



URBAN WIND ENERGY: CHALLENGES and OPPORTUNITIES

Dissertation submitted for the part of the MSc of Water and Environmental Engineering

Student

Rahmi Güneş Oksay- 6172996

Supervisor

Dr.Prashant Kumar

Dedication

For Suna Özyüksel and Serhan Oksay

I would like to dedicate this thesis beloved parents. Everything that I do is possible because of the love, support and guidance they have given me throughout my life.

Mom, Dad, thank you so much. I love you.

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First and foremost I would like to acknowledge my supervisor and mentor Dr. Prashant Kumar. He has been helpful in the development of this thesis by providing personal and academic guidance and generous amounts of his own time and resources. He was very understanding and helpful at anytime that I needed help.

On a personal note I would like to thank my Grand Father Kazım Oksay for supporting me financially for my education and my good friend Hande Güremek for being there with me through out this phase. I will always remember it. Finally, I would like to thank İpek Şahinler for her continued love, patience and support have facilitated this entire process.

Abstract

Population of this world has more than doubled at the 50 years and it will continue to grow even faster. This will cause cities to grow bigger and constant construction of urban structures will be needed to create new livable areas. This will result more energy need in the coming decades. Today the most utilized energy sources are fossil fuels but we have a limited reserve in our world and cause a lot of pollution while they are being processed. This is where the importance of renewable energy is realized. Sources like sun, wind, hydro power, thermal power and many other renewable energy are infinite, free and environmental friendly. Wind energy is one of the most important sources in renewable energy. Through out the history humans have been utilizing the use of wind and still it is still being used by as means of transportation, pumping, energy production and many other ways. Today it is a part of the growing sector of the renewable energy. Led by EU Wind Energy sector is growing and developing each year massively and as the technology grows the amount of energy generated from a single turbine increases dramatically as the cost of this process drops. In the coming decades this sector will generate lots of quality jobs for the people all around the world. that is why Urban Wind Energy is getting more attention for the past ten years as the need for energy consumption increases and as the importance of global warming is accepted worldwide. There are many studies concerning the Urban Wind Energy Turbines but the complicated structure of urban canopy and the low speed turbulent wind proves to be a challenge. This paper will try to introduce the concept of Wind energy and Urban Wind Turbines in today's world and hopefully provide a better understanding about the interactions of low speed urban wind with urban building designs. To achieve these objectives a series of modeling was done using Solidworks and Solidworks Flow Simulation, results show that the small modifications done at the building construction plan can have a important role on channeling the wind, and effecting the speed. These modifications can be applied to urban structures easily because they are not complex, cities like Guildford might be a good place to start.

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Chapter 1: Introduction

1.1.Motivation

I have been always interested about the real word issues such as environmental and energy problems for our future, that is why I have chosen to study environmental engineer as my undergraduate as well as my MSc on this subject. In my opinion future of Earth and Humanity are bound together and strongly related to environmental issues and energy resources, that is why I wanted to broaden my views on these subject and try to contribute to our mother earth by learning and applying my knowledge to real life. This topic is a new topic for me and I wanted to learn more about it because wind is a renewable energy, it is an infinite source and it is an environmental friendly way of generating energy. So if i can contribute to World in a useful way even though it is small or less significant then some other things I will be happy and i will keep trying until my time comes.

This for this paper was inspired from the study of Edward Ng's paper on 'Improving the wind environment in high-density cities by understanding urban morphology and surface roughness: A study in Hong Kong'. The study showed that the urban canopy has an really important role on the urban wind thus urban wind turbines. Understanding this allows city planners to make their decisions with a understanding of urban ventilation of that city.

1.2.Research Objectives

Objective of this paper is to get a better understanding on the wind energy focusing on urban wind energy and urban wind turbines. Urban wind turbine characteristics and technical details will be reviewed. Following that the challenges and the opportunities will be identified. The main objective is to see how urban wind interacts with the urban building design and the effects of slight modification will be observed to see if any improvements can be made to optimize the energy generation from the urban wind turbines by channeling the wind and increasing the speed.

1.3.Research Approach

A critical literature review has been done on the topics of wind, wind energy and urban wind turbines to get a better understanding of the main concept. These topics will give us a brief introduction to each subject and help us identify the challenges and opportunities.

The Solidworks 2011 and Solidworks Flow Simulation 2011 has been used to represent the modeling the urban environment and urban wind flow. The data, that has been used to simulate the wind, is collected from the UK Wind Speed Database 'NOABL' which will represent the wind speed for Guildford Town Center area. The interaction of urban wind with construction types and slight modifications are presented by pictures then compared and the results are discussed.

1.4.Report Outline

Chapter 1, is divided into four sections. The first section is explaining the motivation behind this paper presents and shows the objectives as bullet points. Showing what methods and identifying the source of data, that are used to achieve the objectives. The final section is outlines framework for the Report.

Chapter 2 , starting with an introduction on renewable energy pointing out the importance of the topic. Followed by a description of Wind and its characteristics. Explaining the theory of energy conversion and the potential of the wind so we can understand the concept of the Urban Wind Energy. The Urban Wind Energy part is introducing us to the urban wind turbine classifications and characterizations with explanations and small comparisons and to finalize, the information presented above is used to identify the challenges and opportunities of today's urban wind energy sector are pointed out. Finished with urban wind turbine design concepts.

Chapter 3, the method and materials are discussed thoroughly. Explaining the setup that has been used to simulate the urban design and the source of data is identified.

Chapter 4, Proposing a solution to channel the urban wind in the urban environment, by presenting the results with graphic evidences that are used for comparisons to see the effects of the design on the urban wind. Examples of use of the design are suggested as conclusion.

Chapter 5, Summary of the paper is presented with the literature review from chapter 2 and the results achieved from chapter. Conclusions on the subject is made and Future Scope of Work is proposed.

Chapter 2: Background Concepts and Literature Review

2.1. Renewable Energy

Today there are two alternative sources for energy production: non-renewable energy sources which are petrol, gas and coal, renewable sources like solar, wind, hydro, thermal and wave. In modern communities nonrenewable energy sources have been used since after the industrial revolution.

With the increasing population and development of civilizations, the use of fossil fuels began to increase. However, the fossil fuels have huge environmental impacts such as ‘air pollution, acid rain and greenhouse effects’ and it is a finite resources on our planet and they are expected to deplete within the next centuries at this usage rate (Şahin, 2004a). As the usage of fossil fuel reserves increased with the growing population the environmental pollution caused by their incomplete combustion has become a serious concern. It became a must for researchers to find clean and pollution free energy sources. World is focusing on the dangers of climate change and the necessary precautions which are need to be taken. Not only politics or media but public is becoming more aware of the needs and desire to use renewable power generation for homes. The issue makes the emerging international micro wind industry even more attractive to public.

Because of energy demand and along with the environmental pollution and global warming caused by fossil fuels and nonrenewable energy sources, cleaner, sustainable and environmental friendly energy alternatives have started to being sought. But the importance of renewable energy was not fully acknowledged till the crises about energy caused in western countries which was in 1973. Thereafter, the research for cleaner and effective renewable energy (RE) sources had been accelerated. Especially the air pollution due to thermoelectric power plants was a huge problem after the industrial revolution. ‘The pollution crises are the catalysts for the search and development of RE sources’ even today (Şahin, 2004b).

With the political support RE technologies received in the EU during the last 30 years, the ‘motives, favoured policies and measures to promote the deployment of electricity from renewable energy sources (RES-E) have differed largely. Later, promotion of RES-E was supported as a mean for an EU-wide security of supply in order to strengthen the competitiveness of the European electricity supply industry. Another motive was increasing employment opportunities in areas with lower economic growth. Finally, in the light of climate changes RES-E is seen as a good alternative to thermal produced electricity that emits greenhouse gasses’ (Şahin, 2004a).

The UK generates 3% of its total electricity from renewable energy sources of which 30% is from the wind energy. The target was set to increase RES-E to 10% of total generation in 2002 and then it was revised to 15% by 2015 in 2005. As the wind energy takes up to 30% of the total energy generation, with this target set, it can be said as one of the best placed technologies to help meet the targets (EU WINEUR, 2005).

The most commonly used RE technologies in urban surrounding have been solar thermal installations, photovoltaic and heat pumps. Only recently various manufacturers are introducing new kinds of wind turbines, which are specially developed for urban surroundings which are also known as urban turbines (UT). These turbines generate the electricity on-site where it is going to be used at. This way any transport loss is prevented, owners can show their commitment to promoting green energies.

Urban turbines are however at a slight disadvantage in the market. The reason is because they are new to the market according to lack of knowledge about these products. In order to permit their potential development there is more information related to current technologies, their economics, the regulations, guidelines and procedures needed.

2.2.Wind

Wind energy is dependent on the Solar heat , caused by sun. The solar heat does not have a uniform effect on our earth because of its shape and the degree that it orbits the sun. So these differences of solar heat effects results as the wind. ' 1–2% of solar energy is converted into wind energy' (Eggleston, 1987). As a result as long as we have the sun, we will have wind energy. Which will be basically a form of converted sun energy. It is limitless (as long as the sun exists.), it is free, it is clean and it is naturally formed. All these aspects make the wind energy a reliable source with huge potential for the future. (Ilkılıca, 2010).

Wind turbines of today are being operated on the earth's atmospheric boundary layer (ABL). 'The ABL is the part of the troposphere that is directly influenced by the presence of the earth's surface and responds to surface forcing with a time scale of about an hour or less' (Quaschnig, V., 2005). Within the ABL air mixes turbulently from the change of heat resulted by the sun-heated ground during the day. We can talk about a wind velocity distribution within the surface layer of the ABL, from the earth's surface through the increased elevations. There is a general wind velocity distribution within the surface layer of the ABL (Figure 1). As the elevation increases, so does the wind speed.

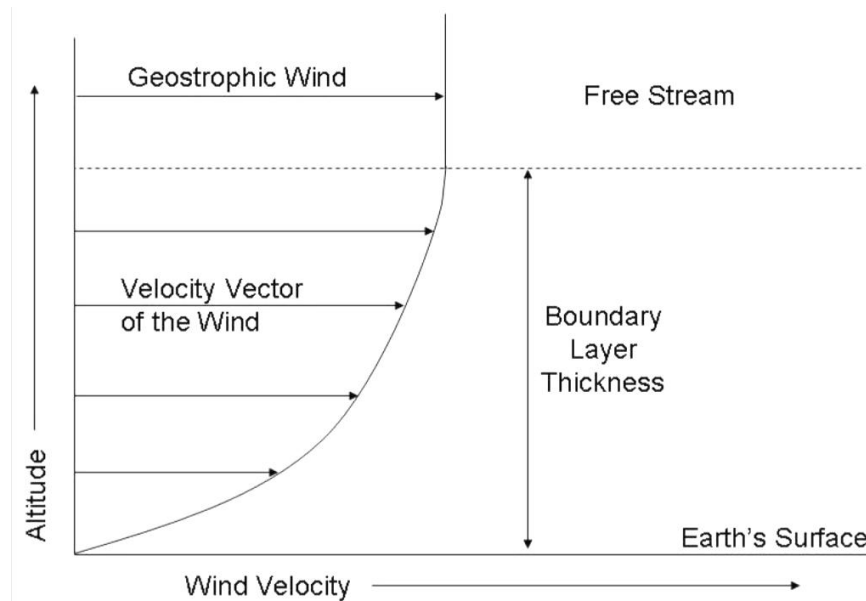


Figure 1 Boundary layer wind velocity distribution (Quaschnig, 2005)

Power law is described below in an equation. As you can see from the formula wind speed depends on the roughness on terrain surface. ‘Above the ABL, in the ‘free atmosphere’ the winds are primarily geostrophic and relatively uninfluenced by the surface of the earth’ (Quaschnig, 2005).

$$U_z = U_{10} \left(\frac{Z}{10} \right)^\alpha$$

U_z = wind speed at height Z in meters

U_{10} = wind speed at height 10 meters (determined empirically)

α = exponent based on terrain surface roughness

Within the first hundred meters of the ABL elevation affects the speed of wind extensively. The windy side of a mountain can almost double the uninfluenced value to higher altitudes where has greater wind velocity. On the other hand, wind speed is greatly reduced on the lee side (Quaschnig, 2005).

Wind can be effected by many different things like forests, buildings etc. This will cause wind to lose speed and slow down. That is why the hub height of our system should be at least tree times higher than the nearest obstacle or should be placed at a distance of 35 times the height of the obstacle, to get our system to work at optimal wind speeds. Wind speed will always increase with height as it is able to move through without any roughness (as in without any obstacles blocking its way). and becomes increasingly less dependent of height at altitudes greater than 100 m (Quaschnig, 2005).

If we try to define wind energy in physics, we can say that the power of the wind energy is the amount of kinetic energy available within a certain unit time. So if we multiply the pressure on the winds projected surface, we can get the force. Then multiplying this force by distance covered to get the energy and subsequently dividing this energy by the unit time over which it is measured.' (Quaschnig, 2005).

This process is outlined in Equations:

Dynamic Pressure:

$$p = 0.5 * \rho * V^2$$

Force:

$$F = p * A = 0.5 * \rho * V^2 * A$$

Energy:

$$E = F * \Delta L$$

Power :

$$P = E / \Delta t = F * (\Delta L / \Delta t) = F * V = 0.5 * \rho * V^3 * A$$

$$P = 0.5 * \rho * V^3 * A$$

where,

p = dynamic pressure

ρ = density of the air

V = wind speed

F = force

E = energy

P = power

A = cross-sectional area of the wind

ΔL = unit distance

Δt = unit time

The speed of wind is effected by the solar rays, so as the earth constantly moves in the universe, different magnitude of solar rays effect our atmosphere causing wind speed to change constantly. 'At extreme cases, with the change of temperature, pressure and elevation the density of air can change up to 30%.' As the temperature drops, it causes density to increase with lower elevations. So colder climates which are closer to the sea level will result in maximum energy capture (Gipe,1999).

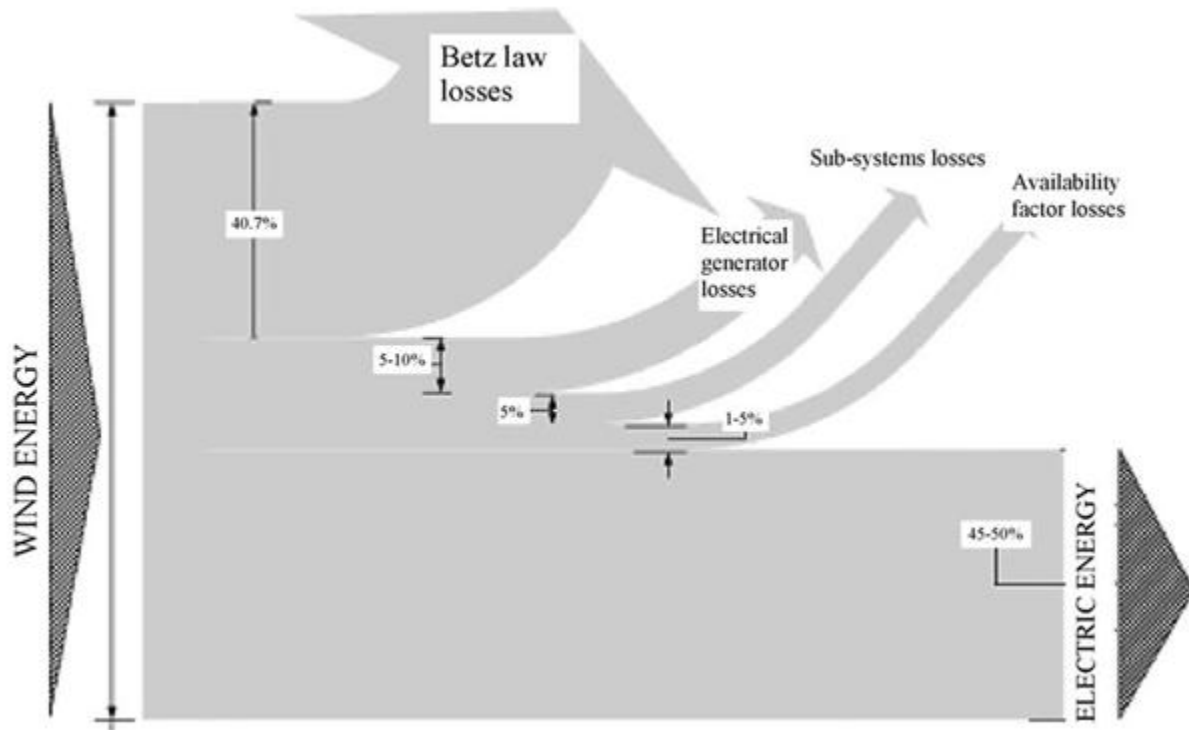


Figure 2 Diagram on efficient wind park – (Koroneos, 2011)

'The theoretical maximum amount of power that can be extracted from the wind using a lift driven device, the Betz Limit, was first determined theoretically by Albert Betz and is equal to $16/27$ (59.3%). The Betz limit is reached when the rotor reduces the wind speed by one third. To come close to this theoretical maximum the turbine needs high rotor speeds with low torque, as high torque produces greater wake losses' (Gipe,1999).

Torque and rotational velocity results in power formation therefore if we decrease the rotor torque and keep the rotational velocity as high as possible then it is beneficial.

As the equation above refers that the power of wind varies with V^3 results in such consequences:

- wind speed determines the site selection. The stronger and steadier the wind the better it is.
- design of the turbine's speed also depends on the wind speed. It is usually twice the average measured wind speed
- turbines may not turn in low winds
- a rapid increase in wind speed can quickly bring a wind turbine to its maximum rated value of power generation resulting in the need for controlling actions (Twidell,1998).

2.2.1. Classification of Wind by Variables

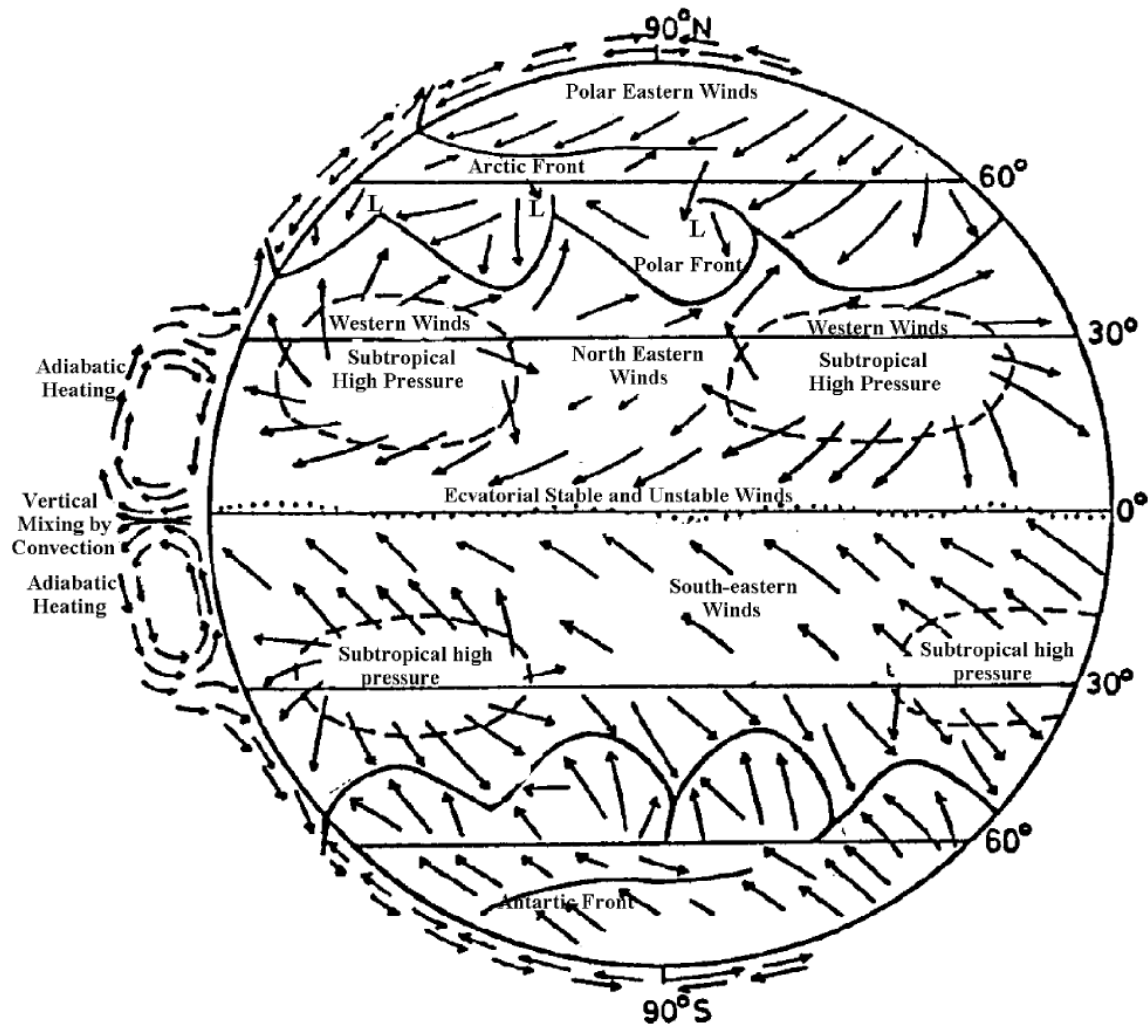
This section will provide a short explanation to certain wind types.

2.2.1.1. Geostrophic winds

Geostrophic wind is the wind with no friction and which blows parallel to isobars. In nature winds are approximations to geostrophic winds near to the troposphere. The wind can only be considered as geostrophic when there is straight isobars and no other forces acting on it. These conditions aren't found much in real circumstances. (Şahin, 2004a)

2.2.1.2. Gradient winds

Gradient winds have non-straight flow and with the consideration of centrifugal force they are more suitable to represent real wind. 'All the winds that occur at low and high-pressure systems with consideration of centrifugal force give a real approach to wind physics' (Şahin, 2001, Arya, 1988). 'Non-theoretical winds depend on the topographical conditions and features, which are sea-land and valley breezes together with adiabatic-catiabatic winds with thermal origin' (Şahin, 2004a).



General circulation.

Figure 3 Dynamic behavior of the Wind at World (Şahin, 2004a)

The figure above shows the behavior of the wind through out the globe.

2.2.1.3. Power Available in the Wind

Potential in the wind in terms of power :

$$P_w = 0,5. \rho. A. v^3$$

P_w = the power in the wind,

ρ = the air density (kg/m^3),

v = wind speed (m/s),

A = swept area of rotor (m^2)

As the wind speed increases the power increases tremendously due to ' V^3 '. Thus nearly all the wind turbine facilities are built in areas with a steady and high wind speed. Another factor when designing the wind turbine is the height. As the height increases so does the wind speed, resulting wind turbine designs to constantly build towers with increased height. Since the power is also proportional to the swept area, the mean diameter of rotors has also been steadily increasing' (Şahin, 2004a).

2.2.1.4. Power produced by a turbine and the power coefficient, C_p

The coefficient of power, C_p , is the ratio of power from a turbine (PT) to the power available in the wind and therefore indicates how effective a turbine is at extracting power:

$$C_p = P_T / 0.5 \cdot \rho \cdot A \cdot v_1^3$$

C_p for a particular turbine varies with the ratio of rotor speed to wind speed. The ratio of the speed of the rotor tip to the wind speed is called the tip speed ratio (TSR), TSR, or more commonly, λ . C_p also depends on the number of blades, blade plan-form, twist, aerofoil section.

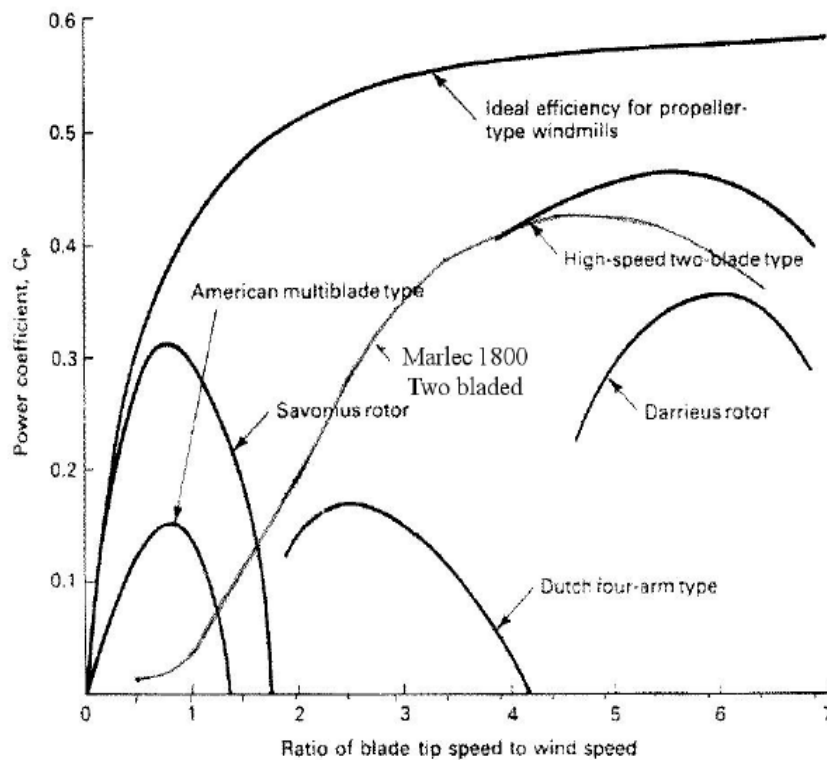


Figure 4 : C_p vs λ curves for various turbine configurations (Şahin, 2004a)

‘The wind speed/rotor speed relationship has important affects the operation of turbines. Varying that relationship can lead to operate some turbines at the highest possible C_p for a range of wind speed. This is called maximum power point tracking. In order to provide the maximum energy from a specific side, the wind turbine can be set to the rated wind speed of operation. A typical guide rule is to make rated wind speed equal to half the site average wind speed.’ (Şahin, 2004a).

2.2.2.UK wind resource

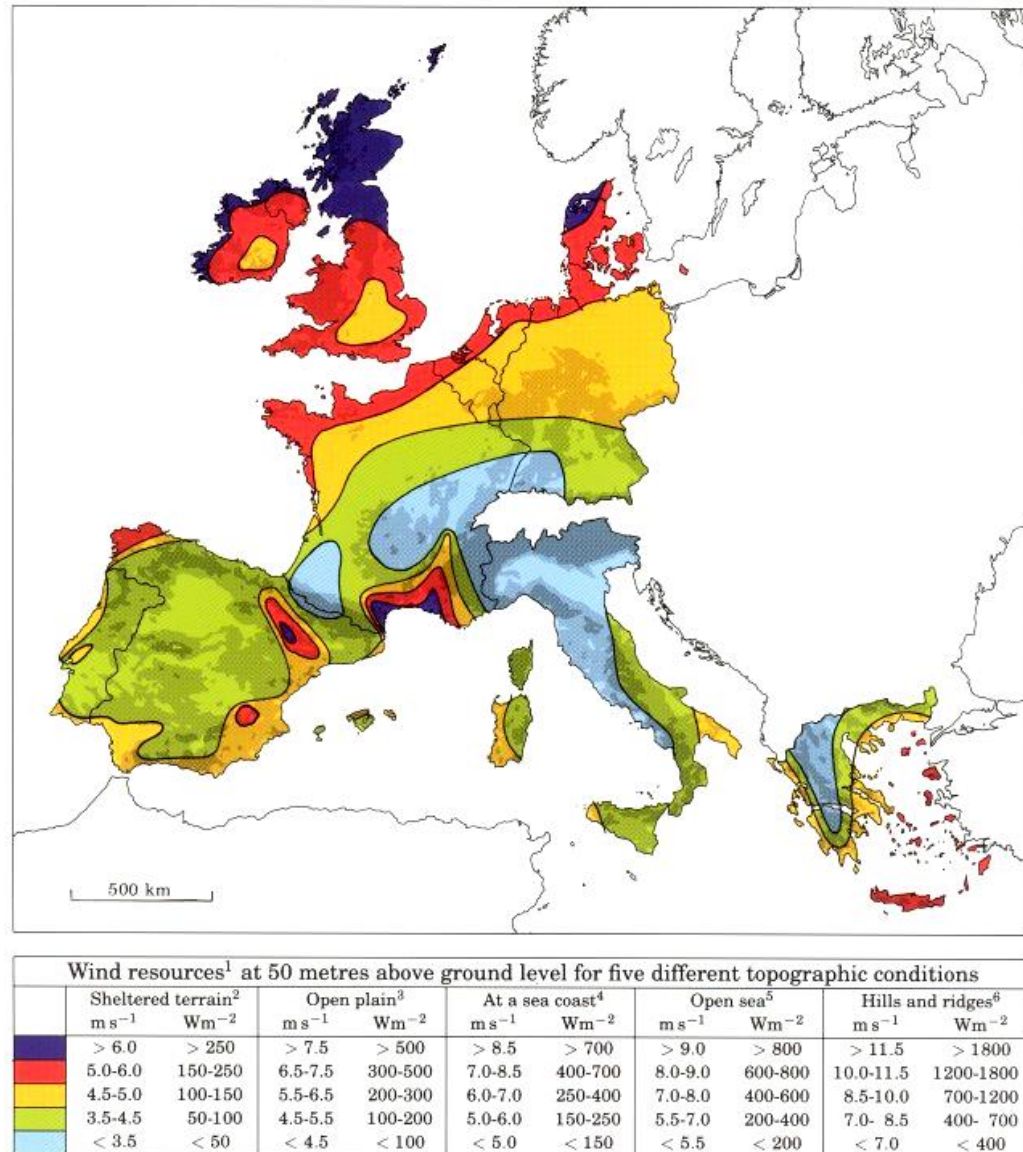


Figure 5 Wind resources at 50 meters above ground level for five different topographic conditions (URL1)

As you can see from the figure taken from the ‘European Wind Atlas’ UK is the windiest country in Europe. Just by using the wind energy, UK can sustain itself without using any other different energy source. ‘A modern 2.5MW turbine at a reasonable site will generate 6.5 million units of electricity each year, enough to meet the annual needs of over 1,400 households, make 230 million cups of tea or run a computer for 2,250 years’ (Millborrow, 2011b).

