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# URBAN WIND TURBINES

Master Thesis

Tallinn 2010

**Author's Declaration**

I have written the Master's Thesis independently.
All works and major viewpoints of the other authors, data from other sources of literature and elsewhere used for writing this paper have been referenced.

Master's Thesis is completed under prof. L. Roosimölder supervision

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**ABSTRACT** - *RESUMEN DE LAS PARTES DEL CONTENIDO DEL PROYECTO:*

The purpose of this project is a feasibility study of using urban wind turbines near populated areas.

Urban wind turbines are rarely used nowadays and they are a new field to discover. This project involves researching different technical and design solutions, their advantages and disadvantages, all the problems which have appeared about noise or shadows, if there are any machines which are already running and any prototypes for the future.

Some design methods are used to analyse the different possible options. These methods will help us to find out the most suitable solutions.

The results of this study will be used by "4 ENERGIA", an Estonian Company which aims are to develop renewable energy industry and operate power production. This project is done in collaboration with the company and the research will provide them valuable information for using urban wind turbines in the future.


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# Abstract

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Urban wind turbines are rarely used nowadays and they are a new field to discover. This project involves researching different technical and design solutions, their advantages and disadvantages, all the problems which have appeared about noise, shadows and more, if there are any machines which are already running and any prototypes for the future.

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# 1. Glossary

List of abbreviations and acronyms used:

- AWEA: American Wind Energy Association
- BWEA: British Wind Energy Association
- EWEA: European Wind Energy Association.
- FTA: Fault Tree Analysis
- HAWT: Horizontal Axis Wind Turbine
- Maglev: Magnetic Levitation
- SAFE: Sequential Analysis of Functional Elements
- SWT: Small Wind Turbines
- VAWT: Vertical Axis Wind Turbine

# 2. Objectives

The aim of this project is first of all to give an overview of wind turbines used in urban areas, trying to cover the maximum possible aspects of this emerging technology and give the most suitable solution for this purpose.

Therefore there will be a classification of all turbines available for urban areas, an overview of problems that might appear while placing turbines near populated areas and a description of all parameters regarding to turbines efficiency.

A pre survey will be done to try to discover the opinion of people about locating such kind of devices near their homes.

After, to try to discover all the aspects to take into account when designing and using these turbines, design methods will be used. Those methods are analysing users, environment, functions and possible failures.

At the end an example of the most suitable solution will be given justifying the choice and also some possible aspects to consider in the future.

# 3. Introduction

Wind energy has been used since the earliest civilization to grind grain, pump water from deep wells and power sailboats. Windmills in pre-industrial Europe were used for many things.

In recent decades, the industry has been perfecting the wind turbine to convert the power of the wind into electricity. The wind turbine has many advantages that makes it an attractive energy source, especially in parts of the world where the transmission infrastructure is not fully developed. It is modular and can be installed relatively quickly, so it is easy to match electricity supply and demand. The fuel – the wind – is free and plentiful, which eliminates or reduces the need to purchase, ship, and store expensive fuels. Perhaps most importantly, the generator does not produce any harmful emissions in the process of generating the electricity, unlike many other generation sources.

But new small designs are starting to appear, called “small wind turbines”. They are electric generators that utilize wind energy to produce clean, emissions-free power for individual homes, farms and small businesses. The most common designs are small horizontal wind turbines, but beyond these, lots of new and surprising solutions are taking part in someone’s head and even in the market.

With this simple and increasingly popular technology, individuals can generate their own power and cut their energy bills while helping to protect the environment.

In this project I want to give an overview of what are the current designs, its characteristics and uses. It aims to find the best solutions for wind turbines closer to urban areas.

## 3.1. Physical Principles of Wind Energy Conservation

The primary component of a wind turbine is the energy converter which transforms the kinetic energy contained in the moving air, into mechanical energy. The extraction of mechanical energy from a stream of moving air with the help of a disk-shaped, rotating wind energy converter follows its own basic rules.

The credit for having recognized this principle is owned to Albert Betz. Between 1922 and 1925, Betz published writings in which he was able to show that, by applying elementary physical laws, the mechanical energy extractable from an air stream passing through a given cross-sectional area is restricted to a certain fixed proportion of the energy or power contained in the air stream [1]. Moreover, he found that optimal power extraction could only be realized at a certain ratio between the flow velocity of air in front of the energy converter and the flow velocity behind the converter.

Although Betz's "momentum theory", which assumes an energy converter working without losses in a frictionless airflow, contains simplifications, its results are quiet usable for performing rough calculations in practical engineering.

**Betz's Elementary Momentum Theory**

The kinetic energy of air mass $m$ moving at a velocity $v$ can be expressed as:

$$E = \frac{1}{2} m v^2 \quad (\mathrm{Nm})$$

Considering a certain cross-sectional area $A$, through which the air passes at velocity, the volume $V$ flowing through during a certain time unit, the so-called volume flow, is:

$$\dot{V} = v A \quad (\mathrm{m^3/s})$$

And the mass flow with the air density $\varrho$ is:

$$\dot{m} = \varrho\, v A \quad (\mathrm{Kg/s})$$

The equation expressing the kinetic energy of the moving air and the mass flow yield the amount of energy passing through cross-section $A$ per unit time. This energy is physically identical to the power $P$.

[1] Betz, A.: *Windenergie und ihre Ausnutzung durch Windmühlen*, Vandenhoek und Ruprecht 1926; Vieweg, Göttingen, 1946

$$P = \frac{1}{2}\ \varrho\, v^3 A \quad (W)$$

The question is how much mechanical energy can be extracted from the free-stream airflow by an energy converter. As mechanical energy can only be extracted at the cost of the kinetic energy contained in the wind stream, this means that, with an unchanged mass flow, the flow velocity behind the wind energy converter must decrease. Reduced velocity, however, means at the same time a widening of the cross-section, as the same mass flow must pass through it. It is thus necessary to consider the conditions in front of and behind the converter (Fig 3.1).

Here, $v_1$ is the undelayed free-stream velocity, the wind velocity, before it reaches the converter, whereas $v_2$ is the flow velocity behind the converter.

The mechanical energy which the disk-shaped converter extracts from the airflow corresponds to the power difference of the air stream before and after the converter:

$$P = \frac{1}{2}\ \varrho\, A_1 {v_1}^3 - \frac{1}{2}\ \varrho\, A_2 {v_2}^3 = \frac{1}{2}\ \varrho\, (A_1 {v_1}^3 - A_2 {v_2}^3) \quad (\mathrm{W})$$

Maintaining the mass flow (continuity equation) requires that:

$$\varrho\, A_1 v_1 = \ \varrho\, A_2 v_2 \quad (\mathrm{Kg/s})$$

Thus,

$$P = \frac{1}{2}\ \varrho\, v_1 A_1 ({v_1}^2 - {v_2}^2\,) \quad (\mathrm{W})$$

Or,

$$P = \frac{1}{2}\ \dot{m}\, ({v_1}^2 - {v_2}^2) \quad (\mathrm{W})$$

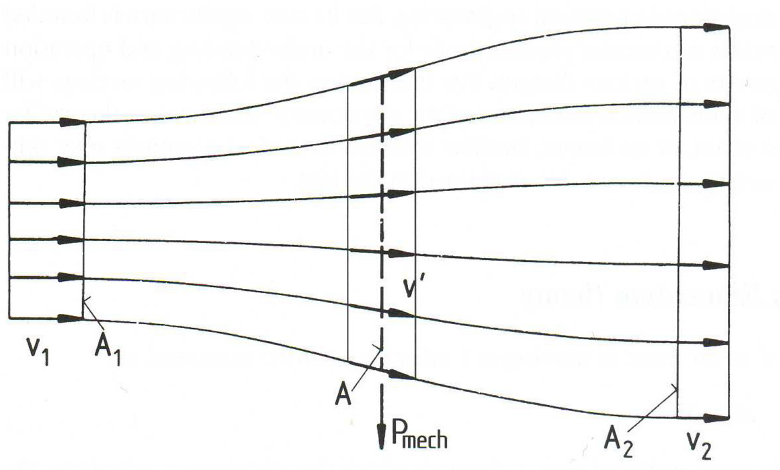



***Figure 3.1.*** *Flow conditions due to the extraction of mechanical energy from a free-stream air flow, according to the elementary momentum theory. [2]*

From this equation it follows that, in purely formal terms, power would have to be at its maximum when $v_2$ is zero, namely when the air is brought to a complete standstill by the converter. However, this result does not make sense physically. If the outflow velocity $v_2$ behind is zero, then the inflow velocity before the converter must be also become zero, implying that there would be no more flow through the converter at all. As could be expected, a physically meaningful result consist in a certain numerical ratio of $v_2/v_1$ where the extractable power reaches its maximum.

This requires another equation expressing the mechanical power of the converter. Using the law of conservation of momentum, the force which the air exerts on the converter can be expressed as:

$$F = \dot{m}\,(v_1 - v_2) \quad \text{(N)}$$

According to the principle of "action equals reaction", this force, the thrust, must be counteracted by an equal force exerted by the converter on the airflow. The thrust, so to speak, pushes the air mass at air velocity $v'$, present in the plane of flow of the converter. The power required for this is:

$$P = Fv' = \dot{m}(v_1 - v_2)v' \quad \text{(W)}$$

[2] ERICH HAU. *Wind Turbines; Fundamentals, Technologies, Applications, Economics*. Ed. Springer-Verlag, Berlin Heidenberg. 2n Edition. 2006.

Thus, the mechanical power extracted from the air flow can be derived from the energy or power difference before and after the converter, on the one hand, and, on the other hand, from the thrust and the flow velocity. Equating these two expressions yields the relationship for the flow velocity $v'$:

$$\frac{1}{2}\dot{m}({v_1}^2 - {v_2}^2) = \dot{m}(v_1 - v_2)v' \quad (\mathrm{W})$$

$$v' = \frac{1}{2}(v_1 - v_2) \quad (\mathrm{m/s})$$

Thus the flow velocity through the converter is equal to the arithmetic mean of $v_1$ and $v_2$:

$$v' = \frac{v_1 + v_2}{2} \quad (\mathrm{m/s})$$

The mass flow thus becomes:

$$\dot{m} = \varrho A v' = \frac{1}{2}\varrho A(v_1 + v_2) \quad (\mathrm{Kg/s})$$

The mechanical power output of the converter can be expressed as:

$$P = \frac{1}{4}\varrho A({v_1}^2 - {v_2}^2)(v_1 + v_2) \quad (\mathrm{W})$$

In order to provide a reference for this power output, it is compared with the power of the free-air stream which flows though the same cross-sectional area $A$, without mechanical power being extracted from it. This power was:

$$P_0 = \frac{1}{2}\varrho v_1^3 A \quad (\mathrm{W})$$

The ratio between the mechanical power extracted by the converter and that of the undisturbed air stream is called the “Power Coefficient” $C_p$:

$$C_P = \frac{P}{P_0} = \frac{\frac{1}{4}\,\varrho A({v_1}^2 - {v_2}^2)(v_1 + v_2)}{\frac{1}{2}\varrho v_1^3 A} \quad (-)$$

After some re-arrangement, the power coefficient can be specified directly as a function of velocity ratio $v_2/v_1$:

$$C_P = \frac{P}{P_0} = \frac{1}{2}\left|1 - \left(\frac{v_2}{v_1}\right)^2\right|\left|1 + \frac{v_2}{v_1}\right| \quad (-)$$

The power coefficient, i.e. the ratio of the extractable mechanical power to the power contained in the air stream, therefore, now only depends on the ratio of the air velocities before and after the converter.

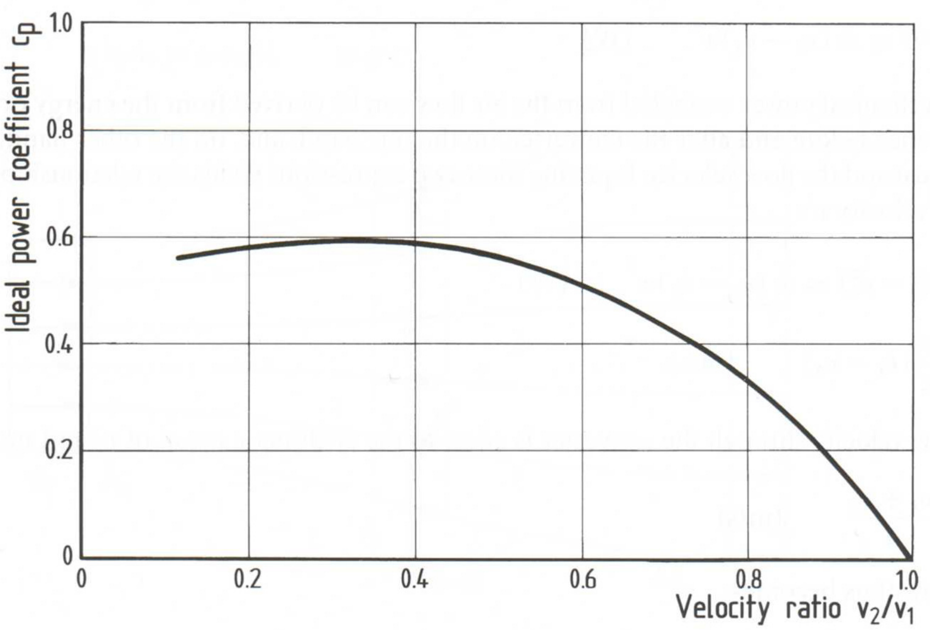



***Figure 3.2.*** *Power coefficient versus the flow velocity ratio of the flow before and after the energy converter. [2]*

If this interrelationship is plotted graphically – naturally, an analytical solution can also be found easily – it can be seen that the power coefficient reaches a maximum at a certain velocity ratio (*Figure 3.1*).

With $v_2/v_1$ = 1/3, the maximum “ideal power coefficient” $C_p$ becomes

$$C_P = \frac{16}{27} = 0{,}593$$

Betz was the first to derive this important value and it is, therefore, frequently called the “Betz factor”.

Knowing that the maximum, ideal power coefficient is reached at $v_2/v_1$ = 1/3, the follow

velocity $v'$

$$v' = \frac{2}{3} v_1$$

And the required reduced velocity $v_2$ behind the converter can be calculated:

$$v_2 = \frac{1}{3} v_1$$

It is worthwhile to recall that these basic relationship were derived for an ideal, frictionless flow, and that the result was obviously derived without having a close look at the wind energy converter. In real cases, the power coefficient will always be smaller than the ideal Betz value. The essential findings derived from the momentum theory can be summarised in words as follows:

- The mechanical power which can be extracted from a free-stream airflow by an energy converter increases with the third power of the wind velocity.
- The power increases linearly with the cross-sectional area of the converter traversed; it thus increase with the square of this diameter in case of circle area.
- Even with an ideal airflow and lossless conversion, the ratio of extractable mechanical work to the power contained in the wind is limited to a value of 0.593. Hence, only about 60% of the wind energy of a certain cross-section can be converted into mechanical power.

– When the ideal power coefficient achieves its maximum value $c_p = 0.593$, the wind velocity in the plane of flow of the converter amounts to two thirds of the undisturbed wind velocity and is reduced to one third behind the converter.

**Wind Energy Converters Using Aerodynamic Drag or Lift**

The momentum theory by Betz indicates the physically based, ideal limit value for the extraction of mechanical power from a free-stream airflow without considering the design of the energy converter. However, the power which can be achieved under real conditions cannot be independent of the characteristics of the energy converter.

The first fundamental difference which considerably influences the actual power depends on which aerodynamic forces are utilised for producing mechanical power. All bodies exposed to an airflow experience an aerodynamic force the components of which are defined as aerodynamic drag in the direction of flow, and as aerodynamic lift at a right angle to the direction of flow. The real power coefficients obtained vary greatly in dependence on whether aerodynamic drag or aerodynamic lift used [3].

***Drag devices***

The simplest type of wind energy conservation can be achieved by means of pre drag surfaces (*Figure 3.3*).

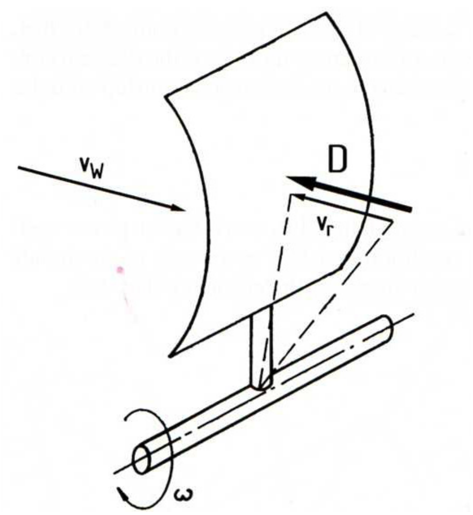



***Figure 3.3.*** *Flow conditions and aerodynamic forces. [2]*

[3] Molly, J.P.. *Windedenergie in Theorie und Praxis*, C.F. Müller-Verlag, Karlsruhe. 1978.

The air impinges on the surface $A$ with velocity $v_w$, the power capture $P$ of which can be calculated from the aerodynamic drag $D$, the area $A$ and velocity $v$ with which it moves:

$$P = D\, v_r$$

The relative velocity $v_r = v_w - v$ which effectively impinges on the drag area is decisive for its aerodynamic drag. Using the common aerodynamic drug coefficient $C_D$, the aerodynamic drug can be expressed as:

$$D = C_D \frac{\varrho}{2} (v_w - v_r)^2 F$$

The resultant power is

$$P = C_D \frac{\varrho}{2} (v_w - v_r)^2 A\, v_r \quad \text{(W)}$$

If power is expressed again in terms of the power contained in the free-stream airflow, the following power coefficient is obtained:

$$Cp = \frac{P}{P_0} = \frac{\frac{\varrho}{2}\, C_D\, A\, (v_w - v_r)^2\ v_r}{\frac{\varrho}{2}\ v_W^3\, A}$$

Analogously to the end approach described before, it can be shown that $C_P$ reaches a maximum value with a velocity ratio of $v/v_W = 1/3$. The maximum value is then

$$C_{P\,max} = \frac{4}{27} C_D$$

The order of magnitude of the result becomes clear if it is taken into consideration that the aerodynamic drag coefficient of a concave surface curved against the wind direction can hardly exceed a value of 1.3. Thus, the maximum power coefficient of a pure drag-type rotor becomes:

$$C_{P\,max} \approx 0{,}2$$

It thus achieves only one third of Betz's ideal $C_p$ value of 0.593. It must be pointed out that, strictly speaking, this derivation only applies to a translatory motion of the drag surface. *Figure 3.2* shows a rotating motion, in order to provide a more obvious relationship with the wind rotor.

***Rotors using aerodynamic lift***

If the rotor blade shape permits utilisation of aerodynamic lift, much higher power coefficients can be achieved. Analogously to the conditions existing in the case of an aircraft airfoil, utilisation of aerodynamic lift considerably increase the efficiency (*Fig. 3.4*).

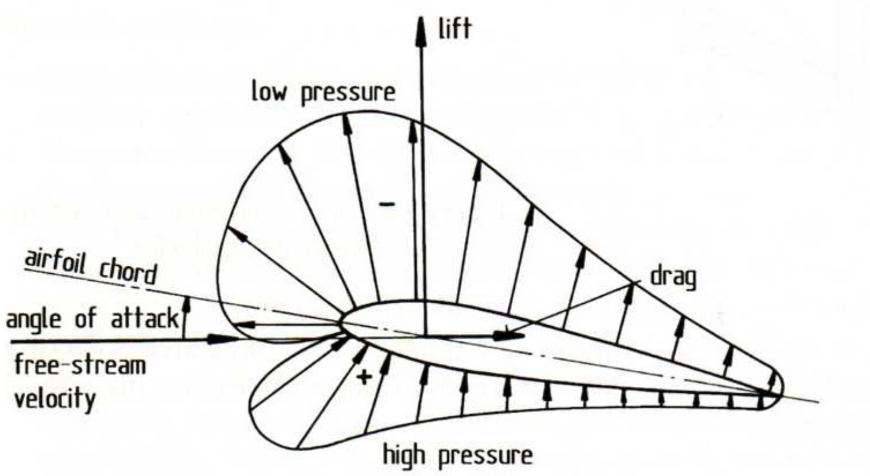



***Figure 3.4.*** *Aerodynamic forces acting on an airfoil exposed to an air stream. [2]*

All modern wind rotor types are designed for utilising this effect and the type best suited for this purpose is the propeller type with a horizontal rotation axis (*Fig. 3.5.*). The wind velocity $v_W$ is vectorially combined with the peripheral velocity u of the rotor blade. When the rotor blade is rotating, this is the peripheral velocity at a blade cross-section at a certain distance from the axis rotation. Together with the airfoil chord the resultant free-stream velocity $v_r$ forms the aerodynamic angle of attack. The aerodynamic force created is resolved into a component in the direction of the free-stream velocity, the drag $D$, and a component perpendicular to the free-steam velocity, the lift $L$. The lift force, in turn, can be resolved into a component $L_{torque}$ in the plane of rotation of the rotor, and a second component perpendicular to its plane of rotation. The tangential component $L_{torque}$ constitutes the driving torque of the rotor, whereas $L_{thrust}$ is responsible for the rotor thrust.

Modern airfoils developed for aircraft wings and which also found application in wind rotors, have an extremely favourable lift-to-drag ratio ($E$). This ratio can reach values of up to 200. This fact alone shows qualitatively how much more effective the utilisation of aerodynamic lift as a driving force must be. At this stage, however, it is no longer possible to calculate the achievable power coefficients of lift-type rotors quantitatively with the aid of elementary physical relationships alone. More sophisticated theoretical modelling concepts are now required, but some coefficients and ideas about this will be given in the chapter *4.1.2 Main parameters and energy efficiency.*

Some rotor types, for example the Savonius rotor, can be built both as pure drag-type rotors and, with the appropriate aerodynamic shape, as rotors which partly utilise lift. This is one reason for the frequently greatly varying figures quoted for the power coefficient.

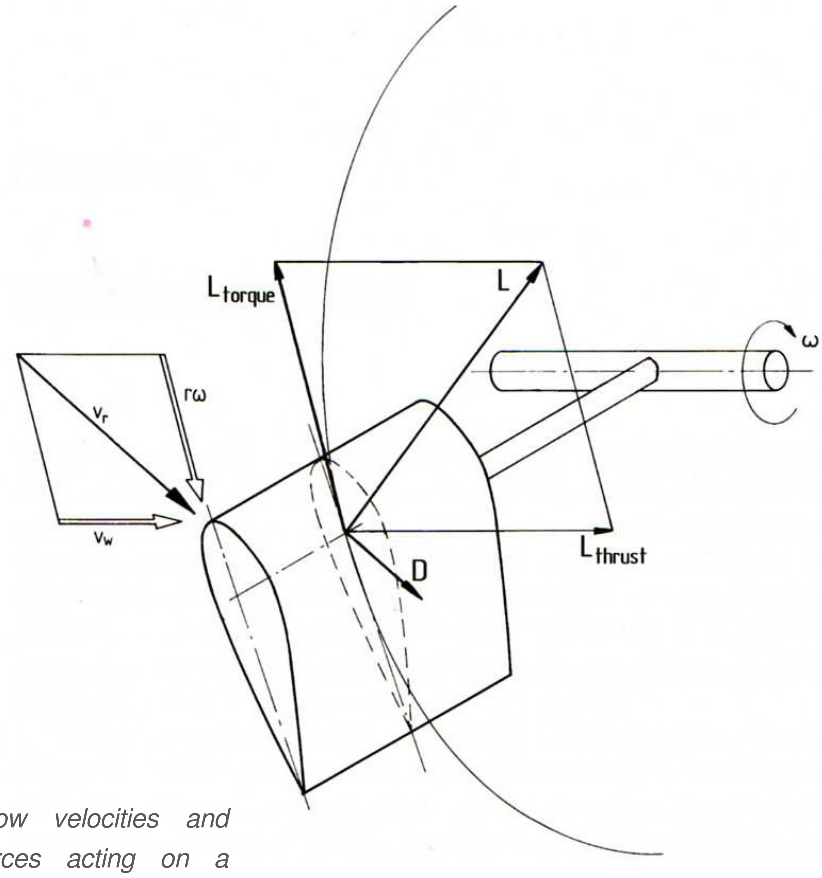



***Figure 3.5.*** *Flow velocities and aerodynamic forces acting on a propeller-like rotor. [2]*

# 4. Urban wind turbines

There are many designs of wind turbines which could be used near urban areas to produce energy. Last years a lot of new designs and solutions are appearing all around the world. Some of them are just ideas, prototypes or impossible solutions, but there are also feasible designs.

The great majority of wind turbines belong to individuals or corporations who use them to generate electric power or to perform mechanical work. As such, wind turbines are primarily designed to be working devices. However, the large size and height above surroundings of modern industrial wind turbines, combined with their moving rotors, often makes them among the most conspicuous objects in their areas. A few localities have exploited the attention-getting nature of wind turbines by placing them on public display, either with visitor centers around their bases, or with viewing areas farther away. The wind turbines themselves are generally of conventional horizontal-axis, three-bladed design, and generate power to feed electrical grids, but they also serve the unconventional roles of technology demonstration, public relations and education.

Sometimes it is difficult to make the difference between urban and not urban wind turbines. What's the difference? Which are urban wind turbines and which not?

In the following chapter we'll see an overview of wind turbines, their characteristics about efficiency and utilities. We'll also know about the problems existing near urban areas and a small survey of the opinion that people have about them.

## 4.1. Overview of existing urban wind turbines

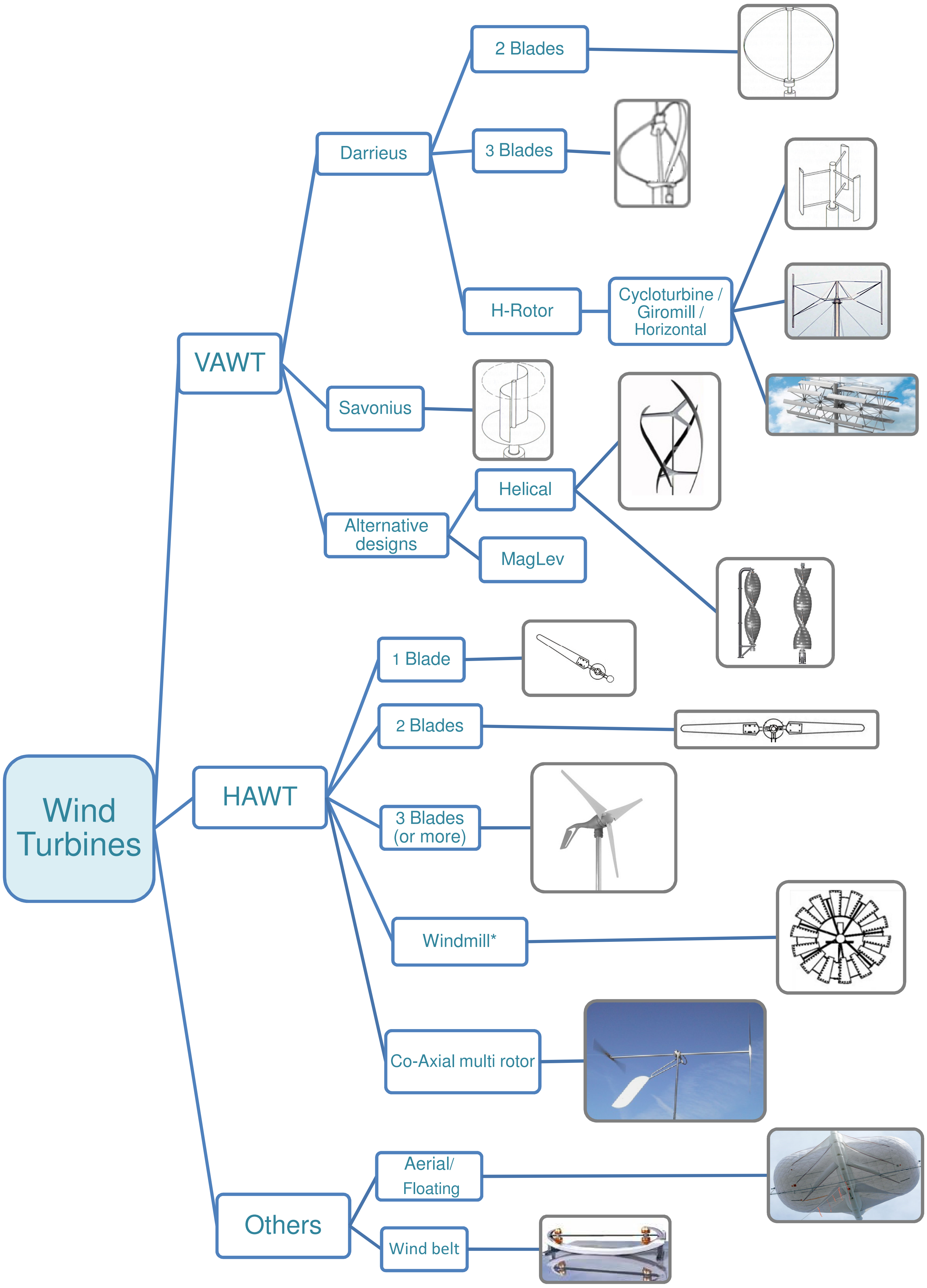
In this chapter the aim is to give an overview of the real designs that are used as urban wind turbines and also from those who are appearing nowadays.

