comparable to water pressure. This pressure is needed to overcome resistances in the circuits that can be compared to the electrical loads. The power that can be delivered increases directly with voltage. Voltage is expressed as number with unit Volt and has typical values of 220 V or 110 V in household networks. Lower values are typically 12 V or 24 V for battery applications. The grid networks operate at extremely high voltages ranging between 10 kV to 400 kV.

Current

The electricity that comes out of a battery is direct current (DC), i.e. the electrons flow in one direction only. Most electrical grids in the world are alternating current (AC) grids, however. One reason for using alternating current is that it is possible to directly transform the electricity up and down to different voltages. This is needed because the transport of electricity over long distances requires a high voltage to minimize losses. Once delivered, the voltage has to be reduced to household values.

Three Phase Alternating Current

The AC networks mentioned above consist normally of three phases. This means that the electricity is generated and transported in three different lines at the same time in parallel which is shown on figure 13. We will not go into details since that is not the scope of this paper. Important to mention is the frequency of the alternating voltage which is usually 50 or 60 Hz.

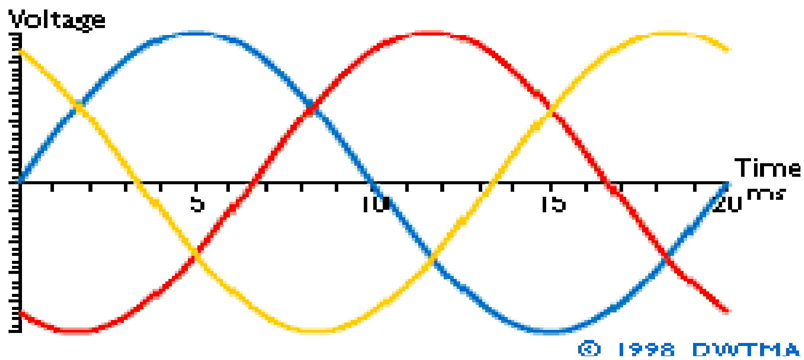

Figure 13: Three phase electricity (DWTMA)

Generation

All electrical generation from a mechanical source like a wind turbine uses electromagnetic induction. Basically, the turbine axis rotates a set of copper windings in a static magnetic field. This causes an electric field across these windings and if these windings are connected to a load in a circuit, a current will flow. The voltage across the windings is therefore dependent of the rotor speed and is also alternating or AC. In common generators that are run by steady speed turbines, the voltage are controlled by the speed of the turbine. When the load increases, the turbine must deliver more torque at the same speed and therefore consume more fuel. With a wind turbine, the speed of the generator varies continuously so in order to produce a useable voltage which is constant, the turbine needs a voltage control.

There are two basic types of generators used on wind turbines: induction generators and alternators. The induction generators are basically the same as induction motors. They create electrical energy in a rotor which is carrying a set of copper windings while rotating in a changing magnetic field exerted by the stator. The conversion from AC to DC is done by a commutator on the rotor. This commutator is connected by brushes to the outer electrical circuit. The consequence of this system is that the rotor becomes quite heavy and the generator is not efficient at low rotor speeds. Also, the brushes need preventive maintenance. This is why this type of generator is used mainly in larger turbines.

The one that is used mostly in small scale turbines is based on the alternator type. This is also the generator type that is used in automobiles. The difference here is that the magnetic field is exerted by the rotor while the electrical power is generated in the stator. This makes the rotor much lighter and enables power generation in much lower rotor speeds. The magnetic field can be created by electromagnets which require a small electric field provided to the shaft by brushes. Another option is the use of permanent magnets which eliminated the use of brushes. This is very favorable for small scale wind turbines since it reduces maintenance a lot. The rectification of the AC to the DC is done in this case by diode bridges.

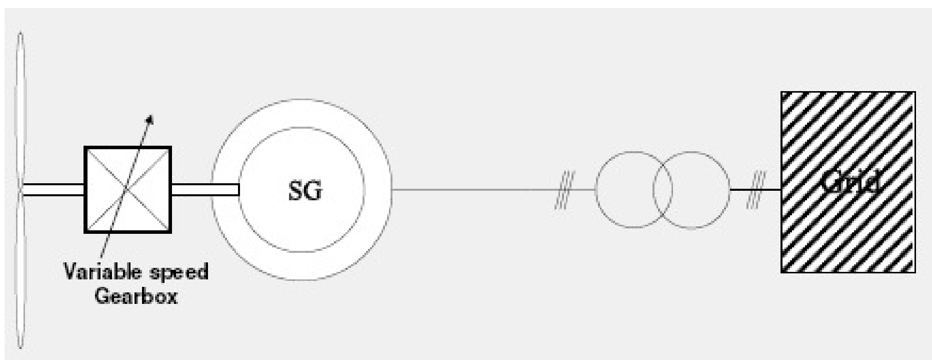

Figure 14: a typical wind turbine: propeller, gearbox, synchronous generator, transformer connected to the grid (Jackson, 2009)

4. SMALL-SCALE WIND POWER

Introduction

The reason for choosing small scale turbines is because both the budget and site surface size don't allow for large turbines. This chapter reviews the small scale wind turbines that are in use today all over the world. The different types are discussed as well as their advantages and disadvantages. In most cases, the turbines themselves are part of an integral system. Stand alone, grid tied or hybrid systems are integral systems that include wind turbines, batteries, inverters, other power generators etc.

In order to be able to assess the wind conditions at a certain site for small scale wind turbines, there are a few recommendations at the end of this chapter along with a short market research report for South Africa.

Definition and types

Definition

With small scale wind power we understand those systems that have a nominal electrical power below 50 kW. These are typically turbines with rotor diameter from 1m to 3m and are used in small local electrical networks. There are many types and applications for these turbines and we will try to give an overview of these in a generalized way with examples.

Horizontal axis wind turbines

The most well known windmill has a horizontal axis. These horizontal axis wind turbines (HAWTs) have the main rotor shaft and electricity generator at the top of a tower and must be pointed into the wind. Small turbines use a wind vane while large ones are turned by a servomotor. Most have a gearbox to increase the rotor speed to suitable generation speed. The turbine is usually mounted upwind of the tower since the tower creates turbulence behind it. This requires very stiff rotor blades so that they can't be bent too far and hit the tower. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount. The downwind types don't need additional systems to correct for wind direction and to increase stiffness but common practice has taught that cyclic turbulence may lead to early fatigue problems and that's why most HAWT turbines are upwind machines.

As shown; the Energy Ball V100 by Home Energy, the Proven100 by Proven Wind and the AirX from Windenergy.

Vertical-axis wind turbines

In contrast to the HAWT, these turbines have a vertical main rotor shaft. The main advantage of this arrangement is that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable. VAWTs can utilize winds from varying directions. Although the advantages seem substantial, this type of machine hasn't become a major player on the market. There has been development on a few types like the Darrieus wind turbine, the Savonius and the giromill wind turbine (beneath from left to right).

The Darrieus or sometimes called "eggbeaters" have a good efficiency, but produce large torque ripple and the cyclic stress on the tower contributes to poor reliability. They generally need some external power source, or an additional Savonius rotor, to start turning, because of the low starting torque. The torque ripple is reduced by using three or more blades which results in a higher solidity for the rotor. Solidity is measured by blade area over the rotor area. The giro mills are a subtype of the Darrieus turbine. They have straight blades and can have variable pitch to reduce the torque pulsation and to increase the starting torque. This also results in a wide, relatively flat torque curve; a lower blade speed ratio; a higher coefficient of performance; more efficient operation in turbulent winds.

The Savonius turbines are drag-type devices with two (or more) sails or fins. They are used in anemometers, *Flettner* vents (commonly seen on bus and van roofs), and in some high-reliability low-efficiency power turbines. They are always self-starting if there are at least three scoops and they sometimes have long helical scoops to give a smooth torque.

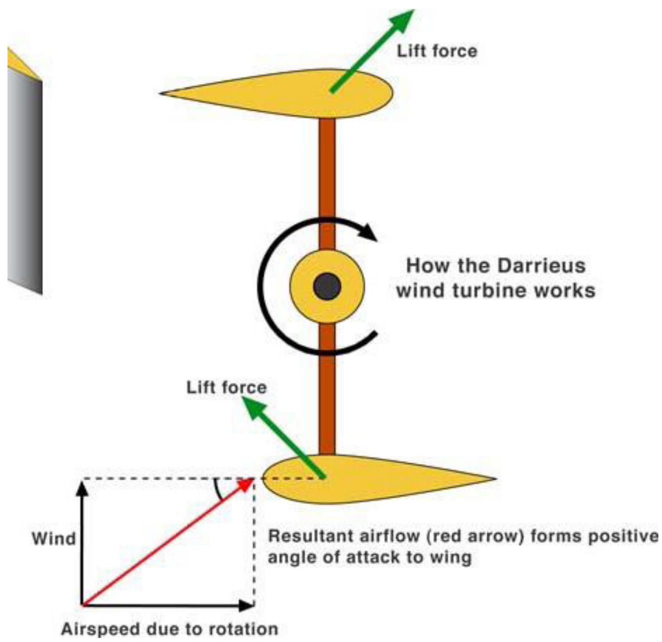

Figure 15: how the Darrieus turbine works (Jackson, 2009)

Systems

Stand alone wind power

As shown in the figure above the stand alone system is using the wind turbine for electricity generation directly. The basic system has a voltage limiter and an inverter connected to the network preferably through a kWh meter. Of course, the problem of energy storage comes up immediately and the most used storage technology is batteries. Others are hydrogen storage, compressed air, pumped water and other less investigated systems. The voltage limiter takes care of over-speed situations from the wind turbine in case of high winds. The inverter can transform DC or AC input at low voltage into the usual network voltage of 110V or 220V. Of course, one can also design the local network for lower voltages of for example 48V since a lot of electronics actually use low voltage DC, but in case of larger consumers, the cost of the wiring will be higher since these will need to be thicker because of the higher currents. For the batteries one should use a charge controller in order to optimize the lifetime of the batteries.

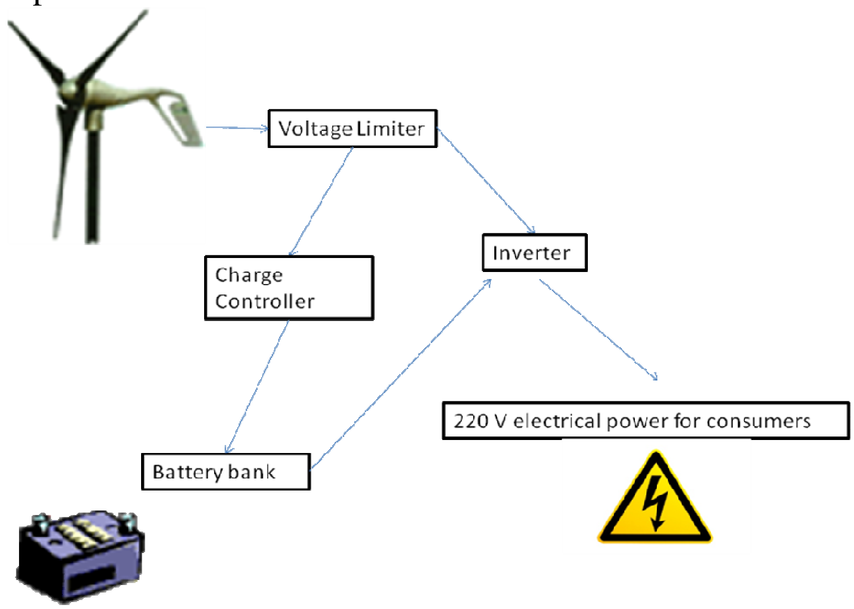

Figure 16: stand alone wind power system

Grid tied wind power

The grid tied systems look a lot like stand alone but differ in a way that the turbine supplies energy to a grid tied electrical network. When installed near a house that is connected to the street grid for example. The turbine can then be used to feed the house appliances directly in parallel to the grid in order to reduce the electricity bill. There can be a battery array that can be charged by the turbine and be used as a standby in case of power cuts. Another option is to feed the power of the turbine back into the grid. When the consumption is low for example and the turbine is producing, the excess in production could be sold back to the grid operator or be used to rotate the kWh meter in the opposite direction. In Europe there are already several different schemes active for small scale wind energy in order to promote and facilitate the spreading of renewable energy systems.

