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Masterarbeit

Evaluation Of Micro-Wind Generation In Urban Environment.

A Case Study In Cork, Ireland.

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ausgeführt zum Zwecke der Erlangung des akademischen Grades eines Diplom-Ingenieurin
unter der Leitung

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ABSTRACT

This work was influenced by research on current state of arts in Irish renewable energy sector. High level of wind availability has caused big development in recent years as well as ambitious plans for the near future in the field of wind energy harvesting. Governmental subsidizes, induced by the 2020 goals, have encouraged development of megawatt wind farms around the country. These very costly projects can often cause environmental issues as well as alter the nature of unobstructed Irish landscapes due to numerous towers as well as lengthy and expensive extensions of the grid, which is currently very poorly developed. Public awareness of wind energy harvesting is determined by those heavy, expensive technologies, which are unavailable to private users. Small scale wind generation has been very slowly becoming more popular among rural households where their performance has been studied and proven satisfactory. Producers of household turbines promise output of their technologies based on their own experiments, which take place in nearly ideal conditions. At the same time, a number of resources allow future users to predict output of desired technology by themselves. Wind speed data, the most important factor determining output those calculations, is also available from a number of sources for each area, leaving future user with a range of options. Capricious behaviour of wind in urban environment raises a question whether satisfactory prediction of a power generation is at all possible in those conditions. Limited monitoring of already implemented systems makes it difficult to evaluate efficiency of technologies available on the market. At the same time, off-grid communities work on developing their own, alternative systems which are cheaper, easier and quicker to produce and implement. There is, however, very little public knowledge on how these systems compare to mainstream technologies, especially in an urban environment.

This thesis tries to address all mentioned issues by:

- analysing wind patterns on various conditions to determine prospects for urban wind energy generation in Ireland.
- evaluating wind energy predictions systems and looking for the most efficient ones that could be utilized by non-professional future wind turbine owners
- undertaking a case study of a turbine project placed in a typical Irish urban surroundings in order to understand difficulties related to small scale urban wind generation and relationship between power output and building demands
- comparing an institutional wind energy utilizing system with cheap, home-made alternative in search for technologies and systems that are most beneficial to private users

Keywords: wind patterms,wind harvesting, power monitoring, turbine’s efficiency, energy predictions, energy demands, community projects, alternative renewable systems, meteorological data.

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1. INTRODUCTION

This study was inspired by desktop research on the state of arts of renewable energy systems in Ireland. Focus on wind harvesting was caused by its relatively high availability and a vast number of private and public projects taking place recently in this country. Governmental aim for expansion of wind power production triggered mainly large scale projects, which are already completed or are currently in the development or planning stage. Background study has shown that efficiency of these systems is still far from desirable and the impact they have on environment and people may be a great price to pay. In the country that consists mostly of scattered settlements, distributed far from national grid and with low built sections, it seems that local solutions may be more effective. Awareness of micro wind turbine technology is currently rising in rural environment, mainly among households placed off the grid, away from any other power supplies. The biggest energy demand, however, is located within bigger settlements, villages and cities. This thesis provides information that may improve knowledge on wind harvesting in urban environment and contribute to its development.

More detailed information on current wind situation in the country along with the most popular ways of harvesting it is presented in BACKGROUND section. After that desktop research the most important issues related to micro urban wind generation have been identified.

1.1. Issues addressed in this research

Micro wind turbines are recently implemented by private users or institutions which do not specialize in renewable energy technologies nor have any specific knowledge on the subject. Technology sounds very promising, however, therefore potential users have enough trust in turbines' efficiency to invest for the sake of future savings. It has to be noted that efficiency of renewable energy investments varies greatly from project to project and depends highly on choice of the right technology as well as appropriate construction and maintenance. Wind is a powerful source, nevertheless its accessibility is highly irregular and in many cases difficult to predict. These fluctuations can have bigger or smaller range depending on location, therefore local weather stations and national wind maps are important tools for determining sites' appropriateness. In rural environment these measurements are of high accuracy, but urban areas induce much more complicated wind behaviour. Still, meteorological stations placed outside of city's built up areas provide the most detailed and easiest to obtain wind documentation, therefore often become the main source of wind speed outline for future wind turbine users. There is more than one authorized wind data source available for most locations and results provided by each one may show great inconsistencies. This raises the question whether either of them can provide material that is sufficiently reliable for urban micro conditions. Similarly, techniques which allow predicting the amount of energy produced by a wind system which use given wind speed data are numerous. Each of them incorporates a number of parameters in order to obtain the possible energy generation and these parameters differ among different tools, yielding diverse results. This situation questions whether prediction of wind turbine output for a particular site is possible without lengthy analysis procedures and with numerous projects erected without professional consultation it is important to know which one may be most useful.

Producers of wind energy systems promise certain level of energy production from their turbines based on their own experiments, which are performed under good wind conditions, on exposed sites. Numerous case studies have been performed not only by manufacturers but also researchers and owners, which help to understand the actual behaviour of wind system in capricious, everyday conditions. Unfortunately most of these studies present wind systems in rural environment, where wind conditions are much more stable than within cities. Negligible amount of studies performed in urban environment leave big uncertainty about performance of turbines in such landscapes. Ireland's big involvement and ambitious plans for wind energy harvesting grounds a demand for such studies before more and more projects are implemented.

Wind turbine technologies are developed all over the world with smaller and greater success. Some designs have been established for years, providing services for thousands of households and businesses, and their producers promise results which have been calculated and examined. These systems are associated with quite significant costs which are promised to be returned in energy savings within a limited number of years. On the other hand, clean energy enthusiasts are attempting to search for their own solutions outside of the institutional stream. Off grid communities as well as private users develop systems at much lower costs, made mainly of reused materials and erected by themselves. This means big savings on construction, repair and maintenance costs but also that the system is up and running within days. These turbines not only provide clean energy and reduce emissions but also induce interactions between interested groups, which share their knowledge and experiences. Output of these systems should be studied and compared to more expensive alternatives in search for most economical and efficient solutions, which may reach a wider range of public.

In order to address those issues this research is divided into 3 main chapters:

WIND STUDY provides information on wind behaviour within urban environment by monitoring weather conditions on most representative sites. It investigates wind patterns and compares the influence of landscape types on the availability of this source. Part of this section concentrates on analysis of publicly available wind data, which may be a cheaper alternative to local, lengthy monitoring. Predictions of wind behaviour, which are based on those records, are then compared with real measurements.

ENERGY STUDY introduces two wind harvesting systems that display very different properties. Case study of popular wind technology is juxtaposed with cheaper, home-made alternative. Measurements of power production from both turbines, in relation to their characteristics, become the foundation for establishing their efficiency. Second part of this section is devoted to evaluation of power prediction methods, which are used to estimate energy generation from both turbines. Results are then compared with the real data in search for the most efficient method.

The last section concentrates on BUILDING DEMANDS by measuring power consumption of a public building. Comparison with results from previous chapters provides information on relationship between power usage and power production from wind.

Results are discussed at the end of the study, followed by relevant tables and diagrams.

2. BACKGROUND

2.1. Energy situation in Ireland

Ireland imports almost 90% of its energy ever since the demand has risen in 1995 along with decline in natural gas production at Kinsale. In 2007, residential and public services sectors made up nearly 60 % of the total energy requirement. Renewable energies covered only 3,3% of gross consumption that year, with wind making up 35 % of that *(Howley, M., Ó’Gallachóir, B. & Dennehy, E. 2008)*. It was a big jump when compared with the fact that is remained 0 % in 1990. Increase in renewable resources utilization was encouraged by the European Commission, which proposed a new directive on the promotion of the use of energy from renewable sources in January 2008 which. It contained targets for 2020 for each EU member state, with Irish targets measuring 16% of gross final energy *(Howley, Ó Gallachóir & Dennehy 2008)*.

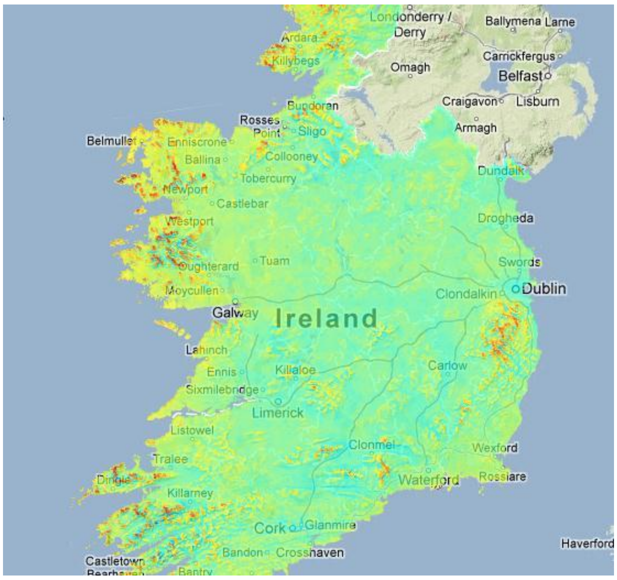


Fig. 2.2.1.Wind speed availability in Ireland. Green colour symbolizes speeds around 6 m/s on average while red stands for speeda close to 12 m/s.. Source: Seai.ie

The gap between other European countries can be even strengthened whenever plans for EU-MENA grid is developed *(Nokrashy 2010).* Trans Mediterranean RE cooperation has established an agreement between southern European countries with their high energy demand and North Africa along with Middle East in order to utilize their big solar potential. High voltage power lines will contribute to Mediterranean Transmission Line Ring and enable transmission of surplus energy collected by solar stations in Africa and Middle East to Europe, at the same time providing new work places and desalination of water (as by-product of solar stations) in the deserts. Only Northern Ireland has been so far taken into consideration in this development, which may become one of the biggest and most profitable investments in energy sector of recent years.