### *4.1.1. Technical and design solutions*

In the page below you can see a classification of the most common and feasible existing wind turbines.

These wind turbines are explained here almost following this order.

*Wind Turbines classification*
*DIN A3 Graph*




***Wind Turbines classification:*** *Most common wind turbines, real urban wind turbines used nowadays, and new designs. (Other prototypes, designs and particular solutions are not included. Some of them are mentioned in the following chapter). * See "Windmills" on this chapter.*

**VAWT**

**Savonius Wind turbine**

Savonius wind turbines are a type of VAWT, used for converting the power of the wind into torque on a rotating shaft. They were invented by the Finnish engineer Sigurd J. Savonius in 1922.

Savonius turbines are one of the simplest turbines. Aerodynamically, they are drag-type devices, consisting of two or more scoops. Looking down on the rotor from above, a two-scoop machine would look like an "S" shape in cross section *(Figure 4.1.1.).* Because of the curvature, the scoops experience less drag when moving against the wind than when moving with the wind. The differential drag causes the Savonius turbine to spin. Because they are drag-type devices, Savonius turbines extract much less of the wind's power than other similarly-sized lift-type turbines. Much of the swept area of a Savonius rotor is near the ground, making the overall energy extraction less effective due to lower wind speed at lower heights.

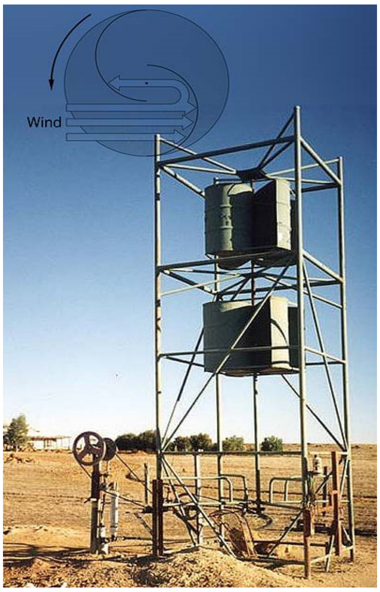



***Figure 4.1.1.*** *Savonius wind turbine with a couple of 4 scoops, used for pumping water.*

Savonius turbines are used whenever cost or reliability is much more important than efficiency. For example, most anemometers are Savonius turbines, because efficiency is completely irrelevant for that application. Much larger Savonius turbines have been used to generate electric power on deep-water buoys, which need small amounts of power and get very little maintenance. Design is simplified because, unlike HAWTs, no pointing mechanism is required to allow for shifting wind direction and the turbine is self-starting. Savonius and other vertical-axis machines are not usually connected to electric power grids. They can sometimes have long helical scoops, to give smooth torque, as is mention in the *Helical Wind turbines* description.

**Darrieus Wind turbine**

The Darrieus rotor was invented by the Frenchman George Darrieus and patented 1931 in the USA. Because of its appearance the rotor becomes jokeful also egg *beater*. It's also a kind of VAWT.


***Figure 4.1.2.*** *A 2 blades Darrieus wind turbine of the former American Flowind company.*

The rotor blades are fastened to the upper and lower end of the axle and rise up arc-shaped outward. The type of arch of the rotor blades follows a funicular curve, so that they are not exposed to bending moment under the centrifugal energy in the enterprise *(Figure 4.1.2.*). Aerodynamically, they are drag and lift-type devices, although the drag is quite negligible.

They have good efficiency, but produce large torque ripple and cyclic stress on the tower, which contributes to poor reliability. Also, they generally require some external power source, or an additional Savonius rotor, to start turning, because the starting torque is very low. The Darrieus develops most of the power whereas the Savonius enables self-starting as well as regulating the maximum rotor speed by adding drag at high wind speeds *(Figure 4.1.3.)*. 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. Newer Darrieus type turbines are not held up by guy-wires but have an external superstructure connected to the top bearing.

***Figure 4.1.3.*** *A Darrieus with a Savonius wind turbine to enable self-starting and rotor speed regulation.*

A subtype of Darrieus wind turbine are the so called H-Rotor. They can either be Giromills or Cycloturbines (or even in an horizontal way).

*H-rotor - Giromill*

1927 Darrieus's patent also covered practically any possible arrangement using vertical airfoils. One of the more common types is the Giromill, in which the long "egg beater" blades of the common Darrieus design are replaced with straight vertical blade sections attached to the central tower with horizontal supports. The Giromill blade design is much simpler to build, but results in a more massive structure than the traditional arrangement, and requires stronger blades.

Development is now starting again on new giromills which take advantage of modern ultra strong light materials to produce turbine blades robust enough to cope with the stresses they are put under.

***Figure 4.1.4.*** *H-rotor Darrieus Giromill wind turbine with 10 m diameter in RotwanHaus (Bayern Germany).*

The Giromill is typically powered by two or three vertical aerofoils attached to the central mast by horizontal supports *(Figure 4.1.4.).* It is less efficient, also requires strong winds (or a motor) to start, and can sometimes struggle to maintain a steady rate of rotation. However, they work well in turbulent wind conditions and are an affordable option where a standard horizontal axis windmill type turbine is unsuitable.

*H-rotor - Cycloturbine*

Another variation of the Giromill is the Cycloturbine, in which the blades are mounted so they can rotate around their vertical axis. This allows the blades to be "pitched" so that they always have some angle of attack relative to the wind. The main advantage to this design is that the torque generated remains almost constant over a fairly wide angle, so a Cycloturbine with three or four blades has a fairly constant torque. Over this range of angles, the torque itself is near the maximum possible, meaning that the system also generates more power. As the rotational speed increases the blades are pitched so that the wind flows across the aerofoils generating lift forces and accelerating the turbine.

***Figure 4.1.5.*** *Small H-rotor Darrieus Cycloturbine with 2 m diameter in a top of a building [4]*

The Cycloturbine also has the advantage of being able to self start, by pitching the "downwind moving" blade flat to the wind to generate drag and start the turbine spinning at a low speed *(Figure 4.1.6.)*. On the downside, the blade pitching mechanism is complex and generally heavy, and some sort of wind-direction sensor needs to be added in order to pitch the blades properly.

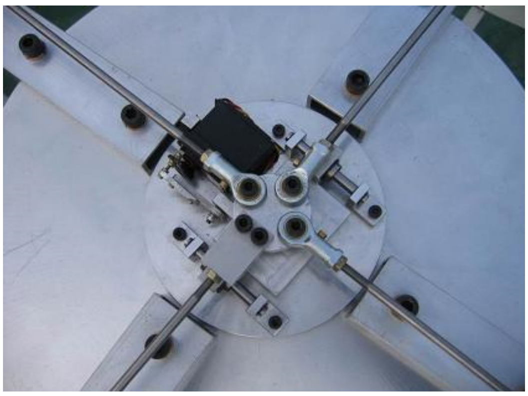


***Figure 4.1.6.*** *Detail of a Small H-rotor Darrieus pitch control.*

[4] CYCLOCOPTER.SNU.AC.KR, Aerospace Structures Laboratory, Seoul Natonal University, Korea . URL:http://cyclocopter.snu.ac.kr/windturbine.htm. Dec. 2009.

*Horizontal configuration Darrieus wind turbine*

This design is based on the Darrieus wind turbine basics, but in a horizontal configuration. It is also using lift forces to rotate and able to use pitch control as H-rotors.

They are thought for urban areas, for roof-top places. The horizontal configurations helps to have a more simple structure and to hide from the neighbours landscape view.

The disadvantage is that they are fixed on the structure, that means that they are not able to catch the wind from all directions. But as shown on *Figure 4.1.7* turbines catch the wind that is flowing from the front wall of buildings, giving a higher wind catching efficiency.

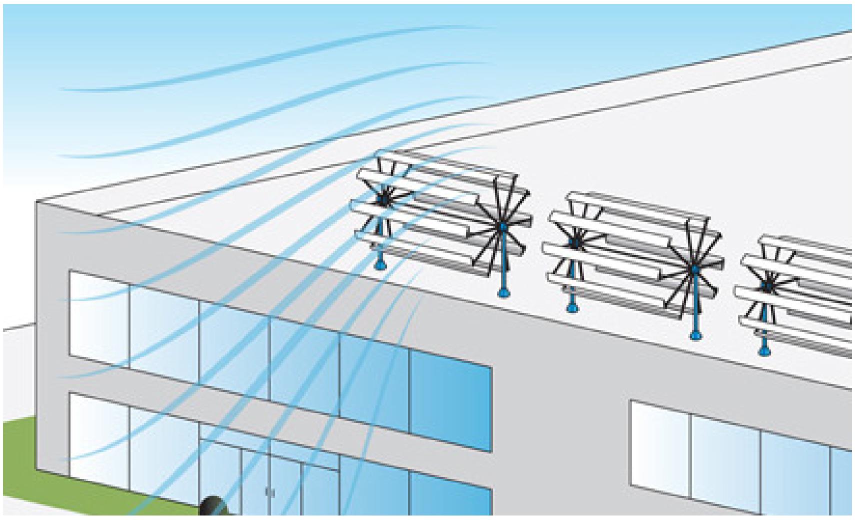


***Figure 4.1.7.*** *Example of a Darrieus wind turbine in horizontal configuration.* BROADSTARS Wind systems company®. Model AeroCam. [5]

The example shown on *Figure 4.1.7.* belongs to the "*BROADSTARS Wind systems company"* which is developing these turbine designs for urban areas. The patent was made on April 2008.

The turbine "AeroCam" is supposed to be a 10 KW ( Rated with 13 m/s wind speed), 3 m diameter and 4,8 m width [5].

[5] *BROADSTARS Wind systems company®. Patent April 2008 AeroCam* *UR*L:http://www.broadstarwindsystems.com/home.php. Dec. 2009.

## Alternative Designs

There are also some turbines that uses Darrieus and Savonius concepts, we can call them *alternative designs*. These turbines are usually helical twisted blades designs or either Savonius with helical blade scoops.

*Helical twisted blades design*

In an effort to improve the efficiency of wind turbine systems, helical wind turbines are now being developed that are up to 25 per cent more efficient than the horizontal wind turbines with normal blades. A helical wind turbine system is more efficient, as its twisted blades are not feathered or stopped by high winds [6].

The new designs can deliver torque relatively evenly at variable wind speeds and the twisted blades have been designed to eliminate noise and vibration when operating in turbulent shifting wind conditions. The turbine rotors are constructed of carbon fiber and epoxy resin and the assembly has very few moving parts, making them easier to maintain.

***Figure 4.1.8.*** *Helical twisted blades wind turbine 5 KW: Model qr5 - © quietrevolution ltd 2009*

Helical turbine systems can be mounted on buildings or towers. Current models have a fairly small output and are suitable for houses and small businesses. However, the design can be adapted and increased in scale for major electricity generation.

[6] WindSystems.Co.Uk – Renewable Energy – Helix Wind Systems Article. URL: http://www.windsystems.co.uk/helical-wind-turbines.html. Nov. 2009.

*Helical blade scoops*

Helical blade scoops designs are just a variation of Savonius rotors. The helical blades are supposed to be more bird-friendly and catch the wind more easily.


***Figure 4.1.9.*** *S322 Wind. With 3,19 $m^2$ swept area and 2 kW rated power, is an example of helical blade scoops wind turbine for urban areas. [7]*

Many manufacturers are starting to develop and sell these kind of turbines for single owners. An example is shown on *Figure 4.1.9.*

Another example is the HEB wind turbine designed by Wind Energy Corp., *Figure 4.1.10,* providing between 25 and 50 rated KW in varying wind speeds. The company's first prototype, made of new carbon materials is thought to be installed in a 30 meters tower.


***Figure 4.1.10.*** *Helical Blade Scoop wind turbine prototype from the Wind Energy Corporation called HEB.*



[7] S322 wind turbine model Copyright © 2005-2009 Helix Wind, Corp. URL:http://www.helixwind.com/en/ Dec. 2009

*Maglev Wind Turbines*

Magnetic levitation is an efficient system for wind energy. The vertically oriented blades of the wind turbines are suspended in the air above the base of the machine, replacing the need for ball bearings. The turbines use “full-permanent” magnets, not electromagnets — therefore, it does not require electricity to run. The full-permanent magnet system employs neodymium (a rare earth) magnets and there is no energy loss through friction. This also helps reduce maintenance costs and increases the lifespan of the generator.

Maglev wind turbines have several advantages over conventional wind turbines. For instance, they’re able to use winds with starting speeds as low as 1.5 meters per second (m/s). Also, they could operate in winds exceeding 40 m/s. Currently, the largest conventional wind turbines in the world produce only six megawatts of power. However, one large maglev wind turbine could generate one GW of clean power, enough to supply energy to 750,000 homes.

Construction began on the world’s largest production site for maglev wind turbines in central China on November 5, 2007. Zhongke Hengyuan Energy Technology has invested 400 million yuan in building this facility, which will produce maglev wind turbines with capacities ranging from 400 to 5,000 Watts. In the US, Arizona-based MagLev Wind Turbine Technologies will be manufacturing these turbines. [8]

***Figure 4.1.11.*** *3D simulation picture from the 1GW Maglev wind turbine project for 2010. Maglev Wind Turbine Technologies, Inc.*

[8] Article in: *Inhabitat* by Mahesh Basantani Nov. 2007. URL:http://www.inhabitat.com/2007/11/26/super-powered-magnetic-wind-turbine-maglev/ Nov 2009.

**HAWT**

**1 and 2 blades wind turbines**

Two-bladed wind turbine designs have the advantage of saving the cost of one rotor blade and its weight, of course. However, they tend to have difficulty in penetrating the market, partly because they require higher rotational speed to yield the same energy output. This is a disadvantage both in regard to noise and visual intrusion. Lately, several traditional manufacturers of two-bladed machines have switched to three-bladed designs.

Two- and one-bladed machines require a more complex design with a hinged (teetering hub) rotor as shown in *Figure 4.1.12.* , i.e. the rotor has to be able to tilt in order to avoid too heavy shocks to the turbine when a rotor blades passes the tower. The rotor is therefore fitted onto a shaft which is perpendicular to the main shaft, and which rotates along with the main shaft. This arrangement may require additional shock absorbers to prevent the rotor blade from hitting the tower.

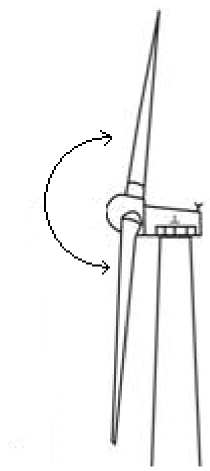


***Figure 4.1.12.*** *Example of a wind turbine hub able to tilt to prevent shocks.*

One-bladed wind turbines are not very widespread commercially, however, because the same problems that are mentioned under the two-bladed design apply to an even larger extent to one-bladed machines.

In addition to higher rotational speed, and the noise and visual intrusion problems, they require a counterweight to be placed on the other side of the hub from the rotor blade in order to balance the rotor.

The reason for the current dominance of the three-bladed wind turbines is rather that a two bladed wind turbine is significantly harder to design, which is a consequence of its asymmetry, whereas the three-bladed turbine is symmetrical. Because of these reasons such kind of designs are not used in urban areas.

***Figure 4.1.13.*** *NASA Mod-0 research wind turbine at Plum Brook Station near Sandusky, Ohio tested a one-bladed rotor configuration, Photo by NASA Glenn Research Center.*

**3 blades (or 4,5 or more blades) wind turbines**

Starting with this chapter, I'll just comment about some 3 blades big turbines installed near urban places. It is not common to install huge turbines near towns and cities, because of the law, and many problems as commented in the next chapter: *4.2.Main environment impacts and problems with existing urban wind turbine solutions near the urban areas*.

But still there are some big turbines working on industrial areas or universities. One example could be the one shown below on *Figure 4.1.14.*

***Figure 4.1.14.*** *A 3 blades wind turbine at Greenpark industrial estate, near Reading, Berkshire, England. Construction finished in November 2005.*

The turbine on top of the 85 m tower is the German-made Enercon E-70. The three fibreglass blades are each 33m. Maximum power output of 2.05 MW is reached at a wind speed of 14 m/s. The turbine supplies up to 1,500 local homes and businesses.

But the most common 3 blades wind turbines that we can find nowadays inside the urban areas are the known as “Small Wind” or “Micro Wind” Turbines (SWT). Those turbines are rated under 100 KW and are used by individuals and they can generate their own power and helping to cut their energy bills, even to return it into the grid. If the turbine is not connected to the electricity grid then unused electricity can be stored in a battery for use when there is no wind.

The number of this small wind turbines has been increasing very fast in the last years. They are emerging to meet several distinct needs. As well as the traditional areas of rural electrification and providing power to isolated homes, boats and telecommunications facilities.

The prospects for significant demand for ‘micro-generation’ in urban areas is prompting technical developments in small wind turbine design, which could result in significant improvements in the economics [9].

[9] Wind Energy – The Facts. English version March 2009. Publication in European Wind Energy Association. URL:http://www.ewea.org/fileadmin/ewea_documents/documents/publications/WETF/1565_ExSum_ENG.pdf

Pay attention that Small Wind Turbines are all the turbines rated under 100 KW, that means that all other turbine designs mentioned before could be also SWT.

So, focalising on SWT with 3 or more blades (multi-blade), right now United States of America leads the market of small wind turbines in production. In Europe, the U.K. the one who is leading in small wind energy. That's why government helps with good taxes, even 30% in the U.S.

Some of those turbines examples are shown on the following pages, with different rated powers, diameters and designs from several manufacturers.

***Figure 4.1.15.***
*A&C Green Energy. USA*
*PowerMax+ 2000G.*
*2 KW.*
*3m diameter.*


***Figure 4.1.16.***
*BORNAY. Spain.*
*Bornay 6000.*
*6 KW.*
*4m diameter.*

***Figure 4.1.18.***
*Vaigunth Ener Tek. India.*
*AR 7500 W.*
*7.5 KW.*
*7.5 m diameter.*

***Figure 4.1.20.***
*Bergey. USA.*
*Bergey Excel-S.*
*10 KW.*
*7m diameter.*

***Figure 4.1.19.***
*Gazelle Wind Turbines. UK.*
*Gazelle 20KW.*
*20 KW.*
*11m diameter.*

All pictures and information has been taken from Associations and Manufacturers Web sites. All the catalogues and pictures links and more sources are mentioned on the *Other Bibliography*.

**Windmill**

A windmill is a machine which converts the energy of wind to rotational motion by means of adjustable vanes called sails. The main use was for a grinding mill powered by the wind, by crushing, grinding, or pressing Windmills have also provided energy to sawmills, paper mills, hammermills and windpumps for obtaining fresh water from underground or for drainage.

But Windmills are not used to produce electric power, that's why it is not considered as a Wind Turbine or Wind generator at all.

**Co-Axial multi rotor**

Two or more rotors may be mounted to the same driveshaft, with their combined co-rotation together turning the same generator — fresh wind is brought to each rotor by sufficient spacing between rotors combined with an offset angle from the wind direction. Wake vorticity is recovered as the top of a wake hits the bottom of the next rotor. Power has been multiplied several times using co-axial, multiple rotors in testing conducted by inventor and researcher Douglas Selsam, for the California Energy Commission in 2004.

The first commercially available co-axial multi-rotor turbine is the patented dual-rotor American Twin Super turbine from Selsam Innovations in California, with 2 propellers separated by 12 feet (3.66 m). See *Figure 4.1.20. [10]:*

***Figure 4.1.20.*** *Example of co-axial multi-rotor turbine. Twin Super Turbine. 2KW. Selsam Innovations. California.[10]*

[10] Information taken from Selsam Innovation own Web Site. URL: http://selsam.com and http://dualrotor.com

## OTHERS

### Aerial/ Floating

The so called Aerial, Floating or airborne wind turbine is a design concept for a wind turbine that is supported in the air without a tower. It's achieved by using helium.

When the generator is on the ground, then the tethered aircraft need not carry the generator mass or have a conductive tether. When the generator is aloft, then a conductive tether would be used to transmit energy to the ground. Airborne systems would have the advantage of tapping an almost constant wind, without requirements for slip rings or yaw mechanism, and without the expense of tower construction. See *Figure 4.1.21.*

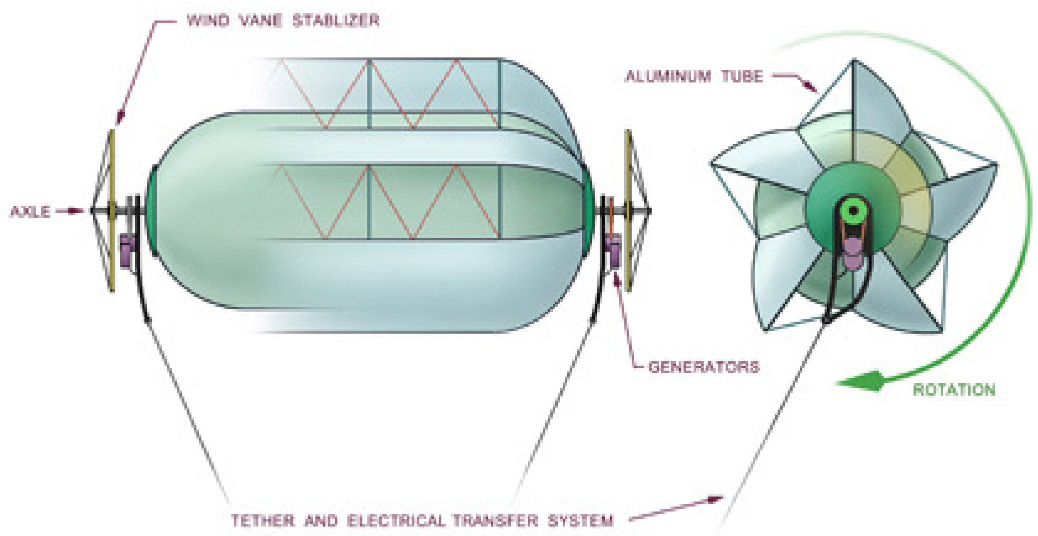



***Figure 4.1.21.*** *M.A.R.S. 10kW proof of concept (April 2008), featured on Discovery Channel.*

Bad weather such as lightning or thunderstorms, could temporarily suspend use of the machines, probably requiring them to be brought back down to the ground and covered. Some schemes require a long power cable and, if the turbine is high enough (even 300 m), an aircraft exclusion zone. When the generator is ground-based, the tether need not be conductive.

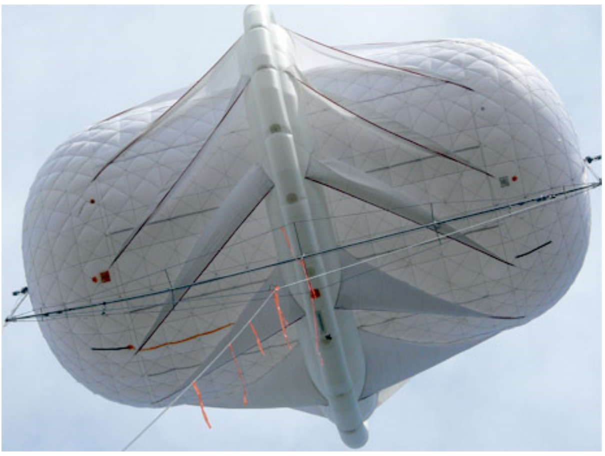


***Figure 4.1.22.*** *M.A.R.S. 10kW proof of concept (April 2008), featured on Discovery Channel. [11]*

Magenn Power, Inc. plans to start manufacturing its Magenn Air Rotor System (MARS) in 2010-2011 with a 100 kW MARS unit being the first size to be sold, shown on *Figure 4.1.23*. No plans for 4kW, 10kW or 25kW MARS as previously stated [11].

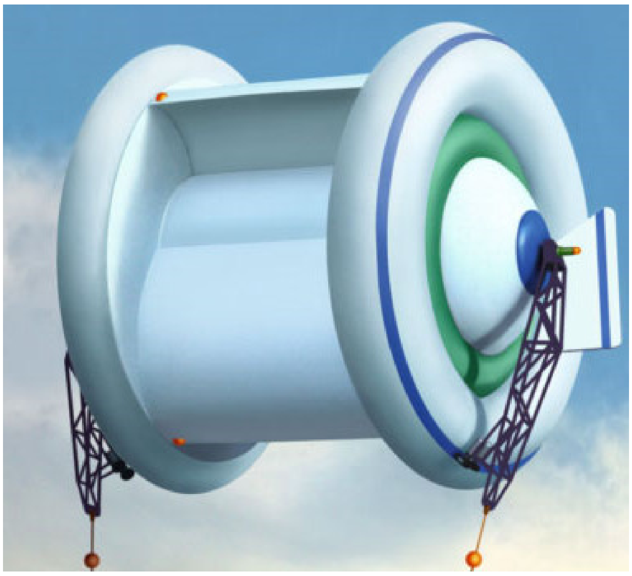


***Figure 4.1.23.*** *MARS 100kW generator, available on 2010-2011. [11]*

[11] Information taken from Magenn Power, Inc. Web Site. Dec 2009
URL: http://www.magenn.com

**Wind Belt**

Instead of using conventional geared, rotating airfoils to pull energy from the wind, the Windbelt relies on an aerodynamic phenomenon known as aeroelastic flutter (‘flutter’). While the phenomenon is a well-known destructive force (e.g., a cause of bridge failure), researchers have discovered that it can also be a useful and powerful mechanism for catching the wind at scales and costs beyond the reach of turbines.

Invented by Shawn Frayne, a windbelt is essentially an aeolian harp except that it exploits the motion of the string produced by the aeroelastic flutter effect to move a magnet closer and farther from one or more electromagnetic coil(s) and thus inducing current in the wires that make up the coil.

Wind Belt patents belongs to “Humdinger Wind Energy, LLC” company. Shawn Frayne is the president of Honolulu- and Hong Kong-based Humdinger Wind Energy. The Windbelt technology is under development in a variety of scales, from Windbelts smaller than a mobile phone up to Windcell Panels capable of installations of tens of kilowatts to many megawatts [12].