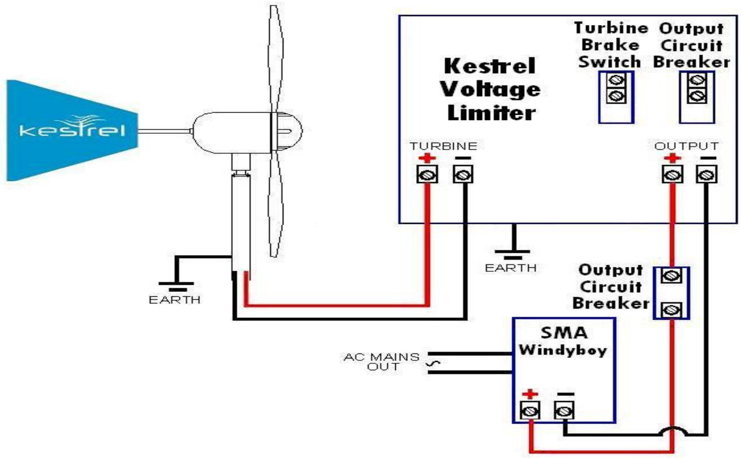

Figure 17: a grid tied proposal by Kestrel Winds

Hybrid wind power

The best solution is to combine the wind turbine with other renewable energy sources like solar PV especially for stand-alone systems. The reason for that is quite obvious since the wind energy is too unpredictable and one cannot rely on that only for its electricity generation. Companies like SMA from Germany specialise in the design of hybrid stand alone systems for local grids like in rural villages. They have state-of-the-art inverter systems that can regulate the voltages and frequencies of all incoming power sources and distribute this to the consumers and battery storages. An example is the Sunny Island inverter shown in the next figure.

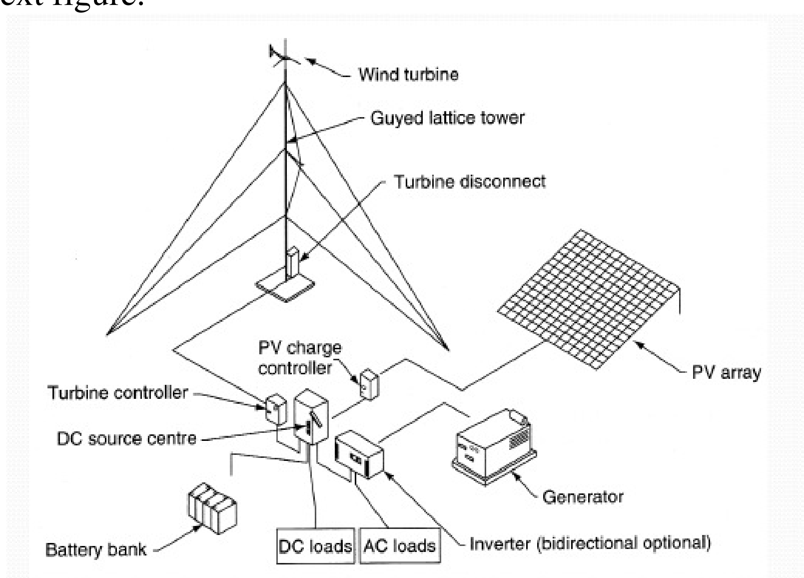

Figure 18: hybrid systems use different energy sources (Jackson, 2009)

Inverter

Inverters are necessary as an interface between a renewable power source and a network. Mostly all renewable energy sources produce unstable electrical signals which need to be modified before being fed into any network. A very nice example is the Windy Boy from SMA which has efficiency between 91 and 94%. It requires a DC input with an overvoltage protection of 500V.

Figure 19: the Windy Boy inverter from SMA

The Windy Boy converts the rectified DC voltage from a wind turbine, which varies with speed, into grid-compliant AC voltage. If tied to a grid, the Windy Boy can measure the voltage, frequency and phase of the current of the grid signal and transform the turbine's input to the same frequency and phase. It will then inject the turbine's electricity in the grid at a slightly higher voltage in order to create a net current.

Site assessment for small scale systems

Wind measurement

Weather stations are the easiest way for home owners to assess the wind and other properties at their location. The cost is around R7, 000 for a versatile weather station which measures solar intensity, wind speed and direction, humidity, rainfall and others and is able to log this in a database. The station typically comes with one sensor for each but is designed for up to 8 extra sensors. Of course, for a wind turbine, the main properties are wind speed and direction, but the advantage of a weather station is that it is a cheaply available device compared to separate wind anemometers which are not that easily available. Another advantage is that it allows assessing the feasibility of hybrid systems since it also measures solar intensity.

Figure 20: a weather station (Lacrosse)

The latest addition to the market of weather stations is the **Power Predictor** from Better Generation in the UK. This is a simplified weather station that monitors wind and solar energy and can calculate energy savings, payback times and carbon footprints with the data measured at your location. It uses a data logger and an internet connection to produce a monthly power report. The cost for this device is about R1, 400 which is far cheaper than the above weather station but it is not readily available yet.

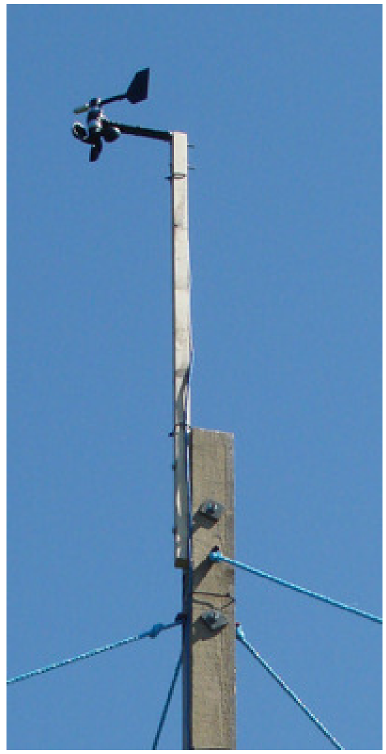

Figure 21: the Power Predictor on a mast

Consumption monitoring

The best thing one can do before purchasing a rather expensive tool like a wind turbine is to assess its own power consumption and try to record it. A tool that can help with that is the e2 from Efergy (www.efergy.com).

Figure 22: the e2 power monitor (Efergy)

Figure 23: the Power Report (Efergy)

This device uses a battery powered wireless display unit, a battery powered wireless transmitter and a current transformer clip. The cost of this instrument is approximately R800.

Batteries

The most used storage systems for small scale renewable energy are battery arrays. They can be wired in parallel for higher capacity and in series to increase the voltage. Batteries usually come in 12V units and by coupling them in series one can reach 24V or 48V. Higher then that is not recommended for safety reasons. Above 48V, the batteries must be electrically insulated to prevent direct contact.

There are two groups of rechargeable batteries on the market for heavy duty service: deep-cycle batteries and starter batteries (most automotive batteries). A deep-cycle lead-acid battery is designed for delivering a consistent voltage when the battery discharges over a load. Starter batteries however are designed to deliver sporadic current spikes and can deliver much higher peak currents for the same size and therefore a better option for cars, although with the modern electronics in vehicles these days, the deep-cycle batteries are sometimes preferred. Another advantage is that deep cycle batteries need a lower recharging current.

The key structural difference between deep cycle batteries and conventional batteries are the lead plates, which are solid in deep-cycle batteries and composed of porous sponge-like plates in starting batteries. Some batteries that are labelled "deep-cycle" do not possess these solid lead plates, however, and are actually "hybrid" batteries. While a deep-cycle battery is designed to discharge down to as much as 20% of its charge capacity over several cycles, companies recommend that a hybrid battery not be discharged beyond 50% of its capacity.

Lead acid batteries designed for starting automotive engines are not designed for deep discharge. They have a large number of thin plates designed for maximum surface area, and therefore maximum current output, but which can easily be damaged by deep discharge. Repeated deep discharges will result in capacity loss and ultimately in premature failure, as the electrodes disintegrate due to mechanical stresses that arise from cycling. A common misconception is that starting batteries should always be kept on float charge. In reality, this practice will encourage corrosion in the electrodes and result in premature failure. Starting batteries should be kept open-circuit but charged regularly (at least once every two weeks) to prevent sulphating.

As already mentioned before, the batteries of a wind power system should be connected to a good charge controller and that is for the following reasons. When a lead-acid battery is overcharged, meaning that the charging voltage remains on fully charged poles, the battery will emit hydrogen and oxygen from each cell, as some of the water of the electrolyte is broken down by electrolysis. This process is known as "gassing". These gasses are released into the environment or vented into neighbouring cells in case of a VRLA battery (valve-regulated lead acid). Wet cells have open vents to release any gas produced, and VRLA batteries rely on valves fitted to each cell. A VRLA cell will normally recombine any hydrogen and oxygen produced into water inside the cell, but malfunction or overheating may cause gas to build up. If this happens (e.g. by overcharging the cell) the valve is designed to vent the gas and thereby normalize the pressure, resulting in a characteristic acid smell around the battery. Valves can sometimes fail however, if dirt and debris accumulate in the device, so pressure can build up inside the affected cell.

When the gases are ignited by any type of spark, they can explode and spread acid and debris around the battery. In case of VLRA batteries, when there are deformations of cells visible from the outside, these batteries need to be discarded immediately.

In renewable energy systems and UPS systems, the most used type of battery is the VLRA type. This is because of the lower electrolyte content, a higher ratio of power to "floor space" and a high peak power capacity, though of relatively short duration.

Charge controller

A charge controller limits the rate at which electric current is added to or drawn from electric batteries. It basically prevents overcharging and may prevent against overvoltage which can be dangerous as explained in the previous paragraph. It may also prevent deep discharging of a battery and perform controlled discharges, depending on the battery technology, to protect battery life.

Figure 24: an example of a charge controller (Kestrel Wind)

Market research

In order to propose a wind turbine to SAB a market search has been done both domestically and internationally. A long list of possible manufacturers was developed. A selection of these candidates was listed in Appendix C. From this list, one recommendation was selected being the e400 from Kestrel Winds (ref Appendix B)

This manufacturer is based in South Africa and the biggest in the country. They seem to provide the most professional service at a very competitive price. The proposed system includes a turbine with voltage limiter and a mast. The inverter is not included.

This wind turbine specification for its power curve and annual estimated produced energy was used further in this report. (Ref Appendix B)

5. BUILDING INTEGRATED WIND TURBINES

Building Integrated Wind

Much discussion and controversy is generated on the topic of building integrated wind turbines. The idea here is simply to install wind turbines in a built-up area and to try to harvest more power than usual from accelerated winds. This comes from following arguments:

1. The wind power increases with height, so it makes sense to use high buildings to reach for more wind power
2. The generation of electricity locally reduces the transmission costs and could reduce the electricity bill if efficient enough.
3. The geometry of buildings could help to increase the wind speed and thus the wind power.
4. The use of wind turbines can be promotionally interesting in a sense that it shows a green image.

A European study published in 2005 examined the potential for such building-integrated wind turbines in the United Kingdom. The study has recommended further research on the wind regime in urban areas and around isolated buildings; the structural and noise implications of mounting wind turbines onto a building; and the optimal design for building-integrated wind turbines. *(Dutton, Halliday, Blanch, 2005)*

Examples: (large and small)

The Swift

A good example of a wind turbine used in building integration is the Swift made by Renewable Devices in the UK.

Figure 25: The Swift by Renewable Devices.