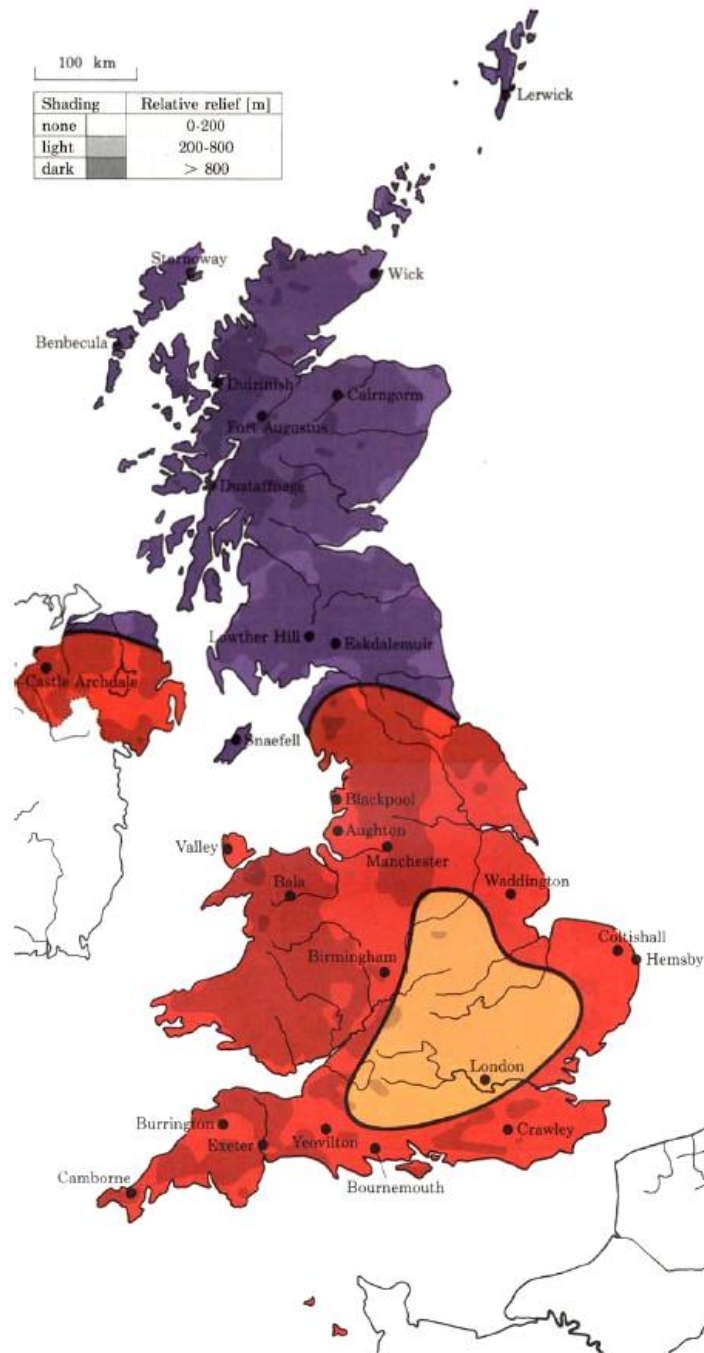


Figure 6 Wind resources at 50 meters above ground level for five different topographic conditions for UK (URL 1)

Even though Germany has the highest generation of wind power in Europe, the UK has the highest wind resources. At the hills and ridges of north and west of the country there is the highest wind speeds. South and east parts of the country on the other hand, has lower resources in comparison. However, even with the lower values within itself the generation potential is still good by European standards.

Currently in UK the wind energy has become the largest renewable energy source. Approximately 2percent of UK's energy need is supplied by wind energy. UK had the capacity to prevent the emission of 3,682,563 tonnes of carbon dioxide per annum at 2009' (Millborrow, , 2011b).

2.3.Wind Energy

Wind is an infinite energy source and it has been around since the beginning, it has been utilized by many civilization throughout the history. This section provides information about wind energy from past and current time.

2.3.1.History of Wind Energy

The power of the wind is being utilized for thousands of years and still it is one of the most important sources of energy. The first wind energy was used for boat navigation on the Nile River around 5000 BC. Later on and for a long time, the wind power has been used to sustain mechanical energy to grind cereals, to carry or pump water, to drain marshes and lakes and for irrigation. The very primitive windmills had vertical axis and it is well-known that vertical axis wind turbines were used by Persians during 700 before Christ. Although later, windmills with horizontal axis became widespread. The very first recorded info about wind turbines is based on an elementary structural horizontal axis wind turbine during the predomination of Alexander the Great. In addition to Persia; China, Afghanistan and Tibet were the other places where the windmills were first used. (şahin, 2004)

“These machines remained unchanged until the 12th Century, when almost simultaneously in France and England the horizontal-axis or Dutch-type windmill made its appearance.”(Hunt, 1981, Bellarmine,1996). “The first horizontal axis windmill appeared in UK around 1150 AD, in France 1180, in Flanders 1190, in Germany 1222 and in Denmark 1259 AD. This rapid spread is most likely influenced by the Crusaders who carried the knowledge of windmills from Persian to Europe. In Europe, windmill performance is continuously improved between the 12th and 19th centuries. By the end of the 19th century, the typical European windmill used a rotor of 25 m in diameter and the stocks reached to 30 meters.” (Şahin, 2004b). In the late 19th century, the windmills were providing the 90% of the Netherlands's energy and 20.000 modern windmills were in use in France. With the rise of

industrialization and the era of steam power, the windmills lost importance but even in 1904, windmills were making up 11% of the Dutch economy. As the time went by, the industrial revolution made the windmill power disappear and settlers introduced themselves to North America. Thus, small windmills became self-regulated systems which catered for livestock and pumping water. The use of small scale wind systems were limited to remote areas, or for battery charging. With the oil crises caused by oil embargo to give a warning to western civilization at 1970's, the interest in the renewable energy sources grew. So the investments in renewable energy sources such as wind started to receive financial support. Some EU countries such as Germany, Spain, Denmark and USA, developed large scale wind turbines at MW ranges. It is known that today's wind turbines are a result of the previous studies. As the studies uncover the secrets behind the aerodynamics technology and other fundamental cores of physics, the wind systems evolved. Thus resulting in an increase at mass production and reliability. Behind all these developments, the main issue is the profitability. Everything is done in order to get more from the wind energy. Because even though the wind is limitless, the earth has its own limits and the spaces available to install these wind systems are limited. So we need to make a good use with our space and technology. 30 years ago a 300kw with 30m diameter was considered the state of art, but today we have got 1-3MW sized systems in mass production that are considered normal. (Şahin, A.D., 2004a).

Since the energy of crisis in 1973, there is an interest in renewable energy sources. “There has been installed more than 120GW of new capacity in more than 50,000 wind turbines over the world.” (Michalak, 2011). Today, the wind energy has reached its peak again and is one of the biggest and fastest growing sectors of economy.

2.3.2. Wind Energy in EU

The wind energy and its development was a crucial issue for the Europeans that they promoted this issue by legal arrangements. For instance, France joined “Eole2005” in 1996, aiming 500MW till 2005. Renewable Energy Sources Act (EEG) started to process in Germany in 2000 and that renewable energy sources which were being used for electricity had priority for grid connection, grid access in transmission and power dispatch. The grid operators’ job was to feed in electricity coming from renewable sources and to appropriate it with the lowest price. In 2008, the law was coordinated and different prices of electricity were introduced depending on their type of production. The two types of electricity were local wind and reference yield electricity. On very good sites, wind installations receive the initial tariff for five years whereas on less ideal sites turbines could receive it for a longer time. The tariffs should be paid maximally for 20 years. European Union accepted the Strategy for Sustainable Development in 2001 and a 20-40% of reduction of emissions by 2020 was supplied.

After this, there was a change in energy policies of European countries. “Decision of the Council of Europe from September 2001 stated the need for greater development of renewable energy sources: 22% of energy by 2010 in energy balance of the EU. In March 2007 the European Commission adopted

energy goals by 2020. They are: the share of 20% renewable energy in the total energy production, increase of energy efficiency by 20% and reduction of CO2 emissions by 20%. Germany has the highest wind power generation within Europe. In 2001 Germany had 2079 wind turbines and a total capacity of 2641MW. 53% of the new installations in 2002 in Europe was in Germany. German market is in 90% cornered by six major companies: Enercon, NEG-Micon, Nordex, Vestas, DeWind. In turn, the Spanish market a major role leads seven firms: Gamesa, EHN, Vestas, GEWind, Ecotecnia, Siemens and Nordex.” (Michalak, 2011)

In Europe with the use of such reliable and clean power generated by a natural renewable resource serves both domestic consumers and high energy use industries reduced power costs even more cheaply than today. On that base, wind energy can be a driver to European economical growth as well as being environmental friendly.

The potential of the wind electricity potential is huge, but to achieve it the right type of planing, communication and investment needed. If all the above factors are achieved, the electricity production from EU has a potential to increase to 83TW (2005) to 965TW (2030), which will result in supplying approximately 25 percent of EU's energy consumption. 'This projection takes into account that consumption is expected to increase by half over the same period' (TPWind Advisory Council, 2006).

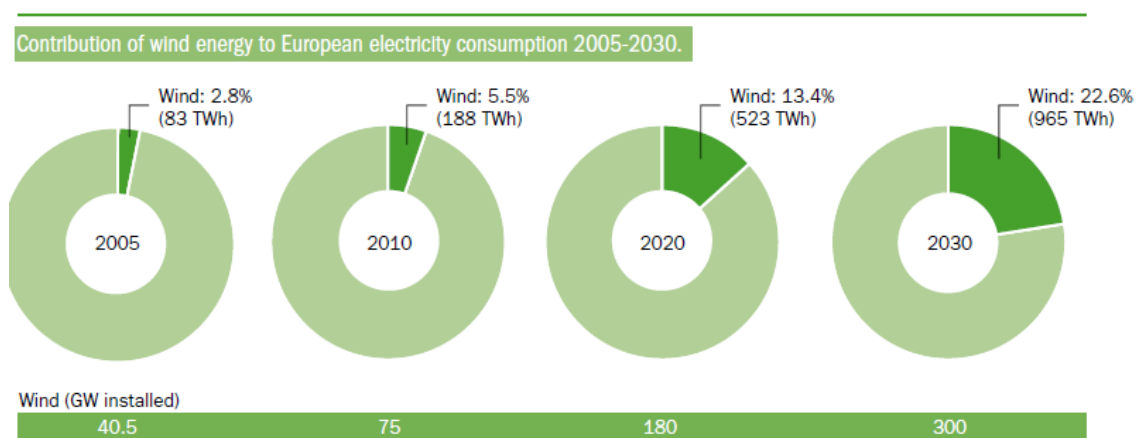


Figure 7 Contribution of wind energy to European electricity consumption 2005 - 2030 (TPWind Advisory Council, 2006)

2.3.3.Wind Market

The wind market is on a healthy course. In the beginning of 2011, 17GW of new generation capacity have been commissioned globally. More capacity, particularly in China , has been completed but not yet connected. Total global capacity is now more than 41GW higher than last year with the added capacity particularly from China. The expectations are for the global capacity to reach 230-240GW by the end of 2011 in other words, 25% higher than at the corresponding period last year. However, this

depends on the progress in China. If the progress slows down the 230GW target may not be reached (Millborrow, 2011a).

Table 1

Continent	Gross potential, TWh/year	Technical potential, TWh/year
Africa	106,000	10,600
Australia and Oceania	30,000	3000
North America	139,000	14,000
South America	54,000	5400
East Europe	106,000	10,600
West Europe	31,400	4800
Asia	32,000	4900
The World total	498,000	53,000

(Millborrow, D., 2011a)

Wind Energy Potential in the world

‘The average price for a wind-turbine in Europe is €1 million per megawatt.’ Some turbine prices have dropped in US since the market has slowed down at 2008 but the development for optimizing the wind turbine performance still continues. The trend is towards big tubines and it is thought that the capacity will not exceed 2-3MW at future for the most part (Millborrow, 2011b).

‘Offshore generation costs can be twice those of onshore, but several published analyses forecast significant reductions. There is some regulatory uncertainty in the UK , as the government continues to develop its proposals for electricity market reform. So far, developers and financiers appear to be split fairly evenly over the merits of these proposals’ (Millborrow, 2011b).

After 11 March Japanese earthquake at fukushima, there might be a need for some modifications for nuclear power plant which will inevitably increase nuclear costs. In the world most of the wind turbine developments are onshore, however there is a huge potential for offshore wind farms. Some countries like Germany, UK and US are strategically planning to increase their offshore investments. If the trends from the past 25 years continues, the global wind electricity that is generated will increase by 55-60GW, and there are many different ongoing projects that will increase this amount. So if we assume that 55GW added to global operating wind capacity in 2011, the annual addition would be 47% more than that achieved in the boom year of 2009. It would bring the world total to around 245GW - 10GW more than projected by the Global Wind Energy Council (GWEC) (Millborrow, 2011a).

Table 2

		End 2010	11-Oct	Extra MW	Change %
1	Europe	86,328	90,728	4,400	5
2	Asia Pasific	56,941	65,952	9,011	16
3	North America	44,231	47,520	3,289	7
4	South America	2,178	2,282	104	5
5	Middle East/Africa	1,052	1,062	10	1
	WORLD	190,730	207,544	16,814	9

(Millborrow, 2011b)

Current world's installed wind energy level

If we are to look at to Table 2, we can see that Europe is the leader at installed capacity of the world, but Asia Pasific region is growing really fast thanks to China and India's new installments.

Table 3

	NUMBER	COUNTRY	End 2010	11-Oct	Extra MW	Change %
EUROPE	1	Germany	27,126	27,510	384	1
	2	Spain	20,674	21,396	722	3
	3	Italy	5,798	6,389	591	10
	5	UK	5,248	5,774	526	10
	13	Turkey	1,278	1,278	0	0
ASIA PASIFIC	1	China	38,280	45,440	7,160	19
	2	India	13,066	14,550	1,484	11
	3	Japan	2,304	2,446	142	6
NORTH AMERICA	1	United States	40,216	42,908	2692	7
	2	Canada	4,015	4,612	597	15
SOUTH AMERICA	1	Brazil	930	1,000	70	8
	2	Mexico	717	717	0	0
	3	Chile	168	168	0	0
MIDDLE EAST AFRICA	1	Egypt	550	550	0	0
	2	Morocco	287	287	0	0
	3	Iran	91	110	19	21

(Millborrow, 2011b)

Top countries in Installed Wind Energy Capacity

UK is at 5th place in the EU (table 3). UK installed wind energy capacity has increased almost 4 times since 2004, in 5 years. This suggest that the wind energy is becoming more and more of an importance in the governments renewable energy politics.

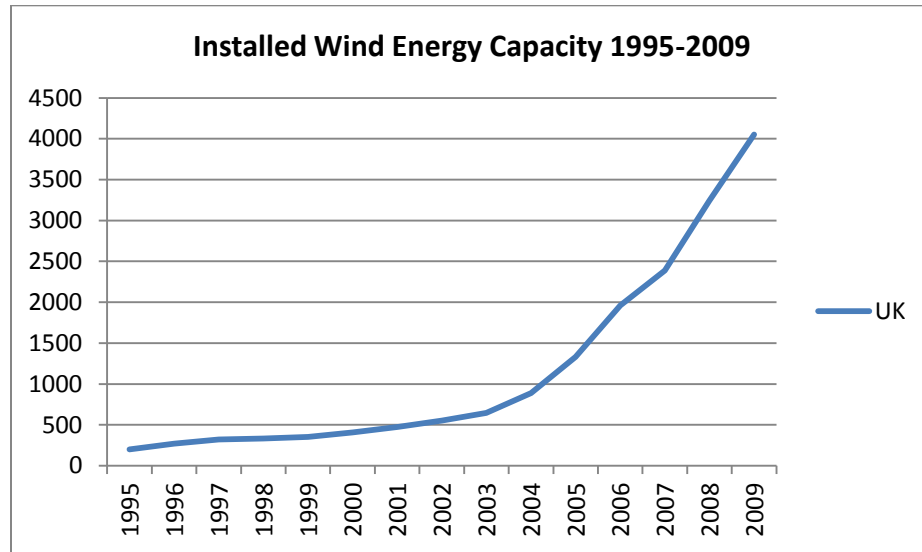


Figure 8 Installed Wind Energy Capacity 1995-2009 (Michalak, 2011)

UK has the highest wind resource potential in EU but still if we compare UK to Germany on installed wind energy capacity size at table 5, we can see that UK has not been investing to this sector as much as Germany does and still has a huge potential for increase in the wind energy sector.

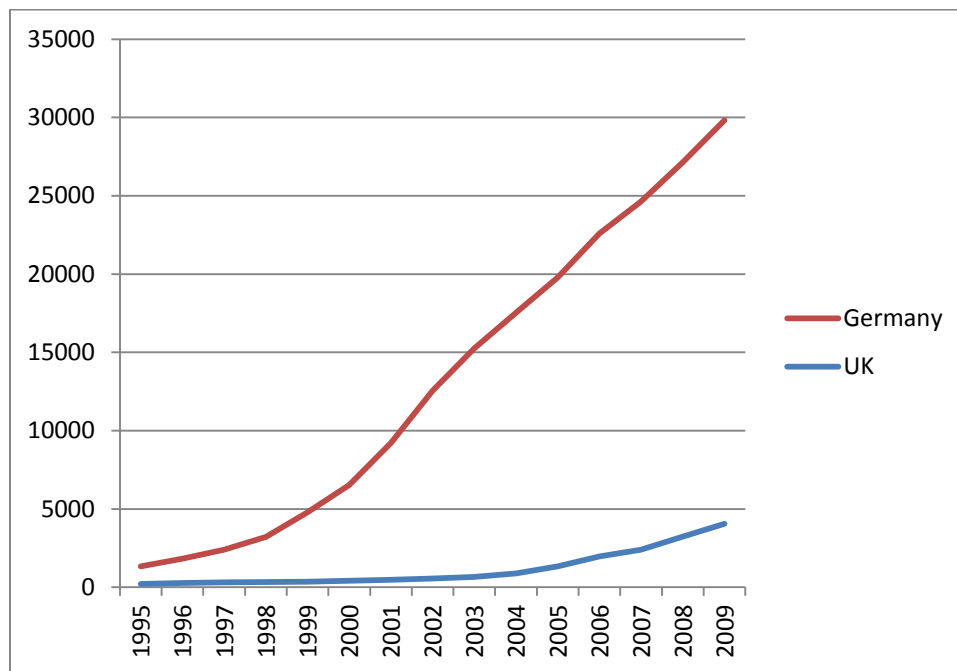


Figure 9 Comparison between UK and Germany on installed capacity of wind energy through 1995 to 2009(Michalak, 2011)

2.3.4. Categorization of Wind turbines

Wind turbines can be categorized according to the amount of their energy generation. Currently we can separate the wind energy systems into 4 different sections in terms of energy production. (EU Commission, Wind Energy Facts)

a.Micro-turbines (< 3 kW): Micro turbine energy production ranges are between 0 to 3 kW approximately. They mostly use (%90) of direct drive permanent magnet generators (PMG) for battery charging. *‘The market is for remote telecommunications, electric fences, domestic systems, nomadic peoples, leisure craft and caravans’* (EU Commission, Wind Energy Facts)

b.Small wind turbines (< 30 kW): These systems are highly reliable and they don’t require excessive maintenance. (EU Commission, Wind Energy Facts)

c. Large wind turbines (< 1.5MW): For these turbines direct drive system benefits from lower costs as well as ‘reduced tower-head mass and nacelle length, efficiency savings of several percent. It is as yet unclear if these benefits are being realised in present designs, but it is quite clear that the new technology is already on a par with conventional solutions. Turbines with direct drive systems range from 200 kW to 1.5 MW (production and prototype machines).’ (EU Commission, Wind Energy Facts)

d.Multi-megawatt design (< 1.5MW): ‘Although the wind industry has demonstrated the technical and commercial feasibility of units of about 1.5 MW, and larger wind turbines have been built, In some land based applications and in the offshore application especially, yet larger generating units are desirable.’ Research shows that UK’s interest in this area is growing and some big designs are discussed (EU Commission, Wind Energy Facts).

‘Multi-rotor systems with a number of rotors on a single support structure are a possible route to units of 5 to 10 MW capacity for good economics with minimum innovation and development costs.’ (EU Commission, Wind Energy Facts)

According to Şahin we can also classify wind turbines according to their design methods. ‘Modern grid-connected wind turbines usually follow the ‘C’ approach, because of better power quality, lower TSRs approach ‘B’, hence lower visual disturbances, and finally, lower material requirements than in approach ‘A’, as the structure does not need to withstand high wind loads, hence lower cost.’ (Şahin, 2004) Further explanation of these types can be seen on table 6 below.

Table 4

Types of Modern Horizontal Wind Turbines	A - Turbines designed to withstand high wind loads	B - Turbines designed to compliant and shed loads	C - Turbines designed to manage loads mechanically and/or electrically
Details	-optimize for reliability -high solidity, but non optimum blade pitch -three or more blades -lower rotor TSR	-optimize for performance -low solidity, optimum blade pitch -one or two blades -higher rotor TSR	-optimize for control -mechanical and electrical innovation (flapping or hinged blades, variable speed generators, etc.) -two or three blades -moderate rotor TSR
Example	Precursor: Gedser mill	Hütter turbine	

(Şahin, 2004)

Types of Modern Horizontal Wind Turbines

2.3.5. Wind Turbines in EU

Wind energy systems develop every decade and achieve greater technology. 30 years ago a 300kw with 30m diameter was considered the state of art, but today we have got 500KW-1MW sized systems in mass production that are considered normal. Compared to the old systems, todays wind tubines can achieve 180 times more electricity and at less than half the cost per kilowatt hour (kWh) than its equivalent of 20 years ago.(TP Wind Advisory Council, 2006)

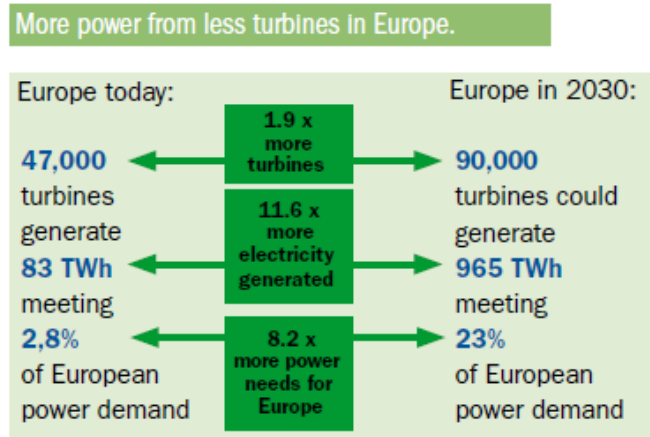


Figure 10 EU today and future (TP Wind Advisory Council, 2006)

So if this trend continues, we can assume that by 2030, the size of an average wind turbine system will reach 2MW onshore 10 MW offshore. Thus lesser amounts of wind turbines will be needed to produce the same energy target. (only 90,000 turbines (75,000 onshore and 15,000 offshore) would be needed to fulfil the 300 GW target). All the current wind turbine systems will finish operating by 2030 and most likely will be replaced by the newer systems, because usually the average life span of a wind turbine system is twenty years onshore and twenty-five years offshore. The number of wind turbines standing in 2030 will most likely be twice the number and yet generating twelve times as much power. (TP Wind Advisory Council, 2006)

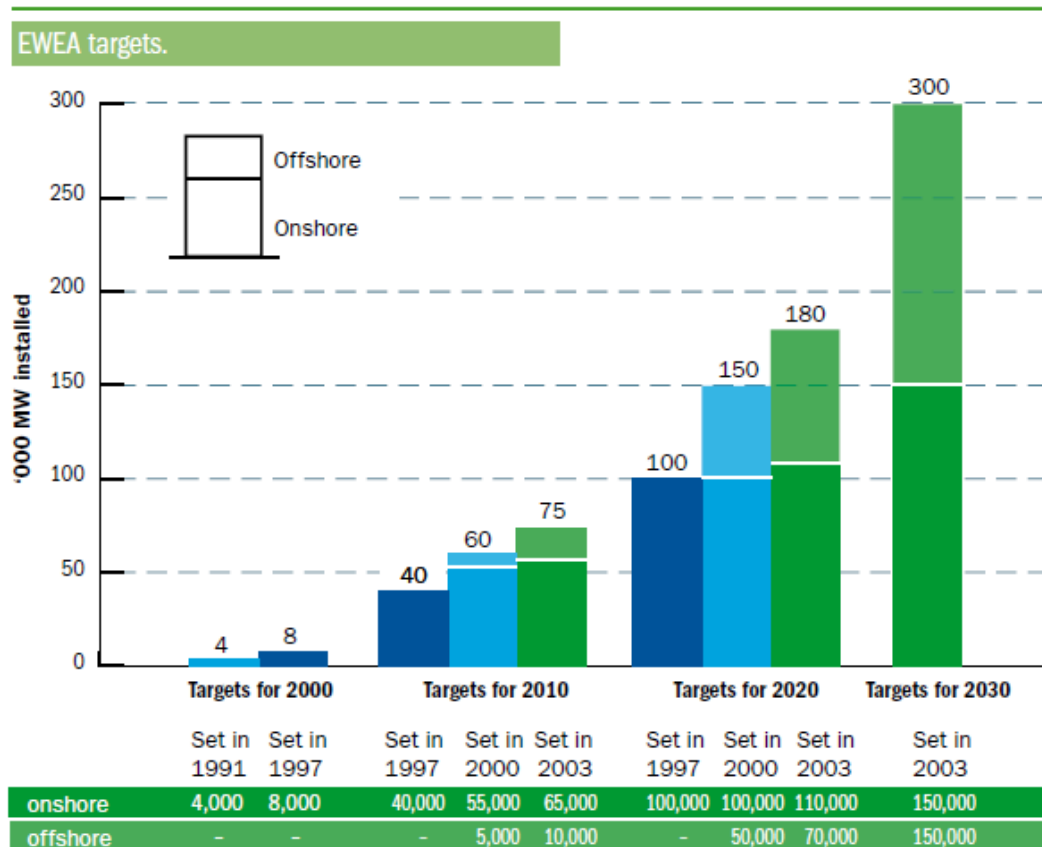


Figure 11 EWEA Targets(TP Wind Advisory Council, 2006)

The EWEA targets are set high as you can see at figure 9. In 20 years EWEA estimates that the current installed Wind Energy capacity will grow at least 5 to 6 times. Targets are set high as the importance of the eco-friendly energy is known by many people and this is necessary for sustainable development.