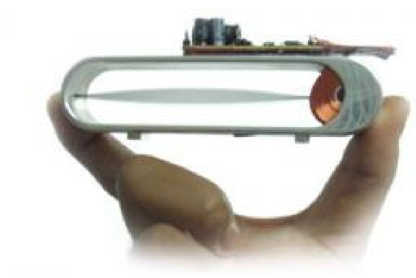
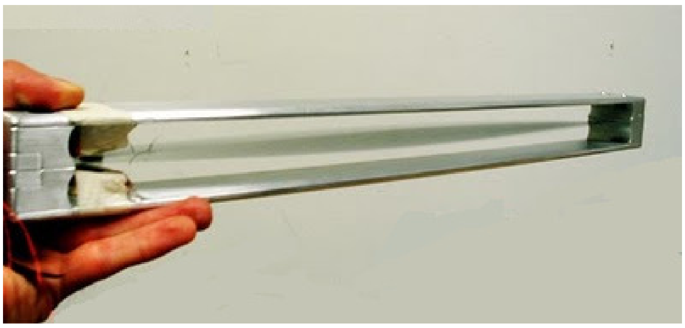


***Figure 4.1.24.***
*microBelt™. 10 cm.*
*1mW - 1W.*

***Figure 4.1.25.***
*Windcell™. 1m.*
*3 W - 5 W. .*



[12] Information taken from Humdinger Wind Energy, LLC Web Site. Dec 2009
URL: http://www.humdingerwind.com

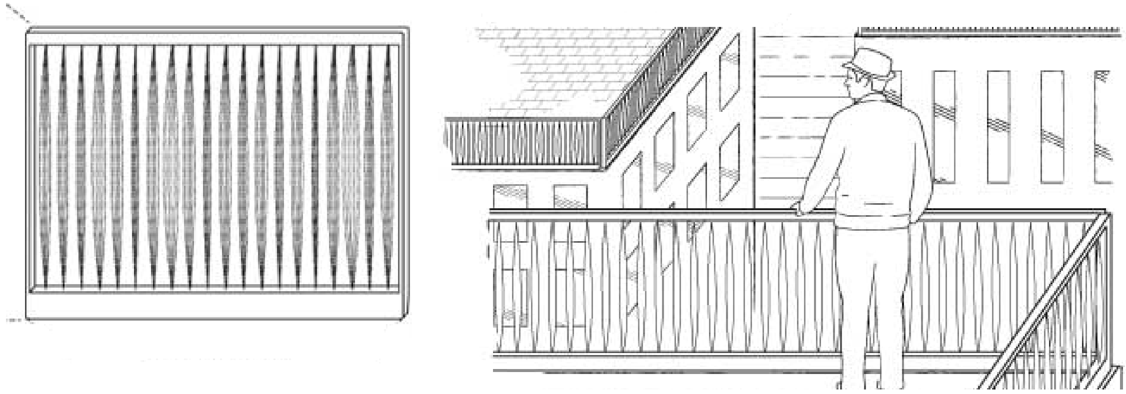


***Figure 4.1.26.*** *Windcell™ Panels. 1m x 1m. 1KW – MW-scale. They might be installed in modular panels on also in a raw.*

### 4.1.2. *Comparison horizontal-axis and vertical-axis wind turbines*

Wind turbines can rotate about either a horizontal or vertical axis, the former being more common. But there are advantages and disadvantages reacted with the performance, design or impact on the environment among others [13].

**HAWT: Horizontal axis wind turbines**

Horizontal axis wind turbines are most commonly used today. The wind blows through blades, which converts the wind's energy into rotational shaft energy. The blades are mounted atop a high tower to a drive train, usually with a gearbox, that uses the rotational energy from the blades to spin magnets in the generator and convert that energy into electrical current. The shaft, drive train and generator are covered by a protective enclosure called a nacelle.

The advantages of HAWT are:

- Variable blade pitch, which gives the turbine blades the optimum angle of attack. Allowing the angle of attack to be remotely adjusted gives greater control, so the turbine collects the maximum amount of wind energy for the time of day and season.

- The tall tower base allows access to stronger wind in sites with wind shear. In some wind shear sites, every ten meters up, the wind speed can increase by 20% and the power output by 34%.

- High efficiency, since the blades always move perpendicularly to the wind, receiving power through the whole rotation. In contrast, all vertical axis wind turbines, and most proposed airborne wind turbine designs, involve various types of reciprocating actions, requiring airfoil surfaces to backtrack against the wind for part of the cycle. Backtracking against the wind leads to inherently lower efficiency.

- The face of a horizontal axis blade is struck by the wind at a consistent angle regardless of the position in its rotation. This results in a consistent lateral wind loading over the course of a rotation, reducing vibration and audible noise coupled to the tower or mount.



[13] *Wind Energy Basics*. American Wind Energy Association (AWEA). 2009
URL: http://www.awea.org/faq/wwt_basics.html

The disadvantages of HAWT are:

- The tall towers and blades up to 90 meters long are difficult to transport. Transportation can now cost 20% of equipment costs.
- Tall HAWTs are difficult to install, needing very tall and expensive cranes and skilled operators.
- Massive tower construction is required to support the heavy blades, gearbox, and generator.
- Reflections from tall HAWTs may affect side lobes of radar installations creating signal clutter, although filtering can suppress it.
- Their height makes them obtrusively visible across large areas, disrupting the appearance of the landscape and sometimes creating local opposition.
- Downwind variants suffer from fatigue and structural failure caused by turbulence when a blade passes through the tower's wind shadow (for this reason, the majority of HAWTs use an upwind design, with the rotor facing the wind in front of the tower).
- HAWTs require an additional yaw control mechanism to turn the blades toward the wind.

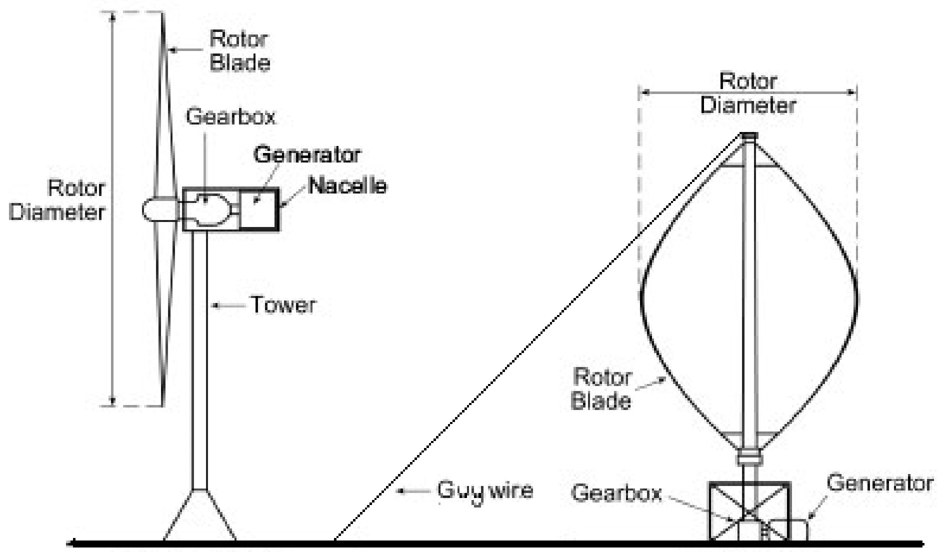



***Figure 4.1.26.*** *Two basic wind turbines, horizontal axis and vertical axis (Darrieus design).*

**VAWT: Vertical Axis Wind Turbines**

Vertical-axis wind turbines are those with the main rotor shaft arranged vertically. Key advantages of this arrangement are 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.

With a vertical axis, the generator and gearbox can be placed near the ground, so the tower doesn't need to support it, and it is more accessible for maintenance. Drawbacks are that some designs produce pulsating torque.

It is difficult to mount vertical-axis turbines on towers, meaning they are often installed nearer to the base on which they rest, such as the ground or a building rooftop. The wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine. Air flow near the ground and other objects can create turbulent flow, which can introduce issues of vibration, including noise and bearing wear which may increase the maintenance or shorten the service life. However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence.

The advantages of VAWT are:

- A massive tower structure is less frequently used, as VAWTs are more frequently mounted with the lower bearing mounted near the ground.
- Designs without yaw mechanisms are possible with fixed pitch rotor designs.
- The generator of a VAWT can be located nearer the ground, making it easier to maintain the moving parts.
- VAWTs have lower wind start up speeds than HAWTs. Typically, they start creating electricity at 10 km/h.
- VAWTs may be built at locations where taller structures are prohibited.
- VAWTs situated close to the ground can take advantage of locations where mesas, hilltops, ridgelines, and passes funnel the wind and increase wind velocity.

The disadvantages of VAWT are:

- A VAWT that uses guy-wires to hold it in place puts stress on the bottom bearing as all the weight of the rotor is on the bearing. Guy wires attached to the top bearing increase downward thrust in wind gusts. Solving this problem requires a superstructure to hold a top bearing in place to eliminate the downward thrusts of gust events in guy wired models.
- The stress in each blade due to wind loading changes sign twice during each revolution as the apparent wind direction moves through 360 degrees. This reversal of the stress increases the likelihood of blade failure by fatigue.
- While VAWTs' parts are located on the ground, they are also located under the weight of the structure above it, which can make changing out parts nearly impossible without dismantling the structure if not designed properly.
- Having rotors located close to the ground where wind speeds are lower due to wind shear, VAWTs may not produce as much energy at a given site as a HAWT with the same footprint or height.

### 4.1.3. *Main parameters and energy efficiency*

Efficiency usually refers to the amount of energy that is extracted as a fraction of the total energy available. This is an important measure for technologies using fuels that have cost, are limited or present a disposal problem, such as coal, gas or nuclear. But regarding to wind turbines for which the fuel is cost-free and unlimited, the efficiency term makes confusion, and other terms take part.

First of all before talking about wind turbines efficiency some parameters should be mentioned and explained.

One of the main facts is the Betz limit, the theoretical maximum energy which a wind turbine can extract from the wind blowing across. As mentioned on chapter 3.1 *(Physical principles of wind energy conservation)* it is just under 60% (0,593) as shown on *Figure 3.2.*

The Betz limit is the maximum theoretical value from the (Rotor) **Power Coefficient ($C_p$)** (also called Rotor Efficiency or Coefficient of Performance).

The second parameter, which depends on the efficiency, the **Tip-Speed Ratio (TSR)**. Is the ratio between the rotational speed of the tip of a blade and the actual velocity of the wind. If the velocity of the tip is exactly the same as the wind speed the tip speed ratio is 1 [2].

$$Tip\ speed\ ratio\ \lambda = \frac{Tip\ speed\ of\ blade}{Wind\ speed}$$

It has been shown empirically that the optimum tip speed ratio for maximum power output occurs at:

$$\lambda_{max} = \frac{4\,\Pi}{n}$$

Where ‘n’ is the number of blades (notice that this is only valid for HAWT, because VAWT doesn’t have single blades).

A higher tip speed ratio generally indicates a higher efficiency but is also related to higher noise levels and a need for heavier, stronger blades. It is shown on *Figure 4.1.27.*

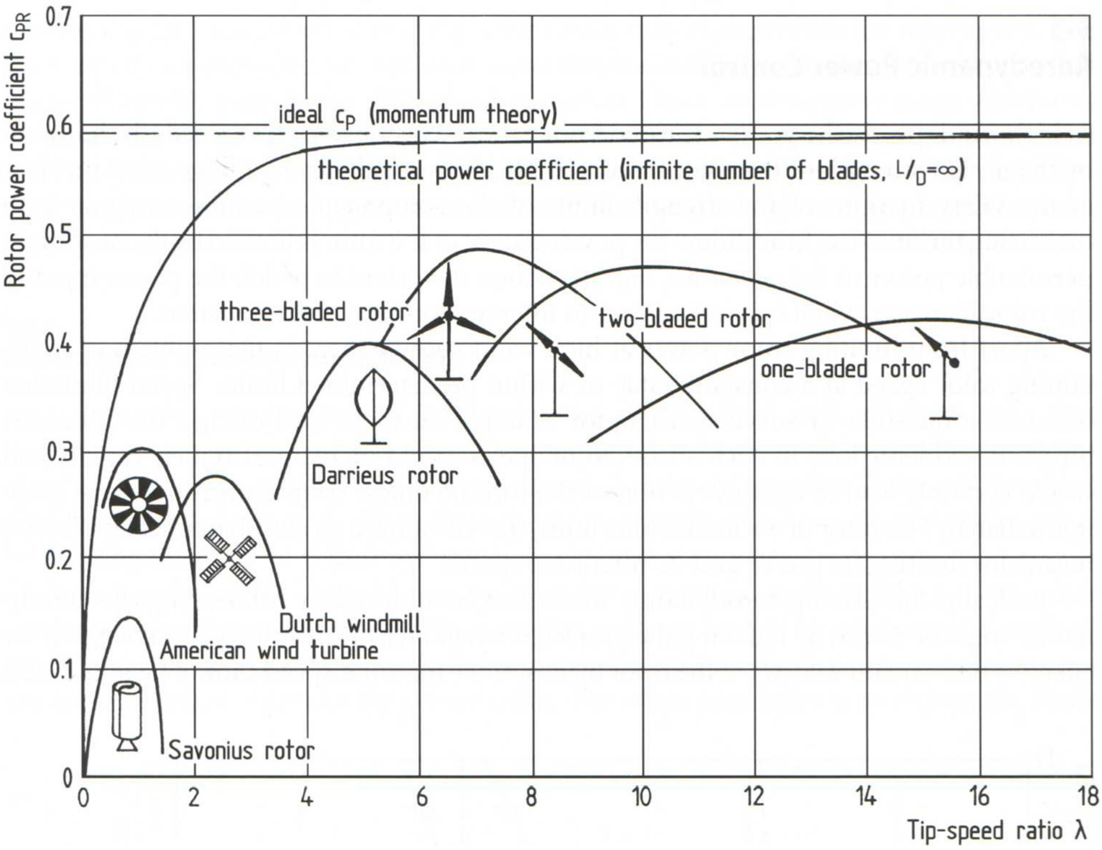



***Figure 4.1.27.*** *Power coefficients of wind rotors of different designs depending on tip-speed ratio [2].*

**Number of blades (n)** and its designs are also important to understand how they transform wind movement into energy. Depending on the use of drag or lift force the result would be different, more torque or high speed.

Blades designs using drag forces like Savonius are well known as giving good torque, and also having higher **Rotor Torque Coefficient ($C_{QR}$)** which is the ratio between the actual torque developed and the maximum theoretical torque. The relation between the number of blades, the rotor torque and the tip-speed ratio is shown in the following picture, *Figure 4.1.28.*

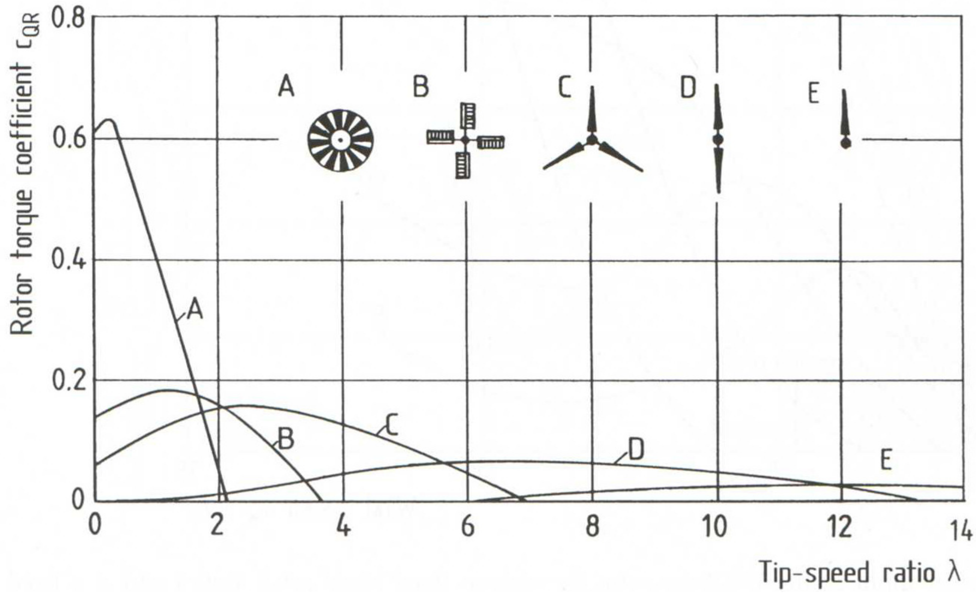



***Figure 4.1.28.*** *Torque coefficients of wind rotors of different designs [2].*

But there are other two more very important parameters that influence in the efficiency, the **Cross-sectional Area (A)** from the rotor and the **Wind Speed**. As mentioned on chapter 3.1 *(Physical principles of wind energy conservation),* the Power Coefficient depends on the square of the area and the cube of wind speed,

$$\text{Cp} = f(A^2, v^3)$$

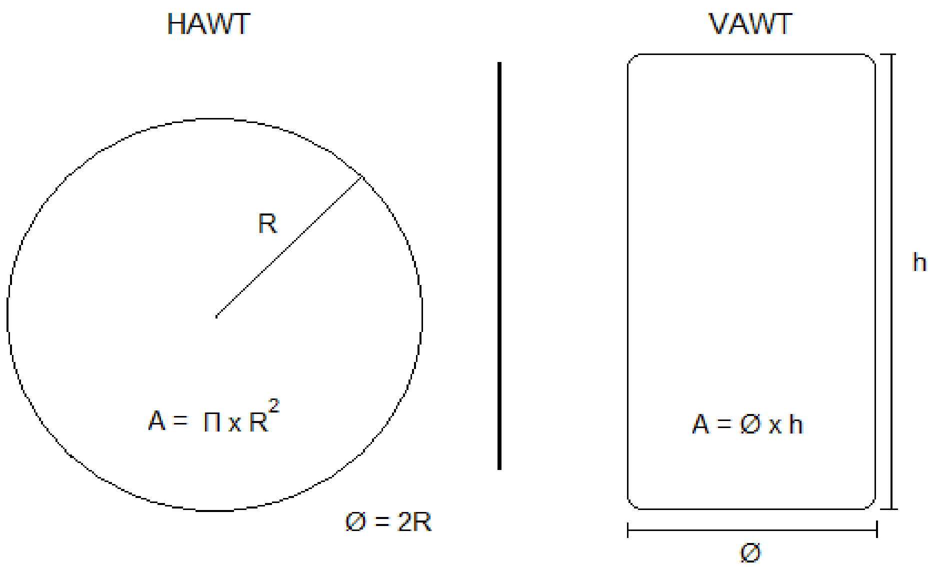



***Figure 4.1.29.*** *Circle and rectangular cross-sectional Area, depending on design, r HAWT and VAWT.*

The Area of a wind turbine depends on its design. As shown on *Figure 4.1.29*. HAWT will have a Circle area while VAWT will have a rectangular area in most of the cases.

A wind turbine is designed to produce a maximum of power at wide spectrum of wind speeds. The wind turbines have three modes of operation; below rated wind speed, around rated wind speed and above rated wind speed operation. As is possible to see on *Figure 4.1.30* each range of speeds is divided why the so called cut-in and cut-down speed (where the cut-in speed is situated a range of winds below the rated wind speed. In that range the rotor is also working but not in the optimal conditions).

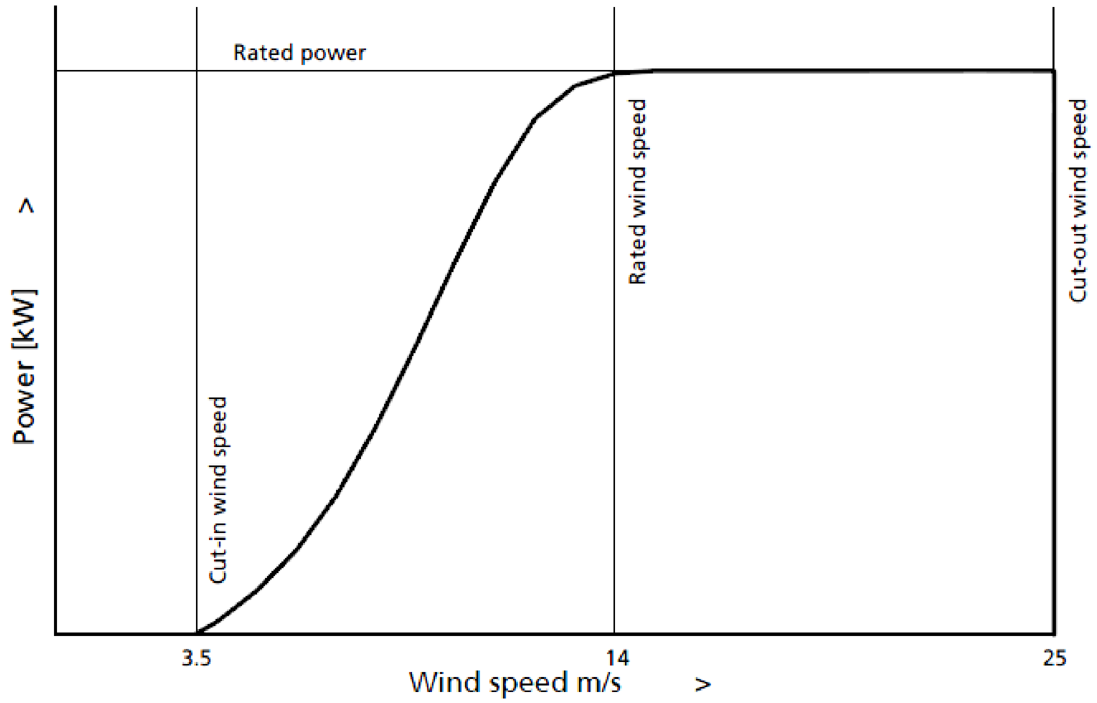



***Figure 4.1.30.*** *Example of Power-Wind speed curve. Each wind turbine has its own.*

VAWT like Savonius have lower cut-in (or also called start-up wind speed) due their aerodynamic designs, using most of the times drag forces (values between 3 m/s and 5m/s). The advantage of these wind turbines designs is that they have self-start turning.

Other designs like HAWT or VAWT H-rotors need to use their own energy to start working ore sometimes they can start using pitch-control (example on *Figure 4.1.6 – chapter 4.4.1 Technical and design solutions*) of blades to use more drag forces for a while.

If the rated wind speed is exceeded (over the cut-out wind speed) the power has to be limited to protect the turbine. There are various ways to achieve this: Pitch control (by decreasing the angle of attack, which reduces the induced drag from the lift of the rotor, as well as the cross-section), Yawing (yaw angle is the misalignment between wind and turbine pointing direction), Electrical braking and Mechanical braking (drum or disk brake).

Another parameter to consider is the **Capacity Factor.** Is the ratio of the actual energy produced by a turbine in a given period, to the hypothetical maximum possible, running full time at rated power.

The Capacity Factor is not an indicator of efficiency. It is an indicator of how much energy a particular wind turbine makes in a particular place. For example: a non efficient wind turbine might have a high capacity factor but it would produce less energy than a efficient turbine with lower capacity factors.

**Efficiency** is the ratio of the useful output to the effort input – in this case, the input and the output are energy. The types of efficiency relevant to wind energy production are thermal, mechanical and electrical efficiencies.

These efficiencies account for losses, most of which turn into heat in the atmosphere and water. The mechanical conversion efficiency of commercial wind turbines is a fairly high, in the range of 75-90% [14].

However the meaning of efficiency is maybe a redundant concept to apply to wind energy, where the fuel is free. The primary concern is not the efficiency for its own sake, but to improve productivity in order to bring the price of wind energy down.

Let's show an example using some of the parameters mentioned before:

- If we take a wind turbine with a rated power of around 5 kilowatts (kW).
- There are 8760 hours in a year (365 days x 24 hours).
- A 2 KW wind turbine will generate around 30% of its maximum theoretical capacity resulting in 13140 Kilowatt hours (KWh) energy generated per turbine per year.
- Taking all of the above into consideration a wind turbine will generate enough green electricity for the average annual needs of 3 homes, using an average demand of 4500 kWh per house based on electricity statistics.

In the following page is a table where you can see the most common average values of the parameters belonging to wind turbine efficiency.

[14] *Capacity Factor, Intermittency, and what happens when the wind doesn't blow?* Renewable Energy Research Laboratory, University of Massachusetts at Amherst. URL: http://www.ceere.org/rerl/about_wind/RERL_Fact_Sheet_2a_Capacity_Factor.pdf

Average parameters table (part 1)

| Type | | | | Rotor diameter Ø (m) | Sectional Area ($m^2$) | **D**rag/**L**ift - | Rated Power (kW) | Power Coefficient max. Cp ( ) |
|---|---|---|---|---|---|---|---|---|
| VAWT | Darrieus | 3 blades (small) | | 1 ~ 3 | 3 ~ 7 | L | 0.5 ~ 2 | ~ 0.25 |
| | | H-rotor | 1 KW < < 10 KW | 2 ~ 6 | 3 ~ 30 | L | 1 ~ 10 | ~ 0.4 |
| | | | 10 KW < < 30 KW | 7 ~ 10 | 40 ~ 80 | L | 10 ~ 30 | ~ 0.4 |
| | Savonius | | | 0.5 ~ 3 | 2 ~ 15 | D | 0.5 ~ 6 | ~ 0.2 |
| | Alternative designs | Helical | Helical twisted blades | 2 ~ 3 | 5 ~ 15 | L | 2.5 ~ 6 | ~ 0.3 |
| | | | Helical blade scoop | 1 ~ 2 | 4 ~ 12 | D | 1 ~ 8 | ~0.25 |
| HAWT | 2 blades | | | 2 ~ 15 | 3 ~ 170 | L | 1 ~ 30 | ~ 0.4 |
| | 3 blades | 20KW < < 100 KW | | 10 ~ 20 | 80 ~ 310 | L | 20 ~ 100 | ~ 0.45 |
| | | 5 KW < < 20 KW | | 4 ~ 11 | 12 ~ 100 | L | 5 ~ 20 | ~ 0.4 |
| | | (3 or more blades) < 5KW | | 1 ~ 3 | 0.8 ~ 7 | L | 0.5 ~ 5 | ~ 0.3 |
| OTHERS | Aerial / Flotating | | | 5 ~ 14 | 50 ~ 400 | D | 10 ~100 | - |
| | Wind Belt | | | - | (linear) | "Vibration" | 1mW ~ 5W | - |

Average parameters table (part 2)

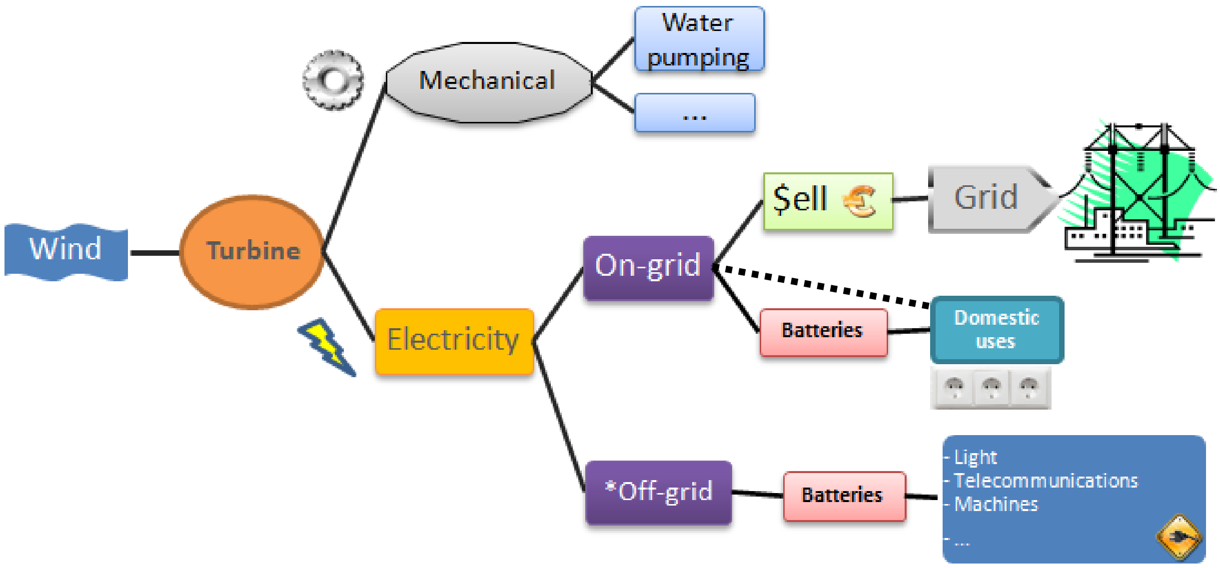
| Type | | | | Tip-speed ratio ( ) | Start-up wind (m/s) | cut-out wind (m/s) | Self starting Y / N |
|---|---|---|---|---|---|---|---|
| VAWT | Darrieus | 3 blades (small) | | 3 - 7 | - | - | with savonius help |
| | | H-rotor | 1 KW < < 10 KW | 2 - 5 | 2 ~ 3 | ~ 30 | pitch. cont. |
| | | | 10 KW < < 30 KW | 2 - 5 | ~ 3 | ~ 30 | pitch. cont. |
| | Savonius | | | ~1 | ~ 2 | no lim. | Y |
| | Alternative designs | Helical | Helical twisted blades | ~ 4 | ~ 4 | ~ 15 | Y |
| | | | Helical blade scoop | ~1 | ~ 2 | no lim. | Y |
| HAWT | 2 blades | | | 6 ~ 12 | ~ 3 | ~ 50 | N |
| | 3 blades | 20KW < < 100 KW | | 5 ~ 7 | 2.5 ~ 4 | 25 ~ 40 | pitch. cont. |
| | | 5 KW < < 20 KW | | 5 ~ 7 | 2.5 ~ 4 | 25 ~ 40 | Y |
| | | (3 or more blades) < 5KW | | 5 ~ 7 | 2 ~ 3 | 25 ~ 40 | Y |
| OTHERS | Aerial / Flotating | | | - | ~ 3 | ~ 30 | Y |
| | Wind Belt | | | n/a | - | - | Y |

### 4.1.4. Different utility possibilities

Considering that thousands of Mongolian nomads use modern micro turbines to boil water for tea, Central Americans use small wind turbines to refrigerate fresh fish for delivery to nearby markets and Antarctic explorers use them to power their isolated base camps, the list is long and sometimes surprising. The applications for small wind turbines are limited only by our imagination.