In order to establish at least partial independence from other nations, the country needs to prepare a strategy that involves their abundance of RE potential. Ireland has an enormous wind potential with north and east coasts being the windiest sites in Europe. With an average of 5-9 m/s *(3TIER 2009)* it could cover all of country’s demand and export the surplus abroad *(Travers, 2010).* Some calculations have shown that wind blowing over the country can produce 8000 MW of power while the peak demand is only 6000 MW *(Trabish 2010).* Wind map in figure 2.2.1 shows the availability of wind over the country with green colour symbolizing average speeds of around 6m/s and red ones showing places where wind speeds are close to 12 m/s *(SEAI 2012).*

2.2. Wind harvesting

Renewable energies are in the state of rapid development pushed ahead by threat of climate change. Advanced technologies, financial subsidies as well as legislatives implemented by European Union are important triggers in this matter. However, despite big advancements in this sector the strategy for further development is not yet exhausted. Most projects are implemented in a top down manner *(Wissen, Grêt-Regamey 2008)* with belief that profits will far outstand the price that has to be paid. It cannot be forgotten that most of these technologies require vast infrastructures, big amount of space and influence the surroundings with their visual and sometimes even sound impacts. This is especially problematic in northern countries where the main renewable resources potential lies in wind, hydro and biogas power. These, in contrast to solar panels, cannot be implemented on existing structures, require a lot of adaptation, big amount of land and their potential is the biggest within borderlines (coastlines, mountains) which are ecologically important. Wind farms built onshore, in less fragile environment, need to be almost twice as big (~150m as opposed to ~80m offshore structures), hydroelectric dams reach around 300m changing water quality and influencing aquatic ecosystems and biomass production depends highly on amount of land and water *(Schobel, Dittricht 2010).* Natural habitats and land quality are not the only factors affected by big wind farm developments. Impacts that affect human beings directly include: the noise; shadow flicker (caused by the movement of blades, impacts nearby houses and may cause health problems); lighting obstruction (required for aircraft safety); MSSR radar obstruction; destruction or repositioning of current land use (especially agricultural lands); and the visual impact (both in the rural areas, affecting the landscape, but also near villages and cities where they compete with architecturally important structures like churches, landmarks or towers of public institutions). The last factor seem to be of highest persistence in public debates, becoming a ground for numerous studies. Visual simulations were performed in order to investigate reaction of the public to those changes *(Taylor, Frazer)* and questionnaires were conducted that aimed to compare opinions of people directly affected by wind turbines (e.g. living in close approximation to the farm) and ones who did not feel the impact of those structures so far *(Warren, Lumsden, Dowd, Birnie 2005).* Both of them seem to hint that the negative view which is popularized by media is largely overdrawn. Majority of people who live near the farms appreciate the contribution of this energy source and are in favour of utilizing wind energy. It seems that the main obstruction of success is the uncoordinated nature of planning schemes and rushing into development.

The investigation of threats posed by big wind farms is within the scope of work done by environmental consultants and is performed under the Environmental Impact Assessment. The goal of EIA is to produce an Environmental Impact Study which will take into consideration aspects related to environment, human well-being, material assets (infrastructure) and cultural heritage (including archaeological and architectural sites). EIS enables a deeper understanding of an impact of any big scale project although it does not mean that those issues need to affect planning permission. It lists all negative and positive impacts and it is up to the local community whether they are significant enough to be discussed, acknowledged or mitigated. Although it should give an objective opinion on the state of arts, it is still an opinion which means that there are no clear boundaries in the definition of neither the depth of the study, significance of any issues nor whether the assessment is actually needed. It is up to the developer to decide whether or not to perform an environmental study.

Along with big wind potential comes the question of where this potential is the highest and can be used best for the profit of citizens. As mentioned previously strongest winds often go in hand with borderlines which have high environmental and cultural value. Within the country there is a national listing of natural heritage areas, special protection areas or special areas of conservation. Both NHAs and SACs cover areas of wildlife protection while SPAs deals mainly with important species of birds. Many of the most windy areas within the country overlap with places under protection leaving the decision on which issue is more important to the government.

With big costs and risks associated with megawatt wind farms as well as difficulties related to locating them close to cities, which present highest energy demands, small scale urban wind systems should be given more attention.

2.3. Urban micro-generation

Previous chapters presented crucial characteristics related to Ireland's energy situation: the big need for expansion of renewable energies sector to avoid further dependence on imported fuels; great wind availability; poorly developed national grid and beautiful natural landscape populated mainly with low rise non-dense settlements. These factors seem to provide a good encouragement for investigation of alternatives to big wind farm projects, which dependence on large infrastructures could damage country's natural beauty.

Figure 2.3.1. compares sizes of currently popular wind turbine designs. Micro wind turbines are up to around 20 meters high and produce the maximum power of 11 kW. Their total installed capacity in Ireland equals approximately 1818 kW, covering over 90% of its total micro generation *(ESB 2010).* This is not much when compared with total energy production in the country. It might be due to economics of micro wind generation in Ireland, which were unclear until recently, making the investment uneconomical *(Boyle, Reynolds 2011).*

Since 2007 it became possible for owners of micro wind systems to export overproduction to the national grid, for three-phase distribution grid (400V) allowing the maximum of 11 kW and single-phase distribution grid (230V) the maximum of 6kW *(ESB 2010).* ESB Networks provides an electrician who is responsible for safe connection of these technologies. Nonetheless, the high price that has to be paid for this technology makes it still unreachable for most. Table 2.3 on the next page provides basic information on some turbines currently available on the market *(Cace, Horst, Syngallakis, Niel, Clement, Happener, Peirano 2007).*

A number of communities around the country have pursued an alternative path in installing micro-wind turbines along with other renewable energy systems to provide power for their households. They work on their own method of producing equipment needed for wind harvesting and do not rely on institutional designs. Some organizations bring together people that might be interested in the subject and need any advice or help to organize their own project. Courses and workshops are provided where necessary skills and tools are provides along with a platform for an exchange of ideas. One of such groups is the Imecofarm. It is a placed on the west coast and provides workshops on 'how to build your own turbine' along with a number of events which aim at raising the awareness among adults and kids *(Imecofarm.com).* Their workshops are based on well-known work of Hugh Piggott, whose designs became the starting point for any amateurs of home-made turbines *(scoraigwind.co.uk).* Hugh is designing wind turbines and associated system which are now used all over the world.

He supervised numerous private projects and shared his own experiences with communities like Imecofarm in attempt to spread the interest in building renewable energy harvesting equipment from home. Hugh's famous Wind Turbine Recipe Book (*Piggott 2009*) contains information on required tools, desirable surrounding, most reliable materials and construction methods of each element of a wind harvesting system. Workshops which teach how to build such turbines are organized in order to allow a few people to construct a fully working, power producing wind turbine together over the period of few days. This interesting and much cheaper alternative to manufactured technology will be investigated in further parts of this work.

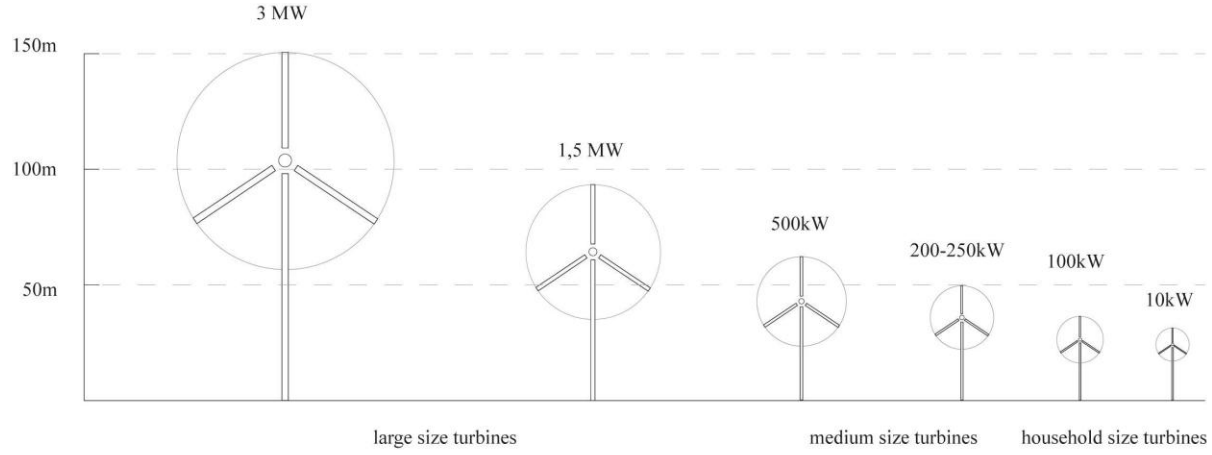


Fig. 2.3.1.Sizes of wind turbines.

Micro-wind generation in cities has not yet been widely investigated and its contribution to overall renewable energy production in the country is still very low. Since wind behaviour is affected greatly by profile of the landscape, the very few studies that were performed in this field concentrated on the effects of obstructions on the air flow *(Sunderland, Conlon 2010).* In UK, Department of Energy and Climate Change made an effort to formulate a method which would allow prediction of wind behaviour for particular places in the city in order to determine the most suitable sites for wind harvesting *(DECC 2008).* This method was based on modifications of wind speeds, which were recorded in an exposed environment, into the expected behaviour in urban terrain. It utilized a mathematical method, grounded on surrounding obstructions and friction they cause, to produce universal correction factors that could later be applied to estimate urban wind speeds. Accuracy of this method, which was applied by Encraft to 26 different sites in their Warwick Wind Trials Project *(Encraft 2009)* was not fully satisfactory, calling for further studies in this subject. WIND STUDY section of this thesis will address this issue in investigated sites to contribute to evaluation of the MCS method.

Table 2.3. Features of selection of turbines available on the market. Source: Cace, J., Horst,E., Syngellakis, K., Niel, M., Clement,P., Heppener, R. & Peirano, E. 2007.

	Fortis Montana	WES5 Tulipo	Turby	Energy Ball	Ropatec WRE030	Proven WT6000	Iskra
Nominal power [kw]	2.7	2.5	1.9	0.5	3	6	5
Nominal power [kw]	10	9	12	15	12	12	11
Start wind speed [m/s]	2.5	3	3.5	2	2.5	2.5	3
Stop wind speed [m/s]	n.a.	20	14	n.a.	n.a.	n.a.	60
Max wind speed [m/s]	60	35	55	>40	60	70	60
Rotor diameter [m]	5	5	2	1.1	3.3	5.5	5.4
Rotor swept area [m2]	19.6	19.6	5.3	1	7.26	23.76	22.9
Mast height [m]	variable	12	variable	11	variable	9	15
Costs [€]	16500	17000	17800	5700	16000	22000	24000

3. WIND STUDY

Wind speed is the main parameter which determines the output from any wind turbine, affecting its frequency and voltage. Knowledge of wind behaviour helps with the choice of the most suitable wind harvesting equipment and allows to predict its efficiency. Since any difference in wind speed affects the power output threefold, accuracy is of high importance. Unless wind situation is monitored by the future user on the site of his choice, a more general data provided by meteorological stations is used. Comparison between those publicly available records with measurements from a variety of sites within urban and rural environments should help to understand how useful predictions based on weather stations data can be.

3.1. Meteorological stations

The Irish National Meteorological Service is a part of the Department of Environment, Community and Local Government, and the main weather forecasting division in Ireland (*Met.ie 2012*). Their mission is to monitor, analyze and predict Ireland's weather and climate as well as provide this information and other related services to customers. In order to meet those aims MET has established a number of climatological stations including 18 synoptic stations and 5 meteorological aviation stations. Data provided online, which includes wind speed records, is publicly available. The past weather data includes daily measurements as well as monthly statistics and 30 year long patterns. Information was obtained in form of average daily wind speeds for the full year 2012.

3 MET stations which are currently operating within county Cork were studied in order to a range of input for comparison with monitored sites. Map in figure 3.1.1. illustrates location of these stations in the county. Diagrammatic representation of an automatic weather station and all its elements is attached in figure 3.1.2.