2.4. Urban Wind Turbines

Two things affect the characterization of the ‘urban wind, lower annual mean wind speeds (AMWS) compared to rural areas, and more turbulent wind flow. The lower AMWS are caused by the rough uneven grounds caused by buildings, street layout and other urban landscape’ which causes wind speed to increase with height slowly. (Dutton 2005)

‘Despite the advantages in bringing local wind generation to cities, the low AMWSs and turbulent flow have discouraged many people who may otherwise have been interested, as wind economics are very dependent on the available wind resource, i.e. the annual mean wind speed’. (Dutton, 2005)

The challenge caused by turbulent wind is change in wind direction, this causes stress on the turbine blades and if the turbines cannot adjust their direction quickly to take advantage of the new wind direction it will slow the energy production. (Dutton, 2005)

The options are to find an optimum place for a good wind and find a machine that can adjust itself according to the wind flow.

2.4.1. Categorization Wind Turbines

Urban wind turbines can be separated in 3 different ways in terms of building ways. (Dutton 2005)

a. Building integrated wind turbines (BIWTs): They are turbines capable of working close to buildings, exploiting the local wind flow caused by any building augmentation. They can be independent or incorporated in the building design.

b. Building mounted wind turbines (BMWTs): These turbines are physically attached to the building structure. The building is used as a tower to catch the desirable wind flow. The structure must support the turbine in terms of loads and within noise, vibration.

c. Building augmented wind turbines ((BAWTs): Where mounted ‘wind turbines are integrated in such a way that the building is used to deliberately alter and augment the flow into the turbine.’

These systems can all be used whether the energy need is for heat or electricity, and they can all be used parallel with solar systems, the advantage of these systems are it can still produce energy after the sun has set or at cloudy days.

2.4.2.Small Scale Wind Energy and Perspectives

When we think of the historical development of wind turbines, we would mostly come across with the large scaled ones which are generally located in exposed areas with higher wind speeds. However there is a new trend recently which increasing number of manufacturers started introducing smaller turbines for individual householders or small businesses. ‘Although the definition of ‘small wind systems’ is generally accepted to include any devices up to a rated power of 50kW (typically 16m diameter), turbines for domestic applications are generally less than a few meters in diameter and generate 2-3 kW of power’. Smaller turbines can be placed onto the roofs, poles etc. This type of turbines are mostly connected to the user's distribution board. As any other wind turbine the energy generated can directly be used onsite with other electricity grid. (Carbon Trust report, 2008)

Urban Wind Energy has started to get more attention in UK. But if we are to compare the wind large energy sector to urban wind energy sector in terms of market share and technological progress we can say that there is still a huge gap. However, over the last year couple of years there is an increase in the building integrated and rooftop applications of small wind turbines and a number of feasibility studies have been carried out and at least 3 projects are currently going ahead, although this type of installation is still very rare. (EU WINEUR, 2005)

It is a fact that the need for power in urban areas is constantly increasing. Innovative ideas for generating power are needed. Instead of finding clear and empty areas, placing the wind turbines on top of existing structures presents a possible solution. Small wind turbine installation is now being used to create systems with better performances. They have lower costs, and higher reliability. In order to reach the high demands of energy in urban areas, urban wind turbines systems are under examination (Şahin, A.D., 2004a). ‘There are 14 companies manufacturing or in the process of developing prototypes of vertical axis (VAWT) and horizontal axis (HAWT) small wind turbines. Thanks to the increasing number of installations being completed experience in the sector is growing.’(EU WINEUR, 2005)

There is a growing interest for small scale wind energy systems in the UK the number of the implanted systems continue to grow even though the market is small. There are many products at development and minor manufacturing phase but there are plans to mass produce these projects. We can say that the manufacturers for the HAWTs and VAWTs are not ready yet for mass production yet.’The ClearSkies programme shows that there has been a larger than expected number of installations over the last 2 years but the market has not yet taken off.’ This could be due to the lack of knowledge amongst local councils, communities, companies, particularly in an urban setting (EU WINEUR, 2005)

2.4.3. Overview of urban wind turbines

There are two types of Urban Wind Turbines, vertical axis and horizontal axis wind turbines. This section will provide a brief understanding of urban wind turbines and the ‘energy generated by wind turbines is governed by two “wind laws”:

-‘Power generated is proportional to wind speed cubed. Doubling the wind speed gives eight times the power. Therefore wind speed at the turbine location is very important; and’

-‘Power generated is proportional to the swept area of the blades. Doubling the rotor diameter yields a four-fold increase in swept area with corresponding increase in power generation’(EU WINEUR, 2007b)

2.4.3.1. Vertical Axis Wind Turbines (VAWTs)

Vertical Axis Wind Turbines can be categorized in two types, Savonius and Darrieus. Darrieus wind turbines have less than the usual type of turbines (typically three) which are based on a lift type system. The central axis acts as the pivot point connecting the blades at top, mid and bottom points or in the H-darrieus configuration where they are joined at their middle. Savonius turbines, can work quieter because of their designs. The design doesn't allow the system to have a ratio tip speed more than 1. They are drag based systems (Webb, 2007)



Figure 12 Darrieus VAWTs (URL 2)
also known as lift VAWTs



Figure 13 Savonius VAWTs (URL 3)
also known as Drag type VAWTs

‘VAWTs don’t need to be oriented into the wind, which could be of particular importance in locations where the wind direction changes frequently’ (Gipe, 2004). Although Darrieus VAWTs are less aerodynamic than HAWTs, they have more efficiency in energy production thus more used in Urban Environment also having less parts makes the VAWTs quiet at operating process so that they are easier to get accepted by the community. ‘VAWTs are also less sensitive to changing wind directions and therefore to turbulence. This is also a very important advantage for the urban environment.’ (Webb,

2007). Structure of these systems are simple and the generator and the moving parts can be installed at ground level giving us an easy way of maintaining it.(Gipe 2004)

Although are some advantages, there are quite few down sides for VAWTs. However there is a disadvantage to these systems. VAWTs generally need electricity from a grid to self start and to reach the cut in speed when adequate wind is blowing. 'This problem can be overcome by specialised design allowing the rotor to divert the air.' (Webb, 2007). They require large amounts of materials to construct and typically lower efficiencies because VAWTs dont operate at high altitudes thus higher the altitude faster the wind velocity and energy converted from it.(Gipe 2004)

2.4.3.2. Horizontal Axis Wind Turbines

These types of turbines are found more common and can be considered conventional thats why they are easily noticable, recognizable. HAWTs are mostly used at large wind farm systems. These systems normally have , three blades that are pointed into the wind stream. They work lift style. In the large wind turbine systems, the design have sensors that can manipulate the rotors and blades to face the incoming wind. This is done using direction sensors and large hydraulic 'yaw' motors. However in smaller systems, this can be typically achieved passively as the turbine head is not as heavy as the bigger systems, wind can cause the turbine to point in the right direction by the fin behind the blades, but there is a big problem with turbulence as it will constantly cause the turbine head to change direction and endure high pressure, resulting in wear and tear. (Bellarmine, 2006)



Figure 14 HAWT (Webb,2007)

Some problems with HAWTs are over-speeding which can result in the machine self-destructing. To counter this error new HAWTs are equipped with a mechanism that is called Furling. This happens when the wind speeds are very high, normally the turbine will get effected negatively however with furling, the system protects itself by bending out of the full forced gusts. The other big problem is Noise, caused by the high speed fans rotating, but this design issue is widely understood, and some

new turbine designs have a ring around the circumference of the blade tips, which successfully silences that whine. Despite these disadvantages, HAWTs are still the most efficient with considerable low costs, it is still industry's main focus'. (Bellarmine, G.T,2006)

Design details of HAWTs from Twidell's studies:

- i) forces in the win vary with the square of the wind speed,
 - ii) the rotational frequency and its harmonics cause unwanted, but predictable, vibrations
 - iii) unpredictable turbulence in wind causes persistent, rapid and frequently violent oscillations,
 - iv) gravity stress cycles are at least 100 times greater on turbine blades than on equivalent fatigue cycles on comparably sized aircraft wings
- (Twidell 1998)

2.4.3.3.Comparison Horizontal Axis and Vertical Axis Wind Turbines

'The horizontal axis wind turbine (HAWT) uses the axial flow method in which the axis of rotation is horizontal. The vertical axis wind turbine (VAWT) uses the diametral flow method in which the axis of rotation is vertical. Both designs convert the kinetic energy of the wind'.

(Bellarmine, G.T,2006)

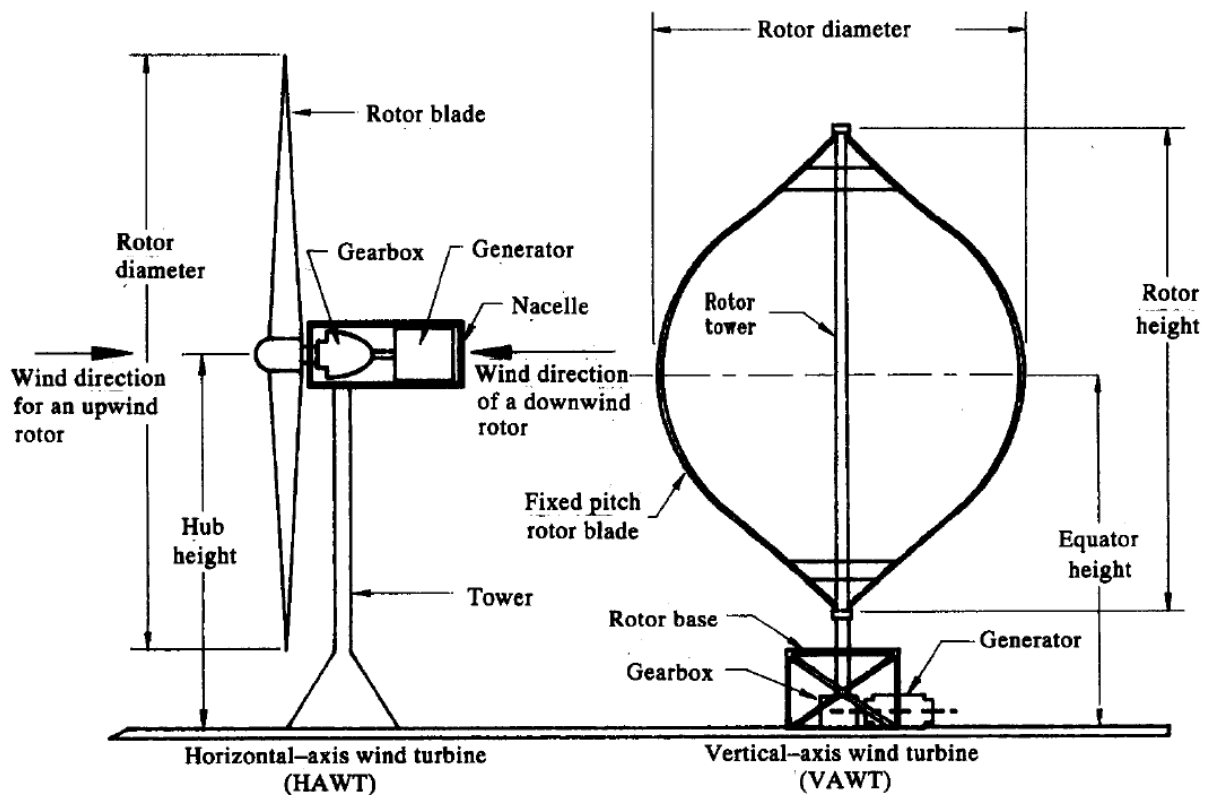


Figure 15 HAWT and VAWT turbines axis comparison (Bellarmine, 2006)

‘The VAWT implements egg-beater-shaped airfoils, which, when in motion, have a constantly changing angle of attack. These turbines are vulnerable to resonant vibrations that lead to structural collapse. However, the VAWT does not require a tower, can capture the wind in any direction, and is cost-effective in installation and maintenance because the generator, gearbox, and other pertinent devices are at ground level.’ (Bellarmine, G.T,2006)

Figure 14 taken from EU WINEUR, Urban Wind Turbines Technology review will point out the general differences between the HAWT systems and the VAWT systems which are divided into two: Darrieus VAWTs also known as lift VAWTs and Savonius VAWTs also known as Drag type VAWTs.

Table 5

	HAWTs	Lift VAWTs	Drag VAWTs
Advantages	1. Efficient 2. Proven product 3. Widely used 4. Most economic 5. Many products available	1. Quite efficient 2. Wind direction immaterial 3. Less sensitive to turbulence than a HAWT 4. Create fewer vibrations	1. Proven product (globally) 2. Silent 3. Reliable & robust 4. Wind direction immaterial 5. Can benefit from turbulent flows 6. Create fewer vibrations
Disadvantages	1. Does not cope well with frequently changing wind direction 2. Does not cope well with buffeting	1. Not yet proven 2. More sensitive to turbulence than drag VAWT	1. Not efficient 2. Comparatively uneconomic

HAWTs and VAWTs Comparison (EU WINEUR, 2007b)

Today systems are very efficient; but still they are still at the beginning of their evolutions. Today these systems are capable of converting around 40% of the wind power to energy which can be comparable to 30-40% thermal power and exceeds the 15% energy production of solar power (Bellarmine, G.T,2006)

2.4.4.Introduction to some basic terms and a short technical review of Urban Wind Turbines in EU

This section contains basic introduction to some of the technical terms that are used in the Urban Wind Turbine Industry. The data is taken from the EU WINEUR, Urban Wind Turbines Technology review, 2007. According to WINEUR ‘32 manufacturers representing 57 wind turbine models have been inventoried which 65% were HAWTs and 35% were VAWTs.’

2.4.4.1. Cut in Wind Speed

‘The cut-in wind speed is the wind speed at which a turbine starts to operate and produce electricity usually’ it is around 3 to 5 m/s but some have it even lower because in the Urban system wind speed is low so this measure is necessary to be able to produce energy.(EU WINEUR, 2007b). The numbers

Table 6

Cut-in wind speed	%
Have a cut-in wind speed < 3 m/s	47
Have a cut-in wind speed $\geq 3 < 4$ m/s	38
Have a cut-in wind speed ≥ 4	14

Average Cut in Speeds (EU WINEUR, 2007b)

We can see from the graph that 86% of these turbines has a cut in wind speed of <4 . This technical ability is necessary in order for the Urban Wind Turbines to survive in the unstable city wind which is usually not uniform because of the urban canopy.

2.4.4.2. Cut out Wind Speed

Wind turbines operate in certain conditions because they are designed for it. They generate electricity according to these design parameters. These parameters exists to optimize the electricity that is generated and to ensure that the system works properly for a long time. So there are minimum and maximum wind speeds which the system can tolerate. The system shuts itself to prevent any damage to the rotor blades when the certain wind speed is breeched, this is called the cut-out wind speed (EU WINEUR, 2007b)

To prevent the machine from getting damaged and some other safety reasons there are four main principals to consider according to a study done by European Union WINEUR at 2007:

1. Passive stall control: When designing the wind turbine blades, the high wind speeds are considered, as it will be unprofitable if the system cuts out constantly and shuts down. Thus the wind turbine blades are made so that if the wind speed increases over the optimum operating levels, the wind turbine blades stalls the turbine and slows it down, and the higher wind speed, the more they stall.

2. Active pitch control: the wind turbines blades can be controlled in two different ways, they can be set so that they actively pitch causing the machine to reduce energy it captures. This can be done either by decreasing the attack angle of the blades with the wind or by increasing the angle causing it to stall.

3. Yaw or Tilt control: the rotor of the wind turbine can be controlled actively or passively in order to respond to different wind situations. 'In Yaw Control, the nacelle is rotated to place the turbine's profile to the wind. In Tilt Control, the nacelle cants back until the axis of rotation is perpendicular to the ground.'

4. No control: the design itself is durable to any weather situation so no control is needed.

The following figure shows the percentage of the cut out speeds for the mentioned wind turbines.

Table 7

Cut-out wind speed	%
Have no cut-out wind speed	54
Have a cut-out wind speed ≥ 20 m/s	36
Have a cut-out wind speed $\geq 15 < 20$ m/s	7
Have a cut-out wind speed $\geq 10 < 15$ m/s	3

Average Cut out Speeds (EU WINEUR, 2007b)

2.4.4.3. Self Starting Turbines

Electricity can be used to start the wind turbines and bring them to the required cut in speed with help, but this system can not be considered as %100 renewable, as it needs a small amount of electricity. 'It is much better when the turbine uses wind as the sole source of energy'. (EU WINEUR, 2007b)

Table 8

Self-starting turbines	%
Wind turbines that are self-starting	95
Wind turbines that are not self-starting	2
Wind turbines for which no indication was available	3

Self Starting Turbines (EU WINEUR, 2007b)

We can see that this function is present at almost all of the wind turbines that has joined this survey. This suggest the importance of self starting technology

2.4.4.4. Noise

One of the main reasons that community is not easily accepting. Urban wind turbines using a mechanical way to convert the wind energy into electricity that we use thus mechanical moving parts means there is always noise. Although some systems are designed to reduce this noise. (EU WINEUR, 2007b)

According to EU WINEUR study done at 2007, ‘There is not a great difference in noise levels between a HAWT and a VAWT, although in general VAWTs are regarding as more silent for the two following reasons’:

-‘The blades do not create the usual whooshing noise that occurs with HAWTs when the blades pass close to the mast each revolution’;

-‘VAWTs usually operate at lower speeds.’

Even though many of the small manufacturers stated that they have not done any testing on noise reduction related issues the figure shows some good results. If we consider 55dB as the normal talking noise we can see from the figure that approximately over 87% of the urban wind turbines are near the talking noise or below it.

Table 9

Noise	%
“Not audible” at the top of the turbine, with a wind speed of 5m/s	26
≤ to 40 dB at the top of the turbine, with a wind speed of 5m/s	37
> 40 ≤ 60 dB at the top of the turbine, with a wind speed of 5m/s	24
> 60 ≤ 80 dB at the top of the turbine, with a wind speed of 5m/s	13

Noise Levels (EU WINEUR, 2007b)

2.4.4.5. Life Time

'Modern wind turbines are generally designed to work for around 120.000 hours of operation throughout their design lifetime of 20 years.' However, this time varies because of the different conditions that the wind turbine is present and maintenance levels. (EU WINEUR, 2007b)

Table 10

Life time	%
Life time of the wind turbine > 25 years	5
Life time of the wind turbine > 20 ≤ 25 years	68
Life time of the wind turbine > 15 ≤ 20 years	20
Life time of the wind turbine > 10 ≤ 15 years	7

Life Time Expectancies (EU WINEUR, 2007b)

The figure above shows the life time expectancies for the urban turbines however this technology is new so there are no valid data of this section that supports the validity of these numbers. (EU WINEUR, 2007b)

2.4.4.6. Maintenance

More than half of the manufacturers stated some minor maintenance might be needed in order to achieve the optimum levels of working however the other half stated that there is no need for any kind of maintenance for these types of turbines. We can say that little to almost no maintenance enough. (EU WINEUR, 2007b)

To optimize the Urban Wind Turbine's functions these actions should be carried according to EU WINEUR:

- 'Replacement of spy joints every 3 to 5 years (depending on the turbine and on the environment maritime or continental)'
- 'Checking brushes and slip rings (according to some of the manufacturers interviewed, brushes may perish over 5 to 6 years)'
- 'Checking nuts and bolts'
- 'Checking the support connections to the building once a year and after any severe weather conditions (in the case of a building-mounted turbine)'
- 'Potential replacement of the shaft seals after 5 years (depending on the turbine)'

2.4.4.7. Roughness

Basically anything which is in the urban environment that is in the way of the wind acts as an obstacle causes a decrease in wind speed. These obstacles are called roughness. Roughness changes the way wind flows and causes turbulence, this results in lower wind speeds in urban environments with a certain amount of turbulence depending on the roughness. That is why roughness is really important (Webb, 2007)

2.4.5.Challenges

This section will provide brief summary about the challenges that are concerning the Urban Wind Energy.

2.4.5.1.Wind Flow in Urban Environment

The wind regime in urban environment is not fully understood.(Webb,2007).’The obstructions associated with urban environments create significant surface ‘roughness’’ which is important because it causes turbulence in the flow at urban environment with low wind speeds. This can cause some problems with the energy generation process and results of poor performance are to be expected with instability and short life time. (Webb, 2007)

2.4.5.2. Complications on Urban Modelling

Urban wind modeling is really hard because of the constant change of the wind speed and many different urban canopy types and equipment. ‘There are general uncertainty relating to knowledge of wind regime in built up areas, lack of knowledge about local flow effects around buildings, need the cataloguing and categorization of the UK building stock in terms of suitability for urban wind turbines’ (Webb,2007)

2.4.5.3.Lower Than Expected Performance on New Turbines

The wind regime in urban environment is not fully understood thus estimating the resource is difficult. If the wind speed is %25 lower than the predicted value the overall performance expected from the Turbine decreases by %40. After the installation of the wind turbine any new buildings built in to the same area might cause a drop or increase in wind source which can cause problems in the future. Plus there is no current obligation to get a certificate for the Urban wind turbine performance for small wind turbines, the power output of the turbine is just given by the manufacturer and not confirmed and performance will unlikely be a part of the purchase contract. So there is a chance to get a lower then stated/expected performance because of these uncertainties. (Webb 2007)

2.4.5.4. Environmental Concerns

Biodiversity and birds , it is feared that the micro sized wind turbines will cause an increase in the bird population as they fly into it without noticing. However there are some that thinks that the mortality rate of the birds will not change because of these micro systems beyond those already caused by birds flying into existing buildings, windows and other obstacle (URL 5)

2.4.5.5. Community Concerns

a. Public safety , Wind turbines parts or wind turbines itself falling is a public concern and because the turbines will be installed in public areas the risk of any hazard is far more greater so more testing is required on turbine robustness in order to see what loads are present at the presence of turbulence and wind shear. Any turbine that is produced at least be certified to be compliant with BS EN 16400 and be CE marked. (Webb 2007)

b. ‘Noise, is a critical issue for small turbines especially in the urban context, as they will always be placed very close to houses’. Many of the small urban wind turbine manufacturers stated that they have not done any testing on noise reduction related issues but figure 18 shows some good results. If we consider 55dB as the normal talking noise we can see from the figure that approximately over 87% of the urban wind turbines are near the talking noise or below it. (EU WINEUR, 2007b). However some scientist believe this problem is underrated. (Gipe, 2000)

According to The ‘UK’s Department of Trade and Industry (DTI) as a general rule, noise emitted from any turbine should not exceed 5dB(a) above background noise, with a fixed limit of 43dB(A) recommended for night time. They recommend that day and night noise limits can be increased to 45dB(A) where the owner of the property benefits directly from the operation of the turbine.’

c. Visual effects, People are not used to seeing wind turbines in urban environment and there is an argument going on that if the community will accept these turbines or not.

d. Shadow flicker and blade-reflected light, It is thought that if these systems are mass built in the urban environment they might cause sunlight to get reflected and disturb the drivers and pedestrians.

e. Vibrations, Vibration from the might go through the structure which might cause noise and disturbance.

f. Electro Magnetic Interference, One of the other common concern is because these systems contain moving parts made of metal and placed on top of the roofs, that they might cause some signal failures for TV or cell phone systems.

g. Lightning strikes, these systems are built on the highest places of the buildings and they are mostly made from metal thus in a stormy weather it is known that this is resulted with lightening strikes. Some systems do have protection measures but some of them do not have it.

h. Economic Analysis, The problem with economic approach is although the energy generation would be free the payback period for the construction costs are not consistent because the it is highly dependent on the winds which are unstable.

2.4.5.6 Opposing Views

There are some opposing views from scientist and some negative results from studies. Here are few examples;

a. 'It is highly unlikely that micro-wind turbines will proliferate among UK urban areas. Output from the numerical modelling in m-wind has demonstrated that accounting for wind shear and shadow effects can reduce the annual energy output by up to 50%. Standard empirical models break down close to terrain level meaning generalized quantification of urban energy yields is uncertain. At such low heights in complicated terrain the wind resource will be governed by local effects. Turbulence and wind shadow effects will be prominent in such cases. This would favour dwellings located on sea fronts where sea breezes occur and for countryside and suburban locations where fields, large open spaces and low objects have a smaller effect upon wind speed at typical rotor heights on domestic properties.' (Bahaj,2007)

b. 'Domestic-scale wind energy generators installed in urban areas are a bad idea, reports the UK's Carbon Trust. The amount of electricity they generate often does not compensate for the carbon emissions released during their manufacture and installation, says the government advisory body. It draws its conclusions after an 18 month investigation into the economics and carbon savings of small-scale wind energy' (Windpower Monthly Magazine)

2.4.5.7. Some identified Bottle Necks by EU Comission

'Different studies and ongoing projects have identified a number of bottlenecks regarding the development and installation of UWTs. In this paragraph, the bottlenecks have been clustered around a few important aspects, namely: turbine technologies, projects, costs, attitudes and permits.' (EU WINEUR, 2007) All following problems have been identified by EU WINEUR.

a.Turbine technologies

- The innovative turbine models designed for the urban environment are still maturing: based on practical experience the turbines are being improved aiming at better efficiency, less noise and improved safety.
- Some turbines are of inferior quality (inferior materials used, poor welding).
- There is very little independent information about UWTs. The majority of information comes from the suppliers/manufacturers and has not been verified.
- There are no norms and standards for the technical quality of UWT and especially VAWT.

Projects

- UWTs are too often placed at unsuitable locations (too low and/or behind an obstacle).
- National governments are not doing enough to support the installation of UWTs. This makes further development of the UWT market fragmented and

uncoordinated and there is little common ground for exchange of “lessons learned”. The absence -The government support also increases project risks.

- It is quite complex to determine the optimal location for UWTs. A simple tool to assist developers needs to be created.

- The electricity yield shows large variation depending on location and turbine model.

- There have been negative experiences: noise, vibration, unexpected faults, and damage by stormy weather (broken blades). In one case a turbine had to be stopped over night due to noise levels and also during sunny days because of flicker.

- UWT projects are typically progressing slower than planned; every new location has specific needs and requires customised implementation.

b.Costs

- The investment costs are too high, especially compared to the benefits.

- The administrative expenses regarding permits are high and out of proportion compared to the investment for equipment and installation. The administrative costs are sometimes responsible for as much as the half of the total investment.

- The indirect costs such as the cost of feasibility studies, structural surveys and site surveys have a significant share within the project costs.

c.Permits

- Obtaining permits for UWTs is complex, takes too long and is different in each municipality or local authority. Because UWTs are not standardised or certified, each permit request needs to be separately assessed and sometimes external experts have to be used, which is expensive and costs time.

- The requests for permits are often incomplete due to lack of information or good communication channels.

- There are no guidelines for the structural or architectural integration of UWTs.

d.Attitudes

- The noise specifications provided by the suppliers / manufacturers are sometimes too optimistic and need to be independently verified as noise is a very sensitive issue for neighbours.

- Practically all suppliers / manufacturers are too optimistic when specifying the expected electricity yield, if this continues it will lead to more and more disappointed consumers and an unsustainable market.

- In urban environments there is a reluctance to accept UWTs due to fears about sun reflection and shadows from blades (flicker), noise, safety concerns related to possible incidents (broken blades) and deterioration of property value in the neighbourhood.

- The communication among the different parties involved appears difficult: the views on UWTs and the knowledge levels differ strongly.