Applications for small wind turbines can be divided into several broad categories: for mechanical purpose like pumping water, generating electricity on-grid or off-grid (at remote sites) producing electricity in parallel with the electric utility or storing it into batteries.

The *Figure 4.1.31* below shows the ways to use this energy:




* Normally Hybrids systems are used (with solar panels or small generators to reduce the amount of batteries) on the remote areas.

***Figure 4.1.31.*** *Classification of wind energy utilities.*

In the urban areas the most probably is to have On-grid electricity generation. This electricity is used for buildings (school, centres, houses, flats,...) for common uses and if there is excess of energy this might be sold to the company or stored into batteries for later demands.

This option allows the possibility to use the grid electricity when there is no wind, and therefore no energy production, avoiding by this way the need of batteries.

In the remote areas where the viability of the grid electricity is impossible wind turbines are supplying energy for lighting, telecommunications towers or other kind of machines. If there is an excess of energy the electricity has to be stored into batteries to be ready for other later demands.

In off-grid systems, wind turbines are working together with solar panels or other small generators to take advantage of the maximum energy available and be assured of continuous power supply.

## 4.2. Main environment impacts and problems with existing urban wind turbine solutions near the urban areas

Environmental impacts are of considerable importance when dealing with urban wind systems. A given development should not benefit the global environment to the detriment of the local environment.

The various environment impacts of any scheme must therefore be properly assessed and measures taken if and where appropriate to avoid unfavourable effects either to equipment, the immediate surroundings or the various stakeholders.

The most common issues relating to environment impact are:

- Public safety
- Noise
- Visual effects
- Shadow flicker and blade-reflected light
- Vibrations
- Biodiversity and birds

There are also other environment impacts like electromagnetic interference, but these depend on the turbine and other aspects and they are to particular to be mentioned here.

*Public Safety*

The public safety implications of wind turbine implementation are the first issue to be considered. These are a particularly important aspect for a planning submission. As with all developments, the risks will have to be limited to a quantifiable, generally accepted risk level.

The most common public safety risks could include major failure of turbine tower and subsequent collapse of the nacelle and blades, shedding of parts or blades during operation and ice forming on the blades during winter.

Examples of turbine failure and even tower collapse can be found in the history of turbine development. However, it may be fair to say that these have generally been as a result of extremely windy conditions or poorly designed installations.

***Figure 4.2.1.*** *Fatal accident of a 60 m and 10 years old wind turbine. Hornslet – Denmark 2008.*

Although the likelihood of a major tower failure over the course of the lifetime of a well-designed turbine is extremely small, it may be the perception of safety that plays an important role in the minds of the public and indeed planners.

For a safety point of view, the minimum separation distance between a turbine (a typical HAWT) and the nearest building or sensitive area can be thought of as the turbine height plus 10% (fall-over distance). But this is for large turbines. There are of course many examples of turbines installed on roofs that do not adhere to these recommendations.

Over the last decades, worldwide, there have been several deaths related to wind turbines. The attached detailed table *(Figure 4.2.2)* includes all documented cases of wind turbine related accidents from the last 40 years which could be found and confirmed through press reports or official information releases up to 30 September 2009[15].

| Year | 70s | 80s | 90-94 | 95 | 96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | 1 | 8 | 17 | 5 | 9 | 16 | 8 | 33 | 29 | 12 | 63 | 51 | 52 | 54 | 54 | 83 | 111 | 68 |

**09 to 30 September 2009 only*

***Figure 4.2.2.*** *Global accidents relating wind turbines since the beginning of this technology. A total of 674 accidents.*

These accidents include: fatal accidents, human injury, blade failure, fire accidents, structural failure, ice throw, environmental damage (including bird deaths), accidents during transportation and others.

Ice build-up will not be an issue in many areas. But for example in Estonia, where the weather can rise very low temperatures, this can be a potential problem. In some turbines, ice build-up can cause an imbalance in the blades and bring the turbine to an automatic shut-down. If the risk of ice falling and ice throwing is considered to be significant and likely to cause damage to structures and vehicles or injury to the general public, a safety zone can be designed and also a maintenance schedule should be thought.

### *Noise*

Virtually everything with moving parts will make some sound, and wind turbines are no exception. Well designed wind turbines are generally quiet in operation, and compared to the noise of road traffic, trains, aircraft and construction activities, to name but a few, the noise from wind turbines is very low.

Noise is measured in decibels (dB). The decibel is a measure of the sound pressure level, i.e. the magnitude of the pressure variations in the air. An increase of 10 dB sounds roughly like a doubling of loudness. Measurements of environmental noise are usually made in dB(A) which includes a correction for the sensitivity of the human ear.

The noise a wind turbine creates is normally expressed in terms of its sound power level. Although this is measured in dB(A), it is not a measurement of the noise level which we hear but of the noise power emitted by the machine.

[15] *Summary of Wind Turbine Accident data*. Caithness Windfarm Information Forum 30 September 2009.
*URL:* http://www.caithnesswindfarms.co.uk/accidents.pdf

Most European countries (i.e. the UK, Germany or Netherlands) have statutory legislation to regulate general noise level limits and, in many cases, specific guidelines and recommendations setting out advice for the assessment and measurement of noise from wind turbines.

Normally rural areas are quiet with a low background noise (<40 dBA) as mentioned on the *Table 4.2.3*. In contrast, in urban areas, the ordinary background noise levels can reach 60-70dBA. The lack of precedents for the sitting of wind turbines in urban or residential locations will usually mean that planning conditions are set on a case-by-case basis based on the existing noise regulation relative to the urban environment.

| Source / Activity | Indicative noise level (dBA) | Human response |
|---|---|---|
| | 0-10 | Just audible |
| Broadcasting studio | 20 | |
| Rural night-time background | 20-40 | Very quiet |
| Quiet bedroom | 35 | |
| Wind farm at 350m | 35-45 | Quiet |
| Car at 65 km/h at 100m | 55 | |
| Busy general office | 60 | |
| Truck at 50 Km/h at 100m | 65 | Intrusive |
| Pneumatic drill at 7m | 95 | Hearing damage |
| Shout at 15 cm | 100 | |
| Jet aircraft at 250m | 105 | |
| | 140 | Threshold of pain |

***Table 4.2.3.*** *Indicative noise level (dBA) of a source of sounds [16].*

There are four types of noise that can be generated by wind turbine operation: tonal, broadband, low frequency and impulsive:

*Tonal*: Tonal noise is defined as noise at discrete frequencies. It is caused by wind turbine components such as meshing gears, non aerodynamic instabilities interacting with a rotor blade surface or unstable flows over holes or slits or a blunt trailing edge.

*Broadband*: This is noise characterized by a continuous distribution of sound pressure with frequencies greater than 100 Hz. It is often caused by the interaction of wind turbine blades with atmospheric turbulence, and also described as a characteristic "swishing" or "whooshing" sound.

[16] Wind Power, A.27. Renewable Energy Technologies, August 1994. The Scottish Office, Environment Department, Planning Advice Note.. URL: http://www.bwea.com/ref/noise.html
"*British Wind Energy Association*"

*Low frequency*: Noise with frequencies in the range of 20 to 100 Hz is mostly associated with downwind turbines (turbines with the rotor on the downwind side of the tower). It is caused when the turbine blade encounters localized flow deficiencies due to the flow around a tower.

*Impulsive*: This noise is described by short acoustic impulses or thumping sounds that vary in amplitude with time. It is caused by the interaction of wind turbine blades with disturbed air flow around the tower of a downwind machine [17].

The sources of noise emitted from operating wind turbines can be divided into two categories:

- Aerodynamic
- Mechanical

Aerodynamic, where the noise is radiated from the blades and is mainly associated with the interaction of turbulence with the surface of the blades. And Mechanical, normally associated with the gearbox, the generator and the control equipment.

Different wind turbines produce different qualities and levels of sound. In the past noise was not so relevant, but fortunately, technological improvement and increase understanding of the mechanisms associated with noise generation has ushered in new manufacturing processes and quieter turbines.

Smaller turbines generally produce less noise and in some cases are almost completely silent. For example, in Savonius or helical blade scoops turbines the sound is almost negligible as a consequence of using “drag forces”.

Urban wind turbine noise could be reduced using a better blade shapes design (using pitch control in large scale) and with a good gearbox acoustic isolation. The magnetic levitation or other improvements could also help to this propose. Most small wind turbines do not have gearboxes or other noisy mechanical systems, and manufacturers have made them quieter through better sound insulation, lower rotor speeds and adjustments to blade geometry.

[17 ] *Wind Turbine Noise Issues*. Anthony L. Rogers and James F. Manwell, 2004. Renewable Energy Research Laboratory, Department of Mechanical and Industrial Engineering, University of Massachusetts at Amherst
URL: http://www.npp.ca/images/WindTurbineNoiseIssues.pdf *Nov. 2009.*

I would like to show a text of Paul Gipe (an expert in wind turbines) to end with this chapter:

> *"…Clearly, the amount of noise emitted by medium-size wind turbines in the burgeoning German market is an important parameter when evaluating a product.*
>
> *Now, try to find the same data on small wind turbines--on any small turbine. Good luck.*
>
> *Neither German publication lists sound power levels for small wind turbines. Why? Because the data simply doesn't exist, or if it does, it is proprietary, that is, the manufacturer knows, but they won't tell. Most manufacturers of small wind turbines have never heard of sound power levels. Those few that do have either never measured noise from their turbines in a scientifically rigorous manner, or they simply thumb their nose and say "It doesn't apply to us."…"* ***Paul Gipe [18]***

But there are still some studies about noise. For example, noise measurements have been made by the National Renewable energy Laboratory of University of Massachusetts on a 900 Watt horizontal wind turbine, the Whisper 40 (Huskey and Meadors, 2001). This wind turbine has a rotor diameter of 2.1 m and was mounted on a 9.1 m tower. The rotor rotates at 300 rpm at low power. The rotation speed increases to 1200 rpm as the rotor rotates out of the wind to limit power in high winds. This operation results in a blade tip speeds between 33 and 132 m/s.

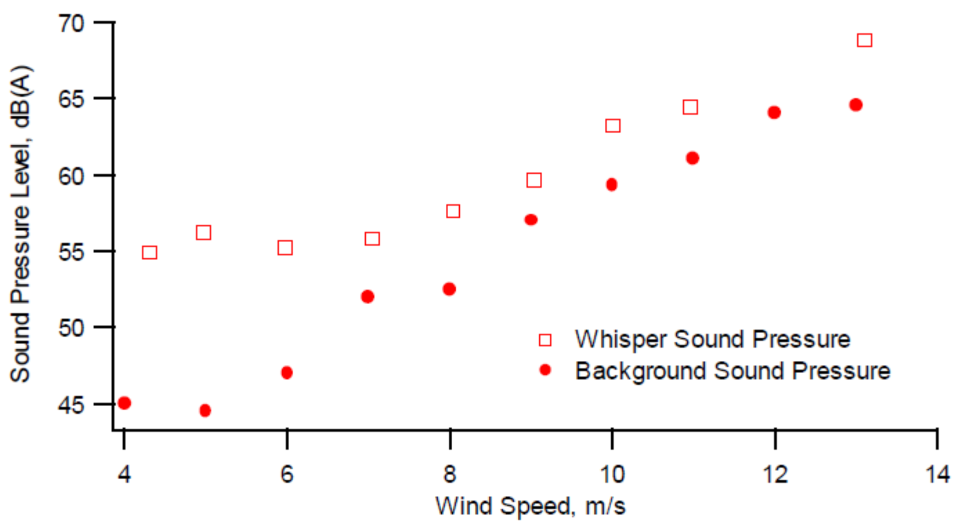



***Figure 4.2.4.*** *Sample measured wind turbine sound power levels. HAWT: 900W, 2.1 m diameter, 9.1 m tower. [18].*

[18] *Noise from Small Wind Turbines: An Unaddressed Issue.*
Paul Gipe (Wind turbines expert). Wind Works Article.
URL: http://www.wind-works.org/articles/noiseswt.html Dec. 2009.

*Figure 4.2.4* illustrates the sound pressure level (with the background noise removed) and the background noise levels at a distance of 10 meters from the wind turbine base. Between 6 and 13 m/s the wind turbine sound pressure increases over 13 dB. This is a very large increase in sound level and would be experienced as more than a doubling of the sound level. Moreover, it increased enough that the background sound level, which also increased with wind speed, was not enough to mask the wind turbine noise until the wind speed increased to over 13 m/s.

Average noise levels for small wind turbines are around 50-57 dB(A) at the nacelle.

*Visual effects*

Noise is not the main problem in wind power development. Visual impact is usually considered the most important and most discussed local or regional effect. It is often presented as a matter of individual taste, though there are some common factors in 'public taste.

One such factor is the perceived contrast of a wind turbine (farm) and its environment: a higher contrast will have more impact, either in a positive or negative way. A peculiarity of turbines is that the rotational movement makes them more conspicuous and thus enhances visual impact. This common notion suggests that wind turbines in a built up area will have less impact relative to a remote natural area (though this may be overruled by the number of people perceiving the impact).

A second factor is attitude: e.g. farmers usually have a different attitude to the countryside than 'city folk' have, and hence they differ in judgments on the appropriateness of a building, construction or activity in the countryside. It is predictable that when residents have a positive association with a neighbouring wind farm they will experience less annoyance from the visual impact. For a wind turbine owner the sound of each blade passing means another half kWh is generated and is perhaps associated with the sound of coins falling into his lap, a lullaby.

But relating to urban areas, visual effects of large structures usually relate to the impairment of nationally or locally designed buildings, monuments or areas of importance to the landscape. Urban wind turbines should also not be incongruous or overly dominant components of the local or distant views. There are many examples of turbines imitating plants or animal shapes used in urban areas.

In small towns or small urban areas a reasonable turbine could serve to create a focal point, or dynamic monument, which could become of importance to the townscape and become a symbol for renewable energy for the future.

*Shadow flicker and blade-reflected light*

Wind turbines, like other tall structures will cast a shadow on the neighbouring area when the sun is visible. If there are houses close to the wind turbine, it may be annoying if the rotor blades chop the sunlight, causing a flickering effect while the rotor is in motion.

Shadow flicker occurs under a special set of conditions when the sun passes behind the hub of a wind turbine and casts a shadow over neighbouring properties. When the blades rotate, shadows pass over the same point causing an effect called “shadow flicker”.

Some people get dizzy, lose their balance, or become nauseated when they see the movement of shadows or the movement of the huge blades themselves.

The seasonal timing and duration of this effect can be accurately calculated from the geometry of the machine, its orientation relative to nearby houses and the latitude of the potential site, using computer software [19]. There are many of them. Any properties which may potentially be affected can be identified and the risk calculated.

Focalising in urban wind turbines, the shadow flicker effect is not a main problem. Most of designs don’t have any big blades rotating or passing by the same point with frequency.

Apart from shadow flicker, problems can be caused by the suns light reflecting off the blades which can produce a flashing effect visible for some distance. This can be mitigated by choice of finishing. Light grey semi-matt finishes are often used, however, other colours and patterns can also reduce the effect further.

*Biodiversity and birds*

In the past this subject has created some heated debate between the wind industry and campaigners. Mistakes have been made where turbines have been installed in migration paths. However, consultation with avian experts is now a standard part of wind manufacturers and installers in order to avoid such misfortunes.

Since around the year 2000, however, the design of utility scale wind turbines has changed greatly with lower blade speeds and more visibility or changing colours and patterns on the blades. The assumption that wind farms are still today killing a large number of birds has turned into a myth.

VAWT are more softer with birds killing, they tend to be bird-friendly. Their blades design and smaller structures help to the purpose. They are also mounted closer to the ground.

[19] Danish Wind Industry Association – Shadow Casting from Wind Turbines. Wind turbine shadow calculator (online).
URL: http://guidedtour.windpower.org/en/tour/env/shadow/shadowc.htm

Sitting wind energy near the end users and away from natural habitats is usually more favourable in terms of limiting the impact on birds and bats. If a particular urban wind turbine is considered to be a threat to wildlife, the planning authority can stipulate to change the place of that turbine, and this would result cheaper than the same process with a large wind turbine.

On a wider scale, it is clear that the continued use of conventionally fuelled power plants could eliminate many hundreds or even thousands of creatures as well as entire species thought, for example, climate change, acid rain, and pollution. So wind turbines seem to be a good choice for the future.

*Vibrations*

We may think that vibrations of turbines could only produce noise, but regarding to urban areas vibrations could be dangerous for constructions. In rooftop wind turbines, this fact should be very good analyzed before installing them.

The use of vertical wind turbines with magnetic levitation technology or vibration isolation helps to reduce the damage.

Due to the structural limitations of buildings, the limited space in urban areas, and safety considerations, wind turbines mounted on buildings are usually small (with nameplate capacities in the low kilowatts), rather than the megawatt-class wind turbines which are most economical for wind farms. A partial exception is the Bahrain World Trade Centre with three 225 kW wind turbines mounted between twin skyscrapers.

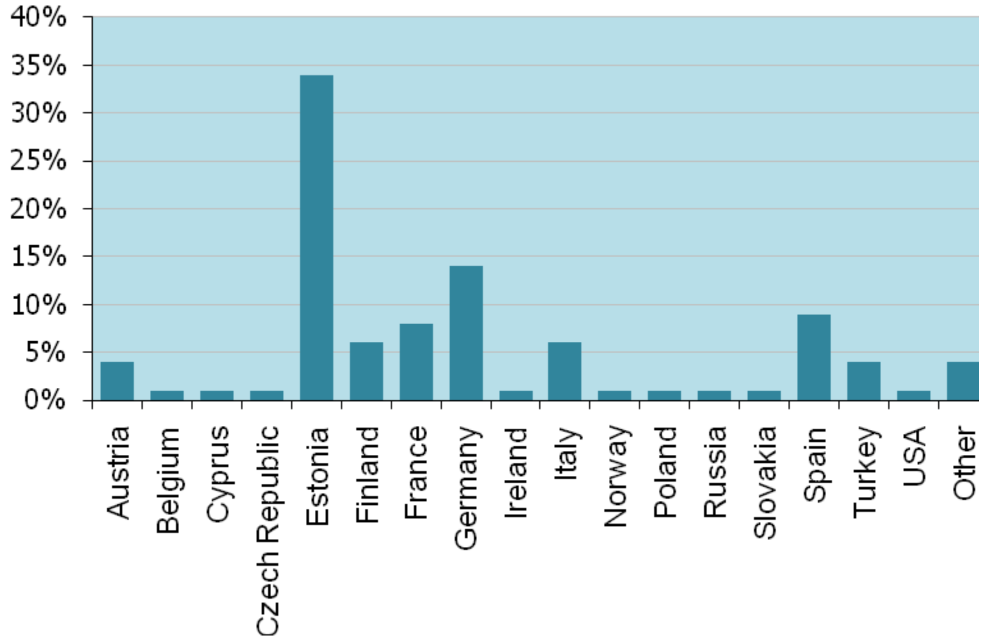
***Figure 4.2.5.*** *Three 225 kW, 3 bladed HAWT mounted between the towers of the Bahrain World Trade Centre. 2008.*

TTÜ 1918

## 4.3. Survey on knowledge of people about urban wind turbines

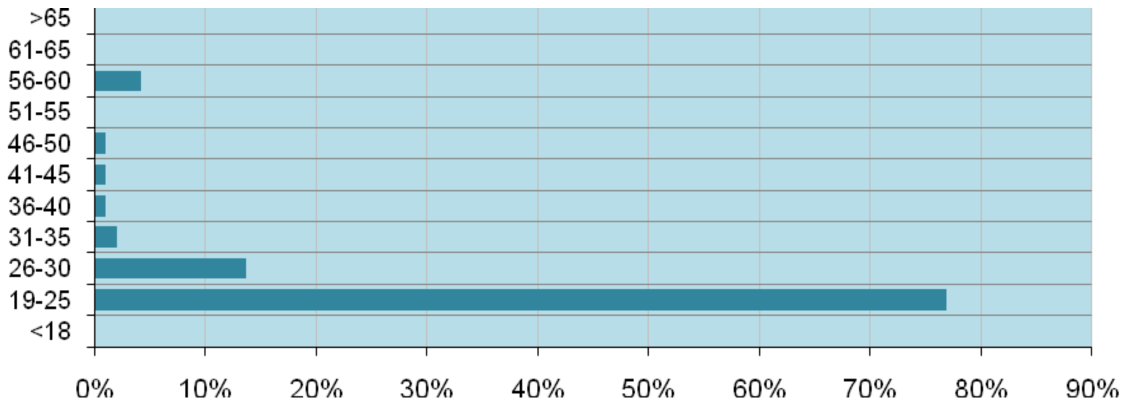
The following sections present the results and analysis of the first survey of this project. The questions asked were designed to get information about the knowledge of people about wind turbines and specially urban wind turbines. This information should help us to understand how known or unknown are these kind of machines by these years.

The survey is based on a sample of 173 people from 16 European countries basically (there are some samples from USA and other countries). The distribution of people is shown in the following graph:




***Graph 4.3.1***. *Distribution of people in %.*

The range of ages from people is between 18 and 60 years old. You can also see the distribution of these ages in next graph:

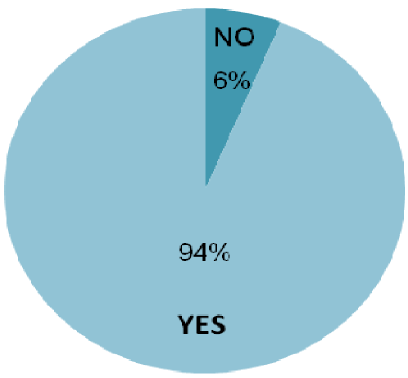



***Graph 4.3.2**. Distribution of ages in %.*

We can notice in *Graph 4.3.2.* that the age range between 19 and 25 predominate over others. That's because the survey was mostly done to Erasmus students.

Below are the 8 questions asked. Each question consists of a graph and its analysis.

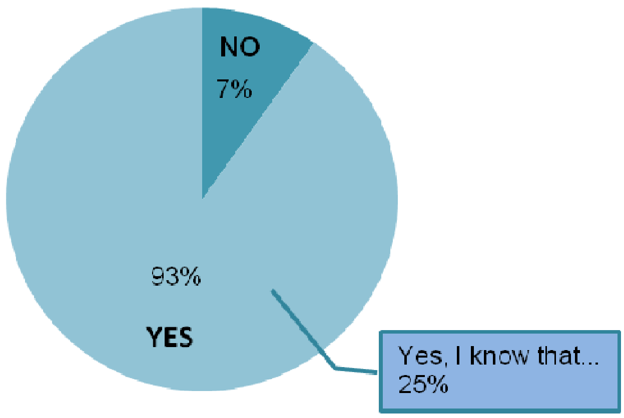
***1. Have you ever heard about wind turbines? (aerogenerators)***




***Graph 4.3.3.** Answer to question 1.*

As you can see in *Graph 4.3.3.* it seems that almost all of the people (94%) have heard the word wind turbines. This is hardly surprising because at least almost everyone has seen once such kind of turbines in the fields.

***2. Do you know something about wind turbines? (aerogenerators)***



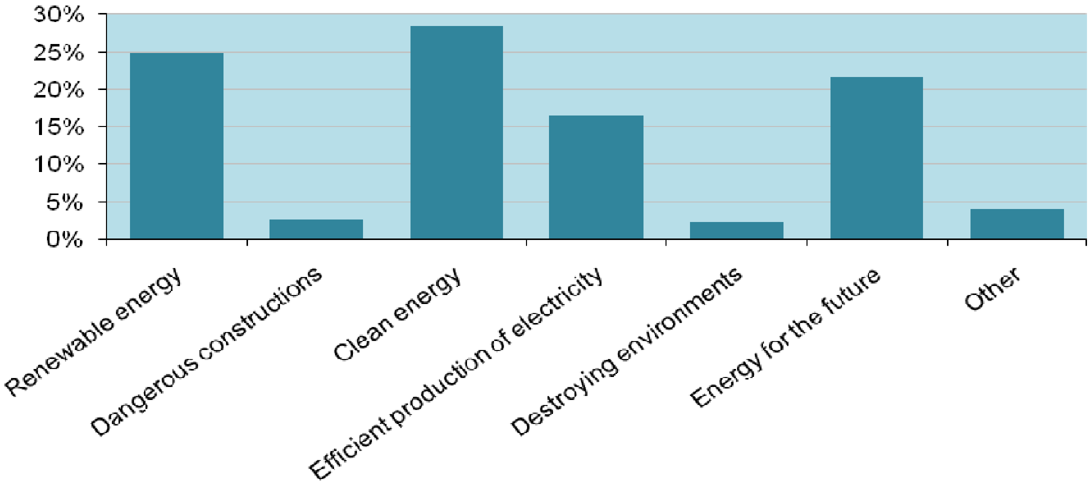

***Graph 4.3.4**. Answer to question 2.*

It seems that the same percentage of people who have heard about wind turbines know something about them. In this question was possible to add extra information. That's why 25% of people could do it. Some of the most relevant answers are:

- They produce ecologic energy.
- It's expensive to construct and produce.
- It's a growing business and a good energy source.

All the full answers concerning to this question are in ANNEX A.

3. ***Wind turbines. A wind turbine is a rotating machine which converts the kinetic energy of wind into mechanical energy. They convert wind energy to electricity for distribution. Nowadays they are used in all over the world to produce electricity. You think that wind turbines are:***




***Graph 4.3.5.*** *Facts about the wind turbines.*

This was a multiple choice answer question. The possible answers were selected some of most common ideas about wind turbines from other people, which are shown of *Graph 4.3.5*.