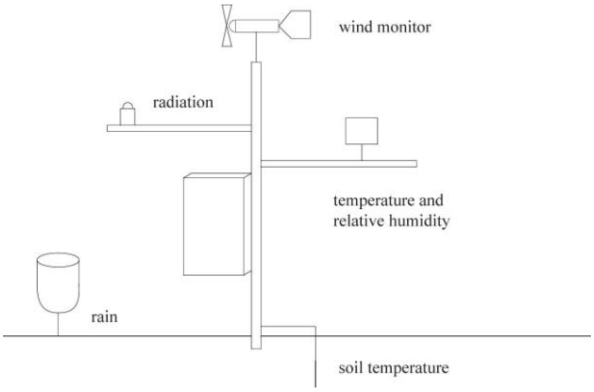


Fig. 3.1.2.Elements of a typical Automatic Weather Station. Source: Met.ie

Fig. 3.1.1. County Cork, southern Ireland. MET Weather Stations: Cork Airport, Roches Point and Sherkin Island.

Cork Airport

51°50'N 8°29'W
154M above mean sea level

Fig. 3.1.3. Manual Aviation Weather Station at Cork Airport

Manual aviation station is placed outside the Cork Airport, approximately 6 kilometres south from Cork city. Station provides the latest radar pictures, TAFS (terminal area forecasts produced by a human forecaster based on the ground), METARS (most common way of weather forecast reporting which includes temperature, dew point, wind speed and direction, precipitation, cloud cover and heights, visibility, and barometric pressure), and upper wind. All parameters, along with weather charts, are updated as soon as the latest data becomes available.

Wind behaviour is measured using the traditional, 10 meters high cup and vane anemometer- rotating cup yields wind speed while wind vane measures wind direction. Readings are taken every half hour and then averaged for each day in order to provide daily wind speed and direction for public use.

Roches Point

51°46'N 08°15'W
41.4M above mean sea level

Fig. 3.1.4. Automatic Weather Station in Cork Harbor at Rcches Point.

The synoptic station is placed in a south eastern tip of Cork, in close approximation to Cork Harbour, around 25 kilometres from the city centre. The Vaisala Milos automatic station (fig. 3.2) installed at the observatory carries out surface weather and upper-air meteorological measurements, as well as environmental monitoring. Wind speed is recorded every half hour using a Vaisala cup anemometer and provided in form of daily average for public use.

Sherkin Island

51° 27' N. 9° 24' W
21M above mean sea level

Fig. 3.1.5. Automatic Marine Weather Station in Sherkin Island

The marine station is placed the furthest south, roughly 80 kilometres from Cork city. Automatic weather station takes real time synoptic measurements and daily climatological measurements which are forwarded by the data logger to the MET office.

Average daily data recorded at weather stations was collected for the full year in order to understand the occurrence of particular wind speeds. All 3 stations display similar average values, ranging from 5m/s to 6,3m/s south or south-west. This is the recommended average wind speed value for wind energy generation. Another promising characteristic is the wind speed distribution, which is very evenly placed around the mean value. Figures 3.1.6-3.1.8 show distributions of wind speeds for each station; more details can be found in Appendix A.1.

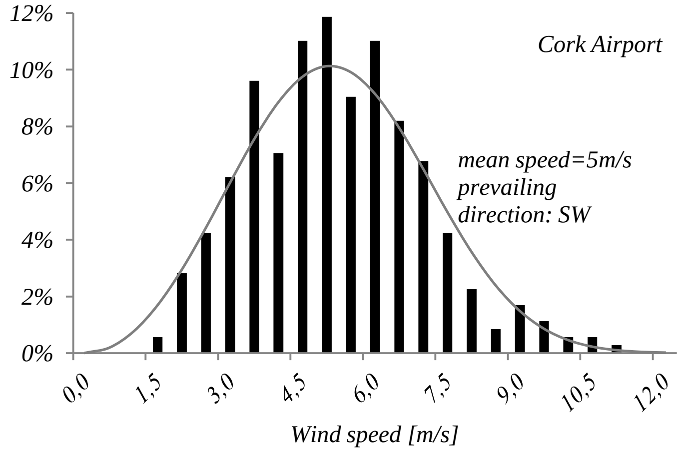


Fig. 3.1.6.Weibul distribution of wind speeds at Cork Airport station. Source: Met.ie

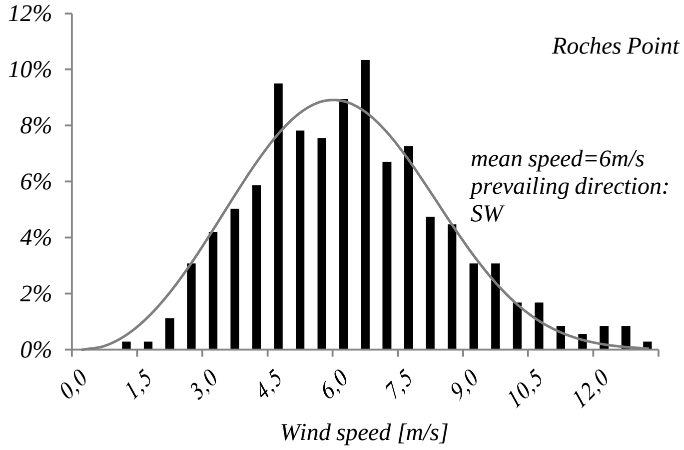


Fig. 3.1.7.Weibul distribution of wind speeds at Roches Point station. Source: Met.ie

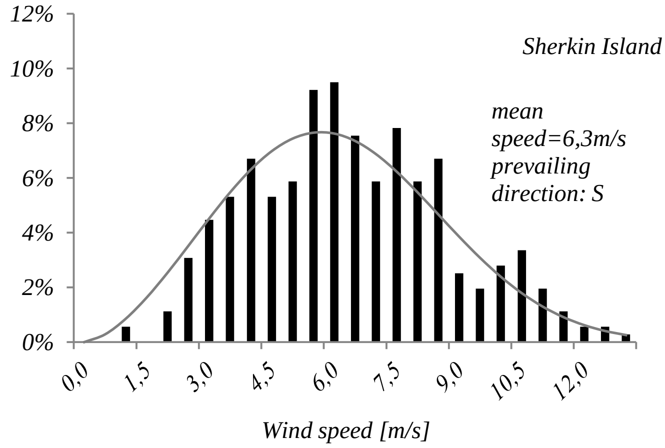


Fig. 3.1.8.Weibul distribution of wind speeds at Sherkin Island station. Source: Met.ie

3.2. Wind speed corrections

MET provides data obtained under good conditions in unobstructed environment, which is very different to urban terrain. A number of modification methods were suggested in order to apply similar data to more complex terrains. One of such methods was the Microgeneration Certification Scheme published in Microgeneration Installation Standard (*DECC 2008*) in UK. It provided evaluation and assessment strategies for contractors working on microgeneration projects for householders, communities and small businesses. MIS identifies a standardised procedure, which uses meteorological data (provided by NOABL in the UK) along with correction factors suited to a particular landscape type *(Encraft 2009)*. This procedure was adopted for the purpose of this study, using Irish meteorological data, in order to analyse wind harvesting prediction methods. MCS warns that these standardised corrections have relatively high degree of uncertainty.

Provided corrections are dependent on type of surrounding terrain and have been divided into 5 main categories:

Category 1
Flat grassland, parkland or bare soil, without hedges and only a few isolated obstructions.

Category 2
Gently undulating countryside, fields with crops, fences or low boundary hedges and few trees.

Category 3
Farmland with high boundary hedges, occasional small farm structures, houses and trees etc.

Category 4
Woodland or low rise urban/suburban areas (e.g. domestic housing) with a plan area density of up to about 20%.

Category 5
Dense urban areas and city centres (e.g. buildings of four-stories or higher) with a plan area density of greater than about 20%.

These main categories are then divided further depending on significant local obstructions within upwind and downwind zones, illustrated in figure 3.2.1. Significant obstruction is identified as any solid item with width >0,5m and height >0,25 of the height of the measuring device, while upwind and downwind zones are based on the prevailing MET wind direction.

The height of the turbine along with information on significant obstructions allows calculating the reference number using the formula below:

$$h_c = h_t - 0{,}8 \times V\, h_o$$

ht- height of the turbine (here, anemometer)
ho- height of the highest obstruction within the zones
hc-reference number

Then, the reference number and identified type of terrain (from Categories 1-5) is used to obtain the correction factor from the table published in the Microgeneration Installation Standard (Appendix A.2). This correction factor is applied to calculate an estimated wind speed for a specific site by relating it to the obtained MET data.

Ve = Cf × Vm

Ve- estimated wind speed
Vm- wind speed from meteorological station

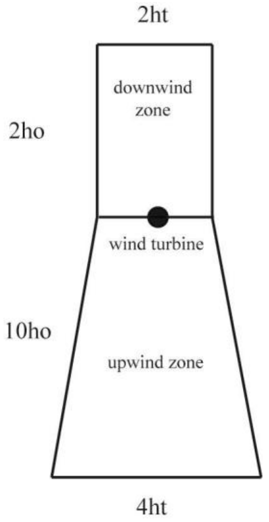


Fig. 3.2.1. Upwind and downwind zones determined by h_t- height of device and h_o-height of the highest obstruction. Source: MIS3003, DEEC, 2008.

3.3. Measurements

In order to evaluate estimated wind speed predictions, wind records have been taken from 5 sites based in Cork city and surrounding areas. Sites were chosen in order to represent the best variety of environmental and terrain conditions. Measurements have been obtained from private stations at heights ranging from 5 to 23 meters above the ground level. Most of those stations use the cup anemometer, which is currently set as standard equipment for wind resource assessment studies. Wind data was provided for the full year with an exception of one site, where availability of equipment allowed only a couple of weeks of measurement.

In order to have a good understanding of the measurement process an additional 6th site was identified within university campus, where anemometer was placed on the lattice mast supporting a wind turbine. Wind speed was measured by the sensors connected with CAT5 computer wires to a wind data logger (fig 3.3.2) placed in the hub room. Wind data logger records information in form of a comma separated vertical files to the standard SD memory card. Measurements were conducted for the 6 months period, July-December 2012.

All gathered data has been standardized to a 30 minute interval and analysed in search for average values as well as wind patterns.

Figure 3.3.1 shows locations of monitored sites, which are presented in more detail in the next chapter.