The manufacturer of this turbine has patented its design for a "*diffuser (the circle around the rotor) which prevents air being thrown at high speed off the ends of the blades. This is the source of the ethereal din and inefficiency common to all previous wind turbines. Also, at high speed, the sculpted rim acts like the inlet of a jet engine, speeding the flow of air through the rotor plane, boosting its overall efficiency and allowing it to generate up to 1.5kW of electric power. Meanwhile, the twin fins at the back hold the turbine into the wind like a weather vane.*"

The Bahrain World Trade Centre

Another famous example is the Bahrain World Trade Centre which was built with three large wind turbines incorporated in its structure.

Figure 26: Bahrain WTC

Figure 27: Bahrain World Trade Centre

The three massive wind turbines, measuring 29 meter in diameter, are supported by bridges spanning between the BWTC's two 240-meter high towers. Through its positioning and the unique aerodynamic design of the towers, the prevailing on-shore Gulf breeze is funnelled into the path of the turbines, helping to create even greater power generation efficiency. Once operational, the wind turbines will deliver approximately 11-15% of the BWTC tower's energy needs

Figure 28: Bahrain WTC wind turbine

Tim Askew, Regional Managing Director for the engineering company, states that the company's goal is to "raise awareness of sustainability within the psyche of our architects and engineers. This project serves to highlight how with determination and willingness on behalf of responsive clients we can actually turn these ideas into reality".

<u>The Aeroturbine</u>

Another example is the Aeroturbine made by Aerotecture International Inc. from Chicago, USA. This company produces turbines specifically for the integration in buildings and custom designs each project. They have already completed several projects in the USA and keep expanding their expertise.

Figure 29: Aeroturbine (Aerotecture Int.)

Figure 30: Aeroturbines on a roof (Aerotecture Int.)

Figure 31: the Aeroturbine 610V (Aerotecture Int.)

Although they design the turbines for building integration they do use a rule of thumb to estimate the desired location of installation. On their website they state: "In order to operate efficiently, Aeroturbines must be installed at least 40 ft. above the ground (because every 40 ft. the wind speeds tend to double), roof mounted or building attached, above or away from surrounding trees and other obstruction, and in an area with average wind speeds of at least 10 mph." *(www.aerotecture.com)*

The beauty of this design is that these turbines can easily be installed as horizontal or vertical and are relatively silent and vibration free. They can operate in relative turbulent conditions and fluctuating wind directions. The disadvantage is that they require expensive base structures once they need to be lifted a height for efficiency purposes.

<u>The Windpods</u>

A similar design is done by Windpods from Australia. They also advertise as being the best solution for urban installations and they present very nice conceptual designs but the company is still very young and looking for first investors.

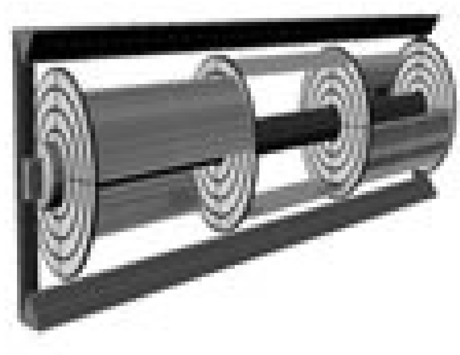

Figure 32: The Windpod (www.windpods.com)

Figure 33: a concept for Windpods

The windpods are meant to use both lift and drag to for propulsion. These two principles were already discussed briefly in previous paragraphs. However, in order to avoid confusion, these were again summarized in the next figures.

In very light winds, the blades catch the wind in the same way as a drag-type Savonius rotor and provide easy starting. However, once the turbine gains sufficient RPM, the rotor starts to act as a lift type device (spins faster than wind speed) with the TSR (Tip Speed Ratio) typically running between 1.5 and 2.

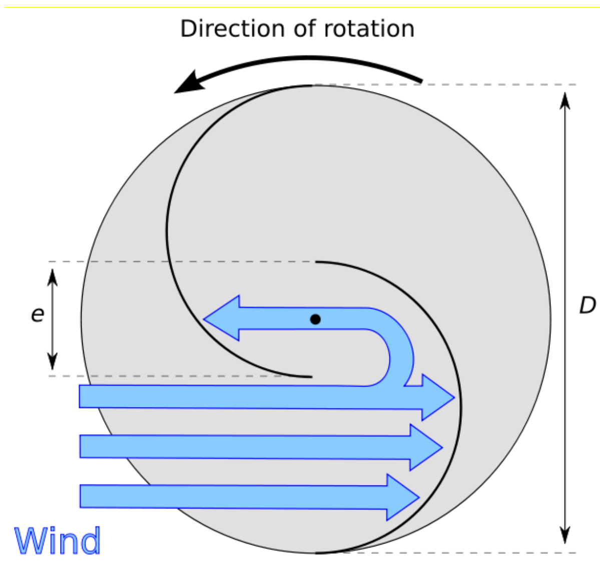

Figure 34: drag principle (Jackson, 2009)

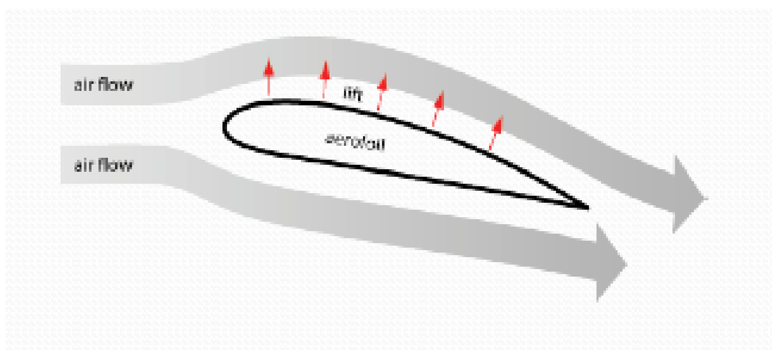

Figure 35: lift principle (Jackson, 2009)

The manufacturer claims that these devices can revolutionize the wind power generation in urban environments since they can harvest the power from rooftops specifically. They are also easily installed and integrated in a building.

Feedback

It is not easy to find accurate data on actual performances of installed wind turbines in urban installations. The reason for this is probably because the turbines seriously underperform. The most detailed report was found on the website www.greenbuilding.com on which Alex Wilson has published an article with the title: "The Folly of Building-Integrated Wind". This title shows the position of Wilson towards building integrated wind turbines immediately. He uses the following arguments. First of all, the testing of wind turbine performance is always done in smooth flow conditions. Turbulence however reduces efficiency radically regardless the design of the blades or the speed of the wind and the wind in built-up areas is mostly turbulent. Secondly, turbines create noise and vibration and these can reduce the living quality in a building. At the same time, this vibration can cause a safety issue. Imagine a turbine blade failure above a crowded area. Wilson refers to some examples of which he did get data and these show that the capacity factors of the installed wind turbines were usually hugely overestimated. Instead of 15%, the capacity factors would often be below 1%! One could then argue maybe that building integrated turbines can have a green promotional effect, but does it really make sense to show turbines that are not rotating?

The question whether it makes sense to use wind turbines in buildings is difficult to answer. Wilson favours solar PV in buildings instead of wind turbines (www.greenbuilding.com). The scientific papers on the subject are limited and encourage further research. However the installation of wind turbines in or between buildings is generally not a good idea. In order to make it economically viable and technologically possible, each site and project requires a thorough analysis. Currently, the knowledge, tools and the available data are insufficient in order to make a correct assessment.

6. SAB BREWERY CAPE TOWN

Introduction: a feasibility study

The brewery of SAB in Newlands, Cape Town has recently developed an interest in renewable energy sources in line with its energy efficiency strategy. The brewery has specifically an interest in energy saving in the area of process heating and electricity. For the process heating, the study of solar water heaters and insulation is ongoing, but not part of this project. The electricity generation from wind power has caught the attention of SAB's Technical Management in view of the global developments in the field. It was requested to do a feasibility study for the brewery in Newlands. This study is incorporated in this paper as a feasibility study.

Problem Formulation

The main objective of this project was twofold: to propose a wind turbine which is suitable for the location and to investigate the best location for this turbine between or on top of the buildings.

Proposed Approach

The project was therefore conducted in two parts. First, a theoretical study was done in order to present a useful background report to SAB. Second, a practical part included the monitoring of the wind speed at the site with two separate weather stations of the type as in the next figure.

Figure 36: weather station (La Crosse)

One station remained stationary on the highest building at the site while the second one was displaced weekly and installed between the buildings. This approach allowed us to compare the wind above the brewery with the wind behaviour lower to the ground between the buildings and with neighbouring weather stations like the one at the airport of Cape Town.

An analysis of the data which were collected over two months in a spreadsheet format has led to the study results presented herewith. All the data were downloaded to a laptop and analyzed with Excel and WRPLOT VIEW, a freeware software package from Lakes Environmental (www.weblakes.com). This software offered an easy platform from which the wind roses could be generated into a useable format for this project.

A correlation analysis between the wind at Cape Town International Airport and the wind at SAB was done.

Results

Location Analysis

Any feasibility study for a wind power project starts with a site study. In the following paragraphs we show the location of the brewery with Google Earth (Google). This enables us to give an overview of the site and the orientation of the buildings in more detail. This is important because the Cape region is dominated by two wind directions: northwest and southeast. These winds are generated by the trade wind system and lead to a fairly predictable average wind direction for each season. AS already mentioned in the paragraph about the wind maps, the prevailing wind directions in Cape Town are northwest and southeast. It is therefore easily understandable that the weather station was installed on the roof in a way that it faces the north south axis in the best way.

From figure 39 it is clear that the general orientation of the buildings is north-south. What is less clear is that the surrounding buildings are of similar heights. This has a negative effect on the wind both above the buildings as in between them which will be shown with the measurements.

The positions of the two weather stations were as shown in Fig 40. The fixed unit was installed on the highest rooftop with the easiest access. This is the roof above the General Management floor. The station was installed on the edge of the old water reservoir as can be seen on Fig 41. The mobile unit was installed in different positions and the choice of these positions was based on the following:

- No obstruction of work flow
- A clear possibility for a venturi between buildings. This means that there was a narrow passage between two buildings that were high enough.
- No safety issues due to installing the station
- Not too far from an office in which the data receiver could safely be installed indoors. The maximum distance for this seemed to be about 50 m (although the manufacturer states 100m).