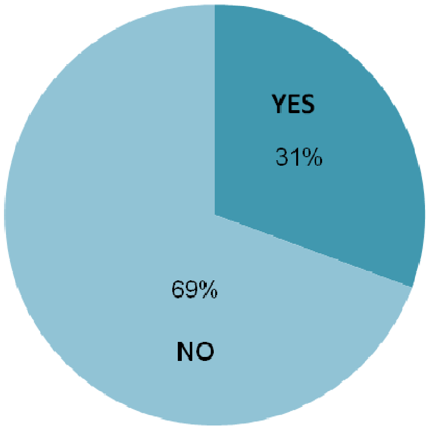
We can see also that the positive facts are more voted than negative. *Renewable energy, clean energy, Efficient production of electricity* and *Energy for the future* have about 6 times more votes than *Dangerous constructions* and *Destroying environments* facts.

There was also the possibility to add extra facts. The 4% of people did. Some of the most relevant facts are:

- One source of electrical energy.
- They generate noise.
- Destroys the overall appearance of the landscape.

All the facts concerning to question 3 are in ANNEX A.

***4. Have you ever heard about the word: Urban Wind Turbines / Urban Turbines?***




***Graph 4.3.6**. Question 4.*

Turning with this question to Urban wind turbines, things are different. Less people know about them. As is shown on *Graph 4.3.6* only 31% have heard about it.

***5. Have you ever seen such kind of urban wind turbines or similar?***

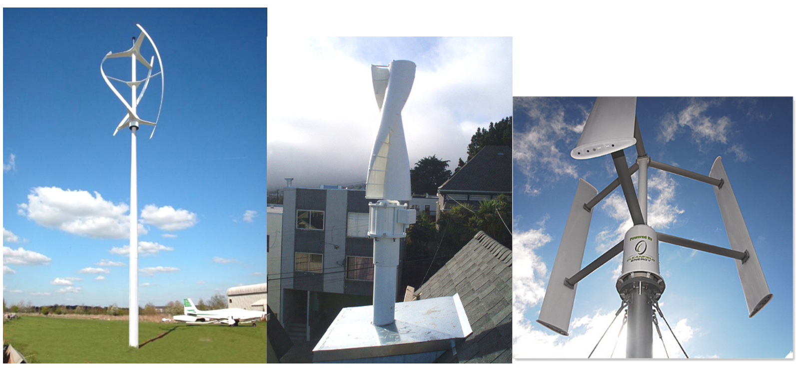
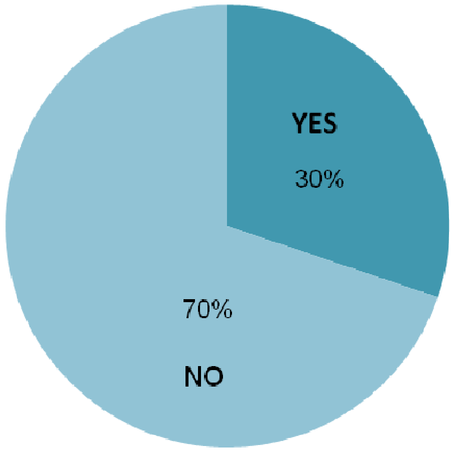


***Figure 4.3.1**. Urban wind turbines examples.*

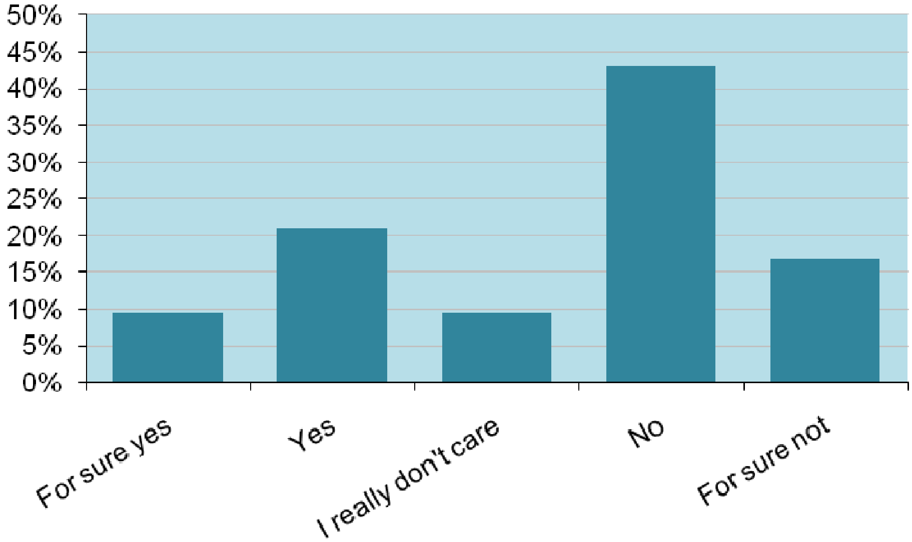
The pictures above, of existing Urban wind turbines examples, were shown in this question.




***Graph 4.3.7**. Question 5.*

As you can see in *Graph 4.3.7.* the same percentage of people who have not heard about urban wind turbines have not ever seen any of those in the photos, 70%.

6. ***Would be a problem for you to have these kind of wind turbines near the urban areas to produce electricity? For example in the roof of the flats or public gardens? –(It's possible to answer and add opinion-).***




***Graph 4.3.8.** Question 6.*

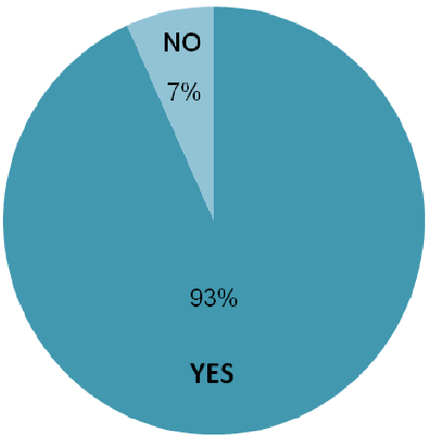
This might be one of the most interesting and personal questions of the survey. Working with numbers from *Graph 4.3.8* one can say that for almost the 70% of the people asked is not a problem or they just really don't care to have those kind of turbines near their houses. So, It seems that it's well-accepted and should not pose a problem for many.

Here was also possible to add an extra opinion. The 17% of people did. Some of the most relevant opinions are:

- Yes, if they are noisy and big.
- Should have a design, that fits in the environment.
- Possible, but it has to fit to the area and it has to be sure that the turbines don't bother the people who live close to the turbine.
- I'm not so sure about them being in gardens, but if they are made to look interesting and somewhat like contemporary art then, why not?. In both cases the noise level of turbines must be lower in order for it to be ok!

All the opinions concerning to question 6 are in ANNEX A.

***7. Do you think that Urban wind turbines could help us to generate electricity for our homes? (-It's possible to add your opinion-)***




***Graph 4.3.9**. Question 7.*

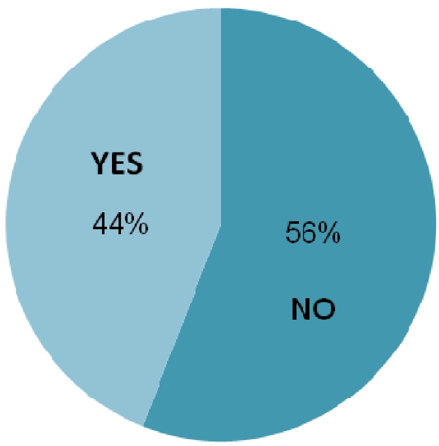
This question is quite relative. Most of the people thought that of course turbines will help us, that's why 93% (almost all) answered YES. But there is still a 7% of people who defends the idea that would be not enough, and they answered NO.

Here was also possible to add an extra opinion. The 20% of people did. Some of the most relevant opinions are:

- It is too less energy but a good first step.
- Yes, but they need another energy support: solar energy, conventional electricity...
- As wind energy is very unstable energy, electric energy generated by wind can supply only battery chargers or very simple machines that do not need constant and secure energy source.
- Hard to say, because it's very dependent from the wind! Further these urban generators are quite small and especially in big cities there isn't so much wind!

You will find all opinions concerning to question 7 in ANNEX A.

***8. Do you know about the problems that may appear from these kind of machines? Noise, shadows, vibrations...?***




***Graph 4.3.10**. Question 8.*

And the last question is quite balanced. But still less than 50% of the people know about those problems as you can see in *Graph 4.3.10*.

That could make us thing about the idea to explain the problems that might appear before trying to install some kind of turbines in urban areas.

And in conclusion of the whole survey, some people seem to know about, but I guess no one has really seen such kind of new wind turbines. The survey is only an indicator about the knowledge of people. Nevertheless they are quite positive in front of some of the questions asked. So I think that this new technology would hopefully someday become somewhat well-accepted for everyone.

# 5. Design methods

After giving an overview about all kind of urban wind turbines, their physical principles, description, main parameters, environment problems and more, now is time to find out which of them are more suitable for urban uses. Some design methods are used for this purpose to analyse the different possible options.

Those designs methods I know are the result of my studies in "*Universitat Politècnica de Catalunya (UPC)*" where I am ending my studies of General Engineering with the specialty in "Products and Systems Design".

## 5.1. Objective and scope

*Objective*

The objective of this design methods analysis is to try to find out which are the most suitable solutions, which are their advantages or disadvantages and analyse all point of views regarding the designs. Those solutions should be efficient, silence, safety and respect the environment.

Therefore it is analysed users, environment, functional analysis, failure analysis and at the end the possible solutions analysis found during the process.

*Scope*

After having collected all necessary information about urban wind turbines and having seen all the current solutions on the market, the scope of the study will include:

- A study about which user will be involved with the project.
- A study of the environment where the turbine is supposed to be located, considering all problems found on previous chapters.
- A functional analysis trying to find out which are the main functions to focalize on, during the design process.
- A failure analysis to prevent and take in advance all the problems that could happen in the future.
- And an analysis of the most suitable solutions or options found during this process.

## 5.2. Users

To identify all users that can be involved with the project is very important. It allows discerning decisions about their involvement in a project to succeed.

When we try to identify all users we must take into account that the single buyer or owner is not the only user that exists, we must start looking from the moment you start thinking about the design until the moment when the object is useless or disappears.

Those users might interact with the object in a direct or indirect way, but all of them are important to understand the needs of the design. See *Figure 5.1.*

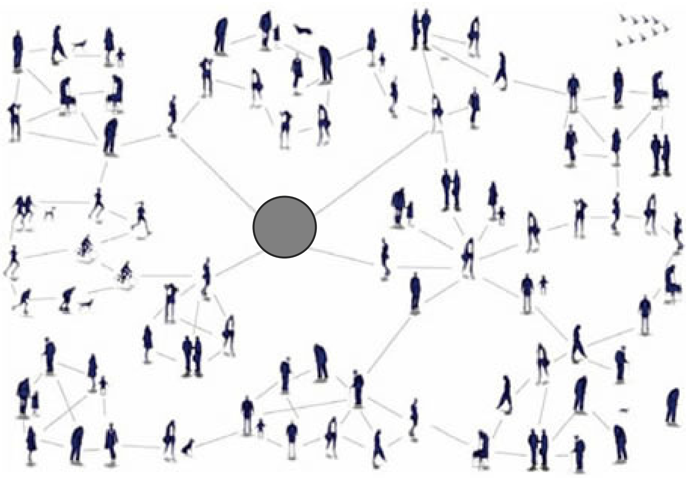


***Figure 5.1.*** *Example of direct and indirect users involved with something.*

The following table shows all the users involved with the a wind turbine located in urban areas. Each user has its description, physical demands, mental demands, actions to do, decisions to take, dangers and instructions.

*Users Table (Part 1)*

| Users | Description | Physical demand | Mental demand | Actions | Decisions | Dangers | Instructions |
|---|---|---|---|---|---|---|---|
| **Designer** | Makes the project | - | To be able to interpret and satisfy existing needs. | To consider all needs and functions to design a suitable solution. | To decide which users, functions and needs are more important to satisfy and why. | Mistake is assessing the customer needs. | - |
| **Engineer** | Calculates the machine | - | Be able to build a resistant turbine, energy efficient and easy to access and repair. | Designing parts/ components of the device to make it simple, efficient and achieve the requirements of the designer. | Choose materials, components to use and shape. Define the characteristics of external part to purchased from suppliers. | Calculation errors that can affect to the turbine performance. | - |
| **Manufacturer** | Builds the different parts | - | Well-specified tolerances and dimensions. Qualified for quality control. | Build the parts following the engineer specifications. | Defining a quality control to decide which parts are correct. | Errors occurring during the manufacturing process. (Mistakes) | Follows the plans and specifications. |
| **Owner (Energy Company)** | Buys or develops the turbine to produce energy and sell it to customers. | - | Be able to understand and calculate the power needs for customers. | Responsible of transport, installation and maintenance of the device. | Decide which and how many devices are needed and which is the best place to locate the device. | Not satisfying the customers. Or mistakes on needed energy calculations. | Follow the instructions and recommendations from the manufacturer. |
| **Owner (Single or building)** | Who buys the turbine for own energy producing | - | - | Take care of the device and call the maintainer if it's needed. | He will need to decide to buy the turbine or not. Final user. | Misuse by not following the recommendations. | Follow the instructions and recommendations from the manufacturer. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Neighbour** | Lives near where the turbine is installed. | - | To be able to accept the turbine and agree with the owner. | To be informed about permissions and agree before the installation to avoid any problems. | Take the decision to accept and agree, even to use a wind turbine also. | Take care that noise, vibrations or shadows don't disturb anyone in the surroundings. | - |
| **Maintainer** | Manipulate the machine in case of failure or maintenance. | Efforts during the change of screws or assembly of parts. Uncomfortable positions. | Knowledge and interpretation of the damage and rotor mechanics. | Repair and / or do the maintenance for the proper functioning of the device | When to change a part or choose to send the device to the manufacturer in case of serious damage. | Possible physical damage during repairing. Not be able to repair it or do mistakes. | Follow some instructions in the manufacturer manuals. |
| **Curious user** | Walks near the turbine and looks | - | Do not come near to avoid possible accidents. | Looks the turbine | Is able to alert the owner in case of something wrong is happening | Can get hurt from the turbine if he comes to near. | He should know that he can't get near or touch the turbine |
| **Thief** | Possible person who pretends to steal. | Parts well fixed to avoid the possible thieves extract them easily. | Turbine located in a closed area or with security. | Tries to steal the turbine or parts of it. | - | The turbine can be stolen or damaged by thieves. | - |
| **Children** | Children who live near the area. | Not to be able to come near the device by himself. | - | Try to play with the turbine. | - | Become really hurt due to play with the device. | Follow possible advice panels near the turbine. |

*Users needs*

It is very important to know every user needs to try to satisfy as much as possible all of them.

| Users | Needs |
|---|---|
| **Designer** | * E.B. and satisfy customer demand. |
| **Engineer** | E.B.  and satisfy customer demand. |
| **Manufacturer** | E.B. . Easy, fast and cheap to manufacture parts. |
| **Owner (Energy Company)** | E.B.. Efficient.  Easy to transport, install and maintain. Long product live. |
| **Owner (Single or building)** | E.B.. Efficient, cheap and easy to maintain. Long product live. |
| **Neighbour** | Anything should disturb him. No noise, vibrations or shadows. |
| **Maintainer** | Easy to change parts,  simple failure detection and easy access to any part of the device. |
| **Curious user** | Low noise, environment friendly and low visual impact. |
| **Thief** | Difficult to be stolen and difficult disassembly parts. |
| **Children** | Protected or difficult access to the device. |

* E.B.: Economic Benefit.

After this users analysis, some conclusions are:

- We need to keep viewing to all users during the designing process.
- A easier, cheaper and better design will satisfy more users and make the device more attractive for each user. Less time → more money.
- Manuals, recommendations and instructions should be done to satisfy users questions.
- The device should be protected somehow to avoid children or thieves come near and get hurt or damage some parts. Draw example in ANNEX B.
- Before installing a turbine, neighbors should be informed about the project due to avoid future problems or disagreements. A letter example is shown in ANNEX B.

## 5.3. Environment

The environment where we want to locate the wind turbines is urban areas. Areas with buildings and other obstacles are not the perfect place for perfect wind conditions, but there are still options to get wind turbines work over there.

Before locating a wind turbine we should follow some steps:

- Wind conditions: Check the average wind speed and wind rose for that area. Also wind turbulences due buildings.
- Which turbine?: Where exactly to locate the turbine in that area and which turbine would be better with that conditions. Size, height, power,...
- Neighbours and surroundings: Notify the neighbours, and some noise and vibration tests should be done.

*Wind conditions*

Before choosing a turbine, the site conditions need to be understood, so that the choice of turbine suits the physical and other constraints. A wind study is needed to be sure that average wind speed is enough. Many turbines only start to work (or 'cut in') at a minimum wind speed. If the wind speed is lower than the cut in speed, then the turbine will not turn at all. The result of the wind study is a wind rose. An example is shown on *Figure 5.2.*

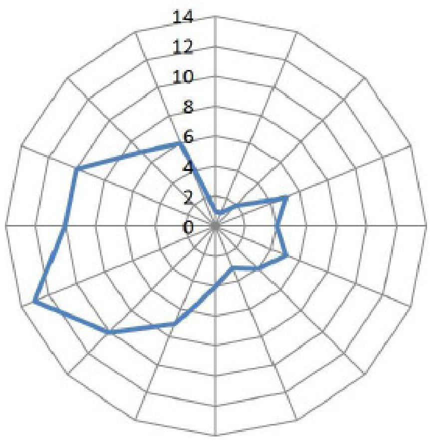



***Figure 5.2.*** *Example wind rose from a given area, in m/s.*

Knowing the most common wind directions and average speeds will help us to decide and choose better the location.

Another factor to consider are the turbulences caused by buildings. To know how the wind flows in a given area a particular study is needed.

Building roofs towering well above surrounding buildings have, in general, good prospects for offering economic wind speeds and, as a rule of thumb, wind speed generally increases with height. But, close to the roof the situation is more complex. There are some recommendations given in books or from associations. *See Figure 5.3.*

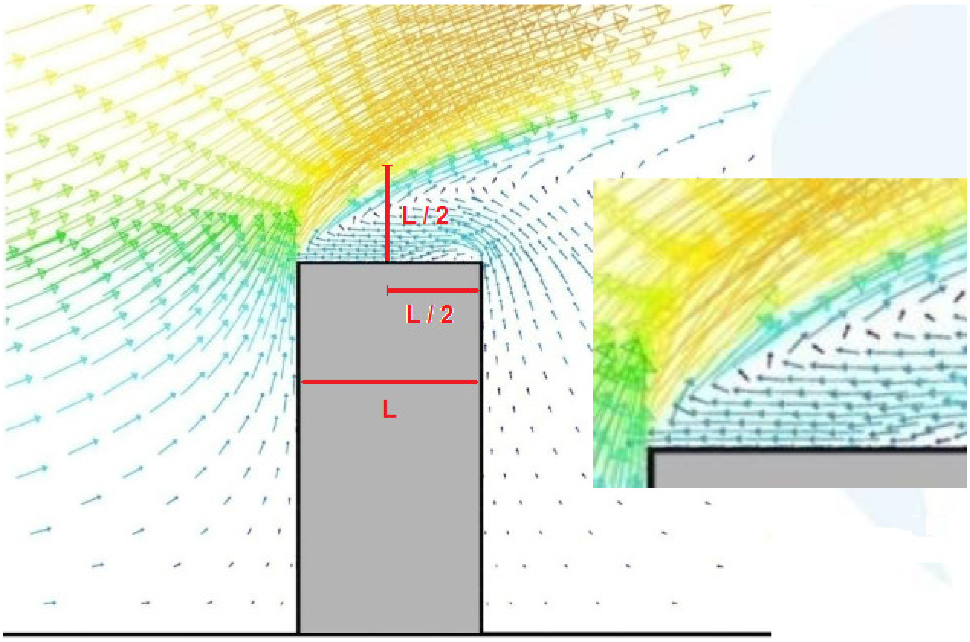



***Figure 5.3.*** *Computer simulation of the airflow pattern around a rectangular building for wind coming from the left.*

In order to avoid the area with low wind speeds, an urban wind turbine should be moved towards an area well above the roof surface. There are some rules of thumb for the calculation of the required height, but for a 'standard' office building example, it is **approximately half the roof width (*Figure 5.3*)**. For a roof width of 10 metres the required height therefore is 5 metres when positioning the wind turbine above the roof centre. It can be shown that wind speed in this area above the roof surface is some 20% higher than the undisturbed wind speed upwind of the building.

According to the power output formula, power increase in the operational area caused by this accelerated wind speed is 1.2 cubed or 1.7. In other words power output for any given system is 70% above the power output at roof height in the absence of the building [20].

[20] *Small wind turbines: Driving performance*. Article in Renewable Energy World 07/07/2009. By Sander Mertens and Eize de Vries.
URL: http://www.renewableenergyworld.com/rea/news/article/2008/08/small-wind-turbines-driving-performance-52701

See also another picture about locating the wind turbines behind buildings on *Figure 5.4.*

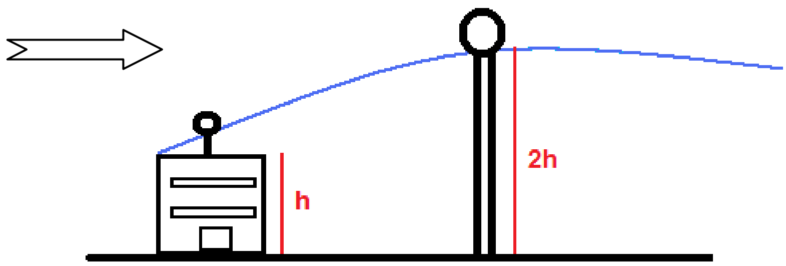



***Figure 5.4.*** *A turbine located behind a building with eight of 'h' should have its blades above the wake area, minimum at '2h'. [21]*

About the noise and vibrations generated by urban wind turbines (See chapter *4.2. Main environment impacts and problems with existing urban wind turbine solutions near the urban areas)* some information should be needed. Normally the manufacturer will provide the sound and noise parameters, if not some simulations programs might be used. *Figure 5.5* shows an example from the Danish Wind Industry Association simulation program of a horizontal 3 blades wind turbine [22].

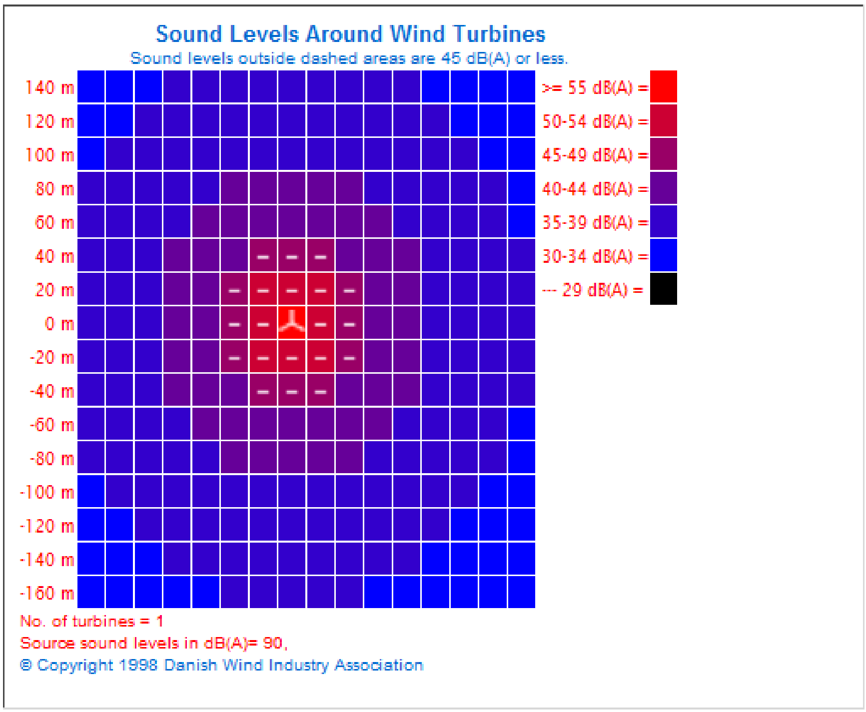



***Figure 5.5.*** *Example of wind turbine sound map.*

[21] *URBAN WIND ENERGY.* Sinisa Stankovic, Neil Campbell, Alan Harries. Published by Earthscan in UK and USA 2009.

[22] Sound Map Calculator for Wind Turbines. © Copyright 1997-2003 Danish Wind Industry Association. URL:http://guidedtour.windpower.org/en/tour/env/db/dbcalc.htm

*Which turbine?*

Depending on wind direction, average wind speed and wind conditions different turbine designs might be installed. The properties of the turbine must be the most appropriate for the conditions of a given environment to have maximum efficiency in all aspects.

On chapter *4.1.1. Technical and design solutions* and chapter *4.1.3. Main parameters and energy efficiency* some examples and average parameters are given.

There are also many manufacturers catalogues on the internet to check all parameters.

*Neighbours and surroundings*

As a conclusion of the users analysis, a notification should be given to the neighbors before proceeding with a project as visible as a wind turbine. Small wind turbines manufacturers also recommend early notifications. The courtesy will in many cases correct misperceptions further opinions against the turbine. An example of a notification letter is written on the ANNEX B. It could answer most questions people have about small wind turbines.

## 5.4. Functional analysis

The main method used for functional analysis is the so called Sequential Analysis of Functional Elements (or SAFE).

### *5.4.1. Sequential Analysis of Functional Elements (SAFE)*

The functions needed to achieve the specifications are listed, all of them, from the designing process until the end of device live. Classifying each of them by relevance and criterion. To choose those functions you must still keep thinking on all users mentioned before.

*Table of functions:*

| # | Functions | Relevance* | Criterion | Level |
|---|---|---|---|---|
| 1 | Easy to maintain | S | cost € | - |
| | | | Time h | - |
| 2 | To be silence | P | dB | 50 |
| 3 | Be resistant to external shocks | S | Kp | - |
| 4 | To be safety | P | Int. mA | 300 |
| | | | Blade hitting | - |
| | | | Blade cutting | - |
| 5 | To be economic | P | € | - |
| 6 | Beautiful design | S | Trend | - |
| 7 | Environment respecting design | P | View | - |
| 8 | Handle with very strong winds | S | wins speed m/s | 60 |
| 9 | Long live | P | Time - years | 20~30 |
| 10 | Resistance to environmental attack | S | Corrosion | - |
| 11 | Produce little vibration | P | Freq. Hz | - |
| 12 | To be bird-friendly | S | # accidents | - |
| 13 | To be efficient | P | KWh / Cp | Betz limit |

*P: primary, S: secondary.

The next step is to confront the functions each other. This will show us which function is more important that which one by filling each cell on the matrix.

| | Functions | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F11 | F12 | F13 | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F1 | Easy to maintain | | F1 | F1 | F4 | F5 | F1 | F1 | F8 | F9 | F10 | F11 | F1 | F13 | 5 |
| F2 | To be silence | | | F2 | F4 | F5 | F2 | F2 | F8 | F2 | F2 | F2 | F2 | F13 | 7 |
| F3 | Be resistant to external shocks | | | | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F3 | F3 | F13 | 2 |
| F4 | To be safety | | | | | F5 | F4 | F4 | F4 | F9 | F4 | F4 | F4 | F13 | 6 |
| F5 | To be economic | | | | | | F5 | F5 | F5 | F9 | F10 | F5 | F5 | F13 | 5 |
| F6 | Beautiful design | | | | | | | F7 | F8 | F9 | F10 | F11 | F6 | F13 | 1 |
| F7 | Environment respecting design | | | | | | | | F8 | F9 | F10 | F11 | F12 | F13 | 0 |
| F8 | Handle with very strong winds | | | | | | | | | F9 | F8 | F8 | F8 | F13 | 3 |
| F9 | Long live | | | | * | | | | | | F9 | F9 | F9 | F13 | 3 |
| F10 | Resistance to environmental attack | | | | | | | | | | | F11 | F10 | F13 | 1 |
| F11 | Produce little vibration | | | | | | | | | | | | F11 | F13 | 1 |
| F12 | To be bird-friendly | | | | | | | | | | | | | F13 | 0 |
| F13 | To be efficient | | | | | | | | | | | | | | 0 |
| | Sum | 0 | 0 | 0 | 3 | 4 | 1 | 2 | 5 | 7 | 5 | 4 | 1 | 12 | |

* Notice that the matrix is symmetric, that's why is the same to fill up only the half of it and sum by vertical columns and horizontal rows together.