Fig. 3.3.2. Wind data monitoring system, UCC

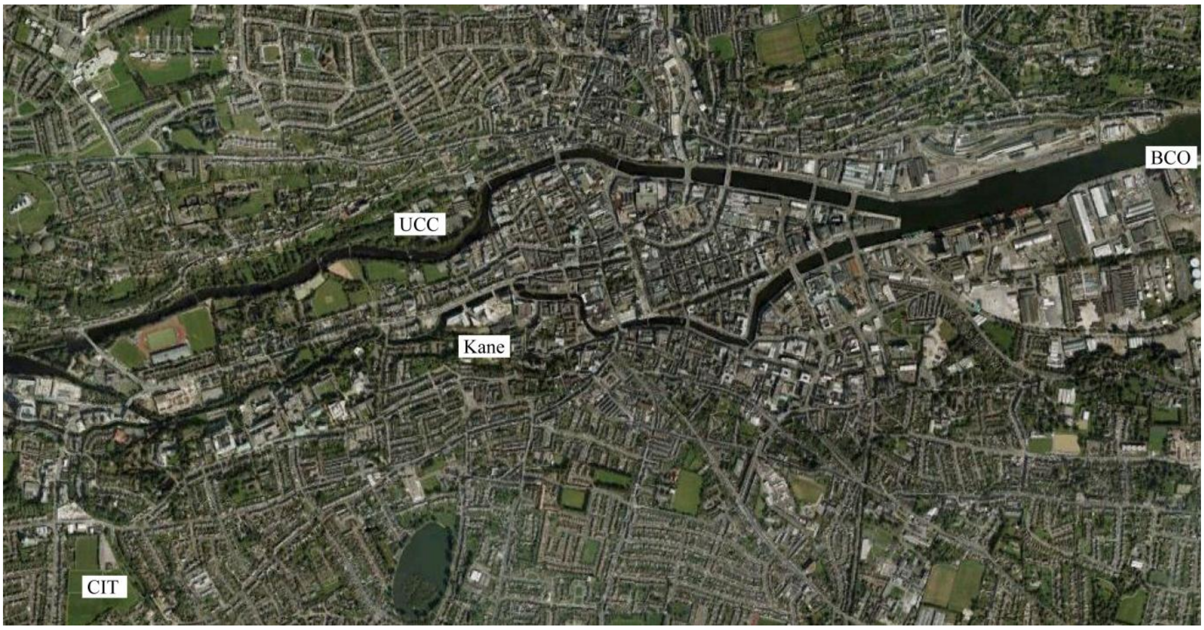


Fig. 3.3.1. Map of investigated sites.

3.4. Sites overview

UCC- University College Cork	
Location	51.9° N, 8.485° W
Area	Cork city University campus
Anemometer type	Cup
Mounting height	15m
Mounting type	Tower
Measurement period	07-12.2012
MET station	Cork Airport
MET mean speed	5m/s WS
Distance from station	8,5
Surroundings	Dense urban
Correction category	5
Correction factor	0,48
Measurement period	01.07-05.12

Fig. 3.4.1. UCC wind turbine and anemometer.

KANE- Kane Building	
Location	51.893° N, 8.4919°W
Area	Cork city University campus
Anemometer type	Sonic
Mounting height	23m
Mounting type	Building top
Measurement period	11-12.2012
MET station	Cork Airport
MET mean speed	5m/s WS
Distance from station	8
Surroundings	Dense urban
Correction category	5
Correction factor	0,51
Measurement period	26.11-19.12

Fig. 3.4.2. Kane building with anemometer placed on the rooftop.

BCO- Blackrock Castle Observatory	
Location	51.900° N, 8.4025°W
Area	Suburbs, Blackrock LoughMahon shore
Anemometer type	Cup
Mounting height	8,5m
Mounting type	Building top
Measurement period	01-12.2012
MET station	Roches Point
MET mean speed	6m/s WS
Distance from station	11km
Surroundings	Suburban
Correction category	4
Correction factor	0,24
Measurement period	01.01-30.11

Fig. 3.4.3. Anemometer on the top of Blackrock Observatory.

CIT- Cork Institute of Technology	
Location	51°53'6"N, 8°32'6"W
Area	Bishopstown University campus
Anemometer type	Cup
Mounting height	5m
Mounting type	Tower
Measurement period	01-12.2012
MET station	Cork Airport
MET mean speed	5m/s SW
Distance from station	4km
Surroundings	Suburban
Correction category	4
Correction factor	0,33
Measurement period	01.01-19.12

Fig. 3.4.5.Anemometer and turbine on CIT campus.

COBH- Cork Harbour Station	
Location	51.850° N, 8.3000°W
Area	Cork Harbour Seaport
Anemometer type	Cup
Mounting height	10m
Mounting type	Tower
Measurement period	01-11.2012
MET station	Roches Point
MET mean speed	6m/s SW
Distance from station	5km
Surroundings	Farmland
Correction category	3
Correction factor	0,86
Measurement period	01.01-30.11

Fig. 3.4.6.Cobh in Cork Harbor.

SCHULL - household in Ratooragh near Schull	
Location	51.526° N, 9.5481° W
Area	Countryside Mizen Peninsula
Anemometer type	Cup
Mounting height	6m
Mounting type	Tower
Measurement period	01-12.2012
MET station	Sherkin Island
MET mean speed	6,3m/s S
Distance from station	25km
Surroundings	Countryside
Correction category	2
Correction factor	0,91
Measurement period	01.01-09.12

Fig. 3.4.7.Wind turbine and anemometer in Ratooragh.

3.5. Results

Average wind speeds

Average wind speed values for the full measurement period presented in figure 3.5.1. show big dispersion within the sites. This diagram, like others in this section, is arranged in order to present information ranging from the most obstructed site (UCC) to the least obstructed one (Schull).

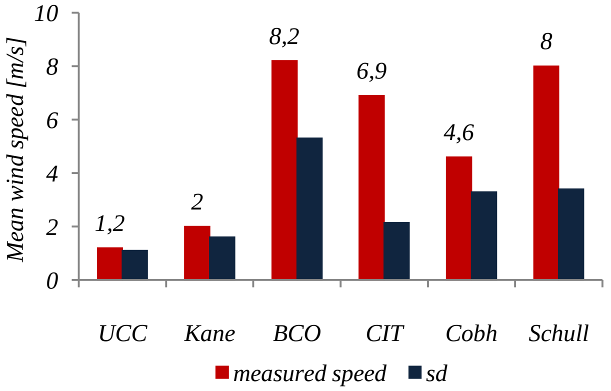


Fig. 3.5.1.Mean wind spead values; all sites.

As expected, wind speeds for the dense urban environment show the smallest values, despite relatively high position of the anemometer on Kane site. Neither UCC nor Kane (both located on the University Campus) display mean values sufficient for wind harvesting (the usual cut in speed ranging between 2,2m/s and -3,5m/s). Surprisingly, the highest average wind speeds are present at the Blackrock Castle Observatory, a suburban area, where anemometer is placed barely 1,5 meter above the building top and Castle towers project high above the measurement height.

Along with average wind speeds the standard deviation S_N value was calculated for each project using the formula below:

$$S_N = \sqrt{1/N} \times \sum (x_i - \dot{x})^2$$

$\{x_1, x_2, x_n\}$- observed values
$\dot{x}$ - mean of observed values
N- size of the sample

Standard deviation shows how dispersed most measured wind speeds are around the mean value and signifies the intermittent nature of this energy source. The higher the S_N value in relation to mean, the more fluctuations can be observed, including high gusts and times in stall. It stands out that Cork Institute of Technology, despite relatively high mean wind speed, has much lower S_N than most sites, making CIT a relatively good place for wind turbine installation.

Interestingly the Blackrock Castle Observatory as well as Cork Institute of technology display higher average values than the MET data (ranging between 5m/s and 6,3m/s), despite being placed in a suburban environment. These differences are summarized in table 3.5 which at the same time reveals problems with MCS corrections. Corrections work well for sites that display lower than MET wind speeds (UCC, Kane, Cobh) but increases the error when wind speeds are higher on measured site (BCO, CIT, Schull). Corrections included in the Microgeneration Installation Standard assume that values measured on an obstructed site are lower than the ones from an exposed area. Despite taking into consideration the type of surroundings, height of the measurement and obstructions, it does not seem to be enough to accurately predict an output on a particular site.

Table 3.5. Wind speed values; MET, MET corrected and measured.

	MET	MET corrected	Measured speed
UCC	5m/s	2,4m/s	1,2m/s
Kane	5m/s	2,6m/s	2m/s
BCO	6m/s	1,4m/s	8,2m/s
CIT	5m/s	1,7m/s	6,9m/s
Cobh	6m/s	5,2m/s	4,6m/s
Schull	6,3m/s	5,7m/s	8m/s

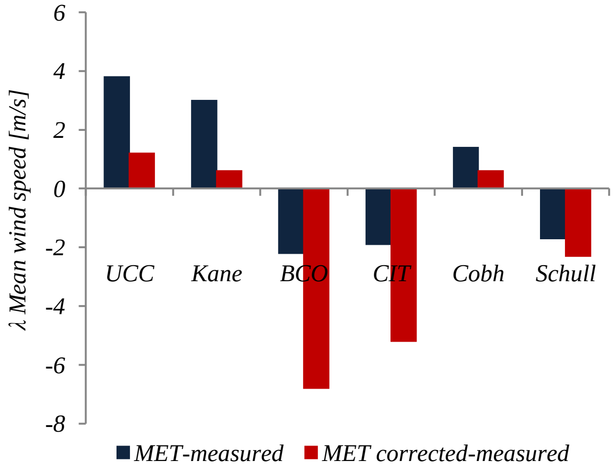


Fig. 3.5.2. Differences in predicted values and measurments; MET and MET corrected.

Appendix A.3 presents data for the full measurement period.

Weibull distribution

Weibull distribution is a good representation of wind speeds variations, by estimating how often certain values can be expected. Distribution of wind speed values helps to define the most suitable turbine, based on its cut in and cut out wind speeds, at the same time predicting power output patterns. Graphical representation of Weibull distribution illustrates wind speed occurrence and is determined by 2 main parameters, shape and scale values. The shape value, often referred to as 'k', is dependent on standard deviation and gives a clear idea about the consistency of distribution around mean. The higher the shape value (2 and above) the more evenly investigated variables are spread out. This, in most cases, yields the highest power outputs. 'K' values below 1 suggest big extremes in distribution, indicating high occurrence of gusts and near zero wind speeds. Both of those conditions are of no use for wind power generation. The scale parameter is proportional to average wind speed and is a measure of spread in data.

Comparison between Weibull distributions in rural and urban settings gives an impression about level of wind fluctuations in urban areas. The most important numerical value is the shape factor which in ideal conditions is ≥ 2. Difference between expected MET shape factor and shape factor obtained from measurements will allow evaluating the relationship between two data sets in more. Table 3.5.a. summarizes 'k' values for measured and MET wind speeds.

Table 3.5.a. Weibull shape paramter; MET, MET corrected and measured data.

	MET	MET corrected	measured speed
UCC	2,83	2,93	1
Kane	2,83	3	1,17
BCO	3	2,78	1,52
CIT	2,83	2,56	3
Cobh	3	2,64	1,7
Schull	2,61	2,57	2,14

Shape parameter and scale parameter are used to calculate Weibull density distribution for each variable using the formula below:

$$F(x) = k/A \times (x/A)^{k-1} \times \exp. -(x/A)^{k}$$

k- shape factor
A- scale factor
x- wind speed value

Results from those calculations are plotted for each site and each input data in order to evaluate investigated predictions (fig. 3.5.3-3.5.8). MET data yields promising Weibull shapes which are always above 2. Corrections, since applied systematically to each measurement, remain within the same range. Measured data, however, differs vastly from those predictions displaying a variety of values depending on the site. CIT and Schull sites seem to be the only ones whit favourable wind distribution, while both of the University College Cork anemometers (UCC and Kane) yield very low values and uneven wind speed distributions.