Figure 37: SAB in Cape Town, the airport and Molteno Reservoir

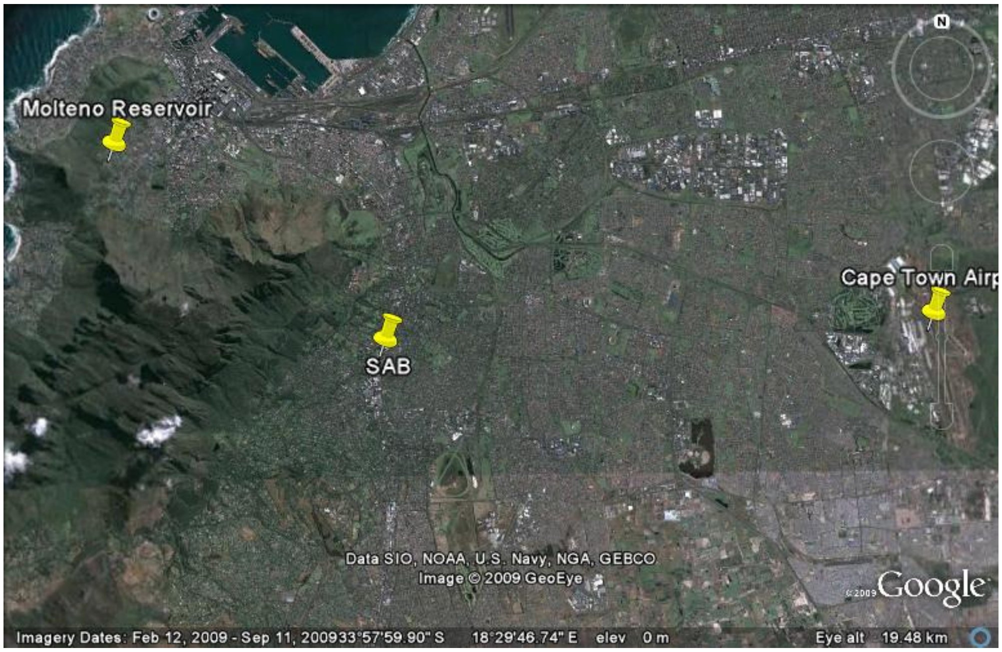

Figure 38: SAB, the airport and Molteno Reservoir

Figure 39: Overview of the buildings of SAB with the orientation

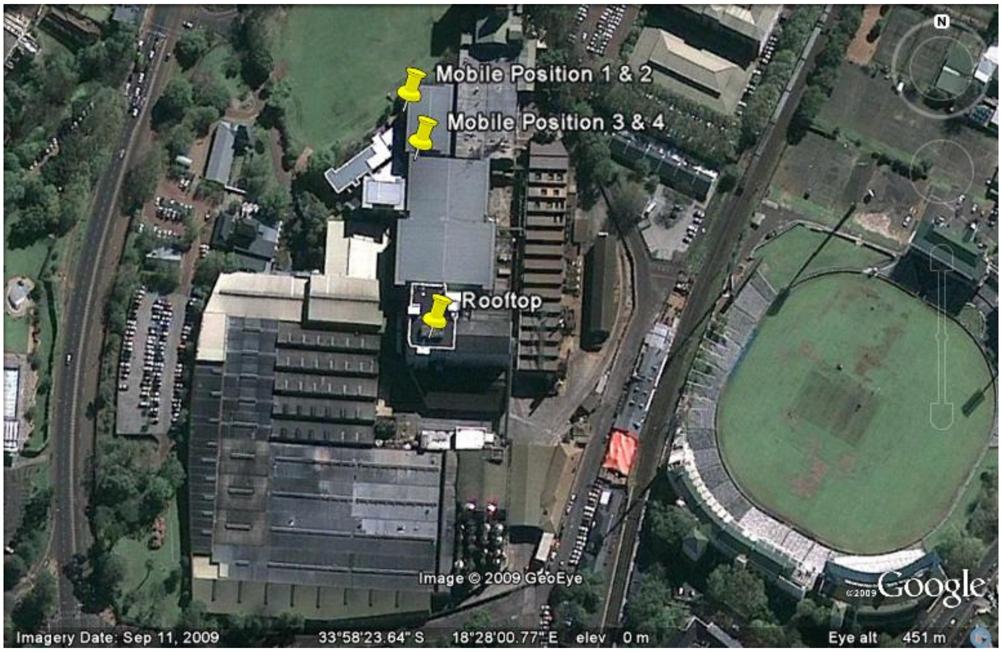

Figure 40: Overview of SAB with measuring positions

Figure 41: The weather station on the rooftop on the water reservoir.

Graphs

The measurement of the wind conditions at a certain site is not as simple as it seems. The effects of turbulence and wake losses and other negative effects are not easy to either measure nor visualize graphically.

The data show different patterns when measured at different intervals. When the measurements are taken every 5 minutes, the variations of speed and direction are much greater than when measured at hour intervals.

Figures 42 and 43 show the wind speed and direction at position 1 for every 5 minutes during 24 hours (on Oct 2nd). Figures 44 and 45 show the same measurements for every hour during the same period. When comparing these, one can see that the measurements at 5 minutes intervals show the turbulent behaviour of the wind much better then when measuring every hour only.

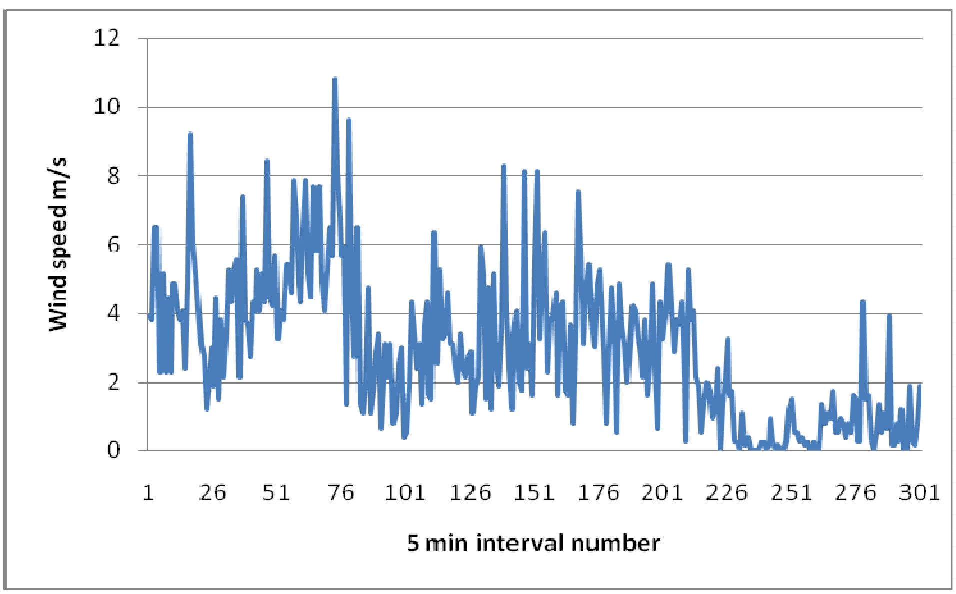

Figure 42: Position 1: wind speed: 02 Oct, 5 minutes intervals

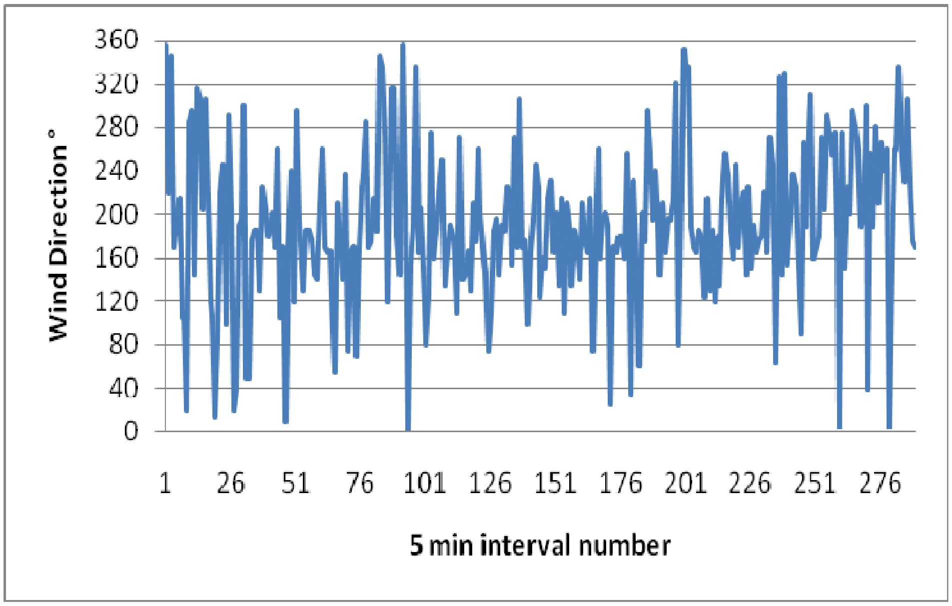

Figure 43: Position 1: wind direction: 02 Oct; 5 min intervals

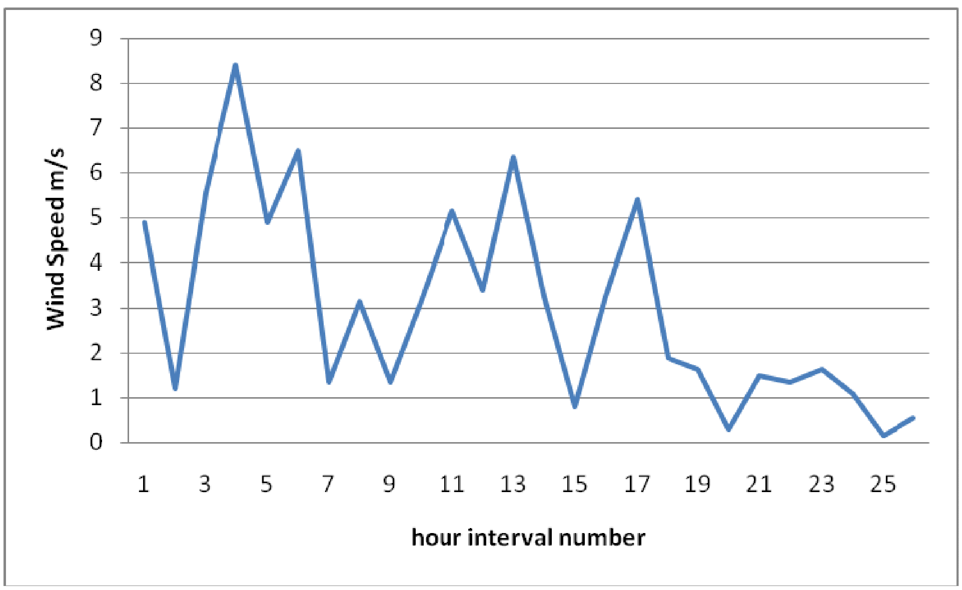

Figure 44: Position 1: wind speed: 02 Oct, hour intervals

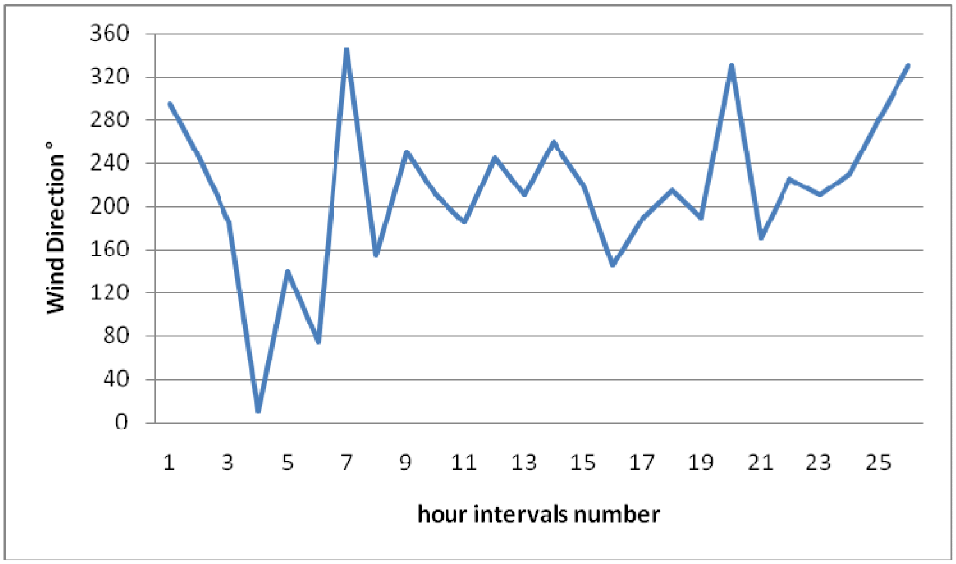

Figure 45: Position 1: wind direction: 02 Oct, hour intervals

When comparing the behaviour of the wind between the fixed unit on the rooftop and the mobile unit on the other positions during a day with half hour intervals, one can see that the mobile unit is much more variable than the fixed unit.

Figure 46 shows the wind speed measured every half hour during 24 hours at position 3 and Figure 47 shows the wind direction at that same spot. One can see the "swinging" of the wind in both graphs very clearly. In Figures 48 and 49, the wind speed and direction for the same period are shown, measured at the rooftop position. The latter show that both the wind speed and direction don't show the "swinging" as is the case in the previous.