After confronting all functions we need to sum up how many time a function is more important than an another. By this way we'll have a rate from the most important to the least one.

The following list shows the order of functions with the rate, % and %accumulated:

| | Functions | Rate | % | % accum. |
|---|---|---|---|---|
| F13 | To be efficient | 12 | 15,38 | 15,38 |
| F9 | Long live | 10 | 12,82 | 28,21 |
| F4 | To be safety | 9 | 11,54 | 39,74 |
| F5 | To be economic | 9 | 11,54 | 51,28 |
| F8 | Handle with very strong winds | 8 | 10,26 | 61,54 |
| F2 | To be silence | 7 | 8,97 | 70,51 |
| F10 | Resistance to environmental attack | 6 | 7,69 | 78,21 |
| F1 | Easy to maintain | 5 | 6,41 | 84,62 |
| F11 | Produce little vibration | 5 | 6,41 | 91,03 |
| F3 | Be resistant to external shocks | 2 | 2,56 | 93,59 |
| F6 | Beautiful design | 2 | 2,56 | 96,15 |
| F7 | Environment respecting design | 2 | 2,56 | 98,72 |
| F12 | To be bird-friendly | 1 | 1,28 | 100,00 |

Notice in the % accumulated row that with only few of the better rated functions we can cover most of the needs:

To be efficient

Long live

To be safety

To be economic

**30 % functions → 50 % Needs**

Handle with very strong winds

To be silence

Resistance to environmental attack

Easy to maintain

**60 % functions → 80 % Needs**

The following Pareto's graphic shows the relationship between the functions and the covered needs:

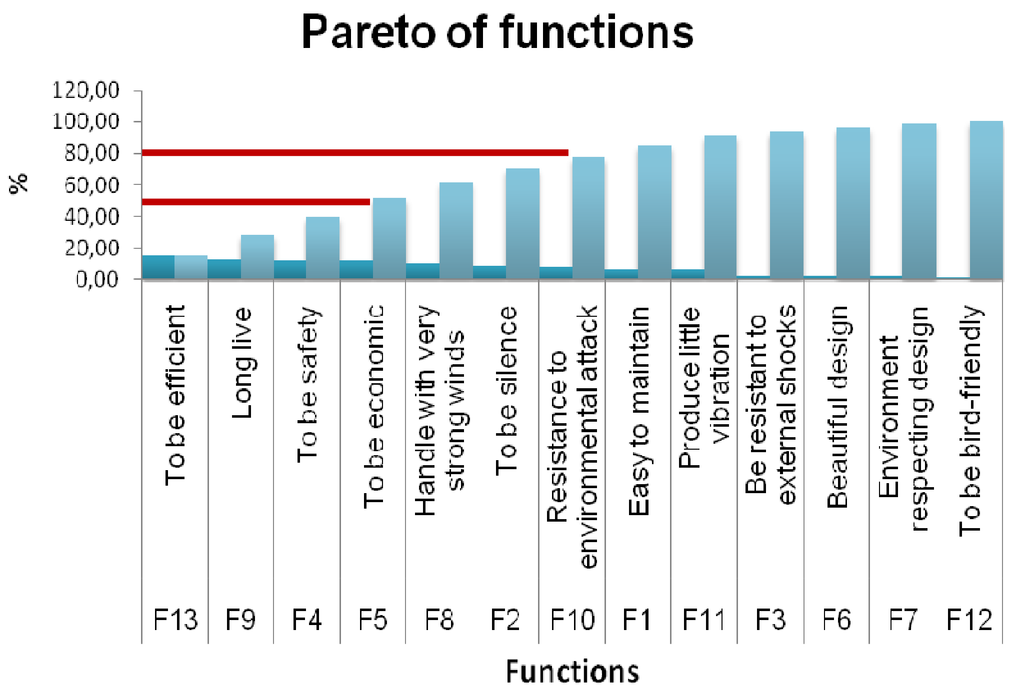



***Figure 5.6.*** *Pareto graphic of functions.*

Some conclusions obtained from this method are:

- It is really good to find out that only the first main functions (30% of all) can cover more than 50% of needs to satisfy all the specifications. Those functions are related to efficiency, long live, safety and profitability, is not strange, obviously wind turbines aim is to produce energy as cheap and fast and as long as possible, and if they satisfy at least those 4 functions we can say that is a good turbine.

- Nevertheless, the less rated functions like "To be bird friendly" or functions regarding to beautiful design need to be considered as well as the most rated. But satisfying this functions will not help to cover the needs and the main aims of the wind turbine.

## 5.5. Failure Analysis

Failure analysis is the process of analyzing to determine the cause of a failure. It is an important discipline in many branches of manufacturing industry, such as the electronics industry, where it is a vital tool used in the development of new products and for the improvement of existing products. The aim of these analysis is not the discover the cause of a failure, the aim is to prevent as much as possible all failures that might happen.

### *5.5.1. HAZOP - Functional analysis of operability*

This method is very important, as its primary objective is to identify security problems. It starts to identify any problems that may occur during the working live of the turbine, taking into account the causes and consequences of those problems.

HAZOP table:

| Word | Deviation | Cause | Consequence |
|---|---|---|---|
| No | Movement | Blocked | The turbine doesn't work |
| More | Wind | Storm or hurricane | The blades can break or the structure fall down |
| Less | Subjection | Broken or damaged part | The structure can fall down or blades fly away |
| No | Enough electricity generation | Bad wind or location study | Not enough power produced to cover energy needs. |

It is just to start having an idea about the most obvious failures. For example the possibility to have hurricanes or too much wind can brake our blades or structure, or a big failure could also to located the turbine in a wrong place just from the beginning. It is needed to take care about those failures by testing our designs in wind tunnels or to extreme conditions.

### 5.5.2. *Cause-Effect "Ishikawa" Diagram*

Ishikawa diagrams (also called fishbone diagrams or cause-and-effect diagrams) are diagrams that show the causes of a certain event. Common uses of the Ishikawa diagram are product design and quality defect prevention, to identify potential factors causing an overall effect. Each cause or reason for imperfection is a source of variation. Causes are usually grouped into major categories to identify these sources of variation. The categories included after doing a "Brainstorming" with other students are:

- Materials
- Environment
- Manpower
- Machine
- Method

The first step is to identify the problem In this case I choose "No energy generation" as it is the worst possible problem in general. Then all the causes that could bring the turbine to the problem are classified into the five major categories. For this part a "Brainstorming" was also done to find out as much as causes as possible:

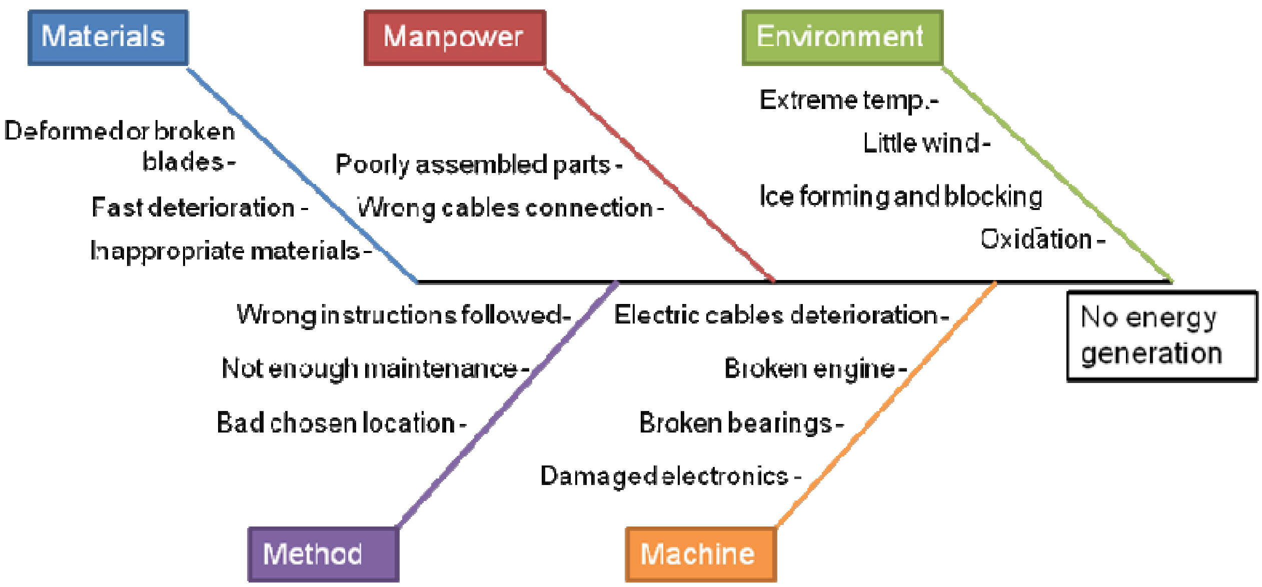



***Figure 5.7.*** *Cause-effect diagram, (Ishikawa).*

### 5.5.3. Fault Tree Analysis (FTA)

Fault tree analysis (FTA) is a failure analysis in which an undesired state of a system is analyzed using Boolean logic to combine a series of lower-level events. This analysis method is mainly used in the field of safety engineering to quantitatively determine the probability of a safety hazard.

The result of this method is to draw the Fault tree diagram. Diagrams represent the logical relationship between sub-system and component failures and how they combine to cause system failures. The TOP event of a fault tree represents a system event of interest and is connected by logical gates to component failures known as basic events.

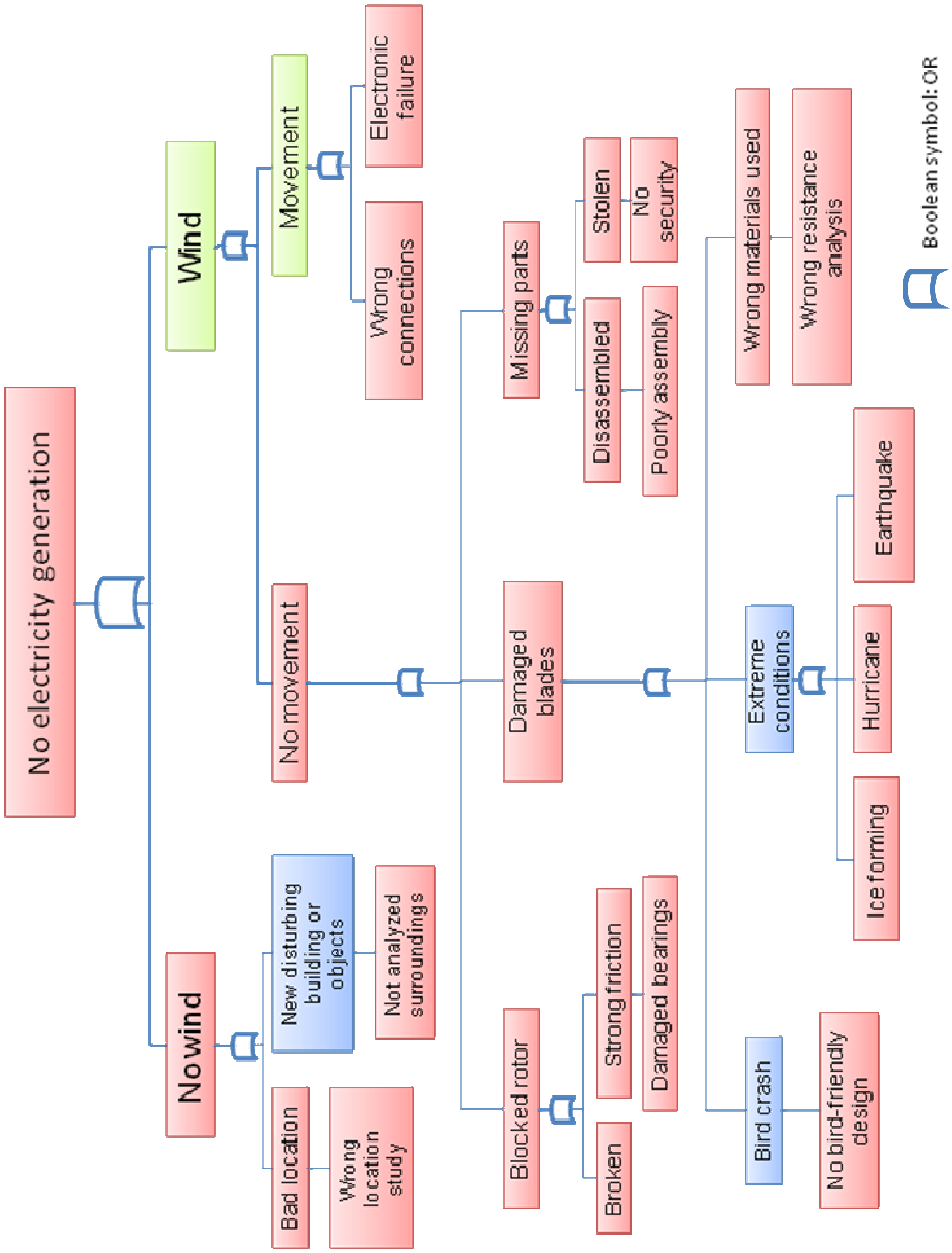
This method is a deductive analysis. It begins with a general conclusion, then attempts to determine the specific causes of this conclusion. This is often described as a "top down" approach.

The main purpose of fault tree analysis is to evaluate the probability of the top event using analytical or statistical methods (for statistical methods some data is needed). These calculations involve system quantitative reliability and maintainability information, such as failure probability, failure rate, or repair rate. FTA can provide useful information concerning the likelihood of a failure and the means by which such a failure could occur. Efforts to improve system safety and reliability can be focused and refined using the results of the FTA.

The steps to follow are:

- Define the undesired event to study: **No electricity generation**
- Study and analyze all causes that might affect the undesired event.
- Construct the fault tree.
- Evaluate the fault tree.

The Fault tree is shown on the following page:


No electricity generation
Wind
No wind
Movement
No movement
Electronic failure
Wrong connections
Missing parts
Damaged blades
Blocked rotor
Stolen
No security
Disassembled
Poorly assembly
Wrong materials used
Wrong resistance analysis
Extreme conditions
Earthquake
Hurricane
Ice forming
Strong friction
Damaged bearings
Broken
Bird crash
No bird-friendly design
New disturbing building or objects
Not analyzed surroundings
Bad location
Wrong location study
Boolean symbol: OR

After constructing the fault tree diagram and having an overview of the rest of failure analysis methods (HAZOP and Ishikawa) some conclusions are:

– Before locating a wind turbine in a urban area not only a wind study is enough. As shown on the fault tree the appearance of new buildings or objects on the surroundings of the turbine can affect the wind conditions. A study of the future of surroundings might help.

– If our turbine contains bearings, they should be temporarily revised. If bearings get damaged, vibrations and noise will appear producing low efficiency and neighbours problems. A solution to this possible problem could be the use of “full-permanent” magnets to get the rotor levitation (for VAWT) and avoid the constant friction and maintenance. The use of magnets could also extend the lifetime of the turbine.

– Make sure that there are not poorly assembled or disassembled parts in the turbine. Those parts can damage the whole turbine or produce accidents. A temporarily maintenance should be done because vibrations and extreme conditions might contribute to the cause.

– The access to the wind turbine parts should be protected somehow to avoid children playing with it or missing parts due thieves. An example is shown on ANNEX B.

## 5.6. Possible solutions analysis

Once we have achieved this step, after having search information about designs, parameters, problems and having analyzed everything with several design methods is time to have a look at all the information given and conclude with which should be the most suitable solution for our purpose.

The first thing we could decide is, if the solution should be a VAWT or HAWT. As is written in the chapter *4.1.2 (Comparison horizontal-axis and vertical-axis wind turbine)* the wind turbines with vertical axis seem to fit better in our urban environment for some reasons, two of them are:

- Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. It is able to catch the wind from 360º. This is an advantage on sites where the wind direction is highly variable.

- The generator of a VAWT can be located nearer to the ground, making it easier to maintain the moving parts. And it means lighter tower or structure to support the turbine.

After that it is also needed to decide how to catch the power from the wind. There are two possibilities: Drag and Lift forces. As it is said before, drag forces will allow us to start in slow wind speed but not allow us to reach very high rotation speed. And blades using lift forces are more efficient and are able to catch more power from the wind in high wind speed giving higher power coefficients. If our turbine should be efficient it is needed to decide the use of lift forces.

But here is possible to have the idea of a combination of both principles for the same wind turbine: drag + lift. There are some examples of VAWT with blades using lift forces and a small Savonius device added into the axis to provide the self starting in lower wind speeds. An example is shown on *Figure 4.1.3.*

Right now having a look at the wind turbines classification on chapter *4.1.1.* (*Technical and design solutions)* we still have some choices with VAWT using lift forces. There are two options: H-rotor Darrieus VAWT or VAWT with helical twisted blades.

As mentioned on chapter *4.1.1.* (*Technical and design solutions – Helical twisted blades designs)* a helical wind turbine system is more efficient, as its twisted blades are not feathered or stopped by high winds.

Those helical designed blades can deliver torque relatively evenly at variable wind speeds and the twisted blades have been designed to eliminate noise and vibration when operating in turbulent shifting wind conditions.

If we want to satisfy the aim of having low noise and little vibrations, the helical twisted blades designs seems to be the better one.

In accordance with the designs methods, to avoid friction, vibration and noise the magnetic levitation should be used to avoid possible failure or future problems.

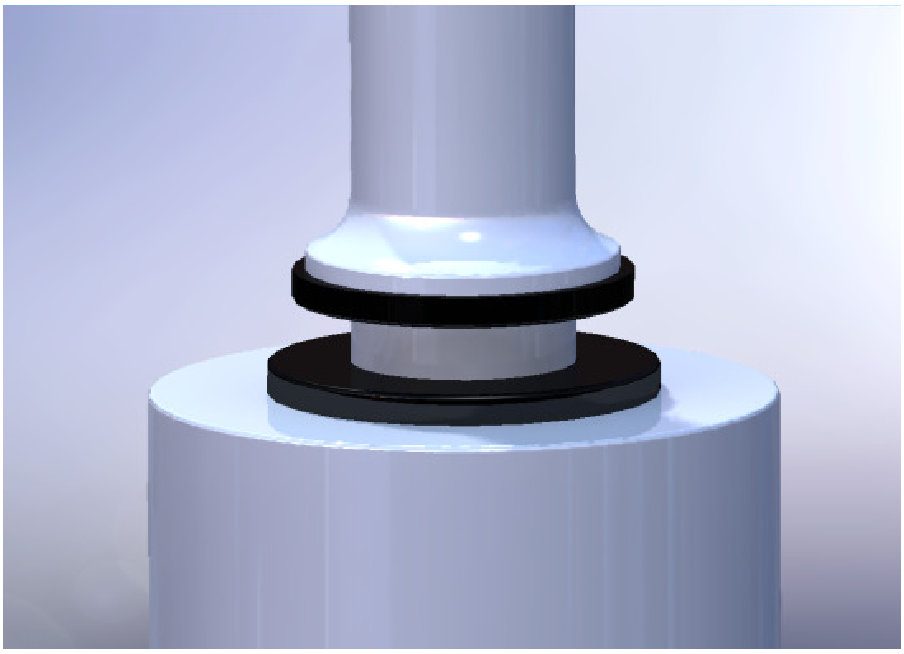


***Figure 5.8.*** *Detail of the magnetic levitation system.*

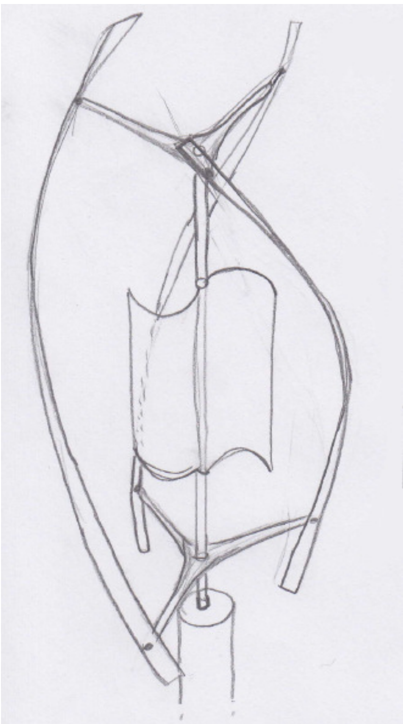
As shown on *Figure 5.8.* the use of full-permanent magnet made of neodymium (black colour components) between the rotor and the support will reduce almost all the friction between both parts.

Usually those turbine rotors are constructed of carbon fiber and epoxy resin (or fiberglass) and the assembly has very few moving parts, making them easier to maintain.

As it is mentioned in the failure analysis the turbine should have few assembled parts, so the use of this materials could help to satisfy this need. Also few parts means that the maintenance would be easier, faster and cheaper. The use of these materials is good against the corrosion and oxidation.

If we try to think about a turbine which contains all the variables mentioned before the result is a helical twisted blades Darrieus wind turbine with a Savonius blade added in the rotor.

There is an example drawn by hand and also one using CAD software:


a.

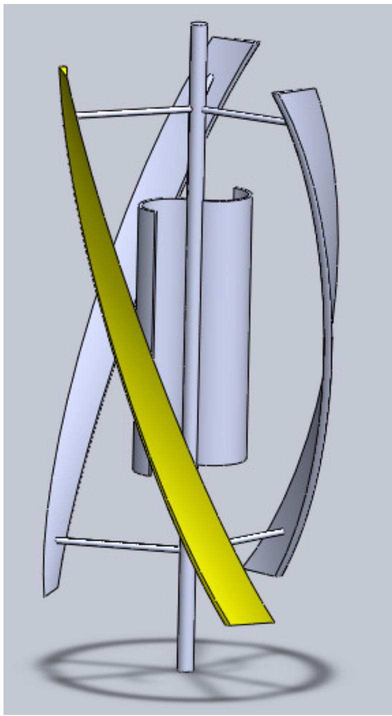

b.

***Figure 5.9.***

*a. Hand drawing example (ANNEX B).* *b. 3D pre-design view.*

### *5.6.1. Solution features*

The result is a Darrieus vertical axis wind turbine with helical twisted blades in combination with a Savonius device added in the rotor axis. The rotor is levitating over the rotor in the vertical axis due the use of neodymium magnets.

A CAD example is shown on *Figure 5.10.:*

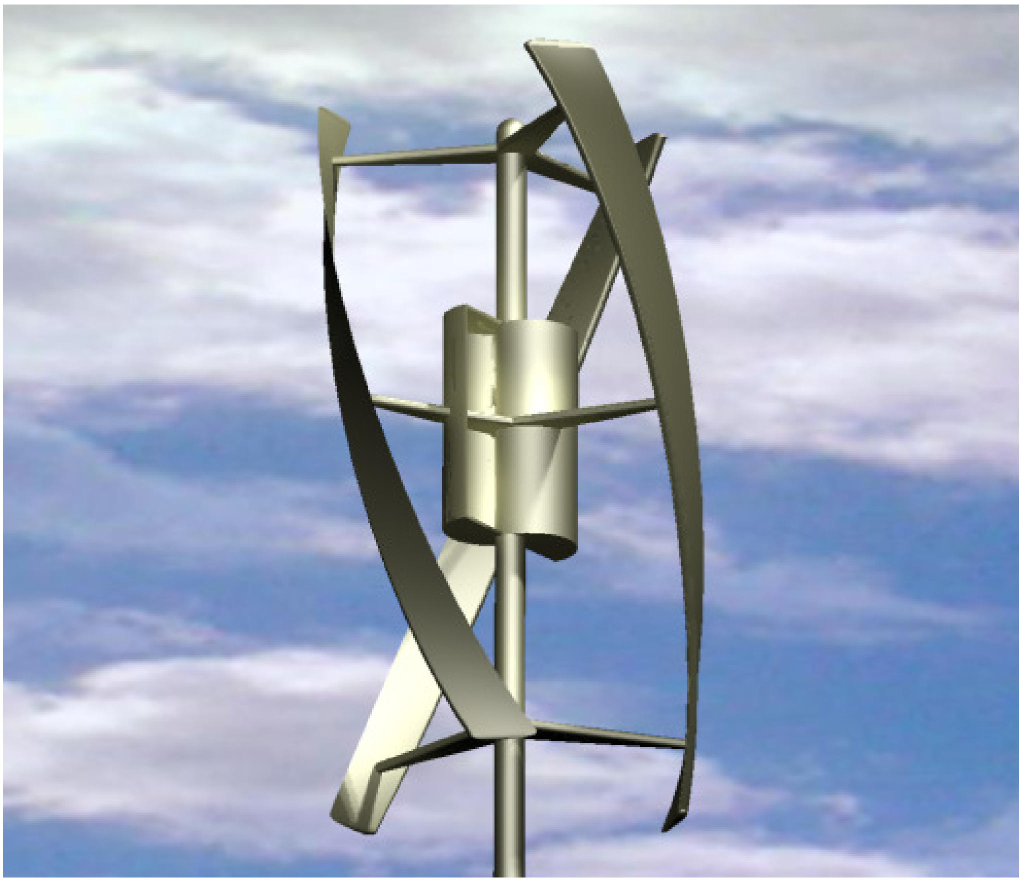


***Figure 5.10.*** *CAD example of the wind turbine solution.*

The turbine is 3 m height and 1,5 m diameter. It contains a support (stator with electric generator) and the rotor. The rotor contains the axis, and 3 blades supported by a set of 3 supports, one on the top, one on the middle and one on the bottom.

The Savonius blades are attached on the middle of the axis.

The rotor is made of epoxy resin and carbon fiber parts to be as light as possible.

According with the table of parameters shown on chapter *4.1.3. Main parameters and energy efficiency* and comparing to other solutions already in the market with same parameters this turbine should have the following values:

| **Characteristics** | |
|---|---|
| Rated power | 5 KW |
| Height | 3 m |
| Diameter | 1,5 m |
| Sectional Area | 4,5 $m^2$ |
| Power Coefficient * | ~ 0,3 |
| Tip-speed ratio | ~ 4 |
| Start-up wind | 2 m/s |
| Cut-out wind ** | - |

* Approx. Maximum.

** The Cut-out wind shouldn't be a problem. The attached Savonius blades brake the rotor using drag forces in high wind speeds.

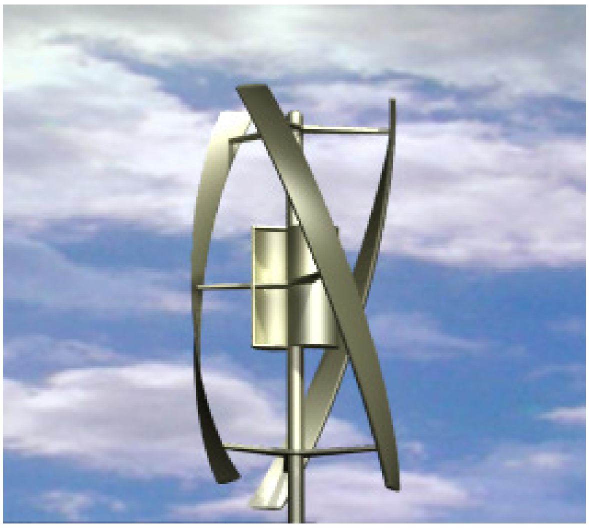


***Figure 5.11.*** *CAD example of the wind turbine solution.*

All views and drawings are attached in ANNEX C.

### 5.6.2. Possible aspects to consider in the future

*Rooftop architecture*

As shown in the hand drawings in ANNEX B, I had also some ideas about using the rooftop architecture to try to drive the wind directly into the turbine.

This could be a next step to improve rooftop turbines efficiency and also a way to mitigate the visual impact or turbines in urban areas. There are many examples of using building architecture to make the visual impact softer.