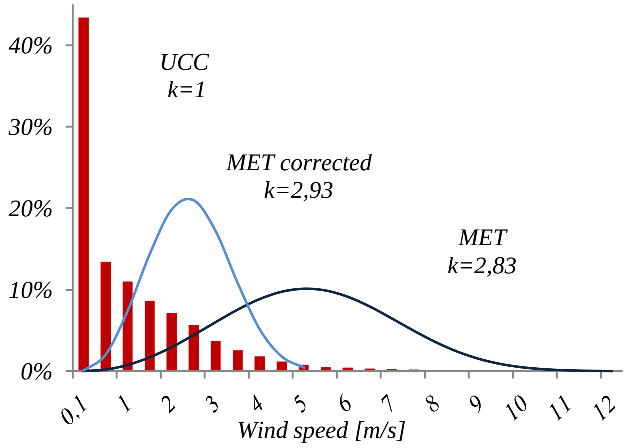


Fig. 3.5.3. Weibull distribution; UCC, MET and MET corrected.

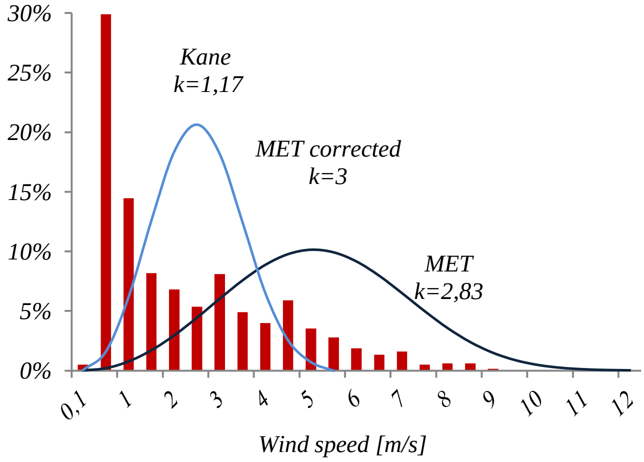


Fig. 3.5.4. Weibull distribution; Kane, MET and MET corrected.

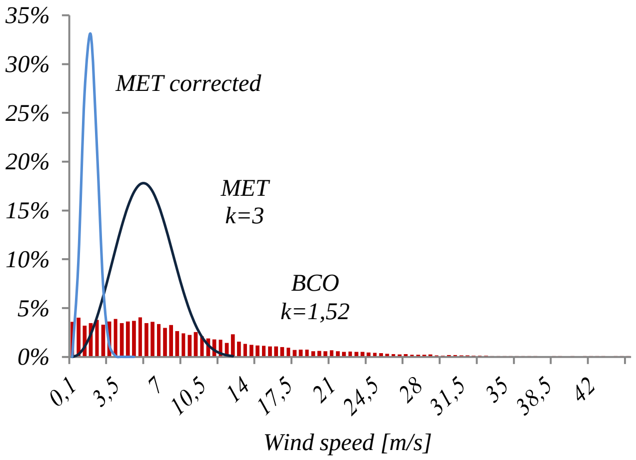


Fig. 3.5.5. Weibull distribution; BCO, MET and MET corrected.

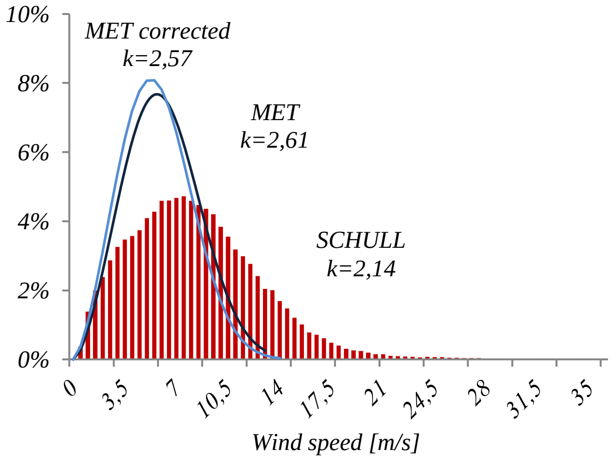


Fig. 3.5.8. Weibull distribution; Schull, MET and MET corrected.

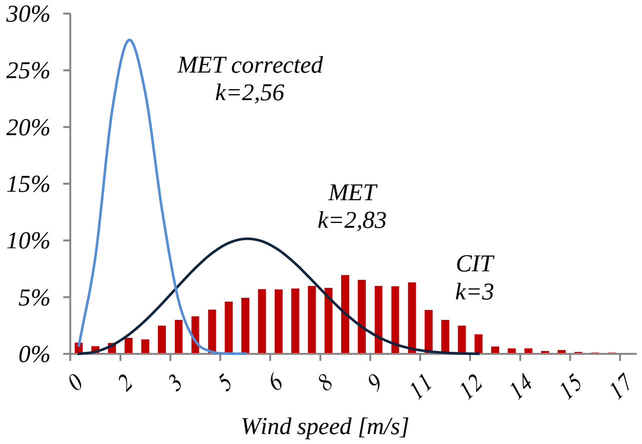


Fig. 3.5.6. Weibull distribution; CIT, MET and MET corrected.

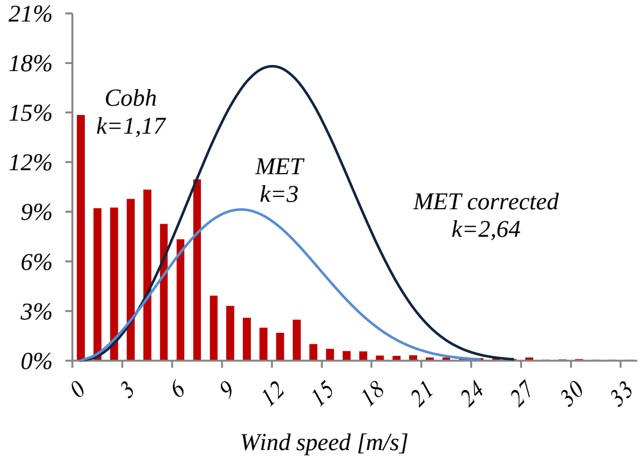


Fig. 3.5.7. Weibull distribution; Cobh, MET and MET corrected.

Time distribution

Energy consumption within most buildings is characterized by distinct, repeatable patterns. Daily consumption in far greater than at the night time due to human activity. Buildings, which are investigated in further parts of this study, are located within university therefore it is expected that their power demands will raise on average shortly after common opening hours and remain high up until late afternoons or early evenings. Power generation from renewable resources should be able to meet those changing demands. Knowledge on wind speed patterns throughout the day may allow adjusting daily demands according to them.

For this purpose an analysis of time related wind availability was performed, included in figure 3.5.9. It is clearly visible that despite different landscape conditions and various obstructions that may alter local wind behaviour, daily patterns remain fairly similar on each site. They all display a raise in wind availability roughly between 8 am and 8 pm . This is a promising scenario, which will be later compared with data recorded from investigated dwellings, in order to see the degree of overlap between wind availability and power needs.

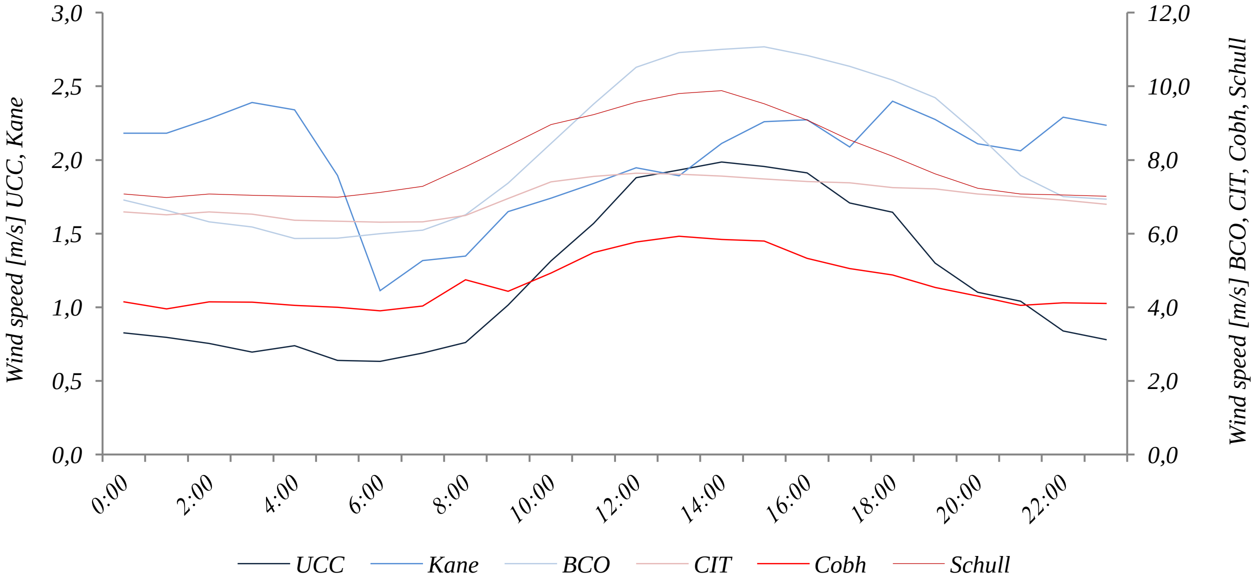


Fig. 3.5.9. Time distribution of wind speeds for all sites.

4. ENERGY STUDY

Power output of the wind turbine is the most important factor looked into in this thesis. Popularity of wind energy harvesting in recent years have caused a big increase in available technologies which involve high hopes. Two diverse groups of small scale wind harvesting products became popular in the country, both representing vastly different costs but also the nature of production and installation, therefore determining the type of clientele. Investigating how these technologies perform compared to each other along with degree to which their performance can be predicted will be useful for future users.

Information on wind speed and system's parameters is a basis for estimation of turbine's power output. Companies that offer wind turbine technology are responsible for providing an estimated annual energy yield based on calculated power curve. This power curve represents values obtained from lengthy measurements of a performance of a specific wind turbine and plotted against available wind speeds. Information provided by the producer plays a big role when determining which system is most suitable for a particular area, especially if some knowledge on wind distribution is obtained beforehand. Therefore it is useful to know how accurate they are, especially for the urban environment, which differs vastly from the ideal conditions under which tests for power performance are undertaken. The alternative is to calculate predicted power outputs using a standard equation, which takes into consideration the most crucial parameters of the turbine. This equation is highly dependent on wind availability therefore previous studies on wind prediction accuracy will have high impact on the results.

4.1. Projects overview

Two projects from the previous wind study have been identified in order to perform this study. They are placed in unlike surroundings and represent vastly different production and installation processes which determined their technology. Table 4.1 placed at the end of the ***Project overview*** section summarizes the most important details of both systems and highlights differences.

UCC, Bergey Excel 10

The choice of the first turbine was based on the representative location of the project as well as the popular nature of its technology, which is widely used around the country and in other parts of the world. The 10 kilowatt turbine was produced by Bergey Windpower, a company that was founded over 30 years ago and is now recognized as the longest established manufacturer of wind turbines for the small wind sector in the world. Producers claim that this design "has proven to provide the best reliability, performance, service life, and value of all of the hundreds of competitive products that have come and gone in that time" (*Bergey.com 2013*).