(EU WINEUR, 2007)

2.4.6. Opportunities

2.4.6.1.Planning Policy That is Encouraging Renewables

At 2004 Planning Policy Statement 22 and a Companion Guide were issued to encourage the appropriate development of renewable energy at local level. PPS22 purpose is to bring the development trend for wind energy to a local level. The policy gives details about renewable energy applications, impact assessments on effects for environment and provide advice on all of the renewable energy systems including wind (EU WINEUR, 2005)

New policies encourage the use of renewable energy systems. Some of the policies involves requirements (such as London Energy Strategy) that the new constructions that occupy a space bigger than a thousand square meters are responsible to generate ten percent of their needed energy from the renewable energy sources. In urban environments and crowded cities, these requirements can encourage the usage of the small wind energy systems. (EU WINEUR, 2005)

2.4.6.2.Carbon Dioxide Reduction, Economic Benefits and Future

According to the carbon trust report on 2005, it is concluded that the contribution of the urban wind turbines are significant. It is estimated that by 2020 just from the wind turbines that are in the urban environment a range between 1.7 to 5 TWh of energy generation with a Carbon Dioxide reduction of 0.75 to 2.2Mt. This area has a huge potential and an existing strength for UK's economy and will create a good offering of jobs.(Dutton, 2005)

Wind energy is both economic and environmental friendly. For it to be economic, cost should be lower than the profits.' In every country, the price of electricity depends not only on the cost of generation, but also on many different factors that affect the market, such as energy subsidies and taxes. Generally, the cost of generating electricity is made up from; Capital cost—building the power plant and connecting it to the grid, Running costs—operating, fuelling, and maintaining the plant, and finally, Financing—the cost of repaying investors and banks.' (Neij L, 1999) Figure below shows the incentives that are provided by some of the EU countries.

Table 11

Country	Finacial incentives		Tax incentives		Production incentives		
	Investment	Govermantal	Tax discount (Relief)	Duty Discount (Relief)	Renewable Portfolio	Incentive to producted electricity	Fixed Tarrif
Austria							
Belgium							
Canada							
China							
Denmark							
UK							
Finland							
France							
Germany							
Greece							
The Netherland							
India							
Ireland							
Italy							
Luxemburg							
Philippines							
Portagual							
Spain							

(Dutton, 2005)

Renewable Energy Incentives at Some Countries

We can see that there is a huge support from governments in order to promote the Wind Energy Investments. But you can see from the graph that the EU leader Germany has the economic advantages for investing on renewable energies which suggest why the Germany might be the Leader in EU for the most installed MW on Wind Energy. If we look at UK we see that there are not as many advantages as Germany's, and UK stands 5th at EU in terms of installed MW Wind energy capacity with the highest potential of wind resources.

2.4.6.3.Funding

The ClearSkies Programme is the governments mechanism of supporting small wind installations. This program also provides access to advice on renewable energy. This program started at 2003 and ended at 2006 but there is a new program that will support a range of small scale renewable energies. These programs are called DEFRA - Rural Enterprise Scheme and the Objective and LEADER PLUS scheme for England. (URL 5 - EU WINEUR, 2005)

2.4.6.4.Free and Renewable Energy

‘For wind turbines, there are no fuel costs, as the wind is free. Once the project has been paid for, the only ongoing expenses are for operation and maintenance. The capital cost is between 75 and 90% of the total. The production cost of a kilowatt hour (kWh) of wind power is one fifth of what it was 20 years ago’ and as the market grows a reduction of cost are expected (Neij L,1999)

Following figure contains some economic details for conventional energy systems.

Table 12

System	Cost factors and life cycle cost (cent/kWh)					
	Capital cost (<i>C</i>)	Maintenance cost (<i>M</i>)	Fuel cost (<i>F</i>)	External cost (<i>X</i>)	Total cost no external (LCC- <i>X</i>)	Total cost with external (LCC)
CSFO	0.5969	0.1371	0.8924	3.8328	1.5928	5.4256
CSNG	0.4974	0.1217	0.7843	1.0496	1.3804	2.4300
GTDO	0.751	0.5124	1.6318	2.5829	2.8438	5.4266
GTNG	0.751	0.5124	1.2918	1.5047	2.5038	4.0085
CCNG	0.5333	0.2797	0.6977	0.8749	1.4807	2.3555
PV	13.351	1.1817	0	0.1792	13.782	13.9612
WEC	1.6689	0.1865	0	0.0469	1.7616	1.8085

(Şahin, 2004) Cost Factors and Life Cycle Cost for Different Systems (cent/kWh)

Conventional steam fuel oil fired: CSFO
 Conventional steam natural gas fired: CSNG
 Gas turbine diesel oil fired: GTDO
 Gas turbine natural gas fired: GTNG
 Combined cycle natural gas fired: CCNG
 Photovoltaic: PV
 Wind energy converter: WEC

We can see from the graph that PV and WEC systems has no cost in terms of resource production. Compared to other systems wind energy has one of the lowest maintenance costs and also has the lowest total cost.

‘Over the past 5 years alone, costs have reduced by some 20%. Wind is already competitive with new coal-fired plants and in some locations it can challenge gas, currently the cheapest option. Wind energy production continues to improve in ways, which reduce cost and improve efficiency.’(Şahin, 2004, EWEA Report,2002)

2.4.6.5.High Quality Jobs

‘Wind sector employment has increased considerably in the last two decades, but only in a few countries, while the potential exists in many. Within the EU (at end 2003) 90% of employment in turbine and component manufacturing was restricted to Germany, Spain and Denmark. According to the figures that exist, the wind power sector currently employs around 64,000 people in Germany (BWE, 2006); around 21,000 in Denmark (DWIA, 2006) and 35,000 in Spain (AEE, 2006).’ The more this sector continues to grow more and more opportunities will open for future jobs. These will be high quality jobs in technical areas triggered by the development of this technology (TP Wind Advisory Council, 2006)

2.4.6.6.Interes from Architects in Fitting Wind Turbines to Buildigns

Architects are showing interest in implementing turbines in the urban environment. Richard Rogers Partnership and Bill Dunster Associates have included building implanted urban wind turbines in to their designs and submissions. Lord Foster is also constantly mentioned in the press as a designer of Large Enercon E-66 Turbine. These examples can be seen at ‘Sky High Exhibition’ curated by Lord Foster at the Royal Academy. Other people like Ian Ritchie and Partners, Cole Thompson Associates have proposed some wind power schemes as well. (Webb, 2007)

2.4.6.7.Estabilished Data Bases

In the’ UK there is a national estimated wind speed data system which is available online user can simply enter a postcode or OS grid reference and the NOABL database will provide an average annual wind speed at three different heights: 45m, 25m and 10m’ (URL 4) Although some researcher found out that the data found on the NOABL might not be so accurate. (Webb, 2007)

2.4.6.8.Supporting Approach

Some of the World's Wind Association Organizations such as BWEA (The British Wind Energy Association) considers small wind systems valuable, as it estimates that it can support approximately two million homes and businesses as the cost of small wind generators reduce while the price of the other sources of non renewable energy increases. Thus we can conclude that the potential of these systems will continue to grow. *"Micro and small wind is the only micro-generation technology in which the UK currently holds world leadership," says the BWEA's Alex Murley.* Wind industry in UK is becoming bigger, it supports a good size of job opportunities and continue to expand into exterior markets.

2.4.7. Some Design Approaches on Urban Wind Energy

There are several approaches to integrating large scale wind energy into urban settings and it is becoming more and more popular as the technology develops. In this section there will be a few examples about the state of the current urban wind turbines.

2.4.7.1. Existing Urban Wind Turbine Designs

- a. Elephant and Castle, London, The structure is going to be the first of its kind. The worlds first building with wind turbines built in, which turbines will generate 1/10th of the buildings energy needs. (URL 7)



Figure 16 The \$172 million Strata Tower in London harnesses wind energy with its three built-in turbines (URL 7)

b.The Bahrain World Trade Center located in Manama, the capital of Bahrain. It is the first skyscraper to have the built in large scale wind turbines which generate 1.5/10 of the buildings energy needs. (roughly the same amount of 300 homes) (URL 8)



Figure 17 The Bahrain World Trade Center (URL 8)

2.4.7.2.Different Urban Wind Turbine Approaches

a.AeroVironment 'is a high technology company that has developed slow speed unmanned vehicles. The includes the Helios which used photovoltaic power to set a new altitude record of 96,000 feet. They used expertise in slow speed flight to design architecturally integrated micro wind systems.' Design is able to capture accelerated winds going towards the roofs and very efficient at slow speeds. (Miles C, 2006)



Figure 18 AeroVironment (Miles,2006)

b.Windside is a 'Finnish company that has developed some innovative vertical axis wind turbines. The company won the EEP Gold Metal Award in Paris in 2005 for a small scale turbine design. These turbines are very quiet, produce power at low wind speeds (5 mph) and are not harmful to birds and wildlife.'



Figure 19 Windside (Miles,2006)

‘The turbines respond to wind in all directions and are able to hand turbulent and gusty wind conditions. Typical size for a turbine is 1meter in diameter and 4 meters tall.’ (Miles C, 2006) This system makes it possible to implant on cell phone towers, posts for street and traffic lights and any other urban canopy.



Figure 200 Possible Applications 1
(Miles,2006)

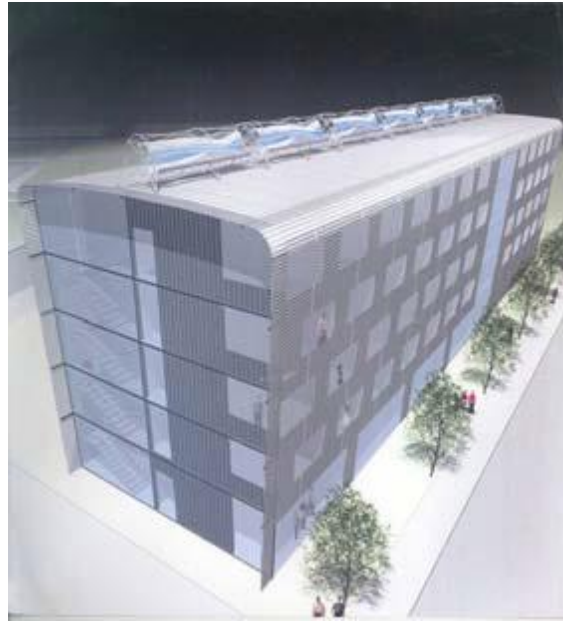


Figure 21 Possible Applications 2
(Miles,2006)

c.Withers has contacted Modern Alloys, a company based in Stanton, California, The company is planning to create a giant urban highway turbine systems. The project is at pilot testing phase (Bellarmine, G.T,2006)

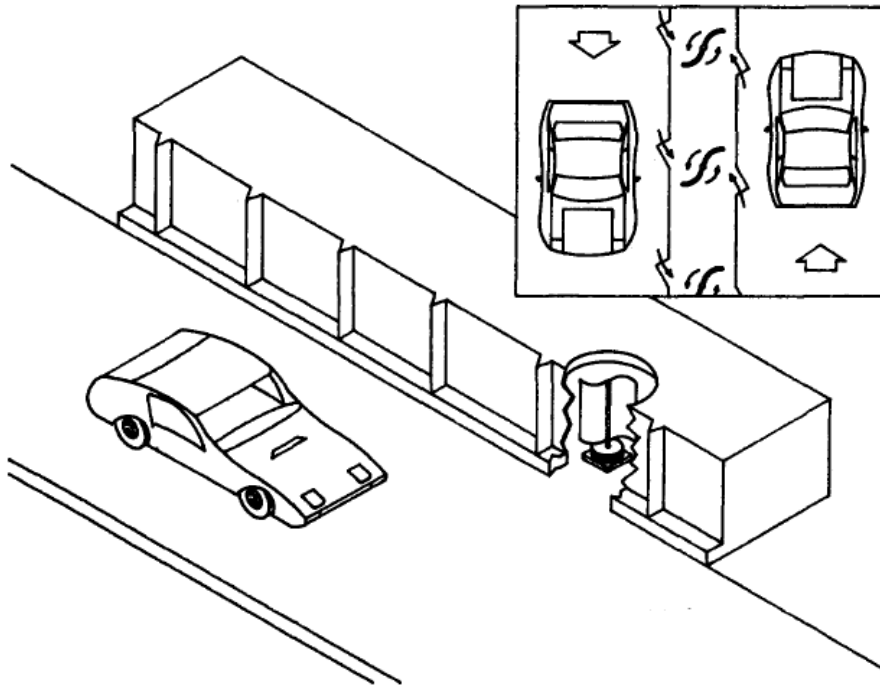


Figure 22 Highway System (Bellarmine, 2006)

2.4.7.3.Future Designs

a Michael Rosenthal Associates, a company from Miami, has designed the following building for the Hospitality design contest. (URL 9)



Figure 23 Michael Rosenthal Associates (URL 9)

b. Designed by the Atkins group, The Lighthouse is at its planning phase which if constructed will be located at Dubai it will have 'for energy generation, it will have three enormous 225 kilowatt wind turbines (29 meters in diameter), and 4000 photovoltaic panels on the south facing façade' the expected energy production will support the buildings energy consumption by more than 60 percent. (URL 10)



Figure 24 The Lighthouse (URL 10)

c. Arizona-based MagLev Wind Turbine Technologies, has been planning the worlds biggest magnetic levitation wind energy system that is called the Maglev Wind Turbines. There will be no ball bearings the system will float above the base with magnetic system. It is expected that it will be the largest conventional wind turbine in the world, producing up to 1GW of power where the biggest systems can generate 6MW. It will be enough to support 750000homes. (URL 11)



Figure 25 Maglev Wind Turbine Technologies, Inc. (URL 11)

Some other designs can be found at Appendix G

Chapter 3 : Materials and Methods

The purpose of this study is to simulate the interactions of the urban wind, which has a low velocity and low altitude, with buildings. By doing so we can see the wind flow and plan our wind turbine designs accordingly.

For this purpose, the wind data from NOABL data base will be use to get the real life wind speed numbers for Guildford. This data will be used in a flow simulation device to see the effects of the modification.

3.1.Materials

Data has been taken from the NOABL DATABASE. The pilot area chosen for the wind data is Guildford Town Center. Royal Post Office code of GU1 3AJ has been used to access the wind data. First the post code will be used with Noabl Database's Post Code converter program (which can be found at URL 12) in order to get the LR Results which will be used in the Noabl's Online Database.

When the post code for Royal Post Office, GU1 3AJ was entered to the post code converter, the LR results of SU998495 was achieved. This code then has been coded into the Noabl's Online Database (online database – URL 15) and the wind result for for the 1km grid square has been taken from Windspeed search for Great Britain. These results are for 45m, 25m and 10m respectively but in this research the 10m results has been selected in order to imitate the low wind in relation with building shapes.

Table 13

4.8	4.8	4.8
4.9	4.9	4.9
4.9	4.9	5

Wind Data from Noabl at 10m

(Squares surrounding the central square correspond to wind speeds for surrounding grid squares.)

The building shape and size designs are selected after consulting an architecture company from Turkey. 20x20x20 m basic cube shape building and a 20x20x30 m basic rectangular shaped building was chosen to be modeled.

3.2.Methods

For this project, the Solidworks 2011 modeling program in parallel with Solidworks Flow Simulator software was used to conduct this experiment. The simulation setup for the solidworks flow simulation program are shown below.

The Input selections step by step :

- Flow Simulation Measurement Units set to IS Units chosen,
- Flow type : External Flow with Exclude Cavities without flow conditions and Exclude internal space selected on Reference axis X selected.
- Modelling Gas – Air (default settings)
- Flow Type Laminar and Turbulent Default
- Default Wall Thermal Condition – adiabatic
- Roughness – 0 micrometer default selected
- Pressure 101325 Pa
- Temperature 293.2 K
- Velocity in X direction used the info from NOABL Data base which is 4.9m/s (at 10m)
- Velocity in Y direction 0m/s
- Velocity in Z direction 0m/s
- Turbulence parameters has been set to, Intensity 0.1%, Length 0.2m
- Result resolution set 4
- Optimize thin walls resolution selected
- Global Goals set for average x component of velocity and average velocity in order to get the related graphs
- Test 1 and Test 6 Wind tunnel dimensions z axis 50m, x-axis 750m, y axis - 0
- Test 2 and Test 3, Wind tunnel dimensions, z axis 50m , y axis - 0m, -x axis 25 m
- Test 4 Wind tunnel dimensions all 50m, y axis -10
- Test 5 Wind tunnel dimensions all 50m, y axis -13, selected to create the same circumstances.
- Then calculations has been performed.
- While plotting the Flow, Number of points set 100 (Arrow) and show velocity on x-axis has been selected.
- Test 2 and Test 3, Plot has been set to be observed from the Front Plane.
- Test 4 and Test 5, Plot has been set to be observed from both the Front Plane and Object Surface.

The graphs and plot data can be found at the Appendices. The pictures will be shown in the results section for comparison.

Calculations are made with the max values (Results and Discussion).

The data that are achieved after the tests will be shown as graphs and the results will be analyzed. The graphs will include the cut-in speeds from the various micro wind turbine manufacturers.

Chapter 4 : Results and Discussions

This study was inspired from the study of Edward Ng's paper on 'Improving the wind environment in high-density cities by understanding urban morphology and surface roughness: A study in Hong Kong'. The study showed that the urban canopy has an really important role on the urban wind thus urban wind turbines. Understanding this allows city planners to make their decisions with a understanding of urban ventilation of that city.

4.1.Results

According to Edward Ng, in terms of reducing the roughness, building construction attached together to form the shape of steps is more effecting compared to building them in distance within another (a test has been performed to see the difference, see appendix G). Following this study 4 different simulations were created with the same environment but different designs to see the relations between the low speed low altitude winds with the urban building shapes. The data for find is used from NOABL data base and It has been chosen 4.9m/s for 10m of attitude. Most of the cut in speeds of the turbines are close to this degree and the expected wind speed in urban environment is usually low.

a.Test 1 - A basic design of a standalone building in the shape of 20x20x20m cube , and a 20x20x30 m basic rectangular shaped building and following study of Edward Ng has been modeled using solidworks. Wind speed of 4.9 has been chosen and the following results has achieved with only x velocity of the wind monitored.

A simulation has been done on the building design to see the difference. The test shows that the roughness increases as there are more objects preventing the wind flow. These objects in this situation are the buildings. In an urban area like this the roughness might be high due to the high density of the buildings. According to our modeling data, if we take the first two buildings in consideration, the incoming wind speed of 4.9m/s is reduced to a number between 1.046 - 0m/s at 30m height (which is the highest point of the building) losing nearly all of its initial speed. The space between the two buildings also causes a turbulence in the wind flow. However as suggested in Edward Ng. study, if we observe the data from the second test, we will find out that the initial wind speed op 4.9m/s is reduced to a speed between 2.93-1.046m/s. Also the turbulence cause by the roughness is reduced compared to the first experiment. We can say that because the two buildings are attached to each other, they have acted like a singular object, instead of two different objects. This resulted the roughness to decrease , effecting both wind speed and turbulence as well.

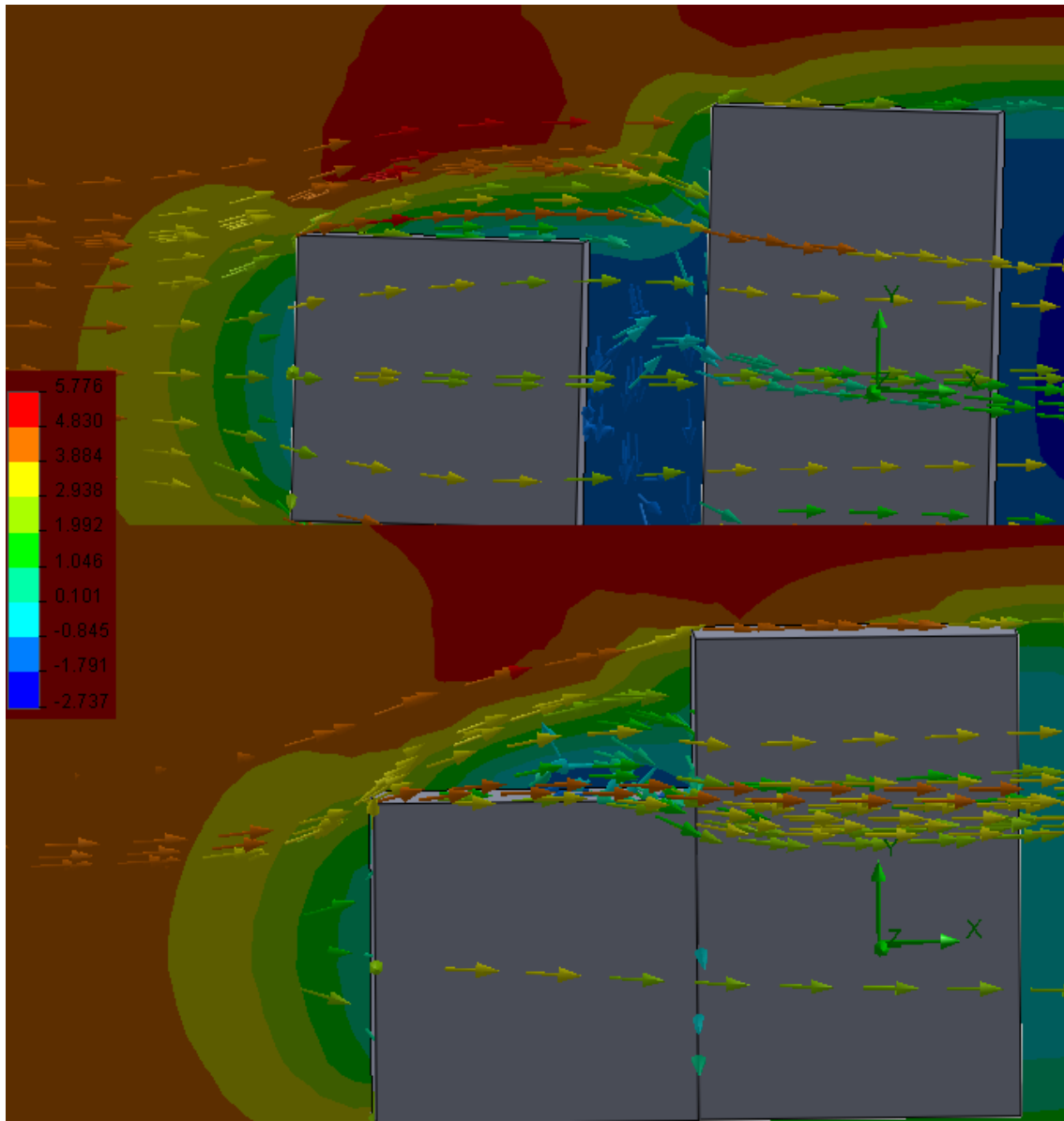


Figure 26

If we observe the figure 26, where the two buildings were separately built, where the initial wind speed of 4.9 has been changed to a speed between 2.93-4.830m/s at the first contact point and changed to a wind speed of 1.99-2.93m/s at the second contact point.

b.Test 2- A basic design of a standalone building in the shape of 20x20x20m cube has been modeled using solidworks. Wind speed of 4.9 has been chosen and the following results has achieved with only x velocity of the wind monitored.

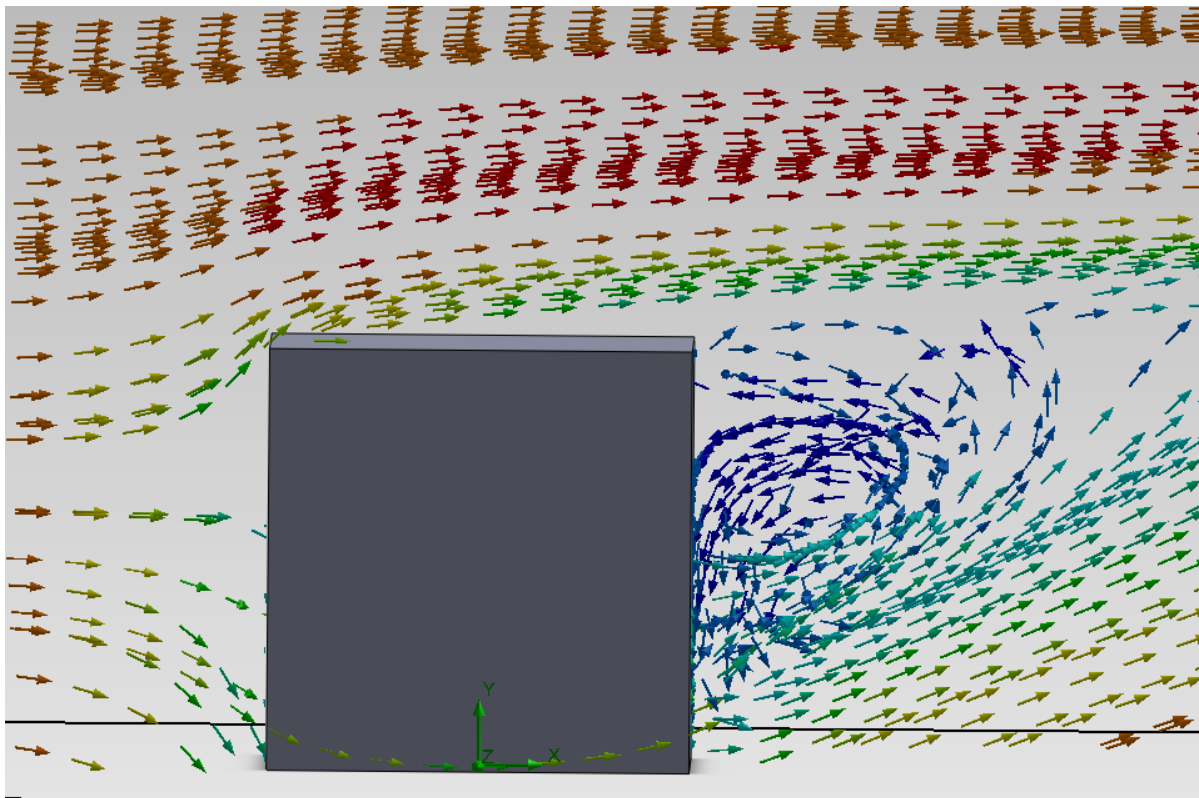


Figure 27 Test 2

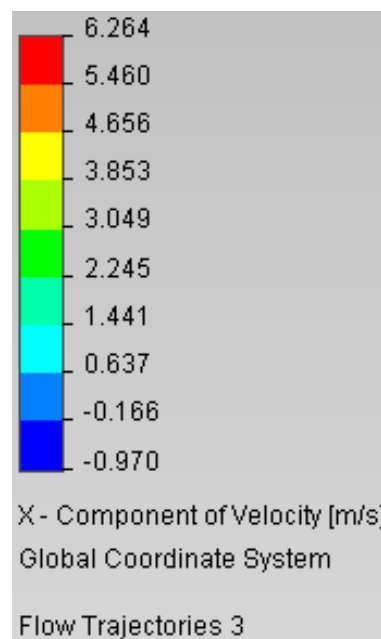


Figure 28 Test 2

It is observed that the incoming 4.9m/s flow has been reduced to wind speed between 3.853 to 2.245 at the highest point of the building which is 20m. The initial wind speed is decreased up to max %54.19. If we look at the wind flow at the points that are just over the roof (from the roof it is measured up to 5m), the wind speed is measured between 2.245 to 5.460 m/s. The wind speed at this section is increased by a max of %11.42 as it gains height. This is the place where the one might put the micro sized wind turbines.

In the most basic form of urban roughness we can see how buildings effect the wind flow and cause turbulence.

But you can see there is a problem with the flow behind the building. Although the wind tunnel specifications are set to match the exactly the origin of the building there should not be any wind flowing from underneath the building. The reason for this problem is not known but it is observed that it is not interfering with the flow from the roof thus it shall be ignored.

c.Test 3 – A basic design of a standalone building in the shape of 20x20x20m cube has been from test 1 has been slightly been modified in order the channel the wind where the urban wind turbine might be installed by installing a panel or modifying the roof structure. 1/5 ratio of ‘Fillet’ option was used to create the shape.