Some of these ideas are shown below:

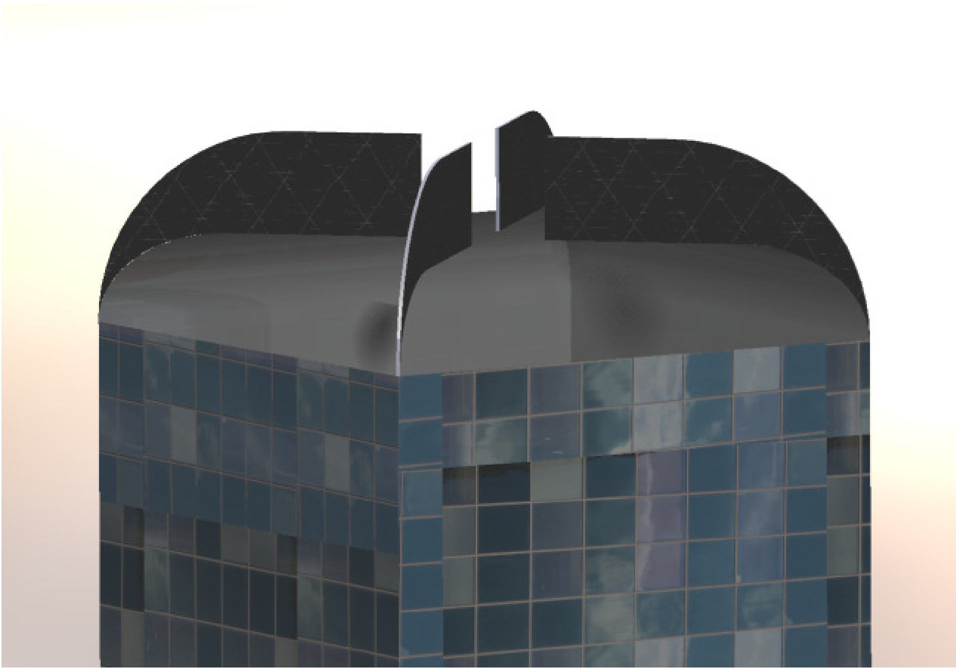


***Figure 5.12.*** *Rooftop architecture. Panels are placed to try to catch the wind and drive it into the middle of the roof where the turbine should be located.*

This could be an idea to improve the wind conditions over rooftops, but maybe the installation of the panels require to be assembled with the building structure, making this option a bit expensive and complicated, or only exclusive for new building construction.

A cheaper and easier solution, instead of the solution before could be only some panels installed near to the curb of the roof wall where the wind is most of the times coming from. Using this panels the wind could be also driven over the height where the turbine is located. An example is shown in ANNEX B, and also in the following picture using CAD:

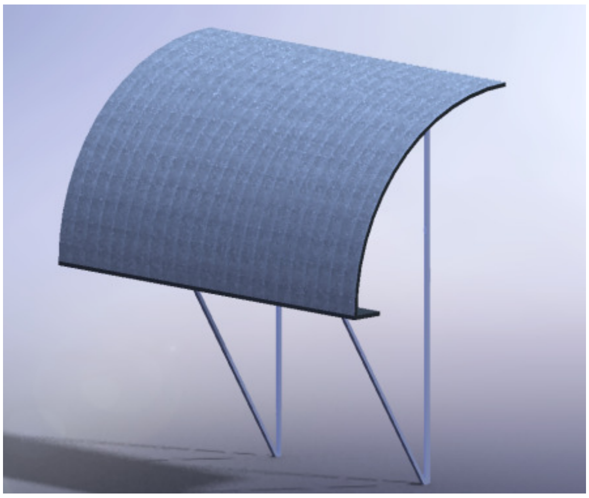


***Figure 5.13.*** *Rooftop architecture. Example of panel that could be used in rooftops.*

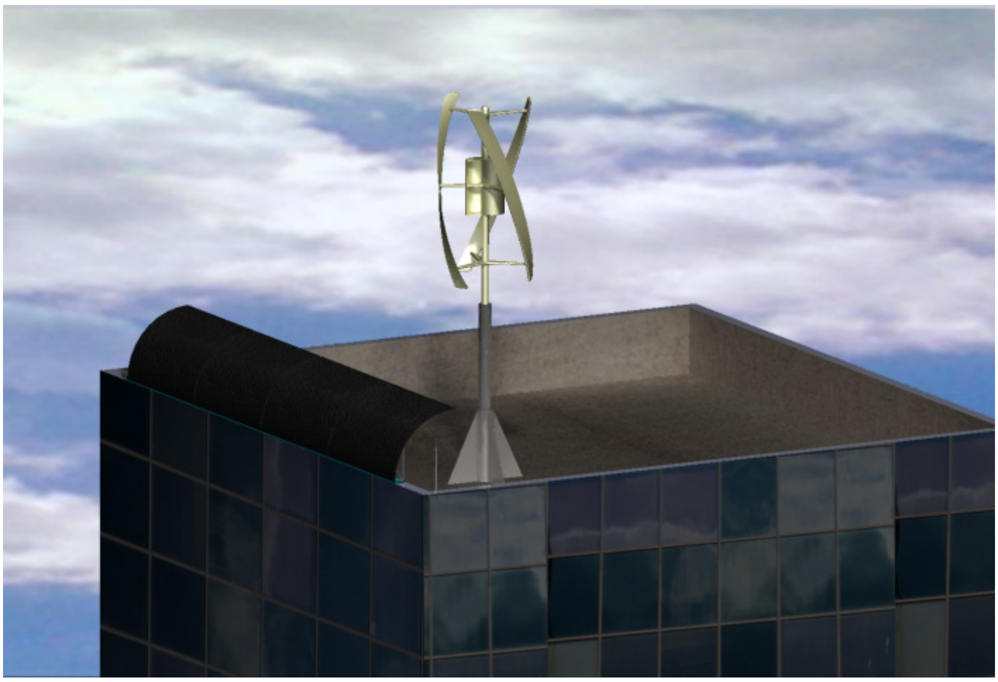


***Figure 5.14.*** *Rooftop architecture. The panels are installed together in the side of the roof where the wind is coming creating a wall to drive the wind.*

*Patents*

As the result of the whole analysis done during the process a good suitable solution of urban wind turbine has been given, but I am probably not the first one who gets such kind of conclusions.

There are many solutions already in the market which might be similar to the solution proposed here. And those solutions are often protected by patents. Those solutions are for example "*Quiet revolution*" and "*Turby*" which have similar design:


a.


b.

***Figure 5.15.*** *Similar design solutions to the solution given here.*
*a. Quiet revolution. b. Turby.*

To be sure about which aspects are already patented and which not an exhaustive patent research is needed.

Some examples of patents I found that could be interesting in a first patents overview are:

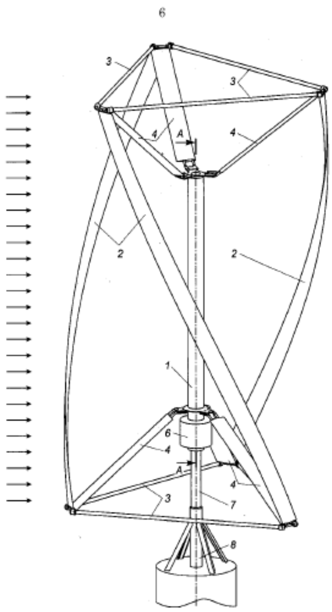


***Figure 5.15.*** *Patent: Wind turbine with vertical axle (variants), 2009-02-28, MD3847 (B1), by BOSTAN ION [MD]; VISA ION [RO]; DULGHERU VALERIU [MD]; CIUPERCA RODION [MD]*

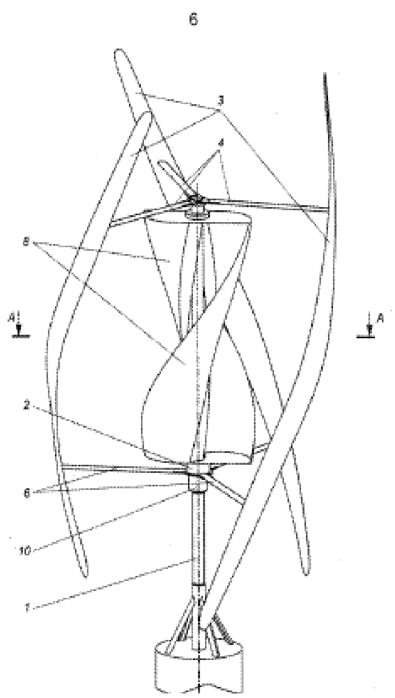


***Figure 5.16.*** *Patent: Wind turbine with vertical axle (variants), 2009-01-31, MD3817 (B1), by BOSTAN ION [MD]; VISA ION [RO]; DULGHERU VALERIU [MD]; CIUPERCA RODION [MD]*

*Flow analysis*

To make sure that the ideas shown before, about rooftop architecture, are feasible and really improving the wind condition some flow analysis are needed. There are many programs to analyze the wind conditions using such kind of rooftop architecture, for example: *SolidWorks* (CFD *Flow* Analysis Software) or ANSYS. But those programs require a good level of knowledge and long time to get real and good results.

An example picture is shown below. This picture has been taken from the Solidworks student version which is a very limited version:

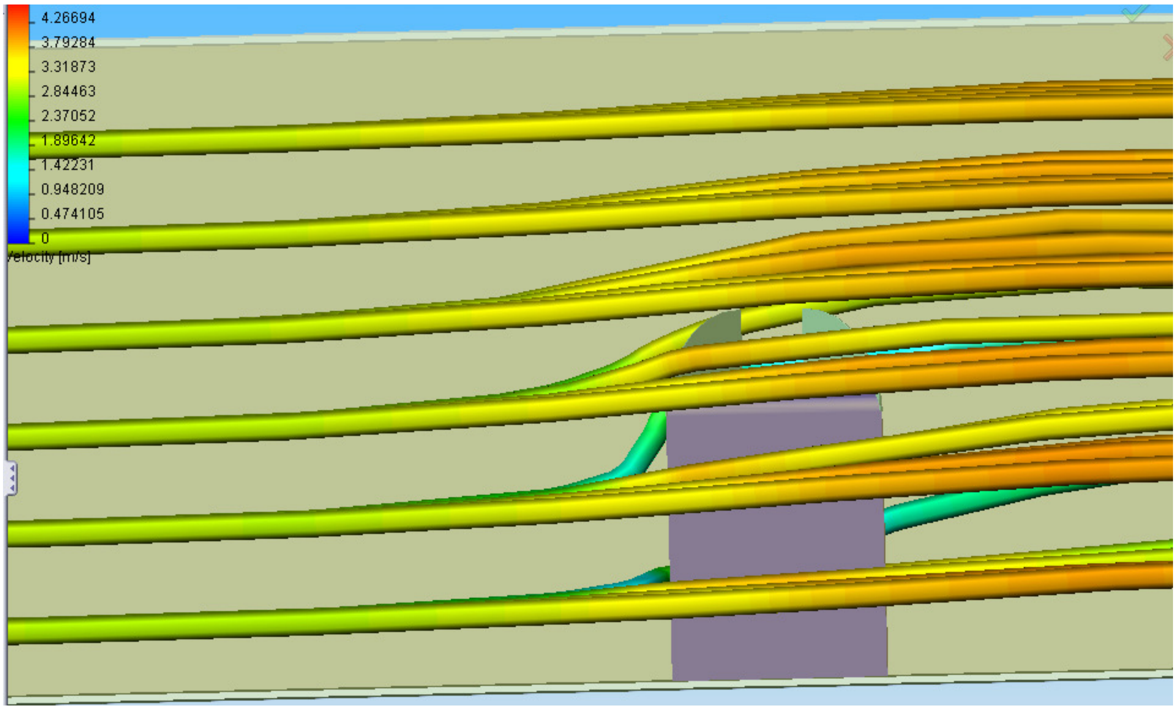



***Figure 5.17.*** *Wind flow analysis example using Solidworks student version software.*

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# Conclusions

In conclusion I would like to say that urban wind turbines is a quite new field in development, where many new ideas and solutions are appearing every day due a big range of options are possible.

A full overview of possible solutions is given. Some of them are real solutions available in the market and some of them are just prototypes, but the border between idea and solution is disappearing very fast nowadays.

Many of the parameters given during the text are most of the times average values or approximations because technical data has almost never been verified by independent institutions and information available on existing installations and designs is very limited.

It seems that using these new wind turbine designs some problems regarding to big wind turbines are not a problem anymore in urban areas like shadow flicker or strong visual impact, but we must take into account new issues like vibrations in building structures or neighbors opinion.

By using design methods is shown that many aspects can influence the location of a new turbine. Therefore what may be appropriate or feasible at one location may be completely unsuitable somewhere else even if superficially similar. In many cases, associated environmental impacts can be satisfactory mitigated if due consideration has been given to the various aspects described in the text.

They could be placed on many large buildings with a flat roof, but also at many locations in industrial zones and next to free standing houses in less densely populated areas. Selecting the optimal location for urban wind turbines is a complex process that should be done very carefully.

Urban wind turbines in urban areas can not only generate energy but also help individuals keep in mind the balance between man and nature, as well as the importance of combining renewable energy generation and energy efficiency in moving towards sustainable societies. Moreover as our energy future is certain to rely increasingly on a multiple renewable sources, wind energy has a place in the built environment for some time to come.

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And finally I would like to thank to the Estonian company "4 ENERGIA" for giving me the possibility to write my thesis with their collaboration, specially to Andre Lindvest who was the person with whom I kept in contact with the company.

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More info and catalogues:

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# ANNEX

## ANNEX A

Survey

**Have you ever heard about wind turbines? (aero-generators)**

Added answers:

1. It’s the most ecologic energy.
2. Oh, as I’m studying mechanical engineering I know a lot. It is a growing business and a good energy source! For instance, when you fly over Europe you can already see a lot of wind turbines fields. I also know about wind turbines being set into water rather than land etc.
3. it is considered as an alternative energy source and is widely used in Denmark, for example. However, I am not sure about its efficiency on a global scale.
4. Their operational constraints because of wind speed, capacities of ones, located in Estonia.
5. Next to my town there are several wind turbines and there were a lot of discussions because they wanted to build some real high ones (120meters) but some people were not amused about that. but in fact it is a good possibility to produce energy without damaging the environment. A disadvantage is of course that it is dependent from the wind!
6. Expensive production.
7. Too expensive to construct.
8. Yes, it is a newer evention, has better efficiency and so on.
9. Some of the generators are made in Finland.
10. it's a kind of green energy.
11. Big plastic thing for generating energy from wind.
12. It's ecological.
13. Very expensive.
14. I know they are a way of producing "green" energy, but they are quite expensive and unsightly. One of the ways to save the planet.
15. I know a little bit about benefits and environmental impact.
16. My university electricity is powered by wind turbine.
17. Generates electricity.
18. Their capacity is usually 2-3 MW; there`re different types of them: some are horizontal and some are vertical. If wind is very strong (I guess over 27?) then they turn automatically off.
19. Converts energy from the wind to mechanical energy.
20. Environmentally friendly energy generators, work on wind, have not a big KPI.
21. They produce electro energy, and they are good for the earth.
22. I know exactly how they works and the importance for the environment even if they produce a relative low quantity of energy compared to fossil resources.
23. they work with wind of course, and it is the reverse of what an electric motor would do, instead of turning electricity into kinetic energy, it transforms kinetic energy into electrical energy.

**Wind turbines. A wind turbine is a rotating machine which converts the kinetic energy of wind into mechanical energy. They convert wind energy to electricity for distribution. Nowadays they are used in all over the world to produce electricity. You think that wind turbines are:**

Category Others:

1. A one source of electrical energy.
2. Heard, that they somehow bother birds.
3. They generate noise.
4. Less efficient when small amount of turbines, huge wind parks on the ocean makes more sense.
5. No problematic waste (compared to atomic energy) bus there are also many of them needed to produce as much energy as other ways of energy producing.
6. Destroys the overall appearance of the landscape.
7. Cost effective.
8. Dangerous for birds
9. Needed for the environment and they need huge investment to really produce a significant amount of electricity. Anyway states has to invest heavily on it but regarding the landscape as well. They have to choose really carefully where to put them not to ruin some really nice landscape.
10. Military does not like them so much since they are ruining the radar picture for everything that is under 200m.
11. Not commonly used in most countries for reasons unknown to me.

**Would be a problem for you to have these kind of wind turbines near the urban areas to produce electricity? For example in the roof of the flats or public gardens? –(It's possible to answer and add opinion-).**

Added answers:

1. I'm not so sure about them being in gardens, but if they are made to look interesting and somewhat like contemporary art then why not. Both cases the noise level of turbines must be lower in order for it to be ok!
2. I don't know if they can be somehow harmful.
3. But maybe it's annoying if it produces moving shadows, noise...
4. Yes if they are noisy and big.
5. Should have a design, that fits environment.
6. if it will help the environment, would be perfect!
7. Possible, but it has to fit to the area and it has to be sure that the turbines don't bother the people who live close to the turbine.
8. But I doubt about their effectiveness because of the band wind (turbulences) near urban areas.
9. No if they are efficient (if they make up for the energy and materials used for their production and installation) and don't make noise.
10. Solar energy fits more into the environment...wind turbines need to much space, also in urban areas there is less wind (or to say, it's mostly not that enough wind) ...so not really efficient.
11. The Chicago wind turbines are very nicely engineered with the building in mind. Sightly and energy efficient!
12. It is absolutely necessary.
13. I don't know.
14. These look cool.
15. I think wind turbines are not easy to use in urban areas: they are not accepted from the people!
16. If it doesn't make any noise, it is OK.

**Do you think that Urban wind turbines could help us to generate electricity for our homes? (-It's possible to add your opinion-)**

Added answers:

1. No opinion.
2. As en extend device, but not as principal.
3. In some cases yes.
4. As wind energy is very unstable energy, electric energy generated by wind can supply only battery chargers or very simple machines that do not need constant and secure energy source.
5. I don't know if they can be somehow harmful.
6. Hard to say, because it's very dependent from the wind! further these urban generators are quite small and specially in big cities there isn't so much wind!
7. It cannot itself produce enough energy but can easily be a source for domestic energy (provide for a part of the consumption).
8. I hope so.
9. Why not if it is feasible.
10. Yes, but they need another energy support: solar energy, conventional electricity.....
11. It is possible, but is it also feasible?
12. I think that this wind turbines are very good solution for energy.
13. Yes definitely but it really depends on location.
14. Only if they are economically viable.
15. It is too less energy but a good first step.
16. They cannot give so much energy to meet all the house demands
17. Maybe.
18. They are to inefficient for a private household.
19. They might not supply constant input, they will need regulators or accumulators to compensate in fluctuations of wind.

# ANNEX B

Drawings

**Example of a notification letter**

Dear Neighbor,

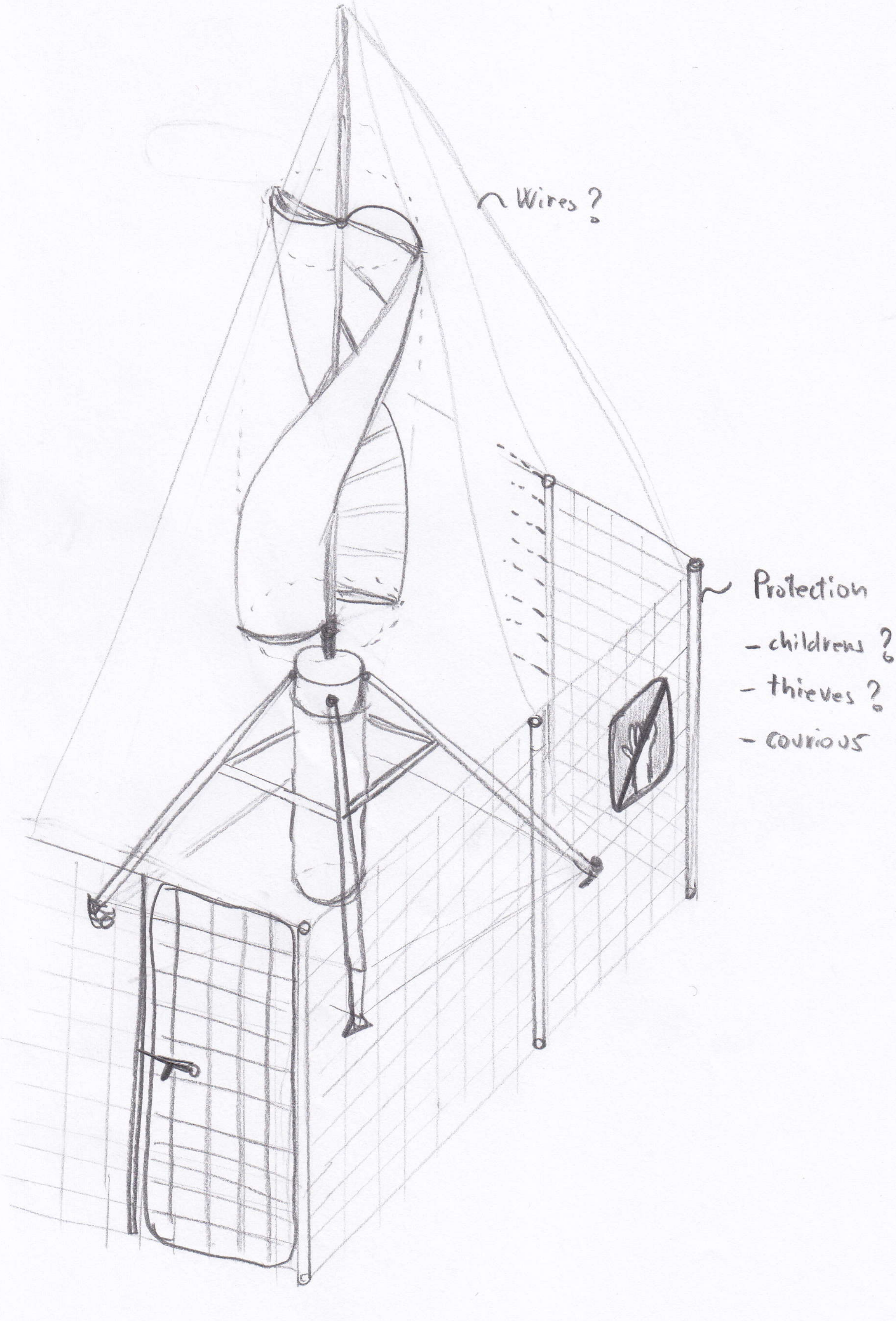
You may be interested to learn that I plan to install a small wind energy system on my property at [address]. This modern, non-polluting system will generate electricity solely for my own use, reducing my dependence on the local utility. Any excess generation will be supplied to the utility system, but I will not receive any income from this exchange.

I plan to install a [turbine make and model] that will be mounted on a ___-foot tower, set back ___feet from the street and ___ feet from the [south/north/east/west] property line. This wind turbine uses a [two/three] -bladed propeller ___ feet in diameter and has only ___ moving parts. It does not turn until the wind speed reaches at least ___ mph. On calm, quiet days the wind turbine will not likely be audible. When the rotor is turning, the sound of the wind passing over the blades will register about ___ decibels (dB(A)), at a distance of ___ feet, which will barely be audible over other noises caused by the wind.

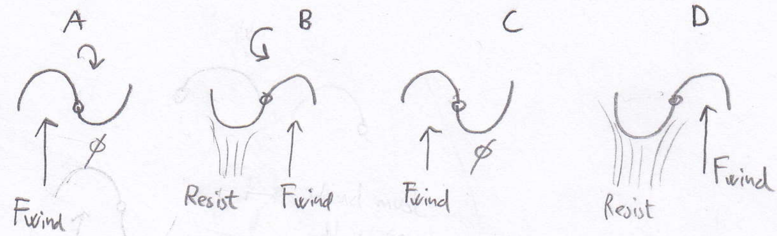
[Manufacturer] has installed ___ [number] of [turbine make and model] in the United States [and overseas]. They have a proven track record of producing energy quietly, cleanly, and safely. If you have any questions about the proposed installation, please feel free to contact me.