Bergey Excel 10 turbine was connected to one of university building's power supply at University College Cork in January 2012. It is situated on university campus, within a low rise built up area which is a dominating urban landscape in Irish settlements.

The project was partially sponsored by SEAI as part of the Better Energy Program (*Seai.ie 2012*). Better Energy is a branch of Government's retrofitting program, which aim is to provide more opportunities for companies and households to reduce their energy consumption. 17,000 euro was granted for the project (almost one third of its total cost) in June 2011 under the condition that project will be in place by end of November that same year. This short time allowance left no possibility for performing site analysis beforehand, even though SIAC offered to do so. Therefore no information on available wind speed, which could have determined whether that site was appropriate for wind harvesting, could have been obtained. This however did not downgrade the main purpose of the turbine, which in this case was to raise the awareness of students and professionals in the city. Wind energy harvesting is still associated with megawatt wind farms and there is little awareness of the availability of small scale local projects that might be suitable for private dwellings and businesses. Also due to shortage of time there was no building permission acquired, determining lower height of the mast, despite its obvious disadvantages. Turbine's construction, however, allows for an easy change of height and location, if it is required to do so in the future.

Fig 4.1.1. Bergey Excel 10 turbine on UCC Campus, looking east.

Fig 4.1.2. Bergey Excel 10 turbine on UCC Campus, looking west.

Ratooragh, Hugh Piggott design

Second turbine is located in the south of the county, in the area called the Mizen Peninsula. It is placed close to the shore and therefore receives strong winds from south and south-west. This countryside area is highly exposed and turbine is situated on one of its elevated parts, projecting above any insignificant obstructions. The owner established a small, private weather station within his premises and has been monitoring weather conditions for years. This allowed him to recognize the wind availability on his site well before making a decision on wind power harvesting. Turbine was erected this year and became part of a private micro generation project. The owner constructed the turbine and erected the mast by himself, contributing to the group of homemade, micro wind generation systems which are popular in the country. Like many others of its kind, turbine in Ratooragh was inspired by one of the “How to build your own turbine” workshops that take place around the British Isles, and are available to anyone who has interest in wind harvesting. During the workshop participants learn how to build a micro scale wind turbine and spend a few days making one together. Most workshops were inspired, and base their designs, on work performed by Hugh Piggott, the author of “Wind Turbine Recipe Book”. The book includes detailed description of turbine parts, where to buy them and how to assemble them. Typical design aims to provide power to one household and can be erected without extensive previous knowledge on wind generation.

The market for both wind turbine building workshops and the home made turbine products is constantly growing in the Islands. Groups and individuals who are interested in both harvesting renewable energy as well as willing to commit their time for this purpose have established a community that exchanges skills and ideas in an attempt to spread their enthusiasm.

Fig. 4.1.3 Hugh Piggott turbine in Ratooragh near Schull.

Please note: Hugh Piggott designed and inspired a large number of various turbines that differ in terms of technology, size, system involved and location. The only turbine studied in this work is the particular project in Ratooragh, which was designed in collaboration between Hugh Piggott and Francis Greaves (the owner). For the ease of presenting the data, turbine in Ratooragh will be referred to as ‘Hugh Piggott’s design’, since he is the person behind the origins of this concept. The outcomes, however, are not the result exclusively of his work, but rather of a process which included an exchange of ideas between two involved parties, therefore any credit goes to both Hugh Piggott and Francis Greaves and measured data should not be treated as a representation of other wind technologies that Hugh Piggott might have been involved in.

Table 4.1. Selected details of investigated wind projects. Source: Bergey Windpower 2011; www.choughs.net.

	Bergey Excel, UCC	**Hugh Piggott, Ratooragh**
Mean wind speed	1,2 m/s	9,5 m/s
Weibull shape	1	2,57
Rated power	10 kW	3 kW
Rotor	3 blades, upwind, horizontal	3 blades, upwind, horizontal
Rotor diameter	7m (38 m^2 swept area)	3m (7 m^2 swept area)
Height	15m, lattice mast	15m, pole
Site type	dense urban	countryside
Yaw bearing	slip rings and brushes	none
Cost	€50.000	€5.000
Generator	permanent magnet alternator	permanent magnet alternator
Gearbox	none, direct drive	none, direct drive
Cut in wind speed	2,2m/s	2,5m/s
Governing system	passive, furling	passive, furling

4.2. Project summary: UCC, Bergey Excel 10

Turbine details

Bergey Excel is an upwind, horizontal design, with 7m rotor diameter (38m^2 swept area) placed on a 15 meter high lattice mast. Its rated power was defined as 8,9 kW with annual production of 13,600 kWh of energy based on 5 m/s average wind speed. The rotor part of the turbine is composed of three pultruded, fixed pitch blades (proprietary airfoil), and attached rigidly to the outside shell of the direct drive, 38 pole permanent magnet alternator.

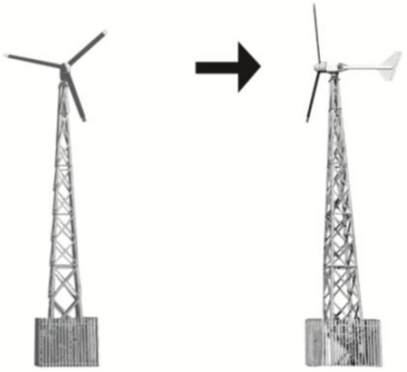


Fig. 4.2.1. Blades facing wind direction.

The inside out configuration of the alternator means that it is the outer shell of the hub that contains the magnets, which rotate around the fixed, internal stator structure composed of copper wires. Rotation of alternator rotor is caused by wind speeds exceeding 3,6 m/s (after the system starts rotating it can keep on operating with wind speeds down to 2,2 m/s), and induces electrical current in copper wires. The rotating hub is connected directly to the static mainframe by slip rings and brushes, located in the 360 degree pivot yaw axis, which allow for electricity transmit between movable and stable parts. Slip rings and alternator are protected by the nacelle component that ends with a tail boom, which allows turbine to align itself to the wind for higher efficiency. Too high wind speeds, however, may damage the machinery therefore it is protected by passive AutoFurl system which is initiated at the speeds around 13-15 m/s, when rotor thrust overcomes the resistance of the tail and furls to a maximum angle of 75^{O} degrees. Wind speeds between 15 m/s and 20 m/s cause rapid furling and unfurling. Turbine is restored from furled position by gravity, whenever wind speed subsides. In case of emergency system can be shut down manually using the furling winch cable, which connects the tail to a handle at the base.

All information in this chapter was acquired from the Bergey Excel Owner’s Manual 2011 provided by the Bergey Windpower Co.

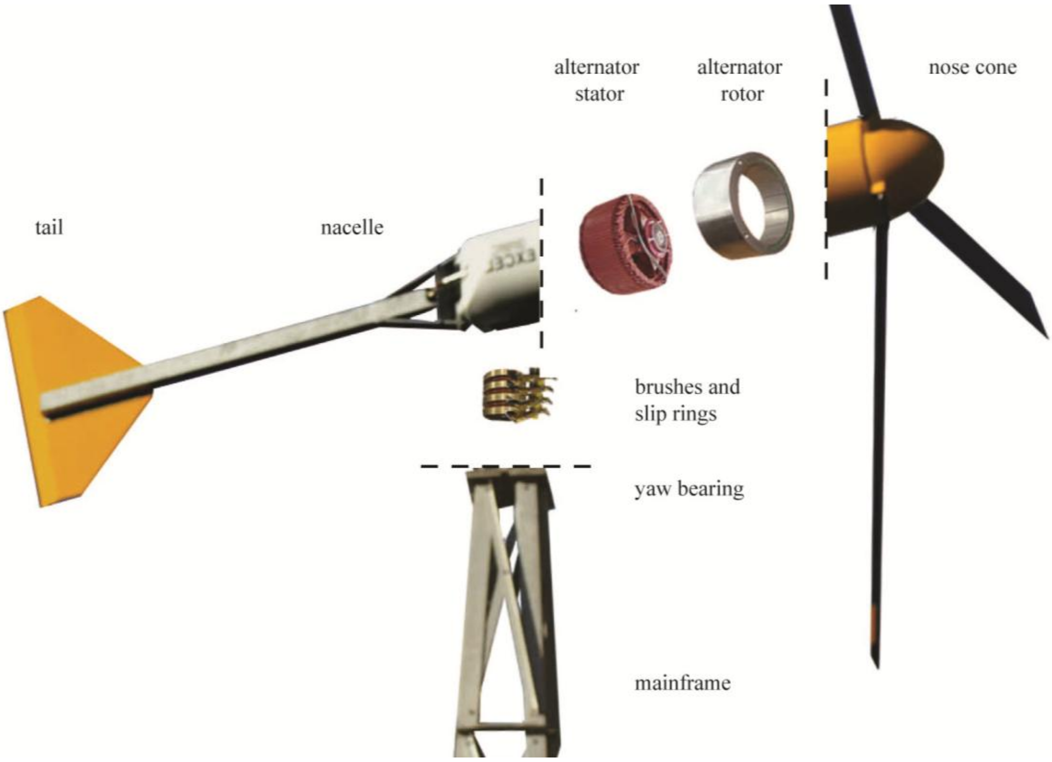


Fig. 4.2.2. Turbine anatomy.

System operation

System produces utility compatible power in form of 220V, 50Hz, single phase alternating current. This output fluctuates depending on wind availability and automatically reduces power purchased from the utility whenever it is running. If turbine does not produce enough energy to meet household demands the rest of required energy has to be bought from the utility. Before power reaches final loads in a required form, the oscillating mechanical power of the wind has to be processed by three vital components of wind generation system: generator, rectifier and inverter (fig 4.2.3).

Generator is placed in turbine's hub. Lack of gearbox means that energy induced in copper wires by rotating permanent magnets is transferred, via the yaw bearing, directly to electrical lines that run down the mainframe. Mechanical wind energy is therefore transformed by rotation of those magnets into electrical energy in form of a 3 phase AC. Voltage and frequency of this energy are variable and dependent on temporary wind speeds.

The AURORA 25kW interface box connects generator to an inverter. It receives a wild 3 phase AC from the turbine and delivers a DC voltage to the inverter. Its main tasks are: rectification and filtering of the wild AC, commanding the work of an inverter and activating breaking resistor and diversion load when necessary.

Rectifier, placed in interface box, is the device responsible for filtering and conversion of electrical input from the turbine into the DC voltage.

It incorporates two independent rectification channels: the one that feeds DC voltage to the inverter while the second one feeds breaker and diversion load. Breaking resistor is initiated whenever the voltage coming from rectifier exceeds maximum voltage input of inverter (600VDC). It can be used on its own or along with the diversion load, which allows for further diversion of energy to an external resistive load in order to control the voltage. Both breaking resistor and diversion load lead to a turbine stall. The interface box is arranged in a master-slave configuration with the inverter and is in control of initiation and continuity of any type of communication within the system. It is responsible for the work of an inverter as well as monitoring of the system through the RS485 connection to a data collecting device (usually a PC).