Although the measurements in both positions show very strong wind speeds (November was in general a very windy month), the quality of the wind at position 3 is much less favourable than on the rooftop for the use as an energy source.

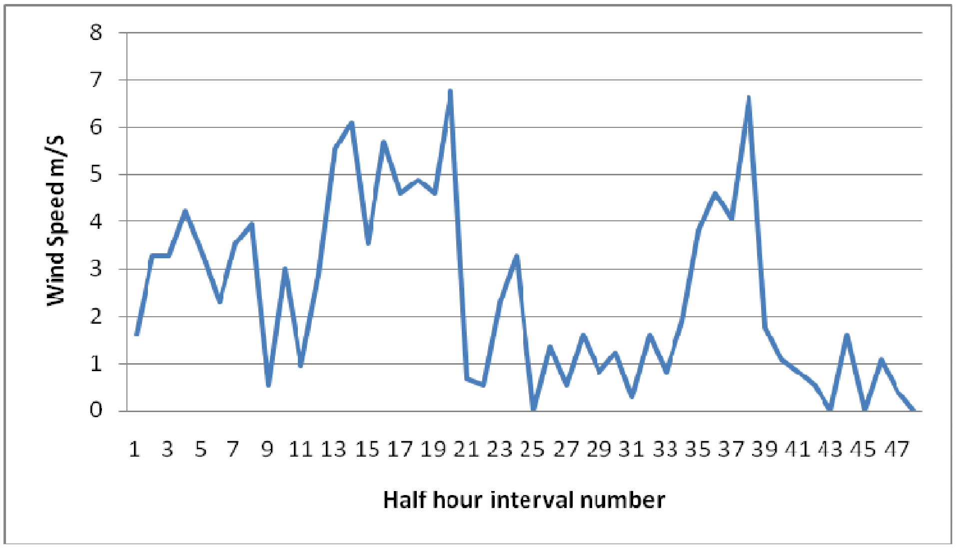

Figure 46: Position 3: wind speed: 02 Nov, half hour intervals

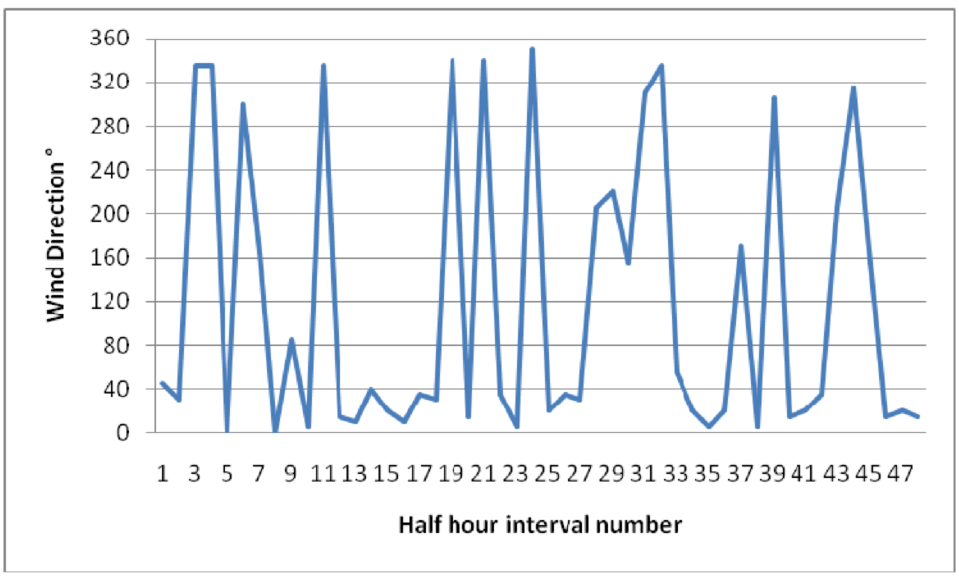

Figure 47: Position 3: wind direction: 02 Nov, half hour intervals

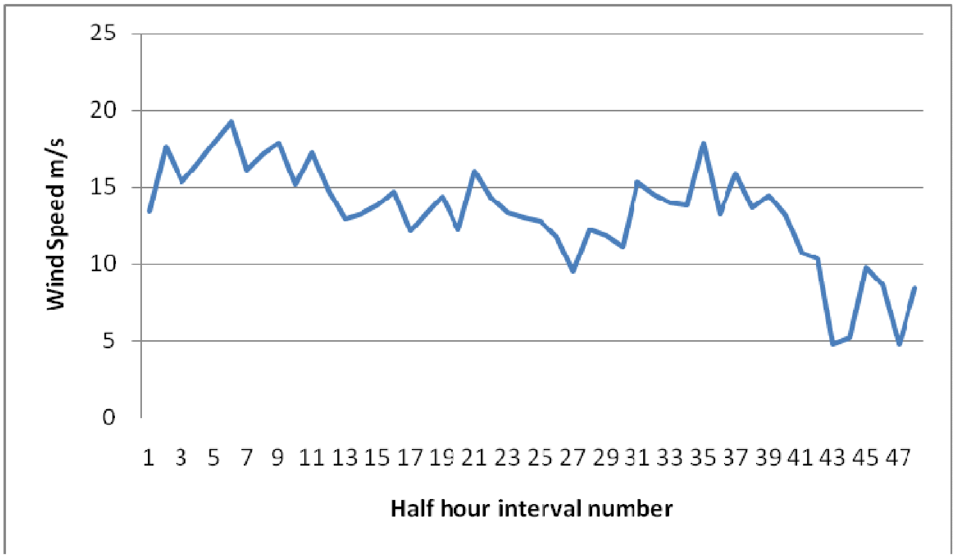

Figure 48: Rooftop wind speed: 02 Nov, half hour intervals

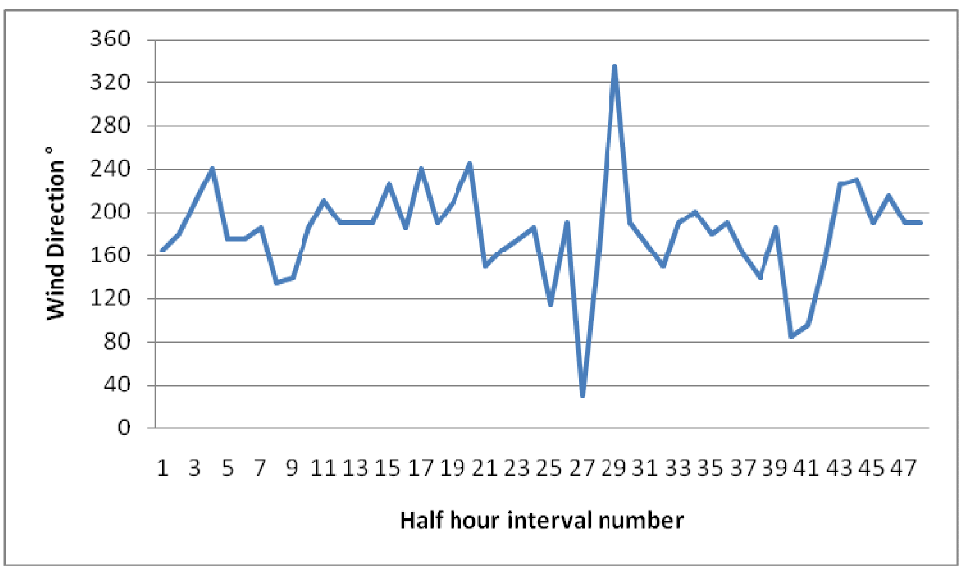

Figure 49: Rooftop wind direction; 02 Nov: half hour intervals

Calculations

Based on the data, the following values were calculated for each measuring position:

1. The average wind speed
2. The average wind direction
3. The standard deviation of the speed and direction
4. The estimated energy production based on the e400 turbine (Ref Appendix B)
5. The annual energy production, AEP based on (2) page 18: this was calculated by extrapolating the energy production during the measurement period to a whole year by using the average speed of the measurements. Here, we assumed this average to be constant during the year. This is however not realistic but on the other hand this enables comparing the cost savings on a yearly basis for different average wind speeds.
6. The capacity factor (CF): this was calculated by using the previous AEP in formula (3) page 18.
7. The difference with the predicted energy production from the manufacturer (Kestrel). For each row in table 1, the average speed of the measurements was used to determine the predicted annual energy production based on the graph in Appendix B.

Note that the capacity credit was not calculated since this is irrelevant for the size of the project and since the electric power is used for in-house application only.

The calculated values don't show a very clear result. We can however conclude the following:

- The capacity factor is a good indicator of the amount of annual savings that can be achieved.
- The calculation of the AEP doesn't take turbulence into account.
- In general, the predictions of the manufacturer for the annual energy production seem always lower than the actual performance. This can be seen in table 1 in the "difference" column. In all cases, the actual produced energy was higher than predicted by the manufacturer. This is especially true in periods of strong winds.

Position	*Average wind speed (m/s)*	*Average wind direction °*	*Average wind compass direction*	*Standard deviation wind speed (m/s)*	*Standard deviation wind direction °*	*Calculated AEP (kWh)*	*Estimated AEP by manufacturer (kWh)*	*Difference (kWh)*	*Difference (%)*	*Capacity factor (%)*	*Yearly savings @ R0,3/kWh (R)*
Airport October	5.8	212	SW	3.25	95	7824	614	1680	21.47	28.80	2,347.20
Airport November	6.58	227	WSW	3.56	83	Na	Na	Na	Na	Na	Na
Molteno October	2.9	176	S	2.07	103.61	1641	1200	441	21.47	6.04	492.00
Molteno November	2.7	119	SE	2.57	105.03						
Rooftop October	1.68	42.60	ENE	4.60	86.27	20785	14500	12656	30.24	76.54	6,235.74
Rooftop November	12.69	224.61	WSW	6.18	94.92						
Mobile position 1&2 (Oct)	2.50	204.11	SW	2.48	90.32	1179.66	800	380	32.00	4.34	353.89
Mobile position 3&4 (Nov)	8.18	190.54	SSW	6.57	103.78						

Table 1: The calculations based on the measurements.

Wind roses

Wind roses show the distribution of the wind direction with the wind speed at a certain location. These are very useful graphic representation of measured data and can be used to assess the behaviour of the wind at SAB.

Figure 50 shows the wind rose of the measurements on the rooftop of SAB during the period of November 1st until November 17th. Figure 51 shows the wind rose for Cape Town International Airport for the same period. When comparing these wind roses one can see a good correlation between the two. It is therefore safe to say that SAB can expect the same wind directions and speeds than at the airport. This is very convenient since there is an abundance of data available from this site at the South African Weather Service.