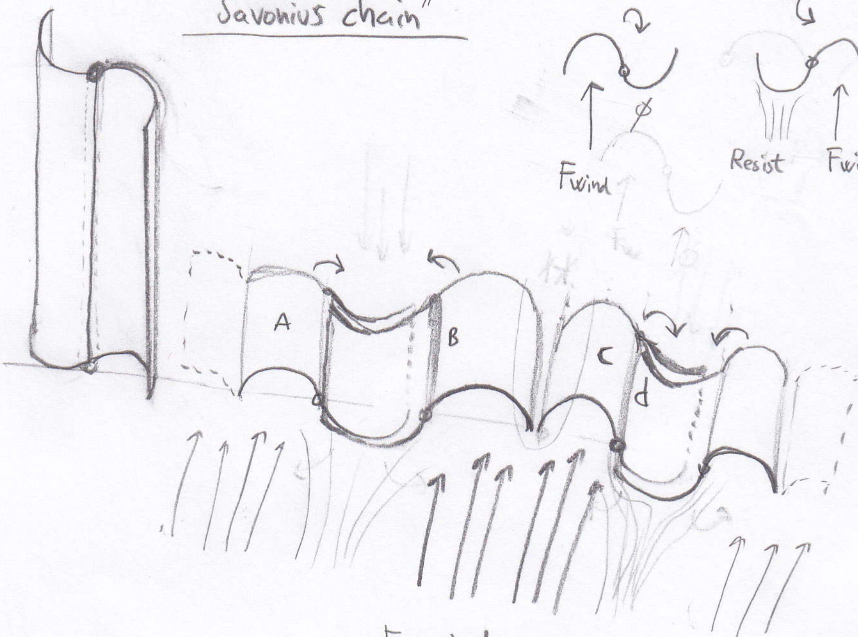
Sincerely,

*Source: AWEA (American Wind Energy Association).*


Wires ?
Protection
- childrens ?
- thieves ?
- courious

## "Savonius chain"




F wind

(only 1 direction)

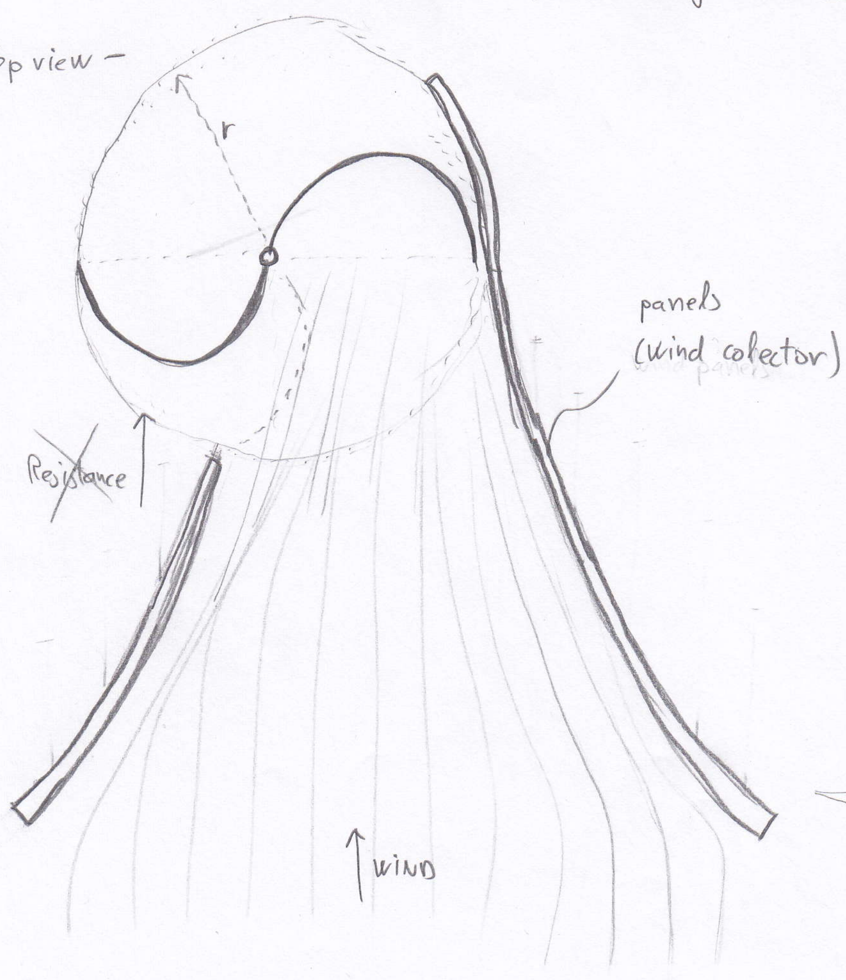
- only 1 direction

(−)
- synchronising needed?
- complex?
- Savonius only drag (↓Cp)
- Friction ⇒ Noise + Vibrations

(+)
- Less resistance (wind/drag)

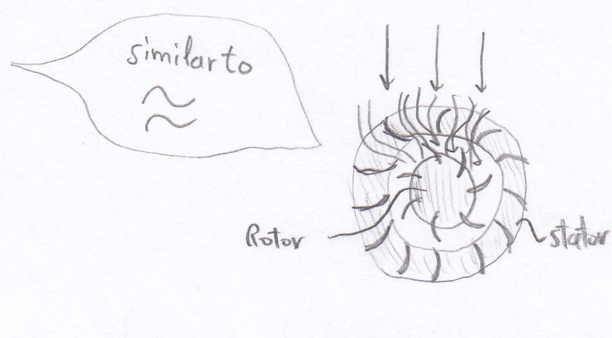
---

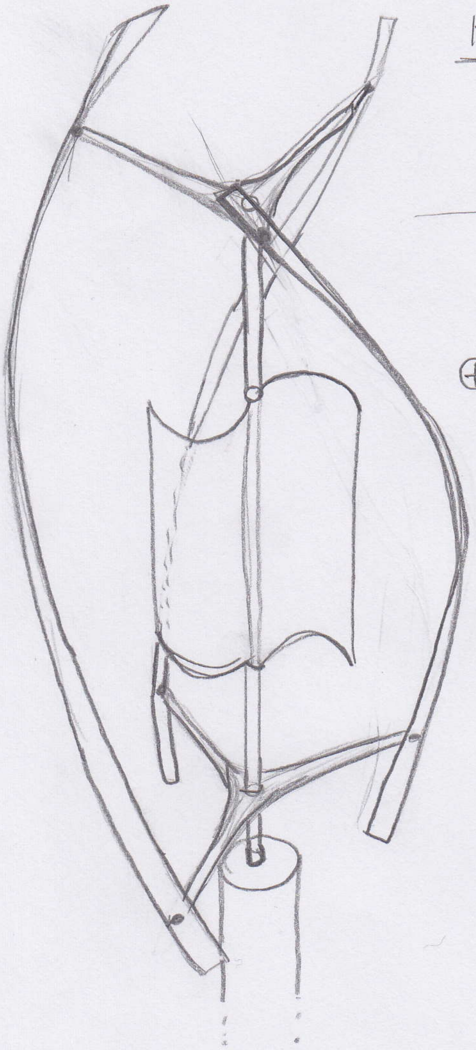
## colector for savonius




(−)
- 1 direction (must be directioned)
- Big structure?
- Savonius ↓ Cp
- No self braking (No resistance)

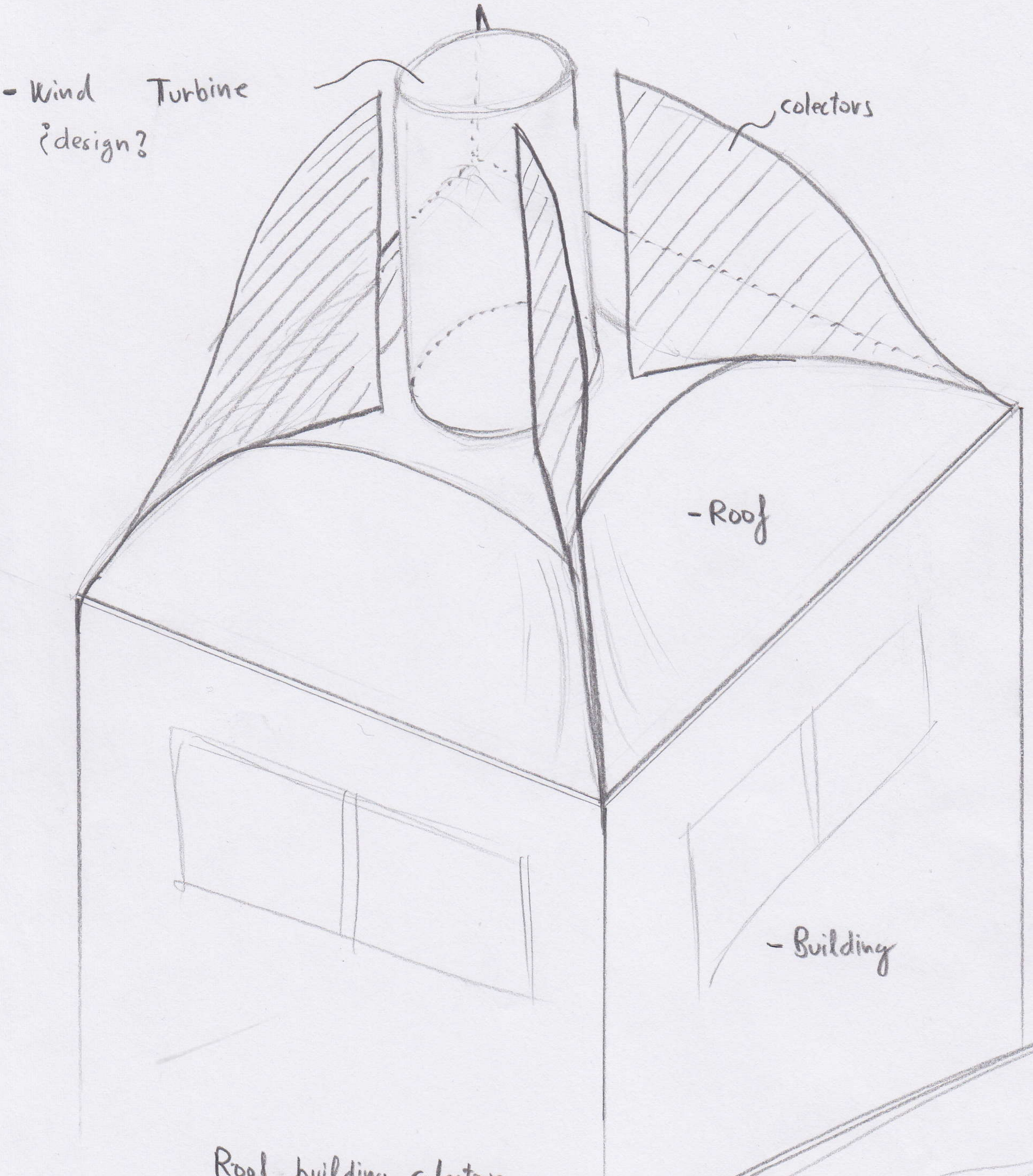
(+)
- ↑↑ more wind (drag)
- Avoids resistance
- More wind ⇒ More speed ⇒ More power



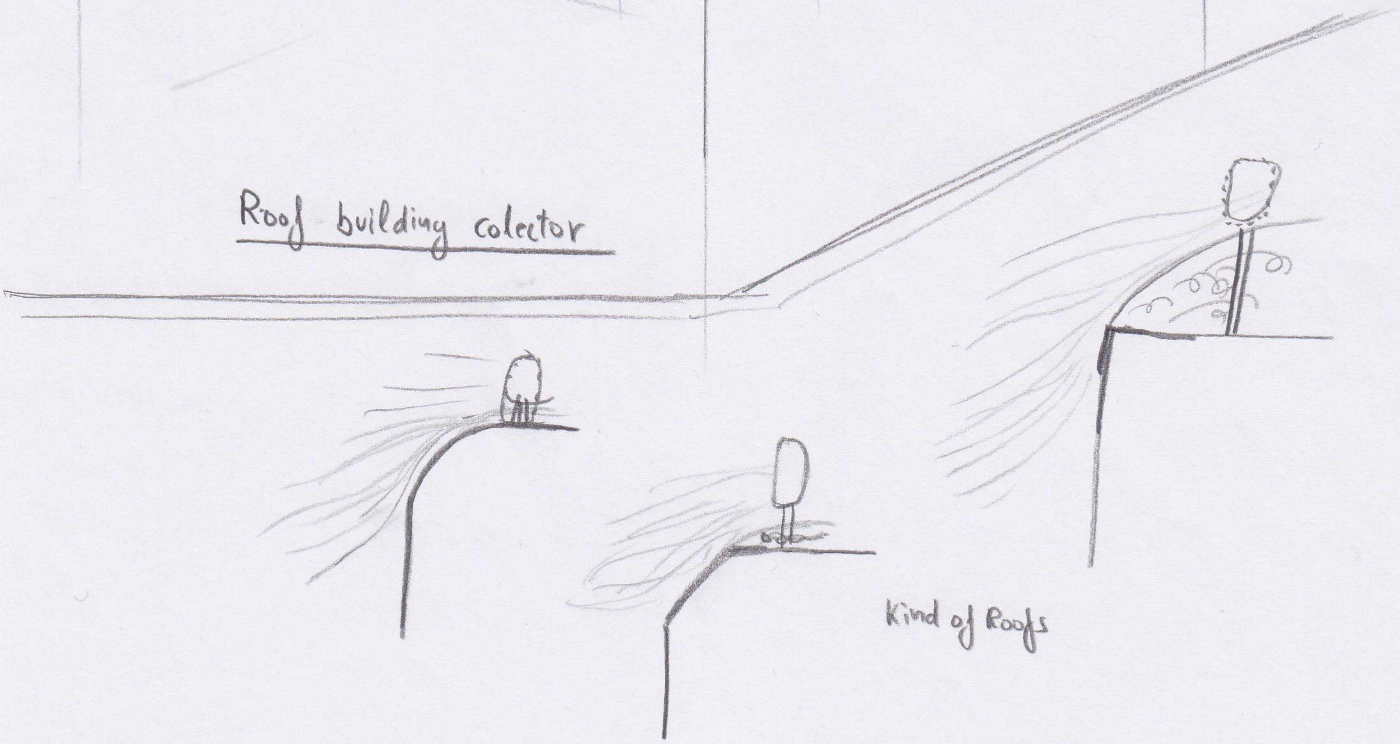


# Helical TWISTED BLADES + SAVONIUS

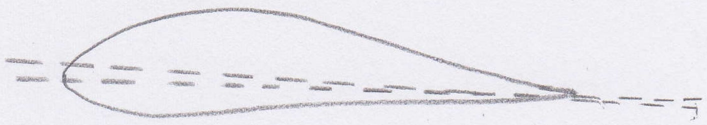
| | Helical twisted blades | + Savonius |
|---|---|---|
| ⊕ | • Lift forces (Cp↑↑) more efficient<br>• 360° direction | • Self starting in slower winds<br>• Self braking at high wind speeds<br>• 360° direction |
| ⊖ | • complex twisted blades<br>• No very birds friendly as other designs | • might cause turbulences? |



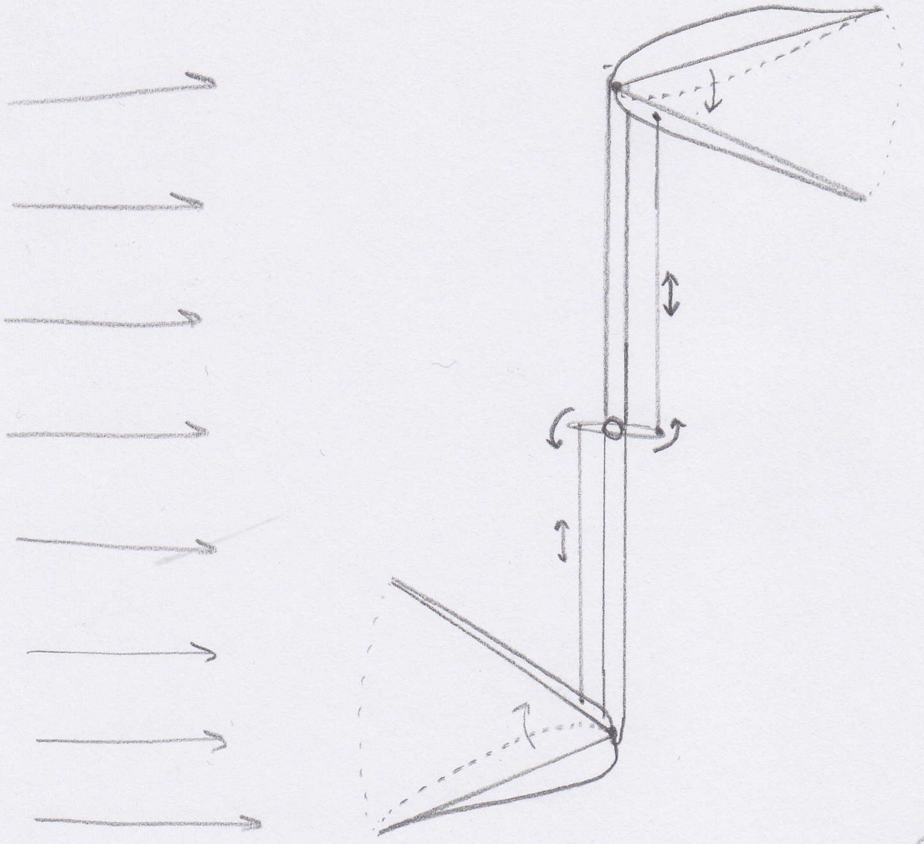

Roof building colector



Kind of Roofs



open blade

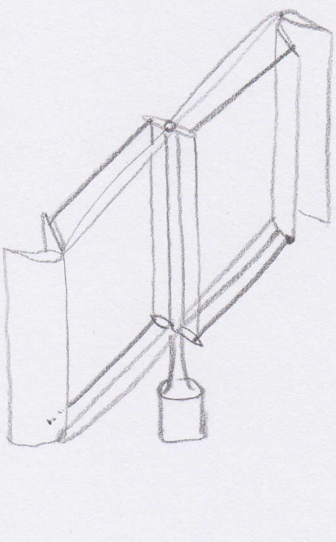


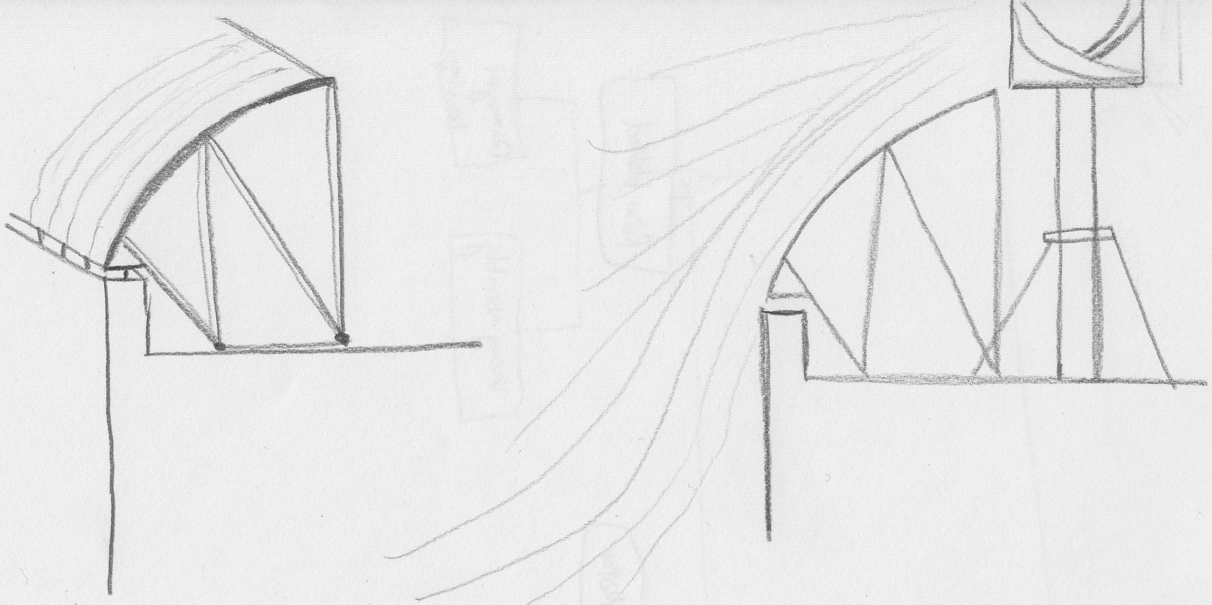
Start

· Savonius (DRAG)

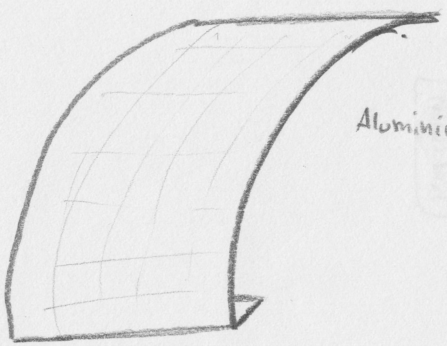
then

· LIFT

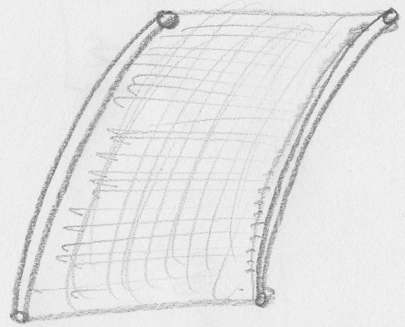




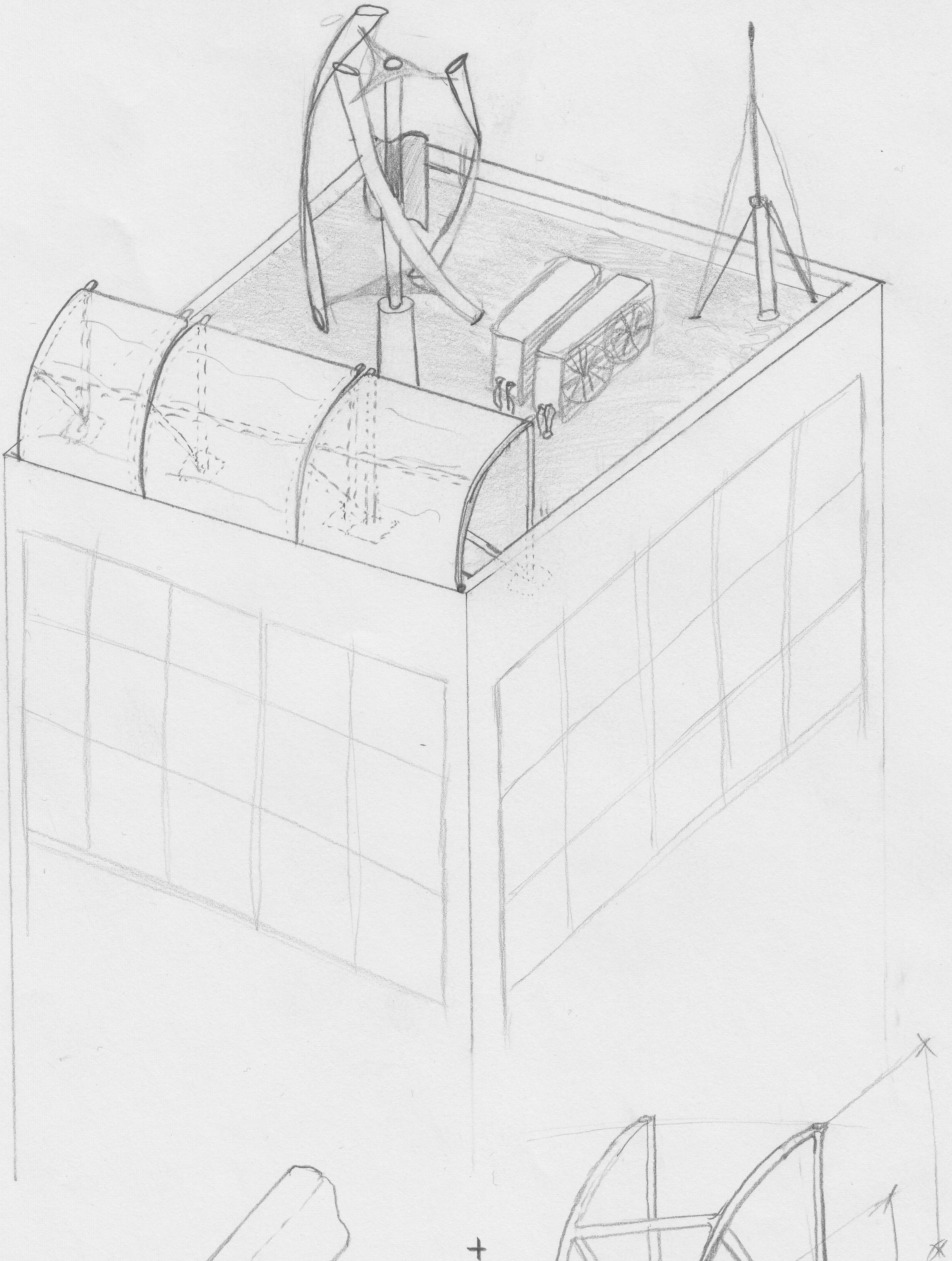
1 piece



Aluminium/composite



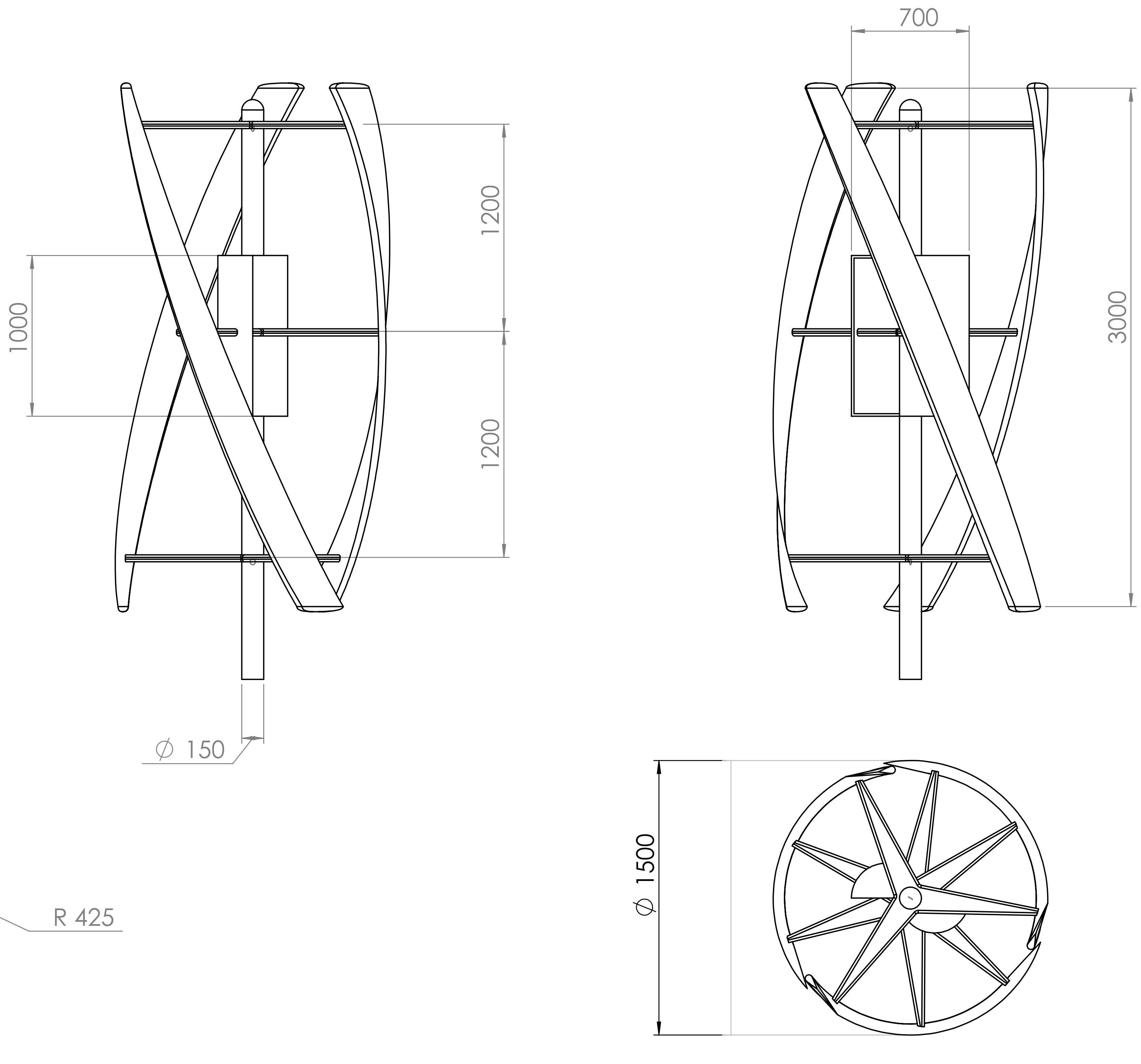
Tubes + plastic cover (printee with camouflage)

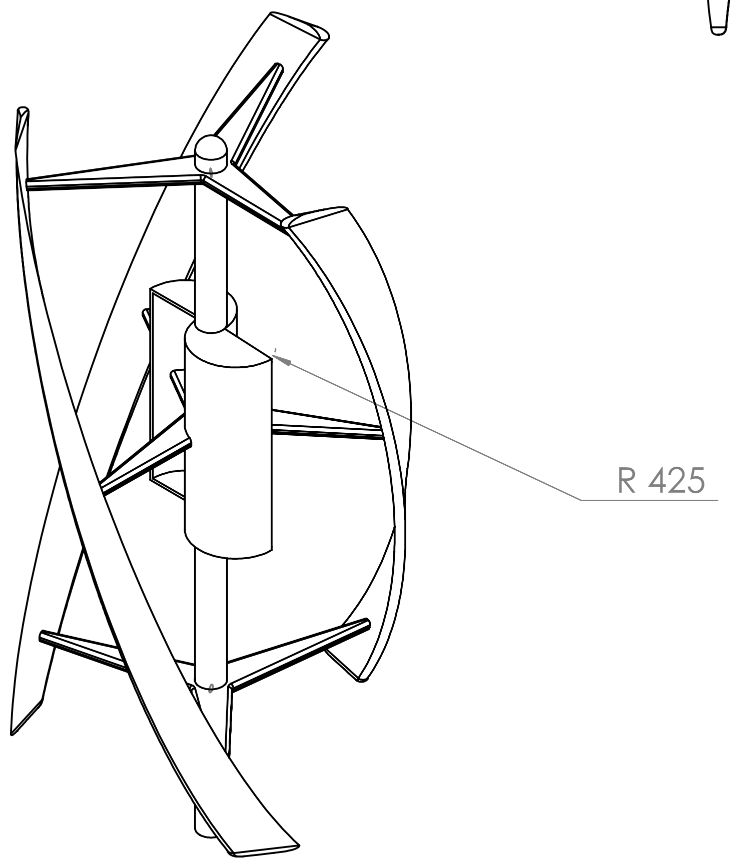


# ANNEX C

CAD

(Software used: SolidWorks 2009 SP3.0 SDK Student Design Kit)




| | SCALE | DESCRIPTION | | STUDY GROUP | |
|---|---|---|---|---|---|
| | SCALE 1:30 | Approximate dimensions | | | |
| DRW: Turbine | mm | TALLINN UNIVERSITY OF TECHNOLOGY | SIZE: A4 | FILENAME: Wind turbine solution | REV |
| DATE: 15/02/2010 | | | | | |