The AURORA Inverter is connected to the circuit by a dedicated 60 Amp 2 pole breaker. It consists of two main components: an input DC to DC converter and output DC to AC inverter; both operating at high switching frequency. Resulting alternating current is compatible with the grid and has a voltage and frequency of 220V and 50Hz or 240V and 60Hz. The minimum of 50V DC produced by the system starts the grid connection. In any abnormal conditions the inverter shuts off turbine's electrical power (turbine continues to spin without power generation, while AutoFurl protects the mechanism), and during any interruptions it automatically disconnects wind turbine from the grid.

All information in this chapter was acquired from the Bergey Excel Owner's Manual 2011 provided by the Bergey Windpower Co.

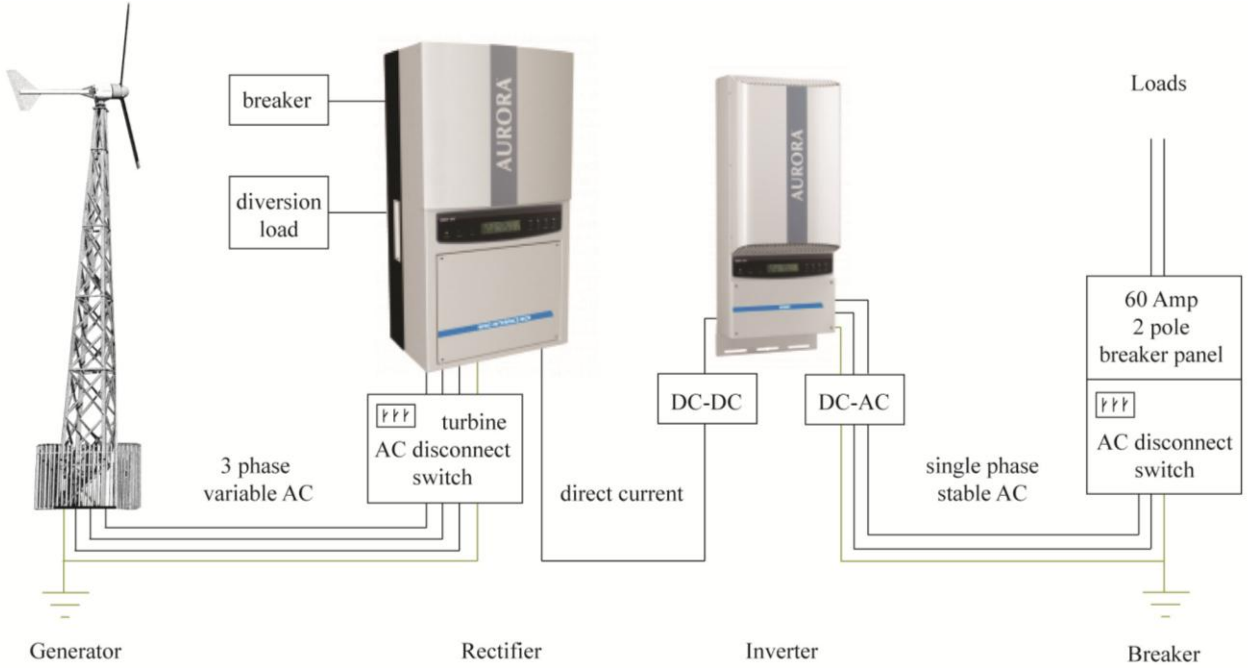


Fig. 4.2.3. Electrical connections between system's components.

Site

Project is located in central part of Cork city, within the North Mall University Campus (figure 4.2.6). Site is placed approximately 100 meters above the sea level, on the north side of the canal. Terrain rises approximately 5 meters from the water bank up to the tree line on the south side, and flattens out throughout the site. It rises again to the north, along the street line, providing an uneven barrier of average height of 15 meters (dashed lines on figure 4.2.5). Turbine, highlighted on the plan as the blue “x”, is placed in central part of the campus. It is surrounded by three university buildings, which are marked in figures 4.2.4- 4.2.5.

The site is largely populated with diverse trees that reach the maximum height of approximately 15 meters. The tallest trees are placed within a few meters of the turbine, to its west and south-west as well as north-east.

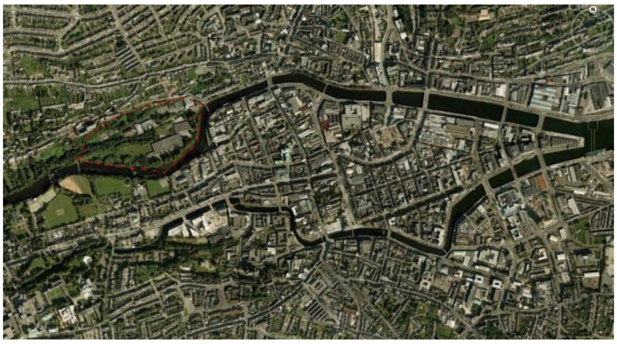


Fig. 4.2.6 Cork city; site is highlighted to the north of the canal.

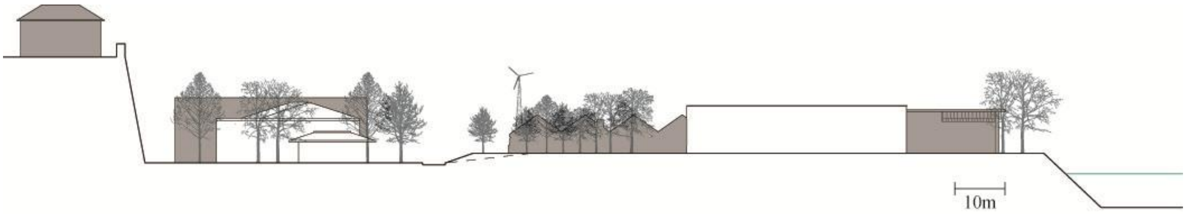
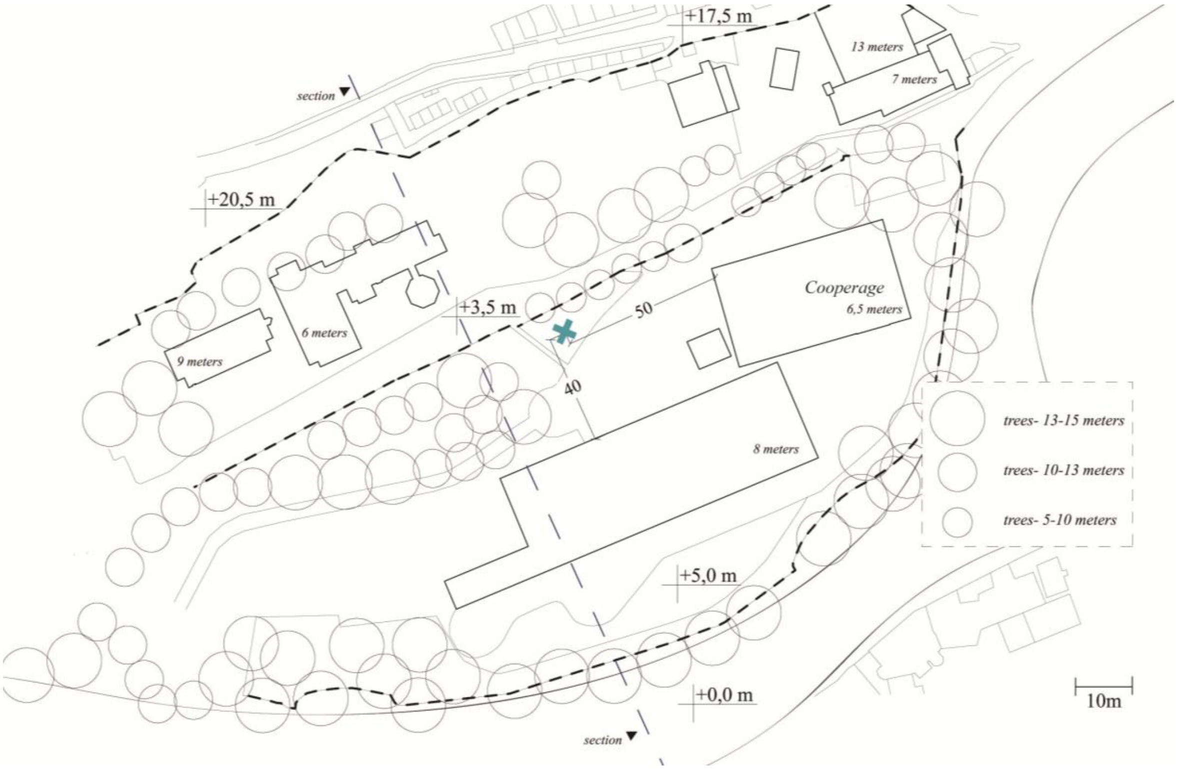


Fig. 4.2.4. Site section looking east-north; marked on figure



4.2.5. Site plan with the dashed *section* line. X represents turbine’s location.

4.3. Project summary: Schull, Hugh Piggott turbine

Turbine details

Turbine is an upwind, horizontal design, with 3m rotor diameter (7 m^2 swept area) placed on a 10 meter monopole tower, anchored to the ground with 4 rods. Its max power was defined as 3 kW.

Blades were cut in a streamline airfoil shape, out of the cider timber, based on Hugh Piggott's suggestions (*Piggott 2009*; figure 4.3.2.a). The back of the blade is curved in order to generate a lift force, pushing the blades back and slowing the wind. The flat front side is the one facing the wind. Mechanical energy in the wind is causing turning of the blades along with attached rotor discs. Two discs contain radially arranged magnets that face each other causing a strong magnetic field between them. This field induces voltage in the stator, sandwiched between the magnets, which are made of coiled, enamelled copper wires mounted firmly onto the frame. Rotor magnets and stator wires together make up an alternator, as presented in the exploded view of figure 4.3.2.b.

The yaw bearing is composed of two pieces of steel pipe, one which is rotating along with the hub and the other one attached rigidly to the tower top. There were neither brushes nor slip rings installed in this system. The cable hangs down the tower freely and twists along with the hub. This mechanism requires rare but consequent maintenance in order to untwist the cable. This is performed at the bottom of the tower and has to be repeated every few weeks, but saves a significant amount of money and helps to avoid possible problems associated with more complicated mechanisms.

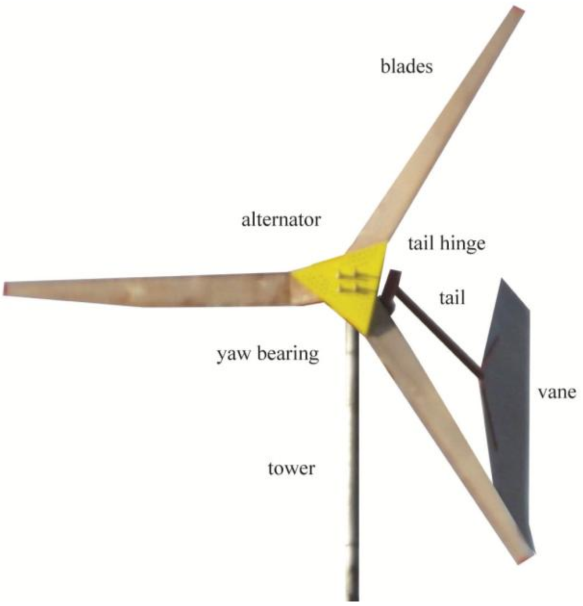


Fig. 4.3.1. Turbine elements.