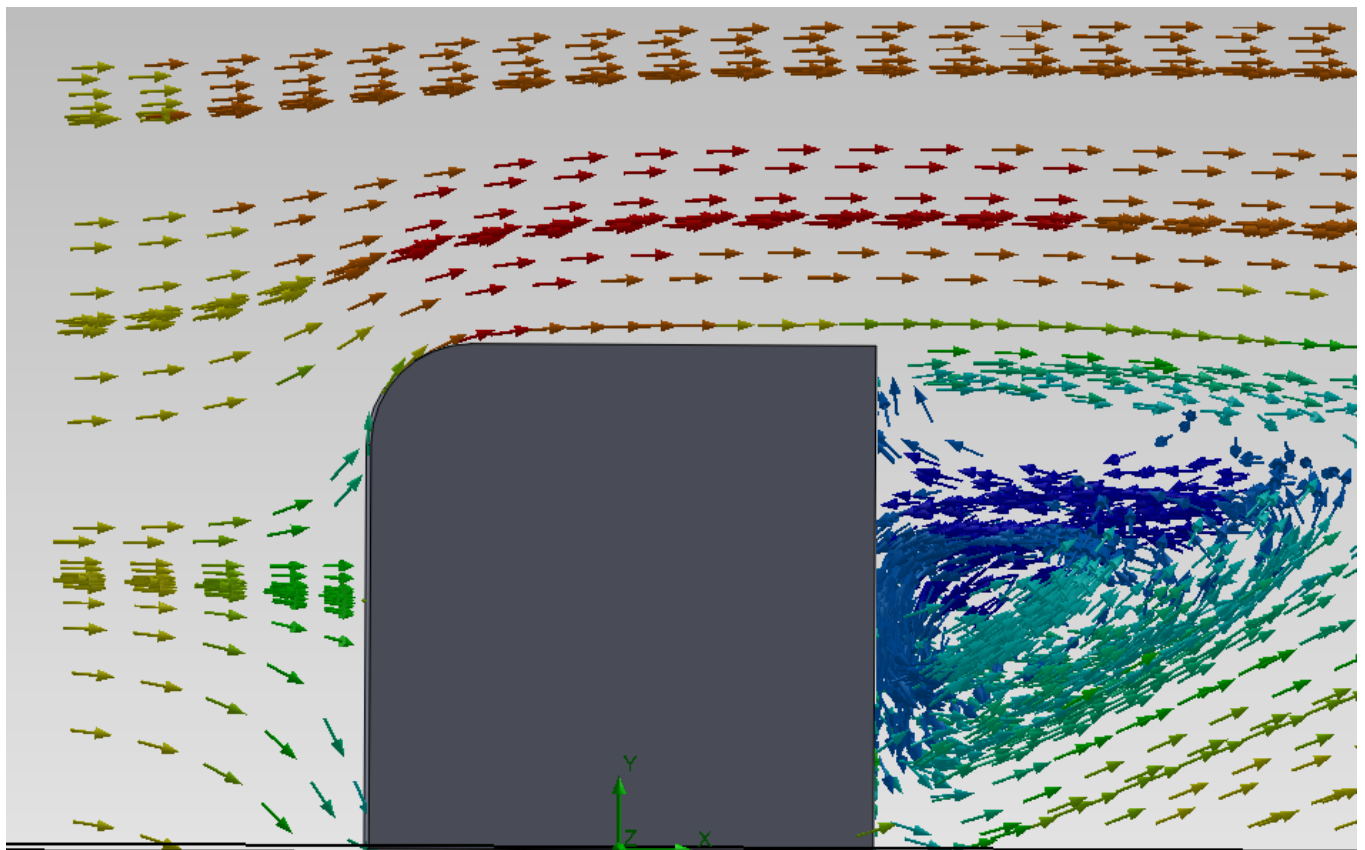


Figure 29 Test 3

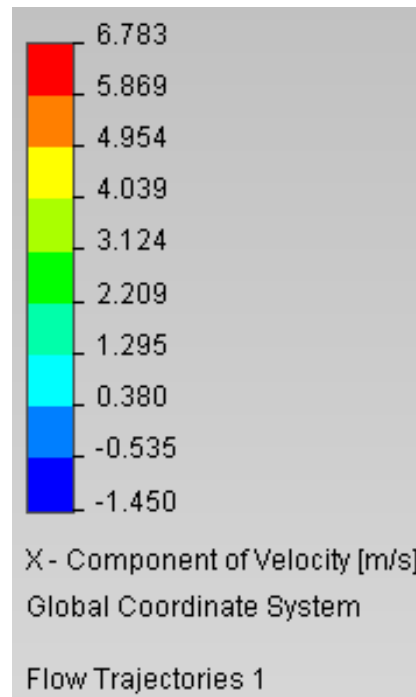


Figure 30 Test 3

It is observed that the incoming 4.9m/s flow has been reduced to wind speed between 4.95 to 5.869m/s, at the highest point of the building. The modification increased our incoming wind speed up to a max of %18.56 percent at the 20meters mark. If we observe the first 5 meters from the highest point of the building, which is the 20-25meters mark. The initial wind speed of 4.9 has been increased to a sum between 4.954-6.783m/s. With the modification changed and the height gained, the initial wind speed increased up to a max of %38.4.

But you can still see there is a problem with the flow behind the building. Although again the wind tunnel specifications are set to match the exactly the origin of the building there should not be any wind flowing from underneath the building. The reason for this problem is not known but it is observed that it is not interfering with the flow from the roof thus it shall be ignored.

d.Test 4 - To get a better understanding of the urban plot on this test, two buildings has been modeled 20x20x20 m basic cube shape building and a 20x20x30 m basic rectangular shaped building and following study of Edward Ng the buildings are designed as the shape of stairs. The incoming wind speed of 4.9 has been chosen and the following results has achieved with only x velocity of the wind monitored. But this time flow is observed both from the 'Front Plane' and the 'Surface of the Roof' views to get a better understanding of wind reaction.

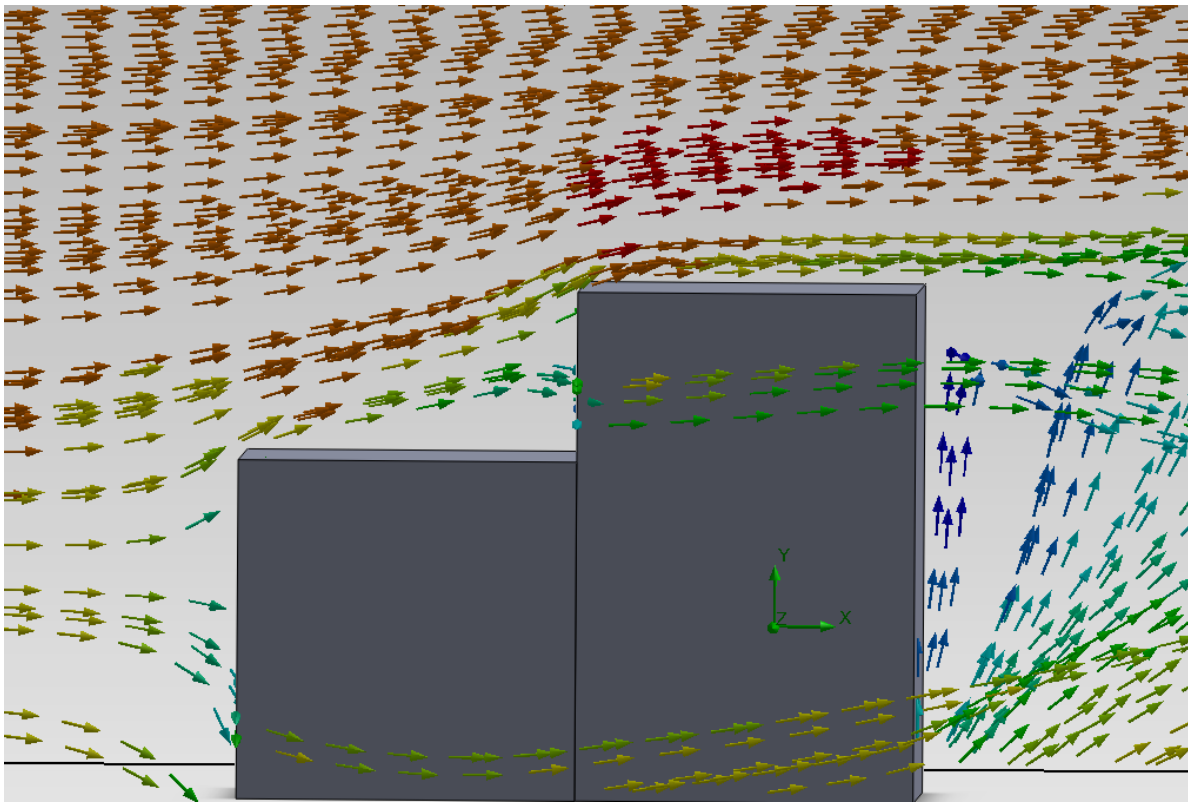


Figure 31 Test 4 Test 4 'Front Plane view'

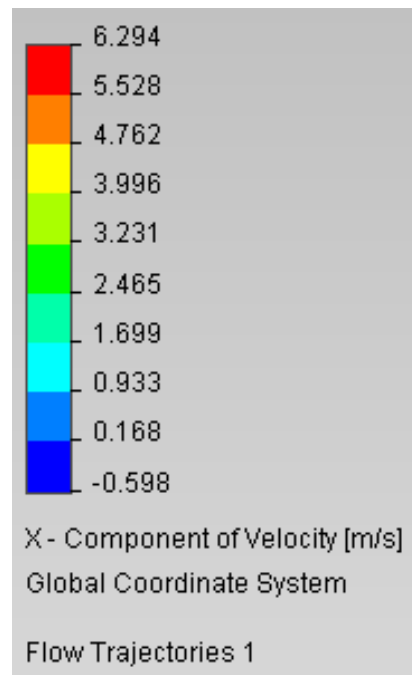


Figure 32

If we are to look at to the building system from the 'Front Plane', we can see that the initial wind speed of 4.9 can be measured around 3,231-5.528m/s, as it passes by the first building mark. At the second building mark, the wind speed can be measured between 3.231-6.294m/s. We can agree that the It is

observed that the wind gains a little bit of speed when it first reaches the roof floor of both buildings then continues normally accelerating. But to get a better understanding how it interacts with the design we need to check the surface reaction of the wind with the roof at figure 33.

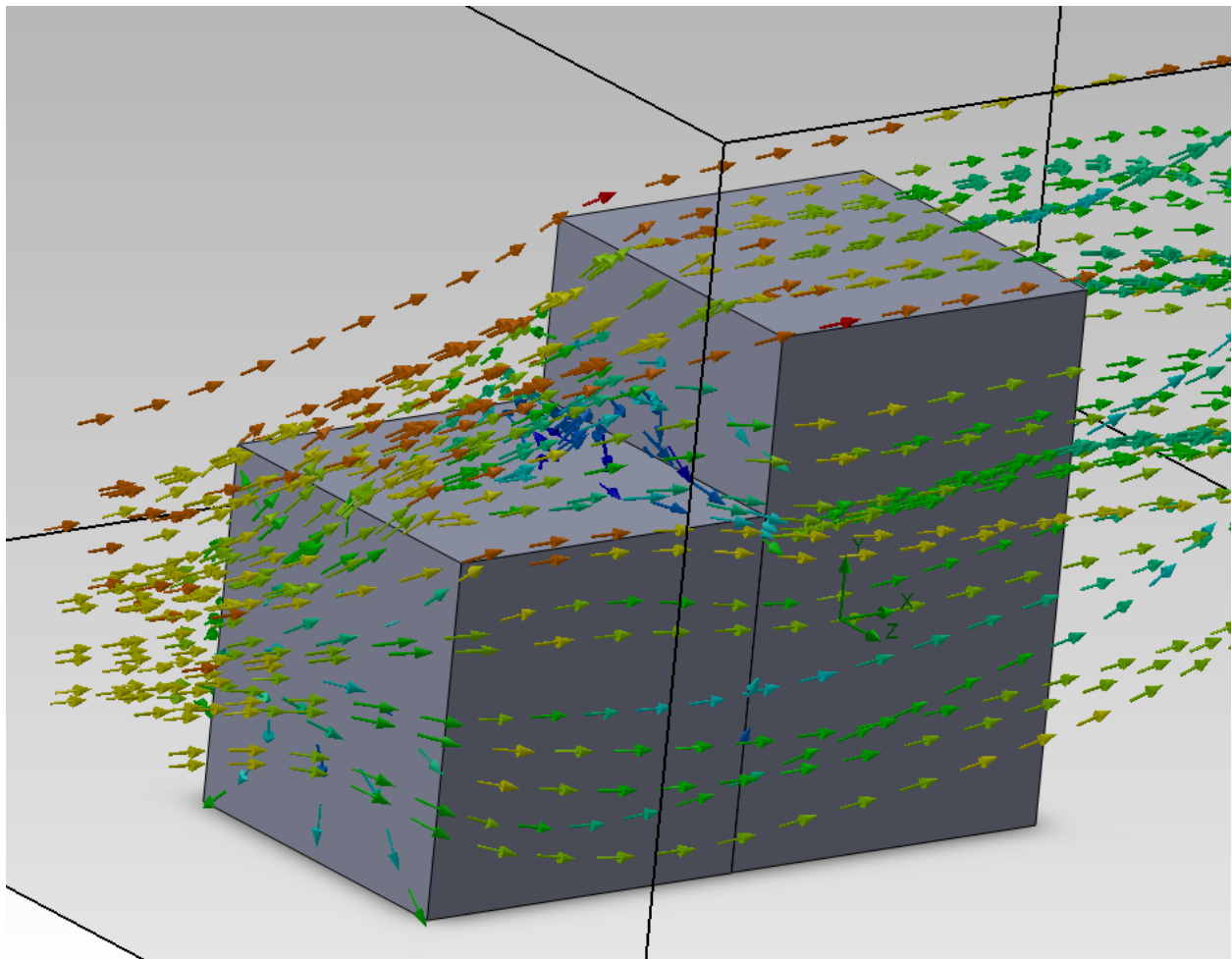


Figure 33 Test 4 ‘Surface Wind view’

The wind acts differently when it is going by the surface of the roof of the building, it is seen that it still creates a vacuum which causes a turbulence in the wind and loses a portion of its power with speed decreasing from 3.996-4.762 to a speed under 0.1 - -0.59 m/s and even flow in the negative x direction. Even though we can still observe that the initial speed of wind that it is observed at the contact point of the first building, maintains a similar speed as it reaches to the contact point of the second building.

If we compare test 4 with test 1, if we observe the figure 26, where the two buildings were separately built, where the initial wind speed of 4.9 has been changed to a speed between 2.93-4.830m/s at the first contact point and changed to a wind speed of 1.99-2.93m/s at the second contact point. According to our step system type building on Test 4, figure 31, the initial 4.9m/s of wind speed has changed to a speed between 3.231-5.528m/s at the first contact point, to 3.231-6.294m/s at the second

contact point. The data clearly suggest that the step style building system decreases the roughness, and increases the wind speed.

However this might not seem important but if we are to put a urban wind turbine on the first floor roof, the flow of the wind is going to be affected and even more slowed down so the wind which will go to the next might be slowed down but more research and data are needed to comment on this matter.

e.Test 5- After demonstrating the idea, where the buildings are designed to simulate the shape of a stair construction system inspired from Edward Ng's idea on figure 36 and 38. The design has been slightly modified by installing a panel or modifying the roof structure. 1/5 ratio of 'Fillet' option was used to create the shape. The same buildings from test 3, where a basic design of a standalone building in the shape of 20x20x20m cube , and a 20x20x30 m basic rectangular shaped building was modeled. Wind speed of 4.9 has been chosen and the following results has achieved with only x velocity of the wind monitored modified to see the effects on the wind.

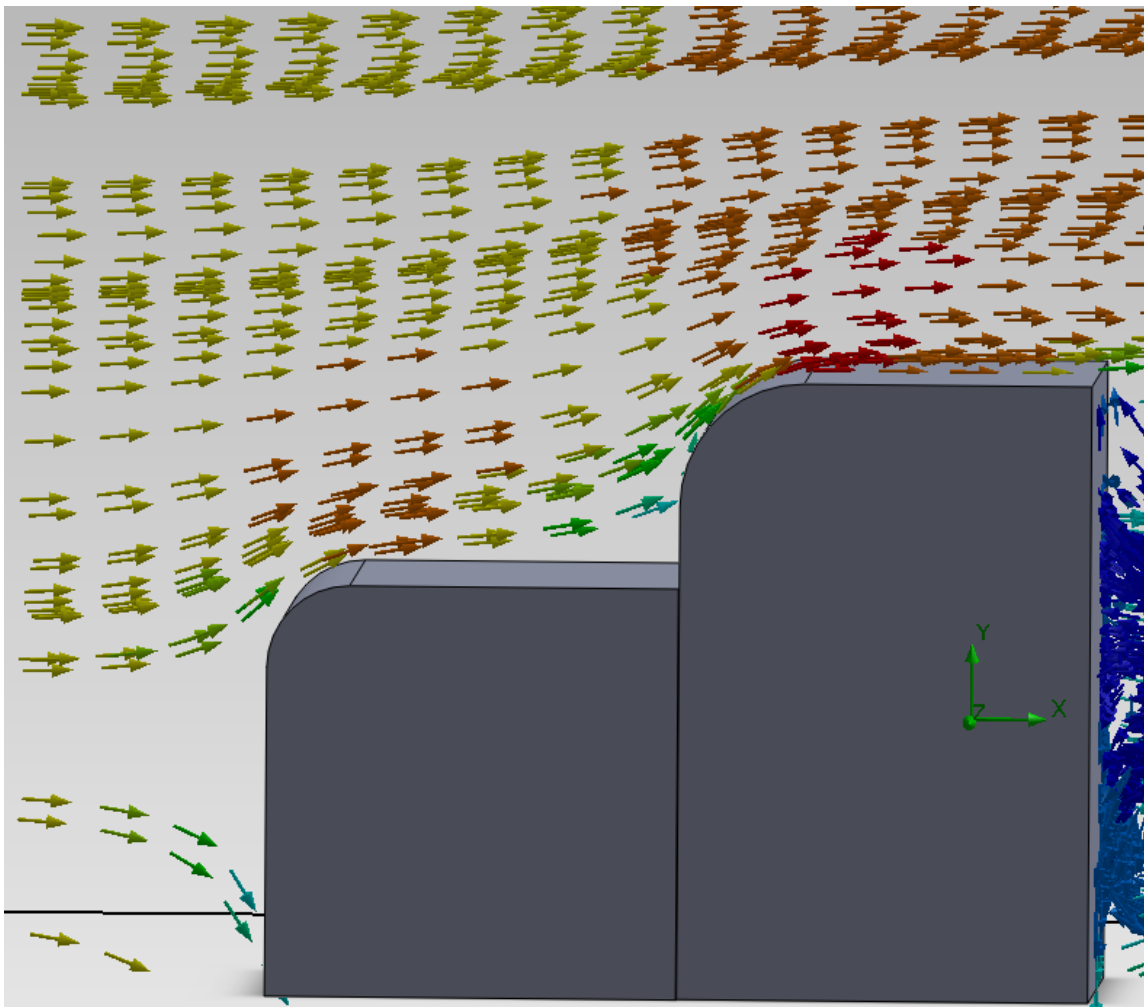


Figure 34 Test 5'Front Plane view'

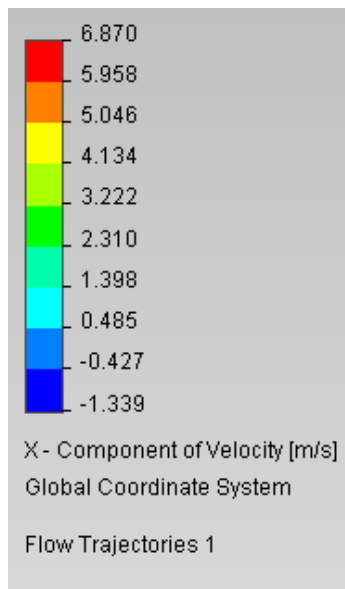


Figure 35 Test 5

It is observed that the wind speed at the point of contact with the first building is between 4.134-5.958m/s, if we measure the wind speed at the second contact point of the building, the wind speed is between 4.134-6.870m/s .

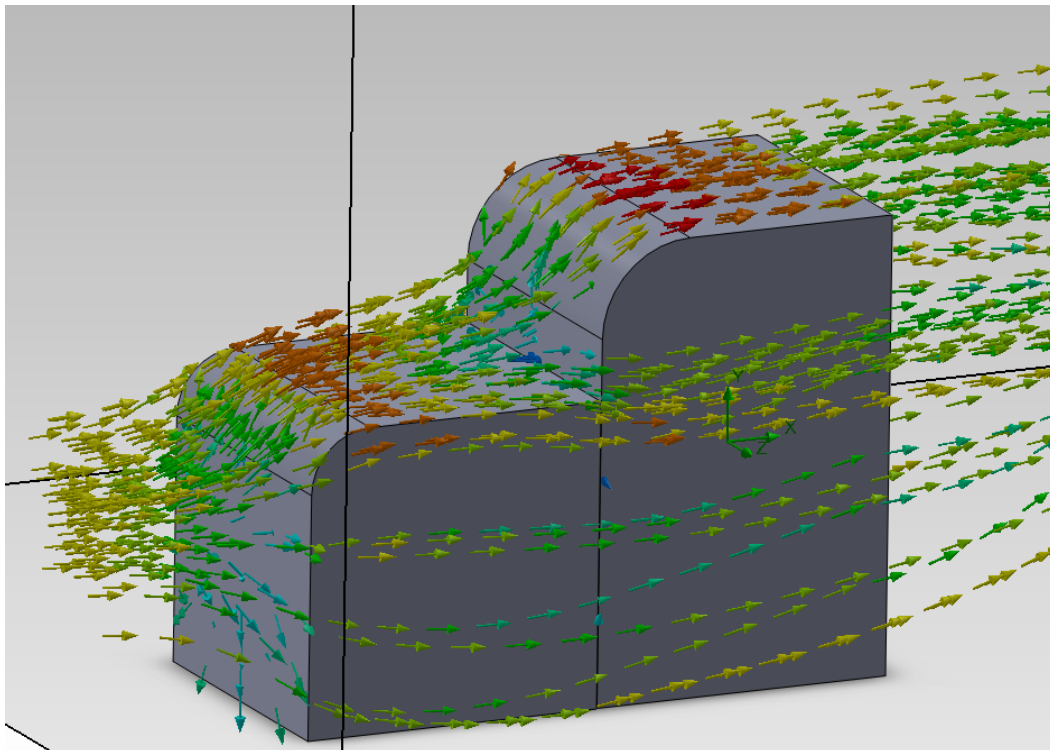


Figure 36 Test 5 Surface Wind view

f.Test 6 - This test is conducted to see that if the initial design modification will have an impact when planning for a regular sized wind turbine. According to Quasching, the hub height of the system should be at least three times higher than the nearest obstacle or should be placed at a distance of 35 times the height of the obstacle, to get the system to work at optimal wind speed.(Quaschnig, 2005)

Same parameters from test 5 is modeled, as where the buildings are designed to simulate the shape of a stair construction system inspired from Edward Ng's idea on figure 36 and 38. The design has been slightly modified by installing a panel or modifying the roof structure. 1/5 ratio of 'Fillet' option was used to create the shape. The same buildings from test 3, where a basic design of a standalone building in the shape of 20x20x20m cube, and a 20x20x30 m basic rectangular shaped building was modeled. Wind speed of 4.9 has been chosen and the following results have been achieved with only x velocity of the wind monitored modified to see the effects on the wind.

However the wind tunnel size is increased to building size times 35 (Quaschnig, 2005), which is the 30m x 35. The 1km point is the optimum distance according to Quasching. In the figure 37, we can see a regular design and our new design are compared. The initial wind speed is 4.9m/s at the first contact point with the first building.

On the regular system the wind is more turbulent compared to our new design. After the wind flow passes by the second building it maintains a speed between 2.427-3.947m/s nearly till the 350m point and then begins to accelerate. The speed picks up after the 350m point and reaches up to 4.707-5.457m/s near the 700m point. which supports the Quaschnig formula.

On our new design, the wind is less turbulent compared to the other design. After the wind flow passes by the second building it maintains a speed between 2.732-4.169m/s nearly till the 225m point and then begins to accelerate. The speed picks up after the 300m point and reaches up to 4.169-5.609m/s near the 450m point.

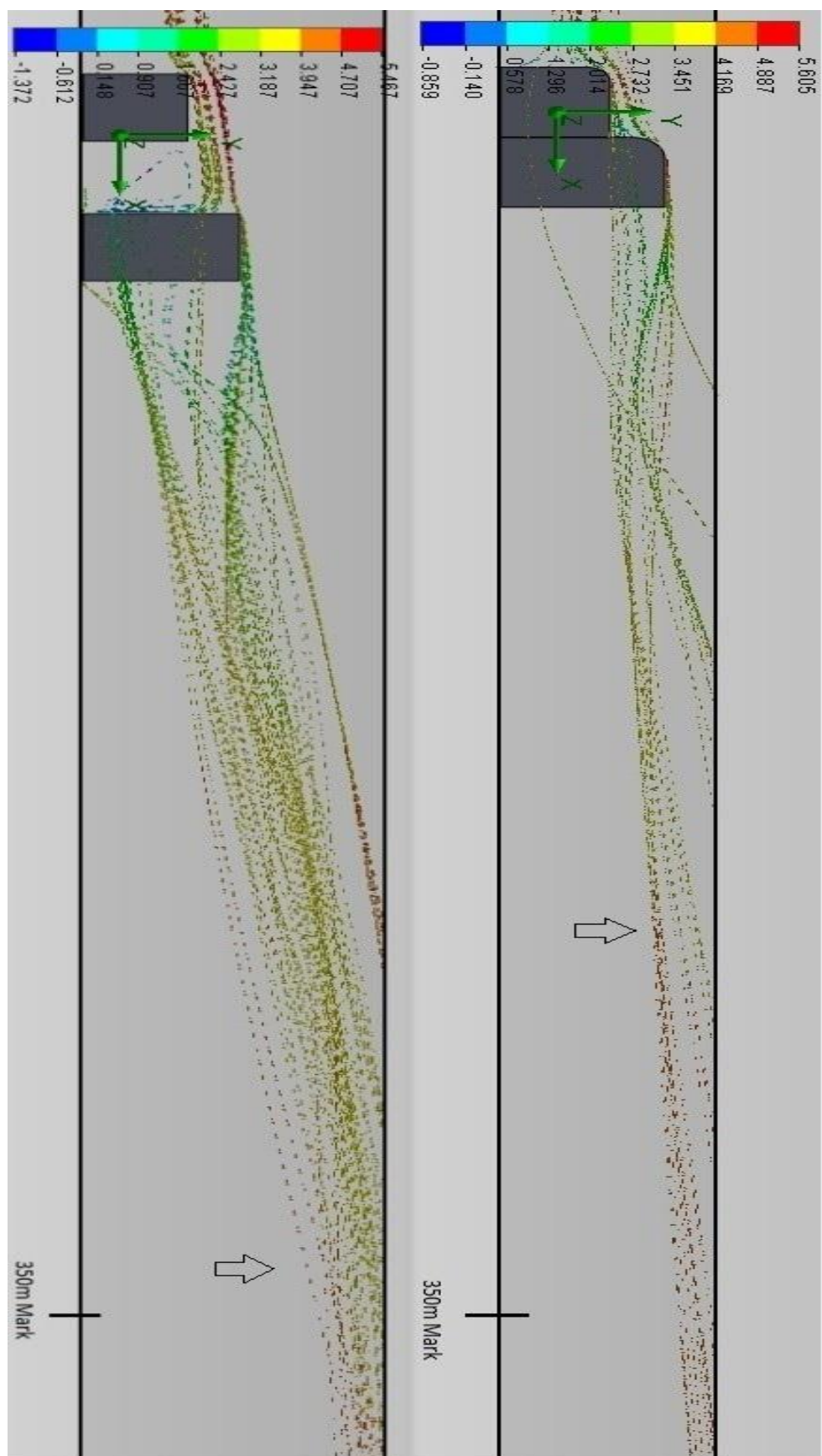


Figure 37 Test 6

4.2.Discussion

The results of the tests are discussed in this section with comparison method, and some supportive material from the EU Wind Turbine Manufacturers.