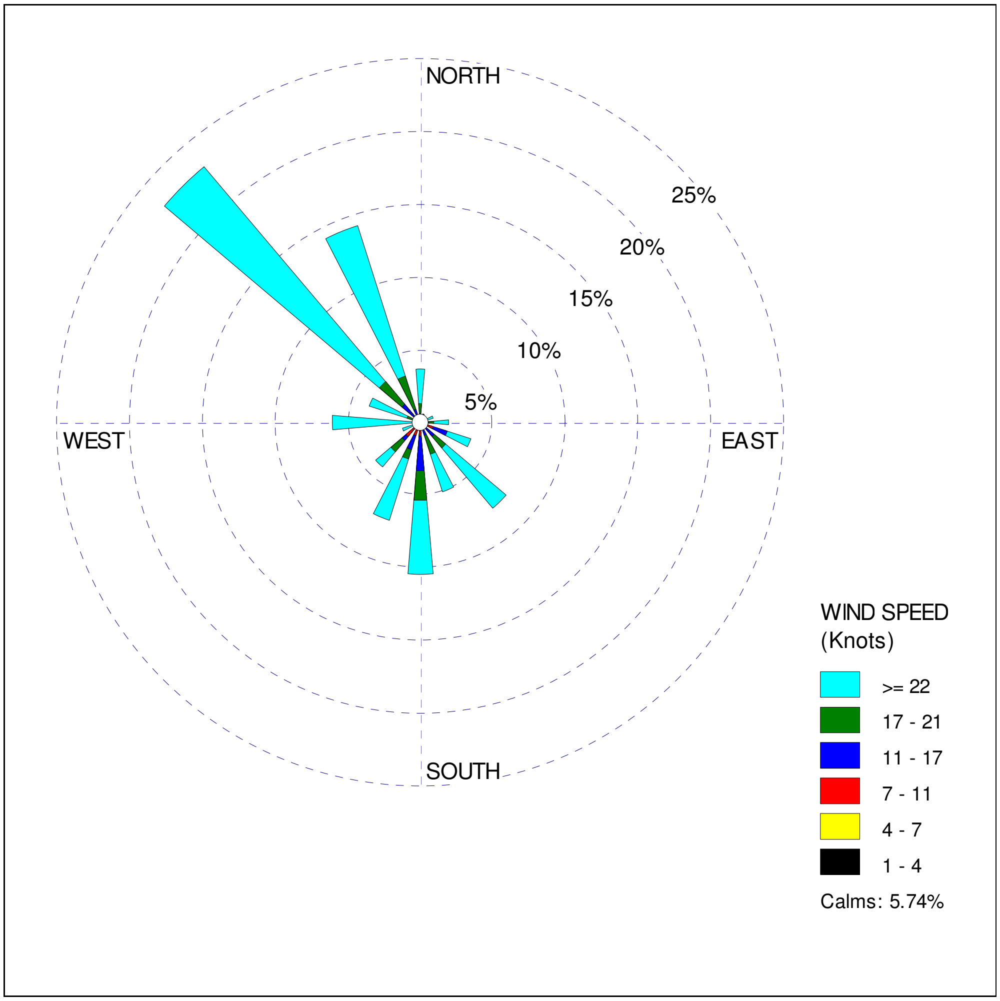

Figure 50: SAB rooftop Nov 1 until Nov 17

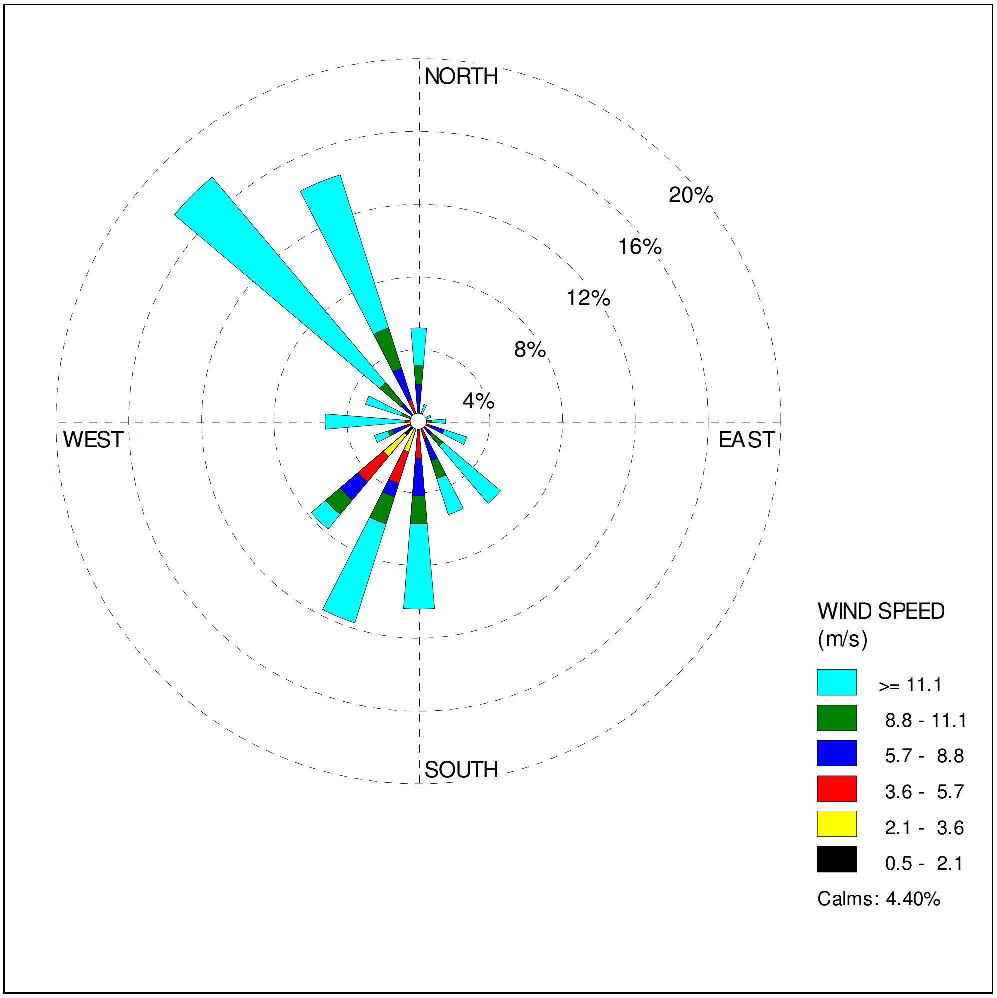

Figure 51: Airport Nov 1 until Nov 17

Figures 52 and 53 show the wind roses for the airport and the Molteno Reservoir during the same period (October). The wind behaves differently at the airport then at the Molteno Reservoir although these locations are not far apart. Clearly the influence of Table Mountain is important here. This proves that it is worth and necessary comparing the wind between neighbouring locations.

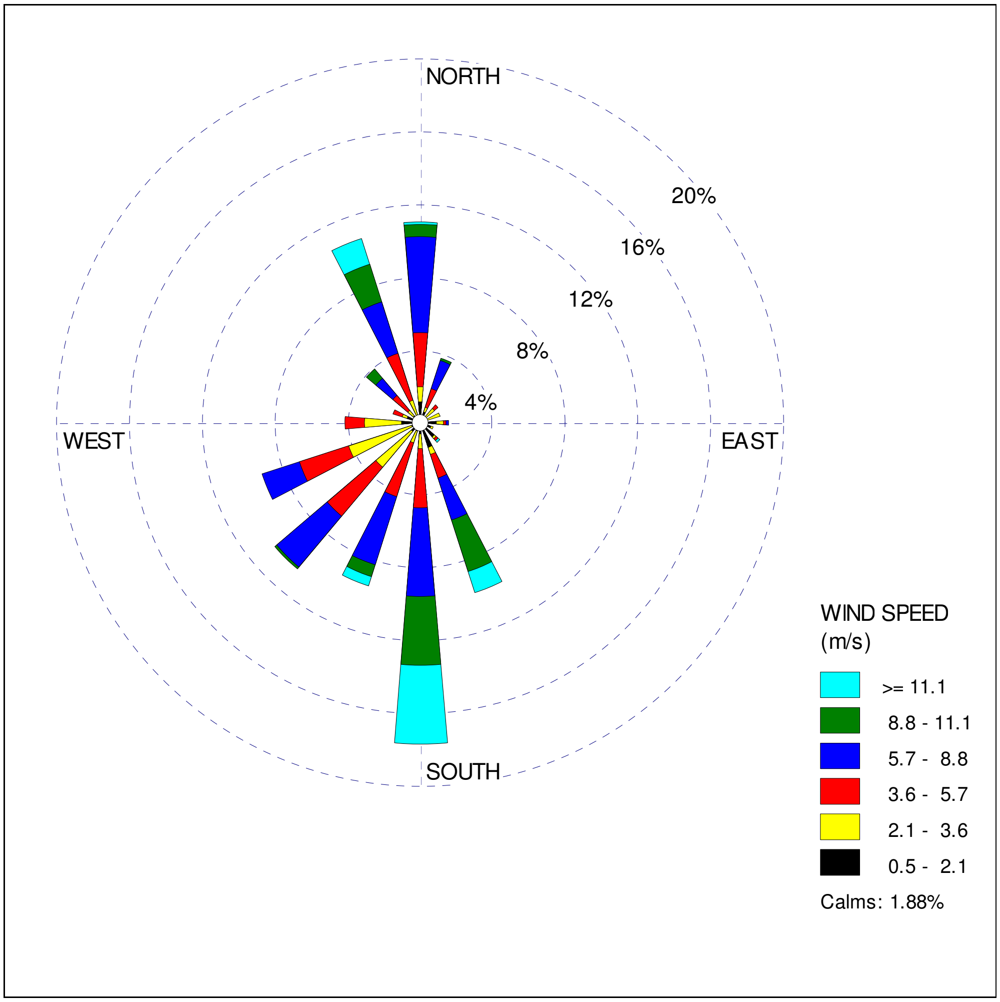

Figure 52: CT Airport October

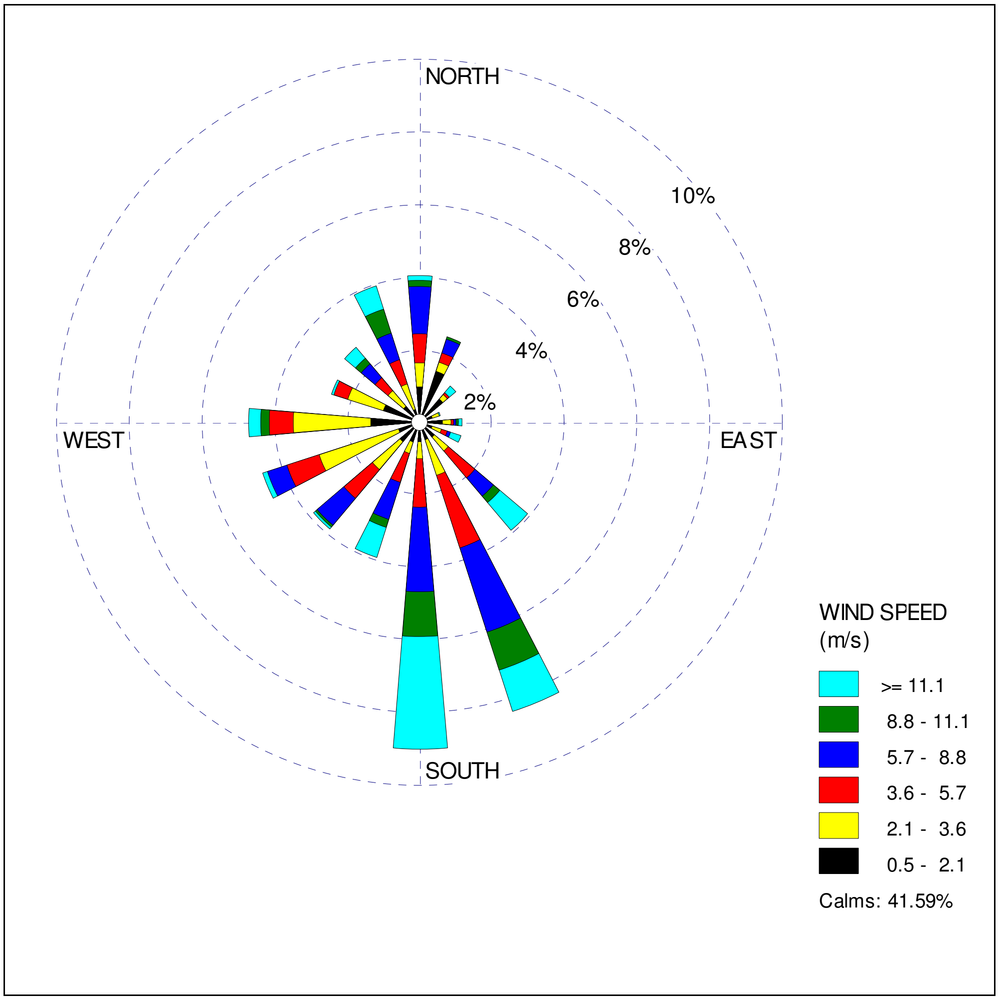

Figure 53: Molteno Reservoir, October

Figures 54 and 55 show the wind roses for the measuring positions 1, 2, 3 and 4 between the buildings.