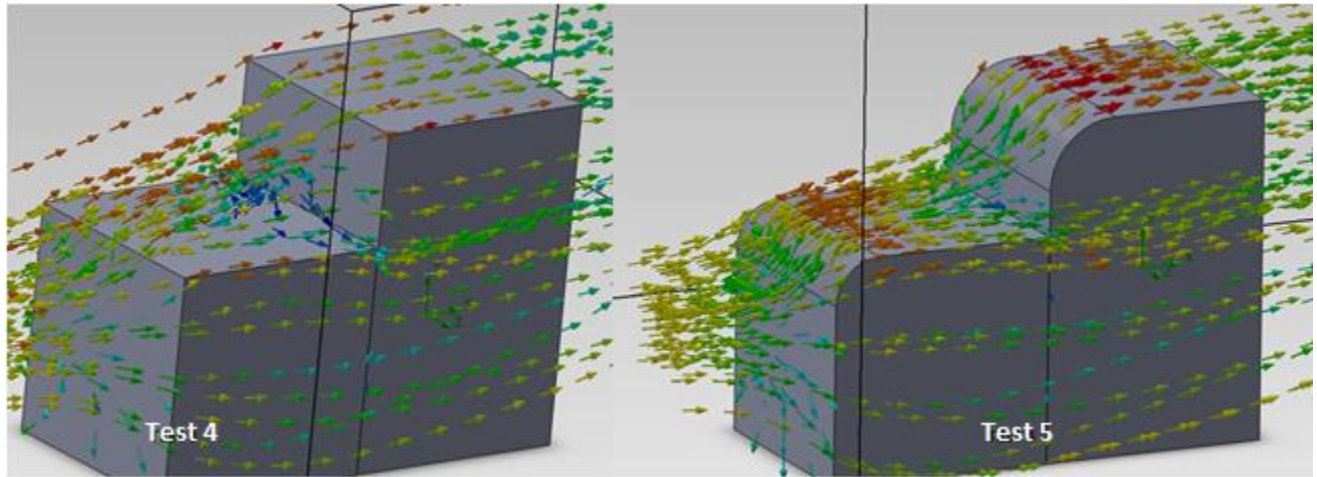


Figure 38 Comparison of Test 4 and Test 5

If we compare the designs in test 4 Normal Design with test 5 Modified Design; We can observe that the not only the wind speed is getting faster than the initial contact speed with the building at the first contact point , but also it is getting even faster when it reaches the roof of the second building, at the second contact point. If we are to accept that the initial speed is close to 4.9 we can see that the wind speed has surpassed the 5.046 limit twice in a row and achieving a speed of approximately 6.870m/s when it reaches the roof of the second building.

If we are to look at to the building system from the ‘Front Plane’ at test 4, we can see that the initial wind speed of 4.9 can be measured around 3,231-5.528m/s, as it passes by the first building mark. At the second building mark, the wind speed can be measured between 3.231-6.294m/s. However,at test 5 it is observed that the wind speed at the point of contact with the first building is between 4.134-5.958m/s, if we measure the wind speed at the second contact point of the building, the wind speed is between 4.134-6.870m/s .

The modification caused a total of %7.77 (calculated with the max values) increase in the wind speed at the first contact point, and a total of %9.15 in the wind speed.

So if we compare the test 1 to test 5, the wind speed at the first contact point has increased by a max of %23.35 (from a max 4.830m/s to 5.958m/s at the first contact point), and at the second contact point the wind speed increased by a max of %134.47 (from a max 2.93m/s to 6.870m/s at the second contact point),.

The modification greatly improved the wind flow and affected the wind speed. This is really important because when calculating the energy generated by the wind turbines, the formula is,

$$P = 0.5 * \rho * V^3 * A$$

where,

p = dynamic pressure

V = wind speed

P = power

A = cross-sectional area of the wind

We can see the effect of the wind speed in the formula as V^3 , thus a slight increase in the speed results a huge increase in the power generated.

Completion of the Urban Wind Turbines in EU in terms of Power, Cut in and Cut out speeds and Max. tolerable wind speed (Catalogue of European Urban Wind Turbine Manufacturers) and Completion of the Urban Wind Turbines in EU in terms of Wind speed to Power Generation have been made. The extended documents can be found at the Appendix A and B.

Comparison is done between the test 1, where normal building design where the buildings were built in regular fashion and within a certain distance to each other, and test 2 where the design is modified so the buildings are designed to be like a step system with an installment of a plate or a slight change on the roof design. 5 different HAWT and VAWT type turbines are selected in terms of their power generation capabilities in different wind speeds. The manufacturer data has been used in the related wind speeds can be seen at The table 14 and Table 15 can be seen below. The difference in energy generations can be seen between the normal design and our modified design within the measured wind limits can be seen at the figures 39 and 40.

Table 14

Wind Speed (m/s)	Travere TI/6/2.1 HAWT 5.5kw	Fortis Wind Energy HAWT 10kw	Gaia Wind A/S HAWT 11kw	Eoltec HAWT 25kw	Pitchwing HAWT 30 kw
3	0.16	0	3	0.5	0.3
4	0.38	0.4	4	1	1.6
5	0.74	1	6	2	3.9
6	1.29	1.8	7	3.5	7.3
7	2.04	2.8	8	5.5	11.8

Complation of some Urban Wind HAWT Turbines in EU in terms of Wind speed to Power Generation (measured in kW)

So if we assume that we installed a wind turbine on the design at the first contact point or the second contact point. The theoretical power generation can be represented as in the figure 38 for the the normal design in the red section and for our modified design in the green section, related to the measured wind speeds at the first and second contact points..

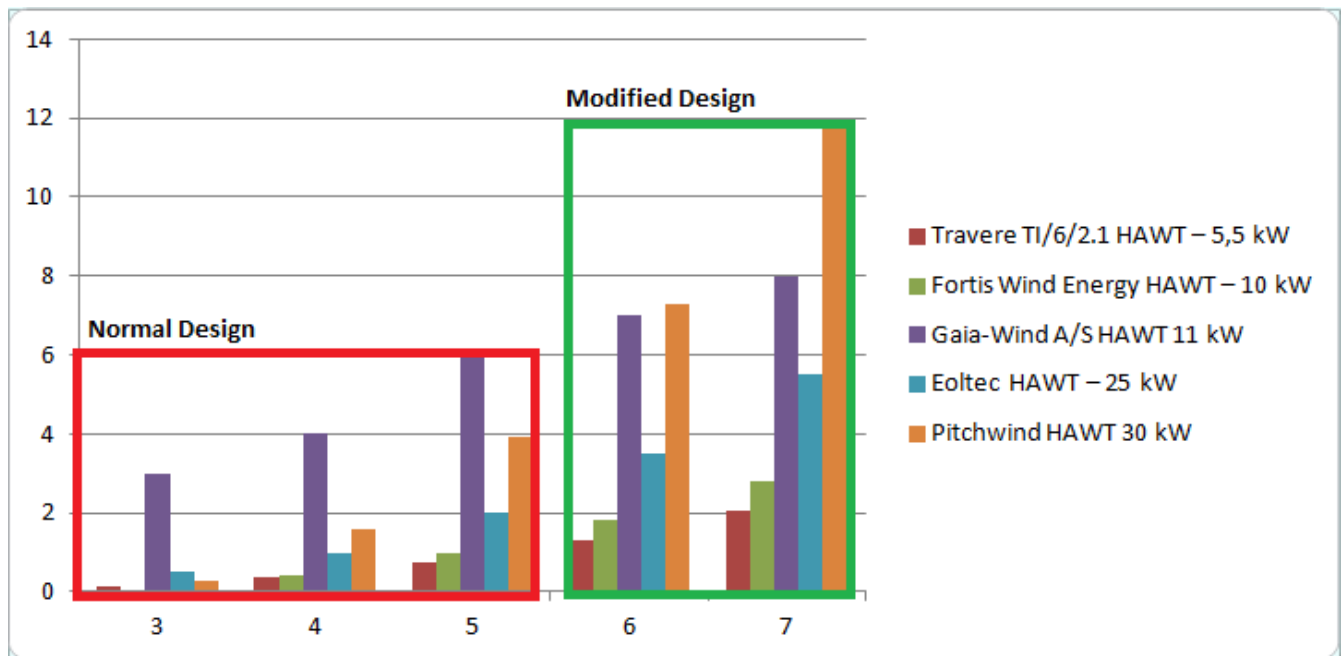


Figure 39 Complation of some Urban Wind Turbines in EU in terms of Wind speed to Power Generation HAWTS

Table 15

Wind Speed (m/s)	Venturi Wind b.v. VAWT – 0,5 kW	Ropatec S.p.a. VAWT – 0,75 kW	Turby B.V. VAWT – 2,5 kW	Ropatec S.p.a. VAWT – 6 kW	OY Windside Production VAWT – 8 kW
3	3	8,6	0	50	60
4	7	20,3	6	100	120
5	13	39,6	56	250	211
6	23	108,7	155	400	300
7	36	162,3	310	700	450

Completion of some Urban Wind VAWT Turbines in EU in terms of Wind speed to Power Generation (measured in W)

So if we assume that we installed a wind turbine on the design at the first contact point or the second contact point. The theoretical power generation can be represented as in the figure 39 for the the normal design in the red section and for our modified design in the green section, related to the measured wind speeds at the first and second contact points.

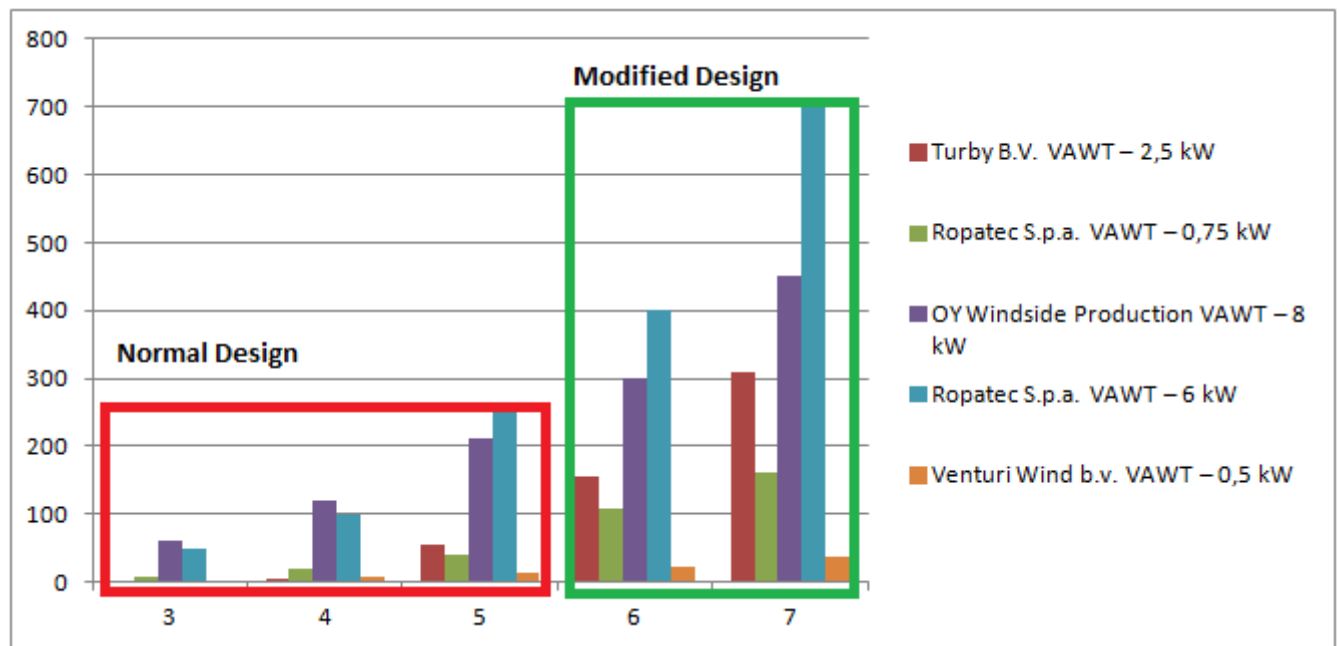


Figure 40 Completion of some Urban Wind Turbines in EU in terms of Wind speed to Power Generation VAWTS

If we are to observe figure 39 and figure 40, we can see that there is major difference in energy production between the normal design from test 1 and the modified design from the test 5. The slight increase of wind speed, increased our power generation greatly.

If we compile all the data we have gathered so far in a single table, we can see and compare the results achieved properly. By doing so we can assess that if the modification will effect the energy production greatly or if the modification is unnecessary.

All the data from the test 1 and test 5, is gathered. The winds speeds at the first and second contact points of both designs are measured respectively as, wind speed at test 1 first and second contact point and test 5 first and second contact point. The initial wind speed selected was 4.9m/s, however the wind speeds recorded at the first and second contact points were measured between 2.93-6.780 m/s (from the max values). If we assume 2.93=3 m/s and 6.780=7m/s for ease of calculation method. Considering the wind speed difference relates as V^3 , so the ratio of 6.78 to 7 will be very different.

A very detailed table is put together from the mentioned data, and It can be found at Table 16.

Table 16

HAWTs (in kW)	Wind Speed (m/s)	Travere TI/6/2.1 HAWT 5.5kw	Fortis Wind Energy HAWT 10kw	Gaia Wind A/S HAWT 11kw	Eoltec HAWT 25kw	Pitchwing HAWT 30 kw
1st Contact Point of the Regular Building Design	4.83 (Assuming 5)*	0.74	1	6	2	3.9
1st Contact Point Modified Building Design	5.958 (Assuming 6)*	1.29	1.8	7	3.5	7.3
Difference in Wind Speed and Energy Production	1	0.55	0.8	1	1.5	3.4
2st Contact Point of the Regular Building Design	2.93 (Assuming 3)*	0.16	0	3	0.5	0.3
2st Contact Point Modified Building Design	6.87 (Assuming 7)*	2.04	2.8	8	5.5	11.8
Difference in Wind Speed and Energy Production	4	1.88	2.8	5	5	11.5
VAWTs (in W)	Wind Speed (m/s)	Venturi Wind b.v. VAWT – 0,5 kW	Ropatec S.p.a. VAWT – 0,75 kW	Turby B.V. VAWT – 2,5 kW	Ropatec S.p.a. VAWT – 6 kW	OY Windside Production VAWT – 8 kW
1st Contact Point of the Regular Building Design	4.83 (Assuming 5)*	13	39,6	56	250	211
1st Contact Point Modified Building Design	5.958 (Assuming 6)*	23	108,7	155	400	300
Difference in Wind Speed and Energy Production	1	10	69.1	99	150	89
2st Contact Point of the Regular Building Design	2.93 (Assuming 3)*	3	8,6	0	50	60
2st Contact Point Modified Building Design	6.87 (Assuming 7)*	36	162,3	310	700	450
Difference in Wind Speed and Energy Production	4	33	153.7	310	650	390
*Data From Manufacturer						

Difference in Wind Speed and Energy Production

Analyzing the table can be divided into two sections, in terms of HAWTs (kW) and VAWTs (W). (Calculations are made according to assumed wind speeds.)

For HAWTs, the data is measured in kW.

The modification improved the wind speed at the first contact point by 1m/s (increased from 5m/s to 6m/s) which resulted a huge amount of energy generation for HAWTs. The data is;

- Travere 5.5kW, the energy generation went up by 0.55kW which is a %74.3 increase from 0.74 to 1.29kW.
- Fortis 10kW, the energy generation went up by 0.8kW which is a %80 increase from 1 to 1.8kW.
- Gaia 11kW, the energy generation went up by 1kW which is a %16.6 increase from 6 to 7kW.
- Foltec 25kW, the energy generation went up by 1.5kW which is a %75 increase from 2 to 3.5kW.
- Pitchwing 30kW, the energy generation went up by 3.4kW which is a %87 increase from 3.9 to 7.3kW.

The modification improved the wind speed at the second contact point by 4m/s (increased from 3m/s to 7m/s) which resulted a huge amount of energy generation for HAWTs. The data is;

- Travere 5.5kW, the energy generation went up by 1.88kW which is a %1175 increase from 0.16 to 2.04kW.
- Fortis 10kW, the energy generation went up by 2.8kW where at the normal design the energy generation was 0 according to the manufacturers data. The increase is from 0 to 2.8kW.
- Gaia 11kW, the energy generation went up by 5kW which is a %166 increase from 3 to 8kW.
- Foltec 25kW, the energy generation went up by 5kW which is a %1000 increase from 0.5 to 5.5kW.
- Pitchwing 30kW, the energy generation went up by 11.5kW which is a %3833 increase from 0.3 to 11.8kW.

For VAWTs, the data is measured in W.

The modification improved the wind speed at the first contact point by 1m/s (increased from 5m/s to 6m/s) which resulted a huge amount of energy generation for VAWTs. The data is;

- Venturi 0.5kW, the energy generation went up by 10W which is a %77 increase from 13 to 23W.
- Ropatec 0.75kW, the energy generation went up by 69.1W which is a %174 increase from 39.6 to 108.7W.
- Turby 2.5kW, the energy generation went up by 99W which is a %176 increase from 56 to 155W.
- Ropatec 6kW, the energy generation went up by 150W which is a %60 increase from 250 to 400W.
- OY Windside 8kW, the energy generation went up by 89W which is a %42 increase from 211 to 300W.

The modification improved the wind speed at the second contact point by 4m/s (increased from 3m/s to 7m/s) which resulted a huge amount of energy generation for HAWTs. The data is;

- Venturi 0.5kW, the energy generation went up by 33W which is a %1100 increase from 3 to 36W.
- Ropatec 0.75kW, the energy generation went up by 153.7W which is a %1787 increase from 8.6 to 162.3W.
- Turby 2.5kW, the energy energy generation went up by 310W where at the normal design the energy generation was 0 according to the manufacturers data. The increase is from 0 to 310W.
- Ropatec 6kW, the energy generation went up by 650W which is a %1300 increase from 50 to 700W.
- OY Windside 8kW, the energy generation went up by 390W which is a %650 increase from 60 to 450W.

For HAWTs our modification provided an energy generation increase between a minimum of %16 to a maximum of %3833 for the selected wind turbines and for VAWTs our modification provided an energy generation increase between a minimum of %42 to a maximum of %1787 for the selected wind turbines. The increase in energy production is considerably high. This proves that our modification will theoretically have a positive impact on an HAWT or a VAWT system.

Thus for people who are interested to install a micro wind turbine system to generate electricity for themselves this system might be an easy and cheap way to increase the energy generation by a good margin If implemented system will generate more funds at the same conditions, resulting in a higher income which will cope up with the initial investment costs and be more profitable in the future.

Also if we observe test 6, On the regular system the wind is more turbulent compared to our new design. After the wind flow passes by the second building it maintains a speed of 4m/s (actual number is 2.427 to 3.947m/s however all the calculations have been made according to the maximum wind speed thus, $3.947=4$ m/s, we assume the wind speed is 4 m/s) nearly till the 350m point and then begins to accelerate. The speed picks up after the 350m point and reaches up to 5m/s (same factor is also applied so , the wind speed of 4.707 to 5.457m/s , from maximum value $5.457=5$ m/s) near the 700m point. which supports the Quaschnig formula (as in the distance to put a new wind turbine from our existing house is 35 times the height of the house, which is 30m times 35, equates to 1050m, the wind starts to pick up around 700m and continues to increase in speed.).

On our new design, the wind is less turbulent compared to the other design. After the wind flow passes by the second building it maintains a speed of 4m/s (actual number is 2.732-4.169m/s however all the calculations have been made according to the maximum wind speed thus, $4.169=4$ m/s) nearly till the 225 m point and then begins to accelerate. The speed picks up after the 300m point and reaches up to 6m/s (same factor is also applied so , the wind speed of 4.169-5.609m/s , from maximum value $5.609=6$ m/s) near the 450m point.

If we compare two designs, we can see that our modification decreased the distance by approximately 125m in order to reach 4m/s wind speed. The modification decreased the distance of the optimal place where a wind turbine can be installed by %12.5.

As a result we can see that the modification have a considerable effect on the energy generation on the micro wind turbines as well as it has a reasonable impact on the calculation of distance where a wind turbine can be built within a distance from a building.

The reason the wind speed for Guildford town center was selected from NOABL database is because the construction style of the town center is similar to the stair type building construction mentioned above seen at the figure 41 and figure 42. So we can say that the result from this test might be applicable for the Guildford town center. If these systems are proven to be valuable. A place like Guildford can be a good place to implement these system.



Figure 41 Guildford 1 (URL 14)



Figure 42 Guildford 2 (URL 15)

But it is hard to modify a building which is already built and it will cost a lot. Guildford is an old settlement with already built environment, this approach might not seem like a solution. However as a solution, instead of constructing the buildings with purpose of achieving this design we can also build a separate structure which can act as wind channeling device that has the same capabilities of this design. This device can be constructed from a light material and will have the similar shape of the curved face of our house design. The proposed system can be seen in figure below. Red colored shape represents the alternative structure.

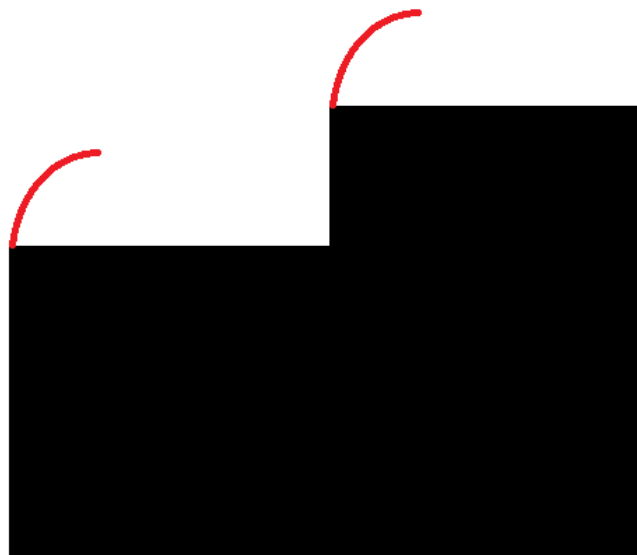


Figure 43 Sample

Furthermore these structures can be implemented with solar panels and with the combination of this wind/solar powered system even during the nights, cloudy days and winters (which they tend to be windier) will keep generating more energy compared to each of them individually. Also if we are to look figure 15 we can see that the cut in speed of the urban wind turbines are around 3 to 4. So if this system can grant us a boost of even 1m/s this might help the urban wind turbines to kick in and start generating energy instead of doing nothing. To get an idea how this might effect the current urban wind turbines, a compilation of urban wind turbines at EU has been made into tables consisting of 57

different type of urban wind turbines. These tables are containing technical details of the turbines such as cut in wind speed etc. and wind speed to energy production relations. They can be found at the Appendice A and Appendice B.

These modifications can be and should be researched thoroughly for a easy and cheap way to boost urban wind turbines energy producing abilities. We can suggest that this system might work but can not conclude how it will be in real life without some further research. To get a solid idea of how this system a series of new research should be done including different types of urban wind turbines implemented on these systems and with an onsite wind measurement system so that the real data can be observed. The plot data for the tests 1 to 4 can be found at the appendices section.

Chapter 5: Summary, Conclusions and Future Scope of Work

5.1.Summary

Wind energy is an important source of renewable energy in today's constantly growing world with needs of food, water and energy to continue its existence. Unlike the fossil fuels, wind energy is infinite. As long as there will be a sun in our sky's it will continue to exist as it is generated by the heat changes through our world which are caused by sun.

The renewable energy sector is growing at a fast pace, because all of the countries want to be able to support themselves just with their own natural sources. Also the threat of Global Warming caused by carbon emissions are becoming obvious as the time goes by. EU has set some achievable goals on renewable energy for 2020. The sector is going into the right direction as it follows EU's policies on Wind energy, which promotes the installation of these systems larger or small.

As cities continue to grow more energy is consumed each day. As a solution people are getting interested of harvesting whatever energy source they can get. So urban wind turbine systems got started to be used. Most of the manufacturers are at the development and manufacturing phase so they are mostly not ready to mass produce neither the market will have a huge leap in the close future because the people are still not yet convinced about the Urban Wind Turbine Technologies. Still if we are to look at the big picture the Wind energy sector is continuing to grow each and every year.

Although the technology might be new and the manufacturers might be inexperienced there are still some good urban wind turbines to consider.

5.2.Conclusions

Urban Wind Energy Systems are still a new technology, it is still at the development phase and lacks experience. The interest is growing towards these systems as the advantages are observed more and it is applied by the innovative companies. Although we started to see these systems in our daily life there is still some doubt from some communities. This is caused by the fear of the complexity of the urban wind flow. Most of the work is focused on to the research for the urban wind turbines, to get them produce more energy etc. but there is a big gap on the understanding about how the wind flows in an urban environment and lack of data because unlike high flowing winds, the urban canopy completely changes the characteristics of the wind therefore making it near impossible to make a full city model without actually performing on site calculations.

Seen from Edward NG work and the results achieved by the simulations performed at this paper shows that there is a huge potential of wind we can use if we are able to integrate the city planning and the building design when considering an Urban Wind Energy Systems to channel this potential into our turbines to create more energy. But we can still say that these systems are just growing and the future of these system is bright.

5.3. Future Scope of Work

Despite all the challenges, people are coming with more and more ideas about the urban wind energy turbines and it is developing in a fast pace. There seems to be a gap in the literature when it is about the urban wind characteristics in cities, how the actual system effects it, and mostly effects of the actual building designs on channeling the wind.

For future scope of this work, first further modifications should be tested using a simulation program to see which will benefit this stair type construction system most. After a series of case studies should be done, with actual on site wind measurement system and data used, with the selected type of modifications applied on site and different types of wind turbines should be tested to see how the wind flow interacts with the surface and the built wind turbine systems.