The wind quality in all the mobile measuring positions was not good. It was in all cases too variable and not strong enough or too strong. This is because the wind roses show wind directions distributions that are very random.

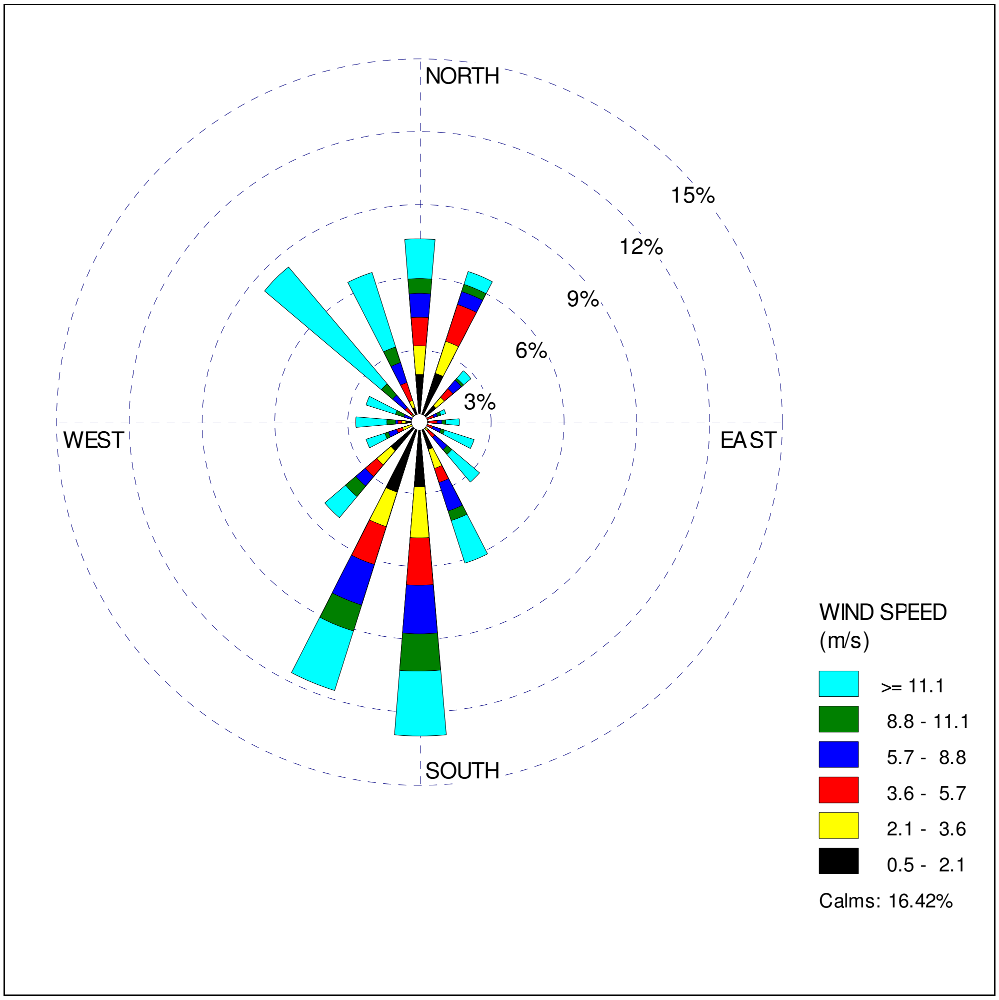

Figure 54: Positions 1&2

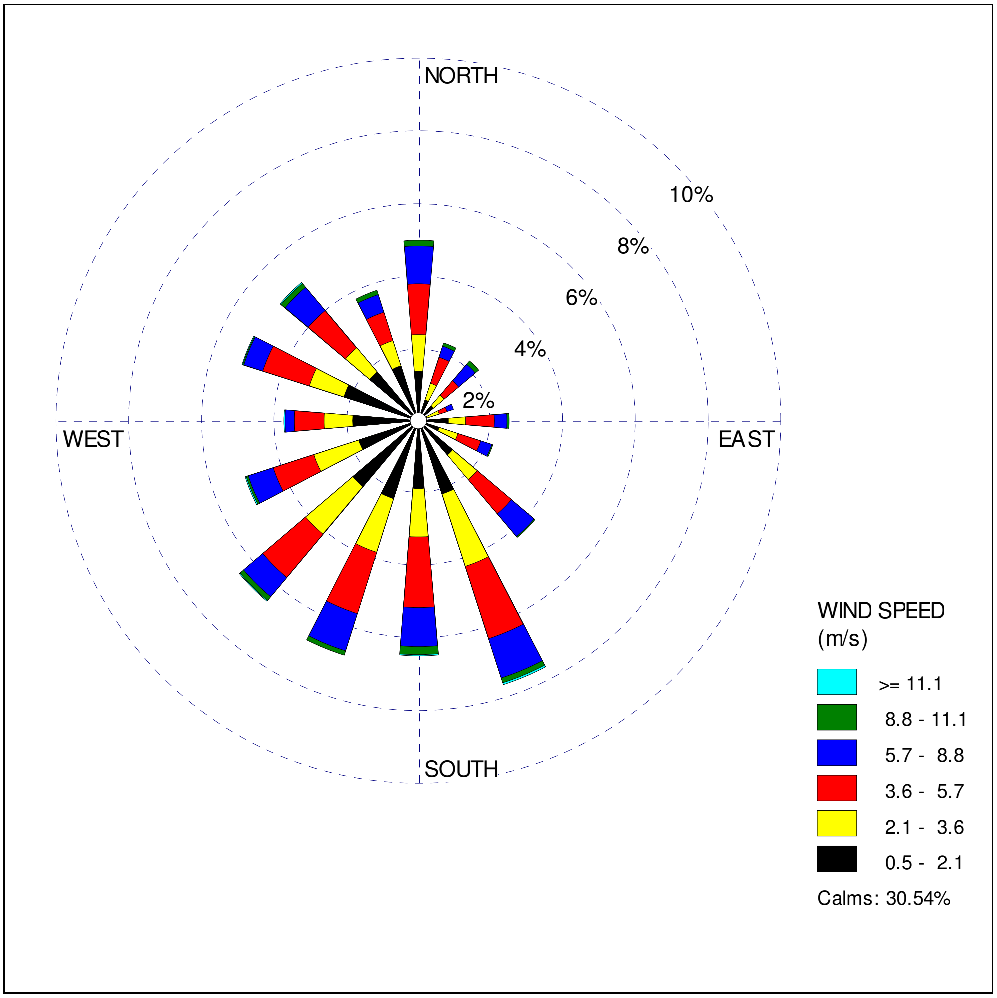

Figure 55: Positions 3&4

Difficulties

The difficulties that were met during the measurements were:

- The measuring sensors transmit their data through a wireless radio signal that has limited reach. This makes it difficult to place the sensors at any desired place.
- The available time for measuring was limited to two months. For a real close correlation, a minimum of one year's data are required (Jackson, 2009).

Conclusion

The wind at SAB shows a good correlation with the wind at Cape Town Airport. The data from the airport can therefore be used for the prediction of the wind energy production at SAB. According to Table 1, the average wind at SAB might be little stronger than at the airport. It seems that the Table Mountain doesn't affect the wind at SAB much.

The best position for installing a wind turbine at SAB Newlands is on the highest available rooftop. The roof on which the fixed unit was installed seems the most appropriate. The annual energy savings for SAB with one turbine like the e400 can be estimated at 6.500 kWh which would allow a saving of R1.950 at an electricity cost of R0,3/ kWh. The payback time of a turbine like the e400 would then be longer than 30 years.

The option of installing a turbine between the buildings is not viable. The measured wind quality at certain selected spots confirms this. Other possible locations are not favourable because at those locations, any wind turbine would disturb the work flow and might cause safety issues.

7. MAIN CONCLUSION

Summary

The theory and background of wind energy and small scale wind turbines was summarized in the first chapters of this report. This is a comprehensive summary that can assist SAB in its future projects regarding wind power at its facilities.

The market research done for this project helped to propose the e400 wind turbine from Kestrel, a South African manufacturer, which can be installed on the rooftop of the brewery without any major concerns. The installation procedure requires little investment and can be done without any special assistance from the supplier. This turbine could generate around 6.500 kWh per year. This investment will however not be paid back when taking into account the very low electricity price of R0, 3 / kWh.

Building integration is an interesting topic, but the available knowledge and research publications are extremely limited. It is generally not a good idea to install wind turbines between buildings as part of a refurbishment. However, when the turbines are included in the basic design of the building from the start, then the potential is much more favourable.

The best position for the proposed wind turbine at the Newlands site is on the highest rooftop available above the General Management floor. The option of installing a turbine between the buildings is not viable because the wind quality is too turbulent at those locations.

Recommendations

A further investigation of the area by using computational fluid dynamics software packages is not recommended.

The continuation of measurements on site is recommended during another year in order to get a better prediction of the potential energy production and cost savings.

The most suitable system for SAB is one or more wind turbines to be installed on the rooftop and connected through voltage limiters and inverters directly to the brewery's main grid without any batteries or other. This will help the brewery in reducing its electricity bill.

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9. APPENDIX

A: The Betz law

The mathematical model is based on the calculation of the maximum theoretical efficiency of a thin rotor disc. To model this, the rotor is replaced by a disc that is perpendicular to a tubular flow. The disc withdraws energy from the fluid passing through the tube. At a certain distance behind this disc the fluid flows with a reduced velocity. A few assumptions were made. There is no traction, the flow is axial to the rotor and the flow is incompressible.

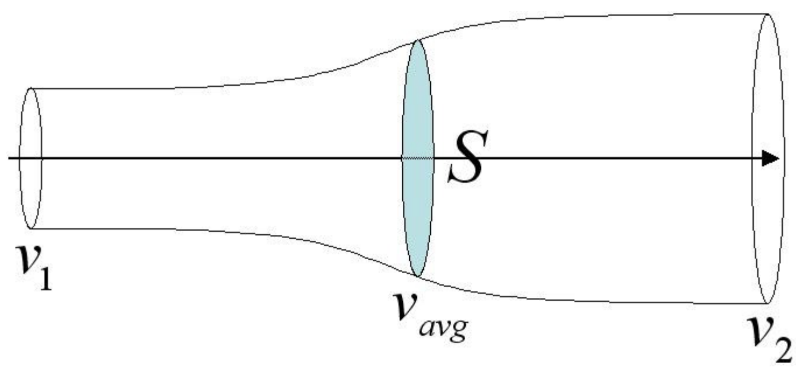


Figure 56: The Betz tube

Let us assume that the average wind speed through the rotor area is the average of the undisturbed wind speed before the wind turbine, v_1, and the wind speed after the passage through the rotor plane, v_2, i.e. $(v_1+v_2)/2$. Betz offers a proof of this (Betz, 1926).