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APPENDICES

Appendix A Compilation of the Urban Wind Turbines in EU in terms of Power, Cut in and Cut out speeds and Max. tolerable wind speed (Catalogue of European Urban Wind Turbine Manufacturers)

Model of the Turbine	Rated Power (kW)	Rated Wind Speed (m/s)	Cut-in Wind Speed (m/s)	Cut-out Wind Speed (m/s)	Max. tolerable wind speed (km/h)
Aircon HAWT - 10 kW	10	11	2,5	32	190
Ampair HAWT – 0,1 kW	0,1	20	3,5	-	N/A
Ampair HAWT – 0,3 kW	0,3	12,6	3	-	180
ATLANTIS Windkraft HAWT – 0,3 kW	0,3	10	3	-	limitless
ATLANTIS Windkraft HAWT – 0,6 kW	0,6	10	3	-	Limitless
Eclectic Energy HAWT – 0,4 kW	0,4	16	2	-	130
Ecofys VAWT – 3 kW	3	14	3,5	20	N/A
Eoltec HAWT – 6 kW	6	12	4	-	216
Eoltec HAWT – 25 kW	25	12	3	-	216
Eurowind Small Turbines Ltd VAWT – 1,3 kW	1,3	12	3 - 4	28 - 32	255
Eurowind Small Turbines Ltd VAWT – 5 kW	5	12	3 - 4	28 - 32	255
Eurowind Small Turbines Ltd VAWT – 10,8 kW	10,8	12	3 - 4	28 - 32	255
Eurowind Small Turbines Ltd VAWT – 19 kW	19	12	3 - 4	28 - 32	255
Eurowind Small Turbines Ltd VAWT – 30 kW	30	12	3 - 4	28 - 32	255
Fortis Wind Energy HAWT – 0,8 kW	0,8	14	3	-	60
Fortis Wind Energy HAWT – 1,4 kW	1,4	16	2,5	-	60
Fortis Wind Energy HAWT – 5,6 kW	5,6	17	2,5	-	60

Model of the Turbine	Rated Power (kW)	Rated Wind Speed (m/s)	Cut-in Wind Speed (m/s)	Cut-out Wind Speed (m/s)	Max. tolerable wind speed (km/h)
Fortis Wind Energy HAWT – 10 kW	10	12	3	-	60
Fuhrländer FL 30 HAWT – 30 kW	30	12	2,5	25	55
Fuhrländer FL 30 HAWT – 100 kW	100	13	2,5	25	67
Gaia-Wind A/S HAWT 11 kW	11	10	3	25	65
Gazelle Wind Turbines Ltd HAWT – 20 kW	20	13	4	20	N/A
Iskra Wind Turbines HAWT – 5 kW	5	11	3	60	216
Jonica Impianti HAWT – 20 kW	20	12,5	3,5	37,5	153
Marlec Engineering Co Ltd HAWT – 0,025 kW	0,025	10	2,6	-	>137
Marlec Engineering Co Ltd HAWT – 0,09 kW	0,09	10	2,6	-	>137
OY Windside Production Ltd VAWT – 1 kW	1	18	2	-	144
OY Windside Production Ltd VAWT – 8 kW	8	20	2	-	216
Pitchwind Systems AB HAWT 30 kW	30	15	2	-	250
Proven Energy Products Ltd HAWT – 0,6 kW	0,6	10	2,5	-	234
Proven Energy Products Ltd HAWT – 6 kW	6	12	2,5	-	234
Proven Energy Products Ltd HAWT – 15 kW	15	12	2,5	-	234
Renewable Devices Swift Turbines HAWT – 1,5 kW	1,5	12	4	17	223
Ropatec S.p.a. VAWT – 0,75 kW	0,75	14	2	-	>150
Ropatec S.p.a. VAWT – 3 kW	3	14	2	-	>150
Ropatec S.p.a. VAWT – 6 kW	6	14	2	-	>150
Rugged renewables VAWT – 0,4 kW	0,4	12	~4,5	-	170
Surface Power Technologies HAWT – 0,46 kW	0,46	12,5	3	-	216

Model of the Turbine	Rated Power (kW)	Rated Wind Speed (m/s)	Cut-in Wind Speed (m/s)	Cut-out Wind Speed (m/s)	Max. tolerable wind speed (km/h)
Sviab HAWT – 0,75 kW	0,75	12	2,5	-	216
TH Rijswijk, University of A.S. HAWT – 5 kW	5	10,5	2,75	>10,5	N/A
Travere Industries HAWT – 0,9 kW	0,9	10	2,3	60	216
Travere Industries HAWT – 1,6 kW	1,6	10	2,5	60	216
Travere Industries HAWT – 3 kW	3	12	2,8	60	216
Travere Industries TI/6/2.1 HAWT – 2,1 kW	2,1	8	2,5	60	216
Travere Industries TI/6/2.1 HAWT – 5,5 kW	5,5	10	3	60	216
Tulipower Tulipower HAWT – 2,5 kW	2,5	10	3	18	42,5 (m/s)
Turby B.V. VAWT – 2,5 kW	2,5	14	4	14	55 (m/s)
Venturi Wind b.v. VAWT – 0,5 kW	0,5	17	2	-	>145
VR & Tech VAWT – 2,5 kW	2,5	8	4	-	limitless
VR & Tech VAWT – 10 kW	10	8	4	-	limitless
VR & Tech VAWT – 25 kW	25	8	4	-	limitless
Wind Energy Solutions WES5 HAWT – 2,5 kW	2,5	8,5	3	20	35 (m/s)
Winddam AWT(1)2000 VAWT – 2 kW	2	12	2	-	234
Winddam AWT(2)2x2000 VAWT – 4 kW	4	12	2,5	-	234
Windsave HAWT – 1 kW	1	12	2,9	15	216
WindWall B.V. WW2000 – 2,9 kW	2,9	10,5	4	20	55 (m/s)
XCO2 VAWT – 6 kW	6	~12,5	4,5	16	N/A

Appendix B Complation of the Urban Wind Turbines in EU in terms of Wind speed to Power Generation

	Wind Speed (m/s)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Model Name	Power Generation																unit
Aircon HAWT - 10 kW	0	0	0,4	0,9	2,3	3,3	4,9	6,7	8,1	9,3	9,8	9,8	9,8	9,8	9,8	9,8	kW
Ampair HAWT – 0,1 kW	0	0	0	0,5	11	21	29	38	48	57	65	71	76	81	85	88	W
Ampair HAWT – 0,3 kW	0	0	4	10	20	34	51	76	110	144	192	248	293	300	300	300	W
ATLANTIS Windkraft HAWT – 0,3 kW	0	0	10	20	-	80	-	180	-	300	-	370	-	370	-	-	W
ATLANTIS Windkraft HAWT – 0,6 kW	0	0	10	50	-	160	-	340	-	600	-	730	-	730	-	-	W
Eclectic Energy HAWT – 0,4 kW	0	0	10	20	40	70	90	125	150	185	220	260	285	325	360	400	W
Ecofys VAWT – 3 kW	0	0	0	100	-	220	420	650	980	1320	1700	2100	2500	2700	-	-	W
Eoltec HAWT – 6 kW	0	0	0	0,2	0,5	1,1	1,8	2,7	3,8	5	5,7	6	6	6	6	-	kW
Eoltec HAWT –	0	0	0,5	1	2	3,5	5,5	8,2	11,7	16	21	25	25	25	25	-	kW

	Wind Speed (m/s)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Model Name	Power Generation																unit
25 kW																	
Fortis Wind Energy HAWT – 0,8 kW	0	0	0	0,03	0,07	0,13	0,20	0,28	0,38	0,47	0,57	0,66	0,74	0,78	0,8	-	W
Fortis Wind Energy HAWT – 1,4 kW	0	0	1	40	110	220	350	460	600	730	880	1020	1150	1280	1400	-	mW
Fortis Wind Energy HAWT – 5,6 kW	0	0	0,1	0,22	0,44	0,72	1,10	1,43	2,00	2,70	3,30	3,90	4,40	4,90	5,40	-	W
Fortis Wind Energy HAWT – 10 kW	0	0	0	0,4	1	1,8	2,8	3,9	5,2	6,8	8,5	9,8	10	10	10	-	W
Gaia-Wind A/S HAWT 11 kW	-	-	3	4	6	7	8	9	10	11	12	-	-	-	-	-	kW
Iskra Wind Turbines HAWT – 5 kW	0	0	96	367	771	1284	1901	2547	3253	3965	4397	4888	5000	5000	5000	-	W
Jonica Impianti HAWT – 20 kW	0	0	0,25	0,50	1,5	2,5	4	6	8,6	11,8	15,6	20	20	20	20	-	W
Marlec	0	0	1	2	4	6	10	14	20	26	28	36	39	44	56	-	W

	Wind Speed (m/s)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Model Name	Power Generation																unit
Engineering HAWT – 0,025 kW																	
Marlec Engineering HAWT – 0,09 kW	0	0	2	14	21	28	44	50	66	83	87	92	121	138	159	-	W
OY Windside Production VAWT – 1 kW	0	10	20	40	70	100	150	210	300	400	550	700	900	1200	-	-	W
OY Windside Production VAWT – 8 kW	0	30	60	120	211	300	450	630	900	1200	1650	2100	2700	3600	-	-	W
Pitchwind HAWT 30 kW	0	0,1	0,3	1,6	3,9	7,3	11,8	17,6	22,7	26,2	28,4	29,3	29,7	29,8	29,9	-	kW
Proven Energy HAWT – 0,6 kW	0	0	15	60	110	190	260	350	480	600	660	700	700	700	-	-	W
Proven Energy HAWT – 6 kW	0	0	0,1	0,45	1	1,5	2,05	3	4	5	6	6,2	6,25	6,15	-	-	kW
Proven Energy HAWT – 15 kW	0	0	0,3	1,2	2,2	4	5,5	7,5	10	12,5	15	16	16	16,5	-	-	kW
Ropatec S.p.a. VAWT – 0,75 kW	0	2,5	8,6	20,3	39,6	108,7	162,3	231	317	421,9	547,7	696,3	736,3	-	-	-	W

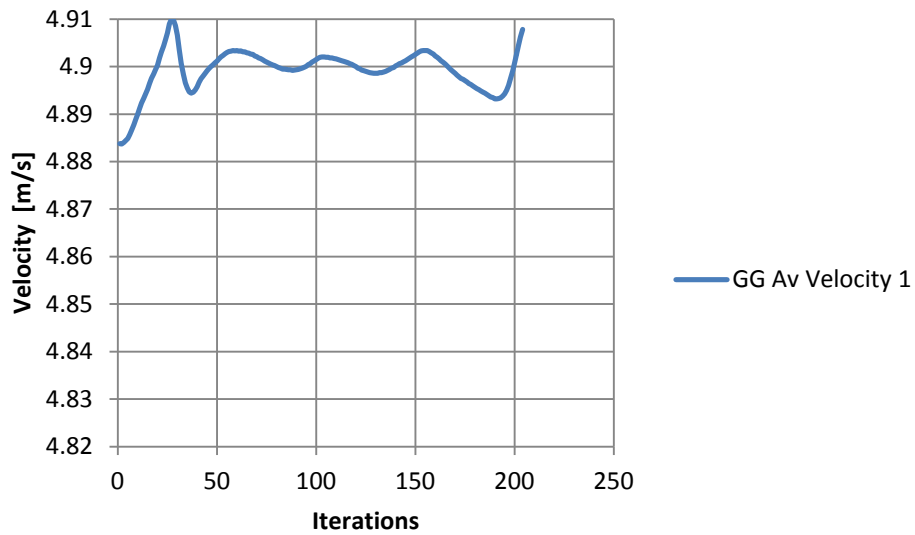
	Wind Speed (m/s)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Model Name	Power Generation																unit
Ropatec S.p.a. VAWT – 3 kW	10	20	30	60	120	220	350	520	740	1000	1300	1700	2200	2800	-	-	W
Ropatec S.p.a. VAWT – 6 kW	0	0	50	100	250	400	700	1000	1500	2000	2700	3500	4500	5600	6000	-	W
Surface HAWT – 0,46 kW	0	0	0	50	75	120	150	200	250	300	360	425	460	450	-	-	W
Sviab HAWT – 0,75 kW	0	0	0	50	100	170	250	350	500	620	750	790	790	790	790	-	W
Travere HAWT – 0,9 kW	0	0,03	0,60	0,12	0,21	0,33	0,49	0,69	0,90	0,90	0,90	0,90	0,90	0,90	0,90	-	kW
Travere HAWT – 1,6 kW	0	0	0,05	0,11	0,21	0,37	0,58	0,87	1,23	1,60	1,60	1,60	1,60	1,60	1,60	-	kW
Travere HAWT – 3 kW	0	0	0,06	0,14	0,27	0,46	0,73	1,10	1,56	2,14	2,85	3,00	3,00	3,00	3,00	-	kW
Travere TI/6/2.1 HAWT – 2,1 kW	0	0	0,14	0,33	0,65	1,12	1,78	2,10	2,10	2,10	2,10	2,10	2,10	2,10	2,10	-	kW
Travere TI/6/2.1 HAWT – 5,5 kW	0	0	0,16	0,38	0,74	1,29	2,04	3,05	4,34	5,50	5,50	5,50	5,50	5,50	5,50	-	kW
Tulipower Tulipower HAWT	0	0	68	243	530	958	1553	2159	2474	2595	2625	2598	2552	2382	2192	-	W

	Wind Speed (m/s)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Model Name	Power Generation																unit
– 2,5 kW																	
Turby B.V. VAWT – 2,5 kW	0	0	0	6	56	155	310	527	812	1171	1659	2136	2500	500	-	-	W
Venturi Wind b.v. VAWT – 0,5 kW	0	0,7	3	7	13	23	36	54	77	106	141	183	232	290	357	-	W
Wind Energy Solutions HAWT – 2,5 kW	0	0	68	243	530	958	1553	2159	2474	2595	2625	2598	2552	2382	2192	-	W
Winddam AWT(1)2000 VAWT – 2 kW	0	0	35	75	110	250	400	600	850	1250	1750	2100	2200	2200	2150	-	W
Winddam AWT 2x2000 VAWT – 4 kW	0	0	0	100	205	400	665	1000	1540	2205	3000	4000	4150	4110	4000	-	W
Windsave HAWT – 1 kW	-	-	-	-	-	-	-	-	-	-	-	1000	-	-	-	-	W
WindWall B.V. WW2000 – 2,9 kW	0	0	0	0,029	-	-	-	1,45	-	2,9	2,9	2,9	2,9	2,9	2,9	-	kW

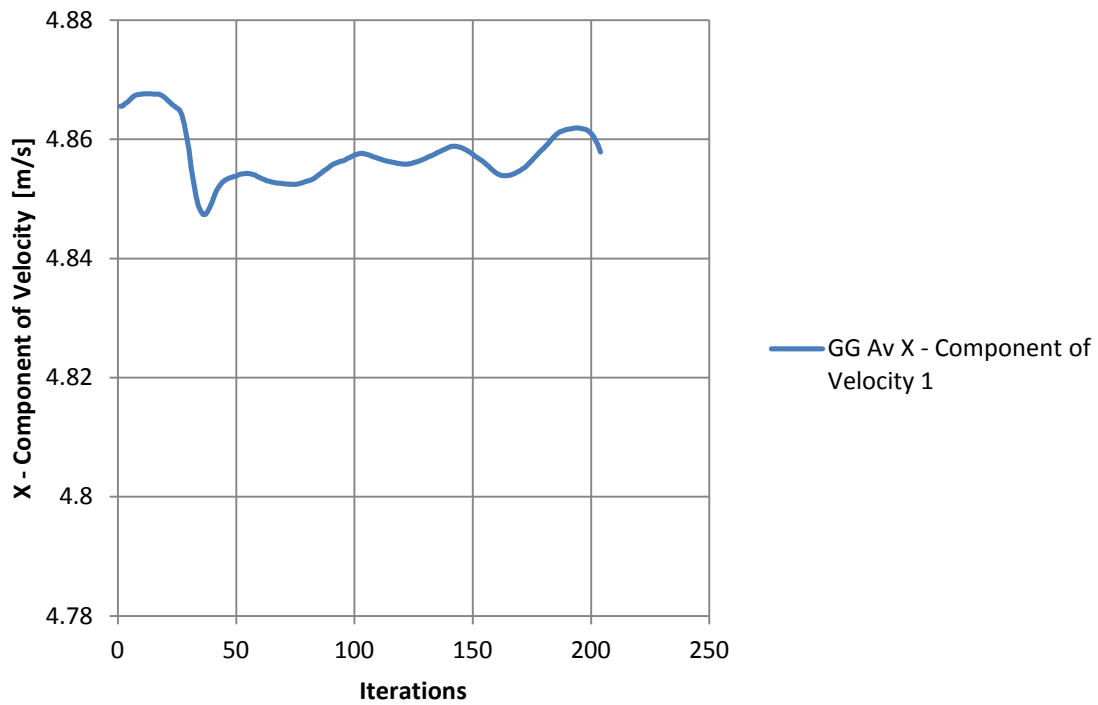
Appendix C TEST 2

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Av Velocity 1	[m/s]	4.858779692	4.857481506	4.856351419	4.858779692
GG Av X - Component of Velocity 1	[m/s]	4.826928388	4.825600617	4.824795413	4.826928388

test 2 avg velocity



test 2 x avg velocity



Velocity (m/s)		X - Component of Velocity (m/s)			
Iterations	GG Av Velocity 1	Iterations	GG Av X - Component of Velocity 1		
	9		9		
	Yes		Yes		
	39.3		77.9		
	0.002428		0.002133		
	0.000955		0.001662		
	4.857482		4.825601		
	4.856351		4.824795		
	4.85878		4.826928		
1	4.889448	1	4.871294		
2	4.889198	2	4.871272		
3	4.889305	3	4.871439		
4	4.889616	4	4.871565		
5	4.889925	5	4.871692		
6	4.890613	6	4.871861		
7	4.891401	7	4.871762		
8	4.892281	8	4.871517		
9	4.89302	9	4.871201		
10	4.893615	10	4.870947		
11	4.894188	11	4.870423		
12	4.894514	12	4.869824		
13	4.894737	13	4.869224		
14	4.894874	14	4.8686		
15	4.894979	15	4.86797		
16	4.895125	16	4.867093		
17	4.895175	17	4.866055		
18	4.895232	18	4.86491		
19	4.895345	19	4.863723		
20	4.895505	20	4.862534		
21	4.896053	21	4.860995		
22	4.896551	22	4.859322		
23	4.896922	23	4.857586		
24	4.897012	24	4.8557		
25	4.89659	25	4.853575		
26	4.895086	26	4.850161		
27	4.89276	27	4.846493		
28	4.889892	28	4.842866		
29	4.886851	29	4.839449		
30	4.883864	30	4.836384		

31	4.880337		31	4.833064		
32	4.877519		32	4.830509		
33	4.875345		33	4.828534		
34	4.873667		34	4.826941		
35	4.872342		35	4.825613		
36	4.87094		36	4.824122		
37	4.869782		37	4.82289		
38	4.868821		38	4.821899		
39	4.868076		39	4.821096		
40	4.867478		40	4.82045		
41	4.866917		41	4.819727		
42	4.866456		42	4.819116		
43	4.866156		43	4.818613		
44	4.865791		44	4.818097		
45	4.865623		45	4.817701		
46	4.865463		46	4.817364		
47	4.865427		47	4.817118		
48	4.865212		48	4.816781		
49	4.865174		49	4.816567		
50	4.865237		50	4.816459		
51	4.865051		51	4.81611		
52	4.864969		52	4.815828		
53	4.864994		53	4.815644		
54	4.864773		54	4.815279		
55	4.864711		55	4.814969		
56	4.864586		56	4.81463		
57	4.864592		57	4.814361		
58	4.864377		58	4.813969		
59	4.864345		59	4.813654		
60	4.864236		60	4.813309		
61	4.864227		61	4.813039		
62	4.864053		62	4.812626		
63	4.863948		63	4.812301		
64	4.863858		64	4.81192		
65	4.863739		65	4.811612		
66	4.863528		66	4.811167		
67	4.863385		67	4.810822		
68	4.863314		68	4.810444		
69	4.863246		69	4.810168		
70	4.863062		70	4.809765		
71	4.862926		71	4.809459		

72	4.862816		72	4.809129		
73	4.862642		73	4.808902		
74	4.862377		74	4.80854		
75	4.862115		75	4.808278		
76	4.861876		76	4.807947		
77	4.861602		77	4.807726		
78	4.861182		78	4.807356		
79	4.860768		79	4.80709		
80	4.860404		80	4.806814		
81	4.85996		81	4.806624		
82	4.859389		82	4.806302		
83	4.858878		83	4.806102		
84	4.858432		84	4.80589		
85	4.857944		85	4.80578		
86	4.85735		86	4.805515		
87	4.856778		87	4.805387		
88	4.856295		88	4.805281		
89	4.855824		89	4.805272		
90	4.855223		90	4.805109		
91	4.854791		91	4.805092		
92	4.854383		92	4.805097		
93	4.854024		93	4.805092		
94	4.85356		94	4.805028		
95	4.853279		95	4.805019		
96	4.853083		96	4.805076		
97	4.852757		97	4.805014		
98	4.852629		98	4.804998		
99	4.852594		99	4.805137		
100	4.852463		100	4.805107		
101	4.852475		101	4.80513		
102	4.852612		102	4.805184		
103	4.85272		103	4.805155		
104	4.852983		104	4.80515		
105	4.853279		105	4.805101		
106	4.853708		106	4.805065		
107	4.854143		107	4.805016		
108	4.854724		108	4.80493		
109	4.855296		109	4.804761		
110	4.855926		110	4.804504		
111	4.856531		111	4.804222		
112	4.857195		112	4.803895		

113	4.857754		113	4.803473		
114	4.858302		114	4.802984		
115	4.85878		115	4.802465		
116	4.859104		116	4.801852		
117	4.859317		117	4.801183		
118	4.859239		118	4.800423		
119	4.858981		119	4.799577		
120	4.858435		120	4.798632		
121	4.857661		121	4.797574		
122	4.856635		122	4.796458		
123	4.855444		123	4.79533		
124	4.85405		124	4.794266		
125	4.852615		125	4.793253		
126	4.851003		126	4.792354		
127	4.849433		127	4.79158		
128	4.847821		128	4.790962		
129	4.846286		129	4.790553		
130	4.844668		130	4.790329		
131	4.843206		131	4.790369		
132	4.841667		132	4.790641		
133	4.840275		133	4.791193		
134	4.838986		134	4.791911		
135	4.837758		135	4.792913		
136	4.836655		136	4.794112		
137	4.835551		137	4.795476		
138	4.834345		138	4.796874		
139	4.833201		139	4.798255		
140	4.832139		140	4.79941		
141	4.832649		141	4.800411		
142	4.836433		142	4.804631		
143	4.841581		143	4.810625		
144	4.847241		144	4.815056		
145	4.846355		145	4.8149		
146	4.847686		146	4.815496		
147	4.848373		147	4.816269		
148	4.848212		148	4.815865		
149	4.848042		149	4.816071		
150	4.849369		150	4.816086		
151	4.849547		151	4.817283		
152	4.849777		152	4.817425		
153	4.85001		153	4.817449		

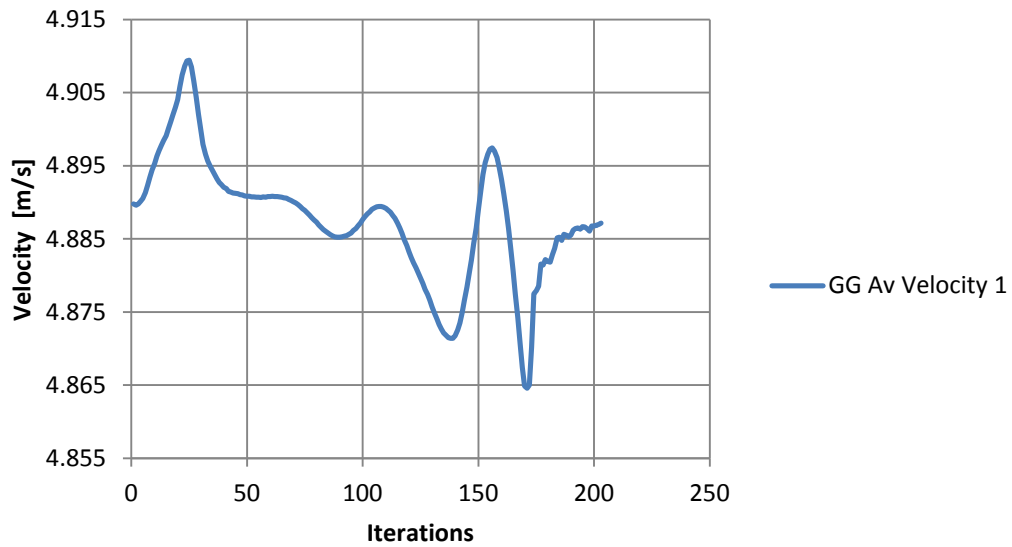
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155	4.850168		155	4.817244		
156	4.850635		156	4.818013		
157	4.851953		157	4.818802		
158	4.851594		158	4.818723		
159	4.851223		159	4.818772		
160	4.85175		160	4.818973		
161	4.851622		161	4.818987		
162	4.851505		162	4.819195		
163	4.852024		163	4.819679		
164	4.852743		164	4.820427		
165	4.853216		165	4.820965		
166	4.853475		166	4.821462		
167	4.854024		167	4.82186		
168	4.854315		168	4.822188		
169	4.854648		169	4.822527		
170	4.854898		170	4.823006		
171	4.855278		171	4.823334		
172	4.855466		172	4.82355		
173	4.855478		173	4.823711		
174	4.855494		174	4.823829		
175	4.855504		175	4.824037		
176	4.855877		176	4.824398		
177	4.856141		177	4.824551		
178	4.856351		178	4.824795		
179	4.856536		179	4.824923		
180	4.85644		180	4.824825		
181	4.856378		181	4.824948		
182	4.856862		182	4.825181		
183	4.857169		183	4.825287		
184	4.857112		184	4.825191		
185	4.856818		185	4.824972		
186	4.856701		186	4.824958		
187	4.856951		187	4.82505		
188	4.857102		188	4.825068		
189	4.857055		189	4.825052		
190	4.857021		190	4.825197		
191	4.857426		191	4.825397		
192	4.857749		192	4.825476		
193	4.857814		193	4.825728		
194	4.857967		194	4.825829		

195	4.858044		195	4.825891		
196	4.857974		196	4.825991		
197	4.857979		197	4.826135		
198	4.858323		198	4.826414		
199	4.858488		199	4.826494		
200	4.858535		200	4.826583		
201	4.85849		201	4.826573		
202	4.858454		202	4.82673		
203	4.85878		203	4.826928		

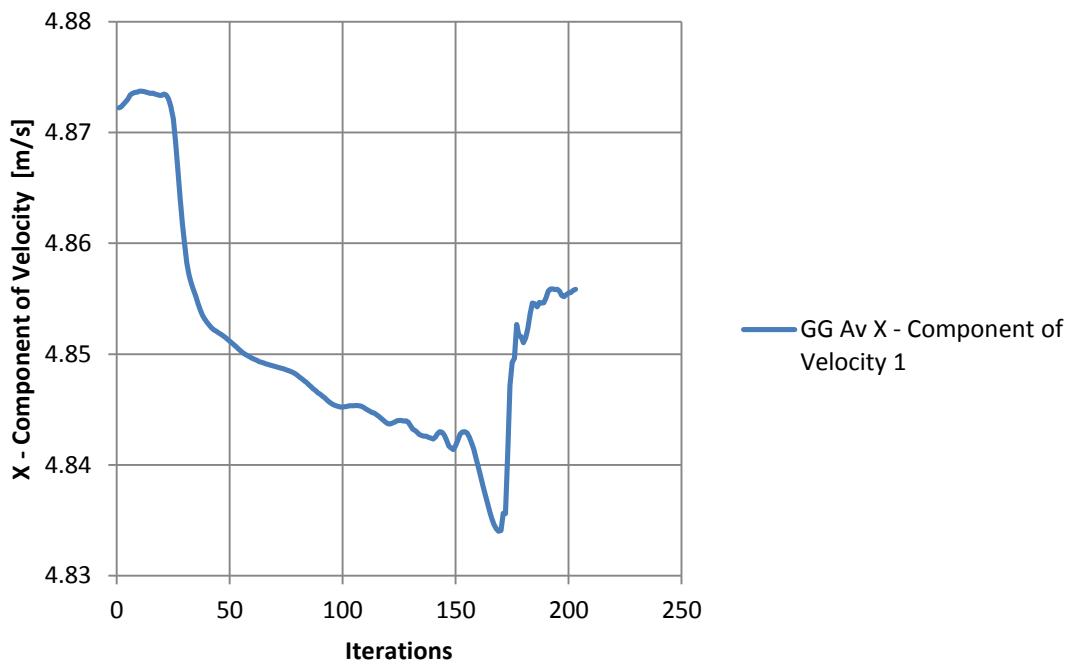
Appendix D TEST 3

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Av Velocity 1	[m/s]	4.887143859	4.88524889	4.881407468	4.887143859
GG Av X - Component of Velocity 1	[m/s]	4.855842865	4.854513447	4.851031498	4.855885806

test 3 avg velocity



test 3 x avg velocity



Velocity (m/s)		X - Component of Velocity (m/s)			
Iterations	GG Av Velocity 1	Iterations	GG Av X - Component of Velocity 1		
	9		9		
	Yes		Yes		
	10.2		13.9		
	0.005736		0.004854		
	0.00059		0.000677		
	4.885249		4.854513		
	4.881407		4.851031		
	4.887144		4.855886		
1	4.889766	1	4.872215		
2	4.889607	2	4.872311		
3	4.889764	3	4.872548		
4	4.890132	4	4.872775		
5	4.890507	5	4.872995		
6	4.89132	6	4.873373		
7	4.892293	7	4.873535		
8	4.893395	8	4.873609		
9	4.894394	9	4.873628		
10	4.89528	10	4.873734		
11	4.896276	11	4.873734		
12	4.897083	12	4.873681		
13	4.897796	13	4.873637		
14	4.898454	14	4.873576		
15	4.899095	15	4.873534		
16	4.900074	16	4.873557		
17	4.900982	17	4.873474		
18	4.901957	18	4.873403		
19	4.902983	19	4.873348		
20	4.904042	20	4.873361		
21	4.905845	21	4.87347		
22	4.907397	22	4.873364		
23	4.908652	23	4.87304		
24	4.909357	24	4.872367		
25	4.909433	25	4.871243		
26	4.90852	26	4.869172		
27	4.906651	27	4.866701		
28	4.90436	28	4.864163		
29	4.902043	29	4.861888		
30	4.899988	30	4.860001		

31	4.89791		31	4.858258		
32	4.896567		32	4.857154		
33	4.895656		33	4.856399		
34	4.894976		34	4.85579		
35	4.89441		35	4.855253		
36	4.893758		36	4.854575		
37	4.893187		37	4.854001		
38	4.892711		38	4.853509		
39	4.892413		39	4.853166		
40	4.892034		40	4.852867		
41	4.891855		41	4.852598		
42	4.89148		42	4.852357		
43	4.891387		43	4.852189		
44	4.891284		44	4.852066		
45	4.891198		45	4.851926		
46	4.891153		46	4.85182		
47	4.89103		47	4.851661		
48	4.891014		48	4.851521		
49	4.890883		49	4.851343		
50	4.890818		50	4.851172		
51	4.890834		51	4.851002		
52	4.890717		52	4.850833		
53	4.890731		53	4.850639		
54	4.890681		54	4.850455		
55	4.890673		55	4.850263		
56	4.890664		56	4.850107		
57	4.890715		57	4.849967		
58	4.890714		58	4.849835		
59	4.890793		59	4.849736		
60	4.890771		60	4.849621		
61	4.890826		61	4.849522		
62	4.890799		62	4.849426		
63	4.890792		63	4.849334		
64	4.890757		64	4.849268		
65	4.890703		65	4.8492		
66	4.890604		66	4.849131		
67	4.890547		67	4.849071		
68	4.890374		68	4.848998		
69	4.890274		69	4.84894		
70	4.890085		70	4.848889		
71	4.889912		71	4.848832		

72	4.889665		72	4.848781		
73	4.889435		73	4.848718		
74	4.889135		74	4.848656		
75	4.888887		75	4.848581		
76	4.888544		76	4.84852		
77	4.888257		77	4.848426		
78	4.887911		78	4.848331		
79	4.887581		79	4.848212		
80	4.887259		80	4.848082		
81	4.8869		81	4.847917		
82	4.886601		82	4.847776		
83	4.886286		83	4.84759		
84	4.886032		84	4.847434		
85	4.88577		85	4.847245		
86	4.885573		86	4.847083		
87	4.885388		87	4.84688		
88	4.885286		88	4.846722		
89	4.885222		89	4.846532		
90	4.885225		90	4.846383		
91	4.885267		91	4.846196		
92	4.885345		92	4.84605		
93	4.885449		93	4.845864		
94	4.885625		94	4.845693		
95	4.885804		95	4.845527		
96	4.886128		96	4.845425		
97	4.886412		97	4.845324		
98	4.886802		98	4.845269		
99	4.887153		99	4.845215		
100	4.88761		100	4.845227		
101	4.888003		101	4.845265		
102	4.888398		102	4.845292		
103	4.888691		103	4.84533		
104	4.889011		104	4.84534		
105	4.88919		105	4.845337		
106	4.889392		106	4.845355		
107	4.889423		107	4.845349		
108	4.889421		108	4.845302		
109	4.889334		109	4.845223		
110	4.889174		110	4.84509		
111	4.888914		111	4.844953		
112	4.888648		112	4.844856		

113	4.888218		113	4.844745		
114	4.887784		114	4.844666		
115	4.887163		115	4.844541		
116	4.886484		116	4.844391		
117	4.885739		117	4.8442		
118	4.884883		118	4.844035		
119	4.884072		119	4.843851		
120	4.883194		120	4.843721		
121	4.882404		121	4.843686		
122	4.881712		122	4.843774		
123	4.881005		123	4.843857		
124	4.880325		124	4.843979		
125	4.87962		125	4.844018		
126	4.878915		126	4.844012		
127	4.878107		127	4.843941		
128	4.877382		128	4.843975		
129	4.876586		129	4.843866		
130	4.87568		130	4.843557		
131	4.874882		131	4.84324		
132	4.874064		132	4.84312		
133	4.873278		133	4.842942		
134	4.872647		134	4.842746		
135	4.872136		135	4.842651		
136	4.8718		136	4.842598		
137	4.871477		137	4.842592		
138	4.871407		138	4.842483		
139	4.871407		139	4.842418		
140	4.871751		140	4.842327		
141	4.872519		141	4.84251		
142	4.873474		142	4.842825		
143	4.874903		143	4.842998		
144	4.876618		144	4.842942		
145	4.878389		145	4.842694		
146	4.880289		146	4.842207		
147	4.882099		147	4.841705		
148	4.88433		148	4.841516		
149	4.886485		149	4.841367		
150	4.889088		150	4.841737		
151	4.891492		151	4.842227		
152	4.893816		152	4.842773		
153	4.895438		153	4.842976		

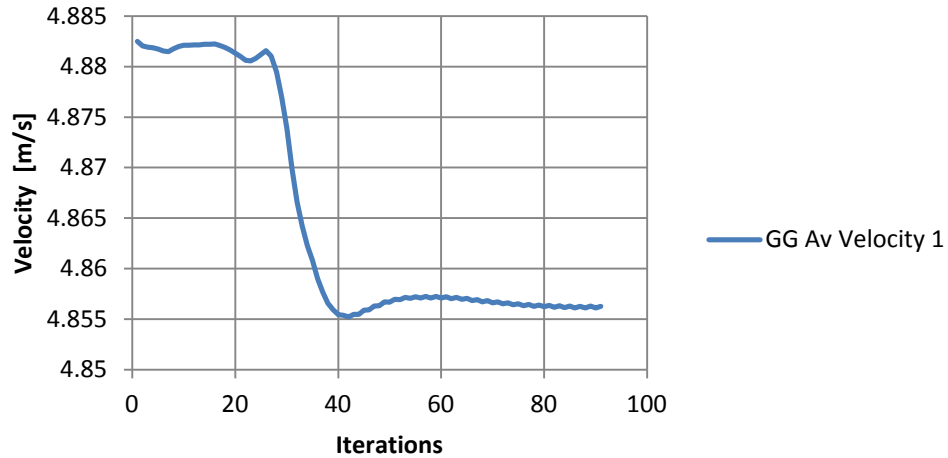
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156	4.89742		156	4.842518		
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158	4.89613		158	4.841407		
159	4.894735		159	4.840596		
160	4.893122		160	4.839828		
161	4.891157		161	4.839006		
162	4.888819		162	4.838164		
163	4.886413		163	4.837406		
164	4.883618		164	4.83665		
165	4.880695		165	4.835869		
166	4.877457		166	4.835161		
167	4.874199		167	4.834639		
168	4.870748		168	4.834245		
169	4.867419		169	4.834032		
170	4.864866		170	4.834086		
171	4.86458		171	4.835649		
172	4.865015		172	4.83562		
173	4.870151		173	4.841049		
174	4.877483		174	4.847157		
175	4.87793		175	4.849266		
176	4.878531		176	4.849602		
177	4.881545		177	4.852682		
178	4.881407		178	4.851668		
179	4.882166		179	4.851569		
180	4.88189		180	4.851031		
181	4.881825		181	4.851457		
182	4.882804		182	4.85233		
183	4.88371		183	4.853617		
184	4.885134		184	4.854614		
185	4.885232		185	4.85455		
186	4.884786		186	4.854263		
187	4.885634		187	4.854679		
188	4.885481		188	4.854608		
189	4.885267		189	4.854641		
190	4.88554		190	4.855111		
191	4.886195		191	4.855694		
192	4.886399		192	4.855865		
193	4.886489		193	4.855886		
194	4.886312		194	4.855833		

195	4.886658		195	4.855843			
196	4.886614		196	4.855667			
197	4.886348		197	4.855262			
198	4.886074		198	4.855178			
199	4.886761		199	4.855353			
200	4.886746		200	4.855498			
201	4.886863		201	4.855568			
202	4.886989		202	4.85572			
203	4.887144		203	4.855843			

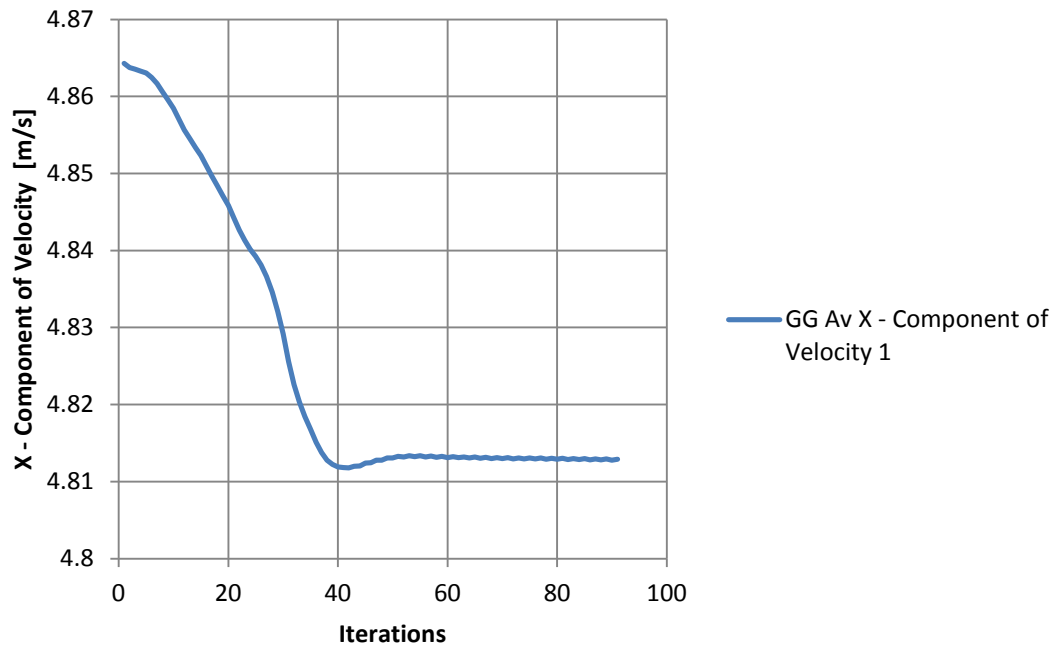
APPENDIX E TEST 4

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Av Velocity 1	[m/s]	4.856275745	4.856513202	4.856121342	4.857163955
GG Av X - Component of Velocity 1	[m/s]	4.8128994	4.812992451	4.812783084	4.813214642

test 4 avg velocity



test 4 x avg velocity



Velocity (m/s)		X - Component of Velocity (m/s)			
Iterations	GG Av Velocity 1	Iterations	GG Av X - Component of Velocity 1		
	9		9		
	Yes		Yes		
	100		100		
	0.000719		0.000432		
	0.000811		0.001553		
	4.856513		4.812992		
	4.856121		4.812783		
	4.857164		4.813215		
1	4.882504	1	4.864303		
2	4.882038	2	4.863771		
3	4.881906	3	4.86355		
4	4.881842	4	4.863292		
5	4.881737	5	4.863043		
6	4.881535	6	4.86248		
7	4.881487	7	4.861685		
8	4.881762	8	4.860607		
9	4.881988	9	4.859569		
10	4.882093	10	4.858482		
11	4.882114	11	4.857045		
12	4.882124	12	4.855642		
13	4.882124	13	4.854498		
14	4.882205	14	4.853374		
15	4.882192	15	4.852329		
16	4.882238	16	4.850993		
17	4.882075	17	4.849672		
18	4.881885	18	4.848425		
19	4.881619	19	4.847119		
20	4.881316	20	4.845833		
21	4.88101	21	4.844214		
22	4.880613	22	4.842641		
23	4.88055	23	4.841302		
24	4.880812	24	4.840177		
25	4.881199	25	4.839226		
26	4.881585	26	4.838129		
27	4.881031	27	4.836619		
28	4.879444	28	4.834608		
29	4.876963	29	4.832091		

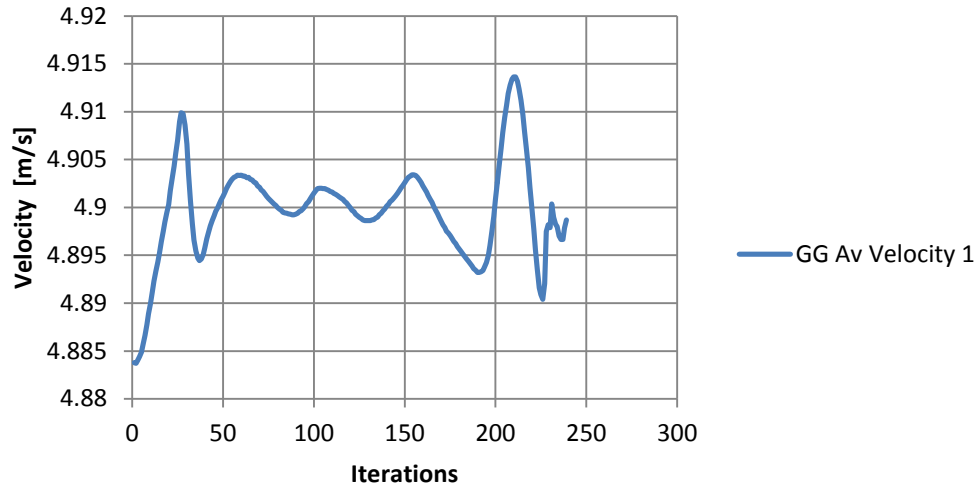
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31	4.869932		31	4.825574		
32	4.866596		32	4.822591		
33	4.864209		33	4.820305		
34	4.862305		34	4.818413		
35	4.860824		35	4.816859		
36	4.859046		36	4.815098		
37	4.857696		37	4.813788		
38	4.856586		38	4.812793		
39	4.85596		39	4.81226		
40	4.855446		40	4.811892		
41	4.855375		41	4.811834		
42	4.855221		42	4.811769		
43	4.855484		43	4.811997		
44	4.85548		44	4.812018		
45	4.855907		45	4.812387		
46	4.855935		46	4.812448		
47	4.856305		47	4.812767		
48	4.856354		48	4.812794		
49	4.856707		49	4.81307		
50	4.856683		50	4.813057		
51	4.856977		51	4.813275		
52	4.856927		52	4.813197		
53	4.857154		53	4.813363		
54	4.857057		54	4.813235		
55	4.857234		55	4.813366		
56	4.85711		56	4.813206		
57	4.857271		57	4.813322		
58	4.857113		58	4.813165		
59	4.857258		59	4.813275		
60	4.857091		60	4.813125		
61	4.857224		61	4.813241		
62	4.857042		62	4.8131		
63	4.857164		63	4.813215		
64	4.856963		64	4.813068		
65	4.857067		65	4.813175		
66	4.856851		66	4.813023		
67	4.856954		67	4.813135		
68	4.856734		68	4.812994		
69	4.856842		69	4.813109		
70	4.856615		70	4.812979		

71	4.856728		71	4.813101		
72	4.856519		72	4.812961		
73	4.856628		73	4.813083		
74	4.856425		74	4.812948		
75	4.856535		75	4.813067		
76	4.856349		76	4.812932		
77	4.856469		77	4.813059		
78	4.856283		78	4.812924		
79	4.856401		79	4.813045		
80	4.856232		80	4.812905		
81	4.856365		81	4.813026		
82	4.856186		82	4.81288		
83	4.856329		83	4.813002		
84	4.856156		84	4.812859		
85	4.856316		85	4.812981		
86	4.856132		86	4.812832		
87	4.856292		87	4.812953		
88	4.856121		88	4.812806		
89	4.856294		89	4.812932		
90	4.856124		90	4.812783		
91	4.856276		91	4.812899		

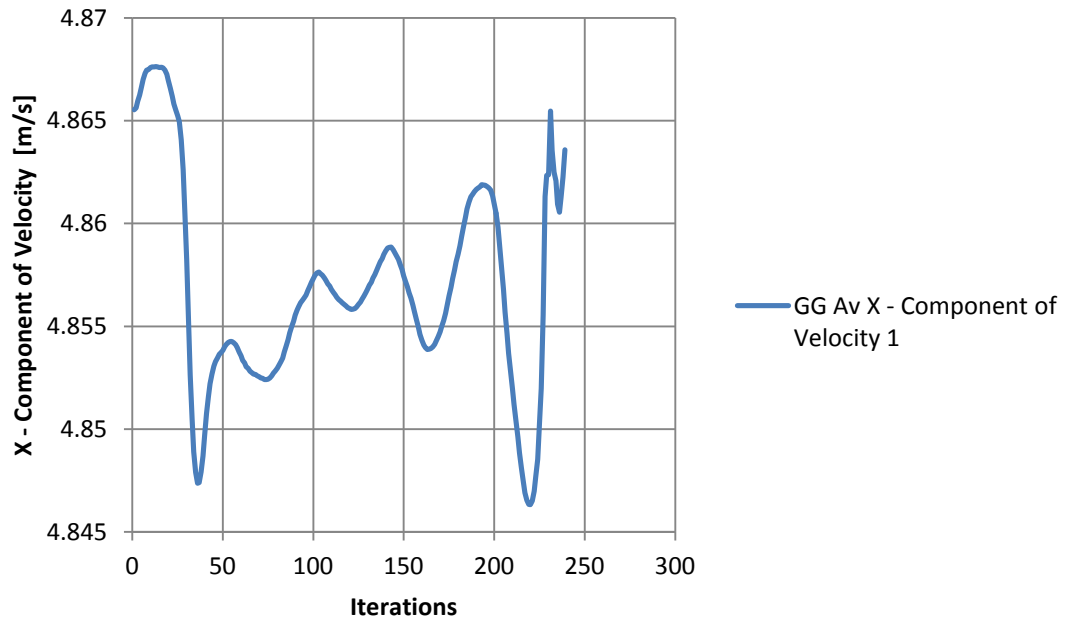
APPENDIX F TEST 5

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
GG Av Velocity 1	[m/s]	4.898703201	4.900722466	4.890397896	4.91363971
GG Av X - Component of Velocity 1	[m/s]	4.863576105	4.854323386	4.846322562	4.865461416

test 5 avg velocity



test 5 x avg velocity



Velocity (m/s)		X - Component of Velocity (m/s)			
Iterations	GG Av Velocity 1	Iterations	GG Av X - Component of Velocity 1		
	9		9		
	Yes		Yes		
	16.1		8.7		
	0.004816		0.006982		
	0.000777		0.000608		
	4.900722		4.854323		
	4.890398		4.846323		
	4.91364		4.865461		
1	4.883786	1	4.865532		
2	4.883718	2	4.865615		
3	4.884013	3	4.865948		
4	4.884428	4	4.866248		
5	4.884874	5	4.866589		
6	4.885671	6	4.867003		
7	4.886625	7	4.867305		
8	4.887753	8	4.867464		
9	4.888885	9	4.867496		
10	4.88994	10	4.86758		
11	4.891213	11	4.867615		
12	4.892305	12	4.867621		
13	4.893337	13	4.867631		
14	4.894284	14	4.867619		
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22	4.903021	22	4.866176		
23	4.90431	23	4.86581		
24	4.905658	24	4.865517		
25	4.907066	25	4.865236		
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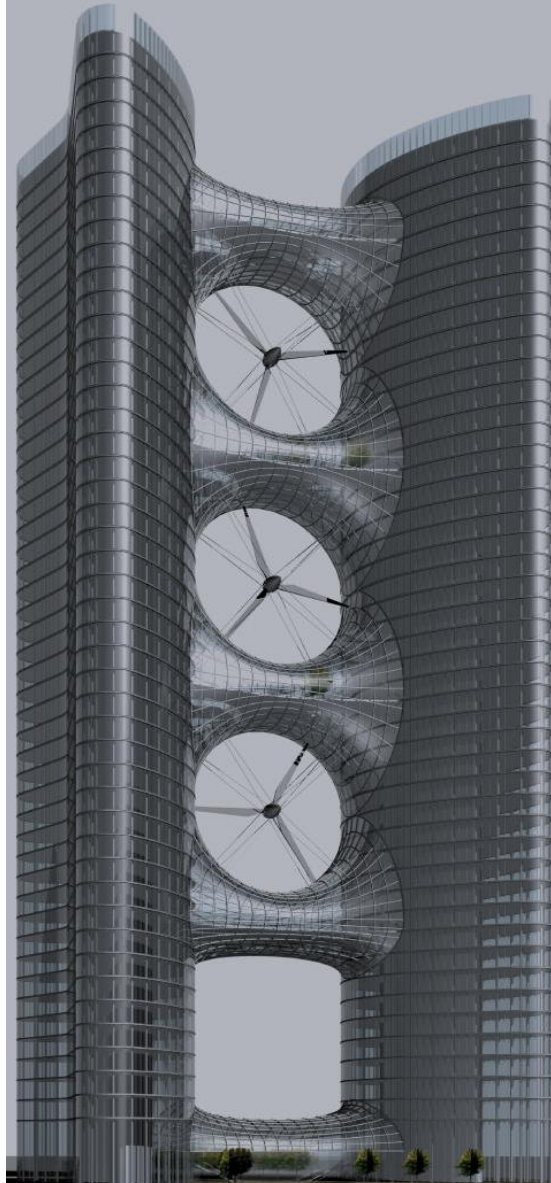
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Appendix G Wind Energy For The Built Environment: The Building as a Concentrator

Wind Energy for the Built Environment The Building as a Concentrator



Introduction

Continuing planning problems with the siting of wind farms on land are driving development of huge offshore turbines. Instances of integration in the urban environment, closer to the main consumers of energy, such as buildings, remain scarce.

Successful urban integration will require proposed developments to fully address the concerns of planners, pressure groups and the general public with regard to their environmental impacts. The turbines must also be capable of producing a significant proportion (c. 20%) of the annual electricity demand of the building in which they are housed or of neighbouring buildings. These buildings must be energy efficient, otherwise the turbines risk becoming a purely aesthetic feature.

The focus of project WECB has been the development of wind enhancement and integration techniques, which improve the annual energy yield per installation by concentrating the flow to moderate wind speeds (3.5 m/s) typical of most urban areas in Europe.



Small scale wind turbine in London

This involved balancing and reconciling aesthetic, aerodynamic, architectural, environmental and structural concerns. These techniques have been successfully demonstrated by the field-testing of a small-scale prototype building or wind concentrator with an integrated HAWT and VAWT during the project.

Draft guidance for UNWECB developments has also been produced. The guidelines cover the conceptual design process and include methodologies for predicting energy yield and categorising and assessing environmental impacts and economic costs.



'Wind Tower' at East Oxford, University of Bath

Wind-Tunnel and CFD Studies

Three generic integration techniques are available in the urban environment:

- Full integration, such that the wind turbines drive the architectural form;
- Retrofitting wind turbines onto existing buildings;
- Landscaping stand-alone wind turbines into urban context.

Higher integrated integration focuses some formidable problems, e.g. rather the turbine (or building) can yaw into the wind, the turbine will be in close proximity to people and property; mean wind speeds are lower in urban areas.

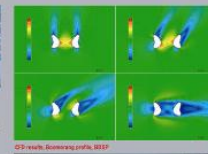
The project explored the use of a wide range of building shapes, from conventional square-based 'stick' shapes - which 'don't work' aerodynamically - through to optimised 2-D shapes. Their aerodynamic potential was assessed using Wind-Tunnel Testing on Scale Models (IC) and CFD Simulations (BSP). The key findings of these early studies are that:

- Optimum performance is obtained for smooth, rounded, fully 3-D building forms.
- Towers with 'skirted' or 'flaring' footprints produced the best wind enhancement.



Multi-Tower WECB tower in London, BSP

- Aerodynamic wings or 'villies' connecting the towers and creating a close-fitting 2-D aerodynamic duct shape (hull) around the turbine are highly effective. They prevent separation of flow and loss of wind enhancement.
- Good wind enhancement can be obtained for angles of incidence up to 40°-50°, and appreciable flow through an aerodynamic duct hole can even occur at very acute angles.
- The level of power enhancement will be proportional to the increase in mass flow rate through the swept area of the turbine (i.e. to the mean wind speed rather than the cube of mean wind speed). The maximum instantaneous power enhancement factor will be less than 2.



Visualisation of flow in a flow tunnel

Field Testing of UNWECB Prototype

A prototype of one of the most promising UNWECB designs - an aerodynamic twin-tower building with a 'soaring' footprint - was built and successfully field-tested. This design evolved through a series of architectural, aerodynamic and structural studies involving all partners.

MECAL, executed the final structural design of the 1/10th scale prototype, which was fabricated in the Netherlands by Mecal, shipped to the UK and erected at the Energy Research Unit at the Rutherford Appleton Laboratory (RAL), near Oxford. The energy yield of both a horizontal Axis Wind Turbine (HAWT) and a Vertical Axis Wind Turbine (VAWT) was measured outside and inside the prototype building by RAL, with and without skirts. Placing the wind turbines inside the building/concentrator produced considerably more power (compared to when they were conventionally mounted at the same height) on an open site. Specifically, for the HAWT testing:

- The concentrator effectively increased the wind speed seen by the turbine by a significant 1 m/s.



Full scale model, Wind-Tunnel Testing, BSP

- The integrated turbine produces enhanced power output for a wide range of incident wind angles (c. 30°) into the building.
- The addition of the skirts further enhanced concentrator performance (particularly at acute wind angles).

Extrapolating the results, using a calculation method developed during the project, suggested that a scaled-up building with an integrated HAWT would produce at least a 25% increase in annual energy yield in a typical urban setting over a stand-alone machine. Further gains could be realised if the turbine could be safely mounted higher from the ground, thereby benefiting from higher atmospheric wind speeds. Future testing at a larger scale with bigger, higher capacity wind turbines will be required to confirm these findings.



Computer Model of connecting 'villies' between the towers

Architectural Integration

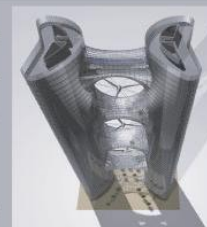
Conceptual architectural designs for several full-scale buildings were completed by the University of Stuttgart, Institut für Baukonstruktion und Entwurf, I2, including designs incorporating multiple turbines. Detailed architectural and computer models have been created and prototyped.

Aerodynamically optimal designs may prove sub-optimal in terms of economic organisation of space. Neither will they necessarily produce energy efficient buildings, particularly if they contain deep sections where space adjacent to the turbines will inevitably be less attractive (and valuable) due to concerns over noise transmission, flickering of the rotating blades, electromagnetic interference with computers and telephones etc.

A sensible means of spatial organisation would therefore be to place intensively used or service areas (i.e. technical, office, stairs, zones) adjacent to the turbines, as they have less demanding requirements than normal office space and can provide a buffering role. The interiors of villas linking twin tower buildings can be used as exciting transitional spaces or 'key sections'.

Structural optimisation of UNWECB is particularly important. Methodologies and prototype designs (based on FEM analyses) have been developed to tackle the unique problems posed by UNWECB, e.g. prevented turbine suspension from building; safety measures to enhance public safety (and perception of safety) in the event of a turbine failure; solving the Blade Pass Frequency vibration problem etc.

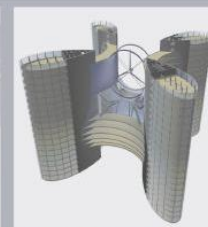
Key external environmental factors for 'urban sites' such as noise emission/propagation and visual impacts have also been studied via computer modelling.



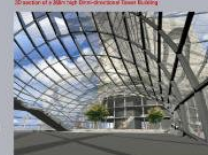
Twin Tower Building with three integrated HAWTs, University of Stuttgart

For a multi-turbine twin tower building, providing that techno-economic and environmental issues can be satisfied, the integrated turbines could provide 20% of the annual electricity demand of the building (i.e. in lighting, computers, plant and equipment) based on an achievable average capacity factor of 0.1 - 0.2.

These designs represent a demonstration of how the concept of integrating wind energy into buildings (UNWECB) might ultimately be expressed. The same principles could be utilised on a more modest scale or in the form of 'energy or wind towers' - i.e. unoccupied structures used to generate electricity that could be placed on- or off-shore.



2D section of a 20m-high Directional Tower Building



Twin Tower, aerodynamically shaped Concentration Fan

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MECAL Applied Mechanics BV
Draaiwerk 10
Postbus 286
NL-7500 AS
Enschede
f.brughuis@mecal.nl



Imperial College
Department of Aeronautics
Prince Consort Road
SW7 2BX, UK
m.graham@ic.ac.uk



Universität Stuttgart
Institut für Baukonstruktion und Entwurf, I2
Geschwister Scholl Str. 24b
D-70374 Stuttgart
stefan.bathling@ipa.uni-stuttgart.de