$$v_{ave} = \frac{(v_1 + v_2)}{2} \qquad \text{(A.1)}$$

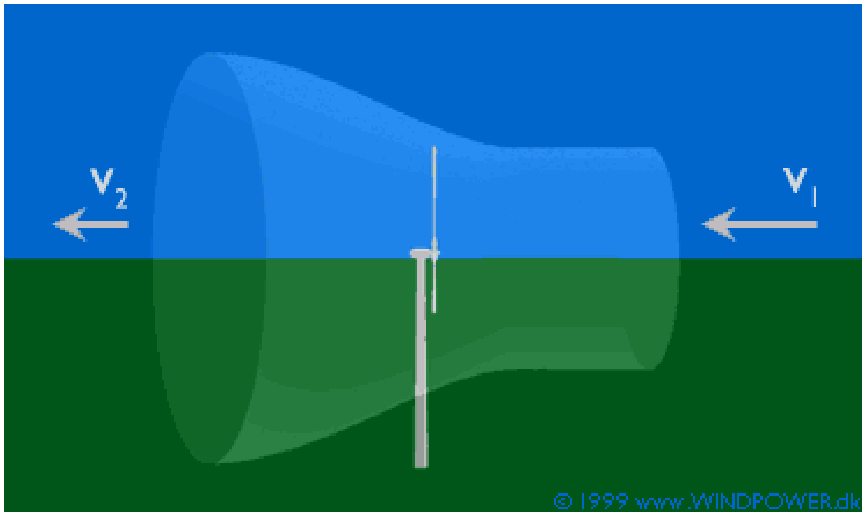


Figure 57: a wind turbine in a Betz tube (www.windpower.org)

The mass of the air streaming through the rotor during one second is:

$$\dot{m} = \rho \cdot S \cdot \frac{(v_1 + v_2)}{2} \qquad \text{(A.2)}$$

With:

$\dot{m}$ = mass flow
ρ = density of air
S = the swept rotor area
$\frac{(v_1 + v_2)}{2}$ = the average wind speed through the rotor area

The power extracted from the wind by the rotor is equal to the mass flow times the drop in kinetic energy per unit mass:

$$P = \dot{m} \cdot \frac{(v_1^2 - v_2^2)}{2} \qquad \text{(A.3)}$$

Substituting $\dot{m}$ from A.2 into A.3 we get:

$$P = \rho \cdot S \cdot \frac{(v_1^2 - v_2^2)}{4} \cdot (v_1 + v_2) \qquad \text{(A.4)}$$

The total power P_0 in the undisturbed wind that is streaming through exactly the same area S, without rotor disc is:

$$P_0 = \left(\frac{\rho}{2}\right) \cdot v_1^3 \cdot S \tag{A.5}$$

The ratio between the power we extract from the wind and the power in the undisturbed wind is then:

$$\frac{P}{P_0} = \frac{\left[1 - \left(\frac{v_2}{v_1}\right)^2\right] \cdot \left[1 + \left(\frac{v_2}{v_1}\right)\right]}{2} \tag{A.6}$$

The function reaches its maximum for $\frac{v_2}{v_1}$=1/3, and from this can be deducted that the maximum value for the power extracted from the wind is:

$$\left(\frac{P}{P_0}\right)_{max} = \frac{\left(1 - \left(\frac{1}{3}\right)^2\right) \bullet \left(1 + \frac{2}{3}\right)}{2} \tag{A.7}$$

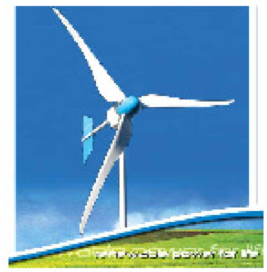
$$= \frac{\left(\frac{8}{9}\right) \cdot \left(\frac{4}{3}\right)}{2}$$

$$= \frac{16}{27} = 59{,}3\%$$

B: The e400 from Kestrel Wind

Tel: +27 (41) 401 2500/ 2599
Fax: +27 (41) 394 8183
e-mail: tracy.vosloo@eveready.co.za

SET - UP QUOTATION (RETAIL)



Type: e400[1] **Watts:** 3kW

Application: Gridtie

Requirements:

	Product:	Cost
1	**Wind Turbine** (available in 200Vdc)	R 61,847.00
2	**Voltage Limiter** compatible with SMA WB3300	R 15,200.00 *
3	**Gridtie Inverter** SMA WB3300 * price available on request	
3	**Tower - galvanised:** 12m Tripod	**TBA** *
	Total	**R 77,047.00**

***All the above costing is tentative

Notes:

*1. Tower option has been taken as 12m Tripod Tower
Towers are available in 15 &18m options if needed

*2. Voltage Limiter is compatible with SMA WB3300

3. Similar machines are available for (straight) battery charging or hybrid applications

4. All prices are excl. Vat, ex-works Port Elizabeth (i.e. no transportation)
All costs are in ZAR for RSA & SADC, for pricing outside of these regions, please contact us.

…./2

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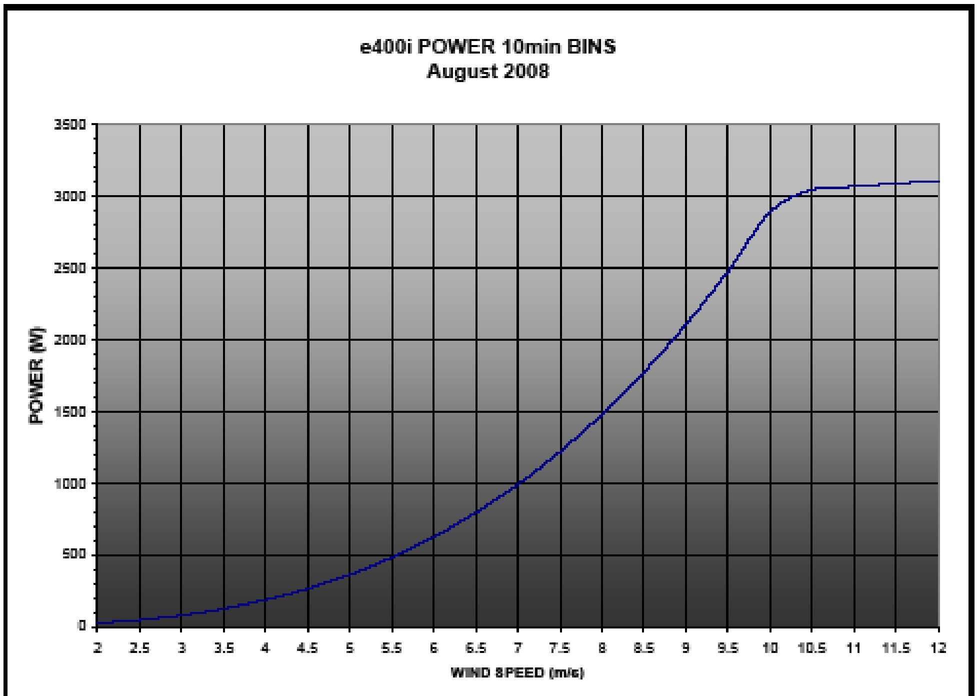
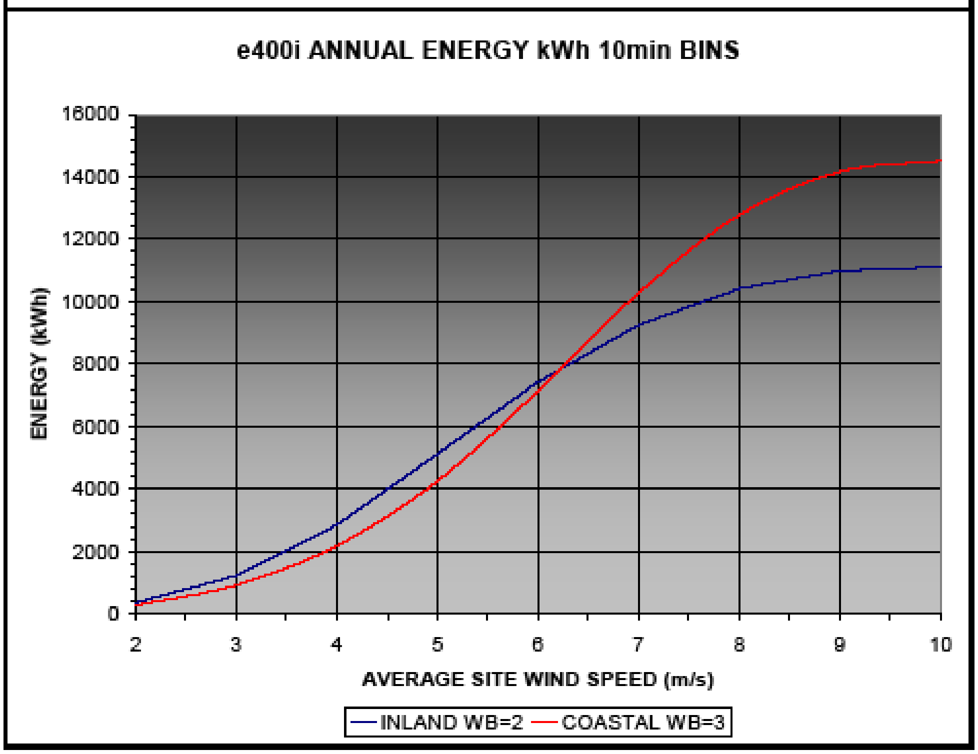
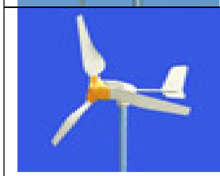
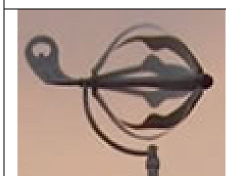
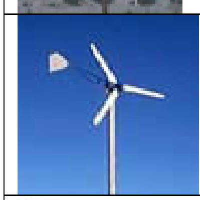


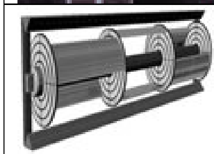
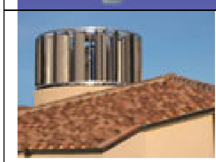
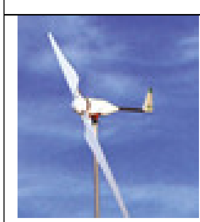
e400i POWER 10min BINS
August 2008
POWER (W)
3500
3000
2500
2000
1500
1000
500
0
2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12
WIND SPEED (m/s)



e400i ANNUAL ENERGY kWh 10min BINS
ENERGY (kWh)
16000
14000
12000
10000
8000
6000
4000
2000
0
2 3 4 5 6 7 8 9 10
AVERAGE SITE WIND SPEED (m/s)
INLAND WB=2
COASTAL WB=3

C: Wind turbine examples

	Windmax hybrid wind generators	WindMax Green Energy	HAWT	500 W – 2000 W	www.magnet4less.com
	ARI	ARI Renewable Energy Co.	HAWT	750 W – 2500 W	www.arigreenenergy.com
	Energy Ball V100	Home Energy	HAWT	500 W	www.home-emergy.com
	Swift	Renewable Devices	HAWT	1500 W	www.renewabledevices.com
	Sirocco	Eoltec	HAWT	6000 W	www.eoltec.com
	Whisper	Windenergy	HAWT	500 W – 3000 W	www.windenergy.com
	Fortis Montana, Passaat, Espada	Fortis Wind	HAWT	800 W – 5800 W	www.fortiswindenergy.com
	Tulipo	Tulipo	HAWT	2500 W	www.tulipower.nl

	10 kW MVAWT	Enviro Energies	VAWT	10 kW	www.enviro-energies.com
	Windpod	Windpods Design Licensing International Pty Ltd	HAWT	na	www.windpods.com
	OWN Urban Windmill	Donqi	HAWT	na	www.donqi.eu
	STATOEOLIEN GSE 4 STATOEOLIEN GSE 8	Gual Industrie	VAWT	1300 - 6000	www.gual-industrie.com
	AR-200W AR-500W AR-1000W AR-5000W	Vaigunth Ener Tek (P) Ltd	HAWT	200 W-5000 W	www.v-enertek.com
	Inclin 250 Inclin 600 Inclin 1500 neo Inclin 3000 neo Inclin 6000 neo	Bornay	HAWT	250 W–6000 W	www.bornay.com
	e150 e220 e300 e400	Kestrel Wind Turbines	HAWT	600 W-3000 W	www.kestrelwind.co.za