Turbine's wind alignment is facilitated by the tail which is attached at the end of a long steel pipe. Placed on the opposite side of the blades it balances their load and shifts them windward, at the same time being pushed backwards due to wind pressure. Another function of the tail is to turn the blades away from very strong winds in order to protect them from breaking. In this particular case this protective mechanism is very important due to site exposure. When wind speed grows too strong, the pressure becomes overwhelming for the tail and it is no longer capable of holding the blades in a position to face the flow. Instead, it furls sideways, allowing the blades to turn away from the strongest winds. Furling of the tail is shown in figure 4.3.2.c

System starts operating at wind speeds close to 3,5m/s and the furling mechanism begins to work around 20m/s.

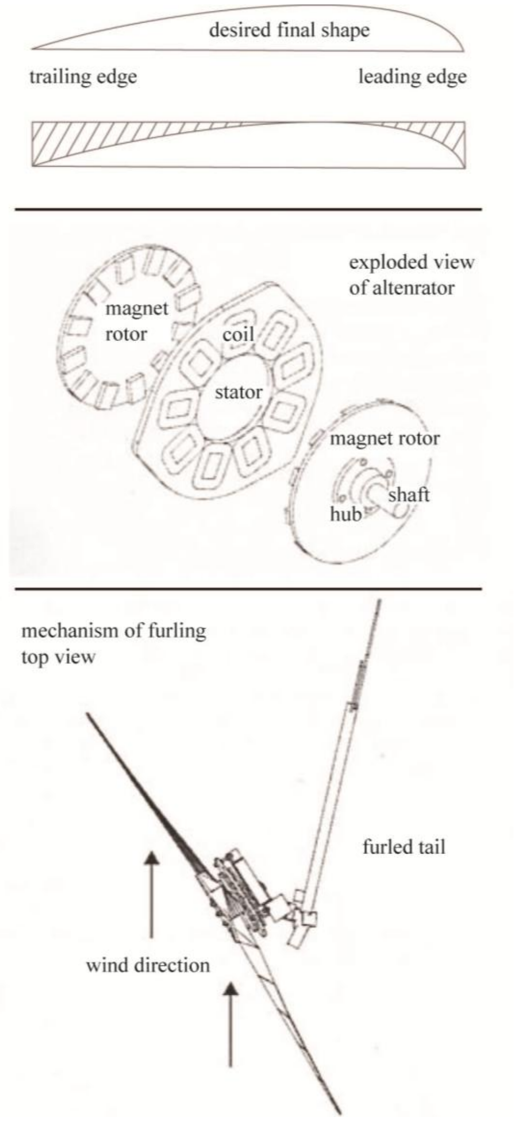


Fig. 4.3.2 Turbine construction. 4.3.2.a. Airfoil shape of the blade 4.3.2.b Components of the alternator 4.3.2.c Furling mechanism. Source: Wind Turbine Recipe Book, Hugh Piggott, 2009.

System operation

System transforms fluctuating wind power into direct current that can be used within the household. Mechanical energy available in the wind is transferred via alternator directly to electrical lines without the usage of a gearbox.

Coils of the stator are connected in three separate groups to distinct output cables, and produce the three phase alternating current as the rotating magnets pass by them (*Piggott 2009*). These groups produce the same voltage that is shifted in time due to their relative position to each other as well as the magnetic poles. Current than passes down the monopole tower through the main break switch, which can be used in case of an emergency or during maintenance works in order to safely disconnect the turbine.

Another safety feature, placed within the system before the current is filtered, is the Trip Relay. It can be used to diverse some of the load to the 1kW Dump Load, whenever voltage increases above the value set on the trimmer.

Three cables carrying the 3 phase, variable alternating current connect to terminals on the rectifier. There, the AC is filtered and rectified to a desired, 48V direct current that can be utilized in the final load. Current from rectifier passes through electricity meters and connects to two control units, as illustrated in figure 4.3.3.

The task of two LDR 48-30 controllers, which are switched on and off by the Arduino Control System, is to regulate the load exerted on the turbine, protecting the entire system.

System is not connected to the grid and does not have any battery storage. This means that any energy produced by the turbine has to be used immediately by the household and cannot be sold or deposited for later. Under such circumstances the application of power produced by the turbine has to be well thought through. In this case, the owner decided to use the energy for water heating. Once heated, water remains within the usable temperature range for a period of time therefore can be stored for later use. Two 1kW immersion heaters, a hot water tank and an under floor heating buffer tank, are connected to separate control units and both run on a 48 voltage direct current.

Information in this chapter was acquired from choughs.net website supplied by Francis Greaves.

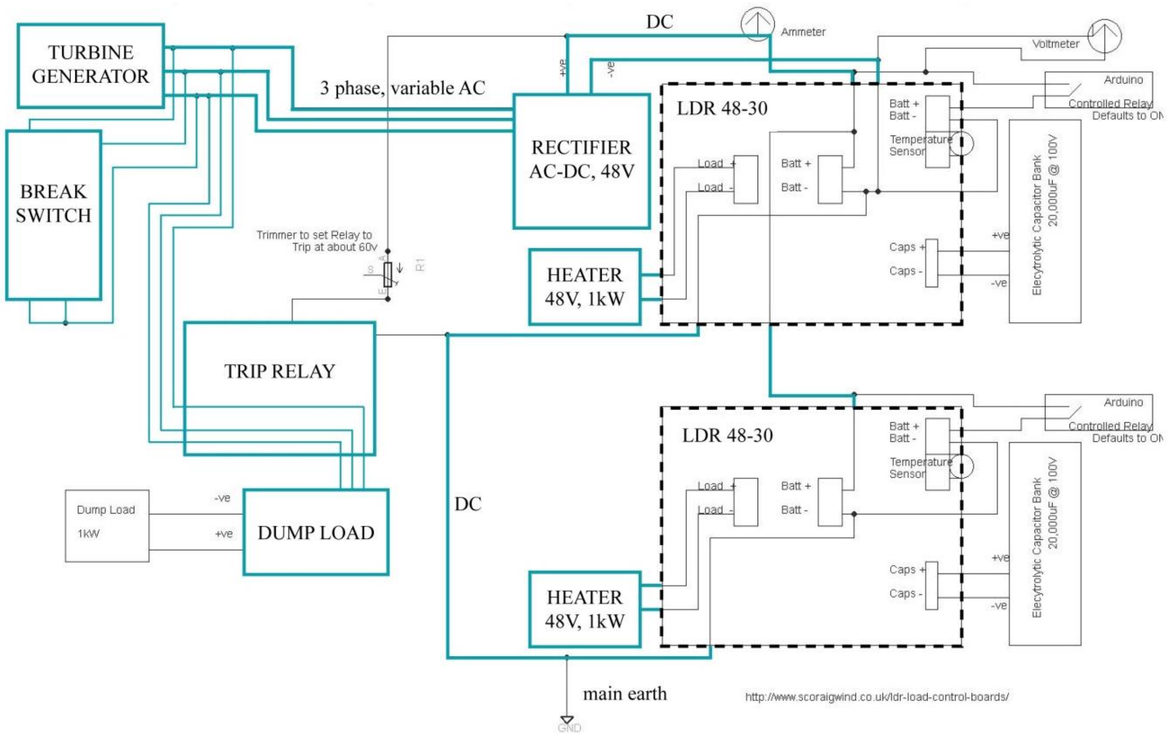


Fig. 4.3.3. Electrical connections between system’s components. Source: www.choughs.net.

Site

Ratooragh is an area in the Mizen Peninsula, far south of Ireland. It is a slightly hilly landscape with rare, scattered dwellings. Turbine is placed near one of the households, approximately 2 kilometres from the shore. The land drops down slightly between the site and water on the south west side. Prevailing winds come from south west in this area and they reach the blades without any obstruction. The household supplied by the wind system is situated 15 meters away from the turbine in natural dip. The hub reaches high above the rooftop.

There are no other obstructions within a significant distance. The land starts rising again on the north-east side, what may modify rare wind coming from that side.

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Fig. 4.3.3. Ratooragh, looking south-west.

Fig. 4.3.3 Ratooragh, looking north.

Fig. 4.3.3. Ratooragh, site plan

4.4. Power predictions

In order to recognize whether or not a particular site is suitable for wind energy harvesting, the future owner needs an estimation of probable energy output. Identifying a wind pattern, as investigated in the previous chapter, is the first step in order to do so. Wind data, in combination with some details of a wind system, allows predicting the average power output specific to the area. This helps to determine whether wind harvesting can bring a significant profit, and if so, which system would be most appropriate. Predictions of the output can be based either on turbine specific information, which is provided by the producer, or on more general power calculations. Both of these methods are investigated in this chapter.

Wind power equation

A probable outcome of a wind harvesting system can be predicted from the standard wind power equation. This equation is independent of a particular turbine design and therefore can be used before a specific producer is chosen. Calculation of the power available in wind is based on the airstream condition as well as basic turbine geometry. The equation uses wind speed value to the third power therefore this variable is by far the biggest determinant of the result. It can incorporate the average wind speed value and yield an estimated average power output (W) however due to a fluctuating nature of this energy source more detailed information on wind behaviour gives more comprehensive calculations. It allows obtaining the results in form of the power output range as well as the total production for a defined period of time.

Power available in the wind is estimated using the formula below *(RWE Npower 2010)*:

$P_w = 0,5 \times A \times g \times V^3$, where

P_w- power available in the wind (W)

g- air density (kg/m$^{3)}$; at the sea level this equals approximately 1,22 kg/m^3

V- wind speed (m/s)

A- swept area (m^2), calculated from the surface area formula:

$A = \pi \times R^2$, where

R- rotor radius (m)

Calculated wind power is the basis for estimating how much usable energy can be effectively extracted from the system. This result is based on the efficiency of the whole system, which is restricted by Betz's upper limit to 59,3%. This limit is consequential of wind's behaviour, which after passing through the turbine has to retain certain speed in order to continue the flow. If all of the energy from the wind was extracted, the zero energy on the downwind side of the turbine would cause a blockage and the airstream could not pass through. The Betz limit is based on conservation of mass and momentum of the air flow, and is independent of turbine design (result was based on an idealized actuator disc). Efficiency of every turbine varies slightly depending on the wind speed, with most micro scale systems oscillating between 25 and 40%. This value should be provided by the producer; for Bergey Excel 10 it ranges between 11%-30% with wind speeds between 2,5m/s and 9m/s being 27% on average). When turbine's efficiency is known, the power extracted from the wind can be calculated as follows:

$P_e = P_w \times Cp \times Ng$, where

P_e- power extracted (W)

Ng- alternator efficiency; for small magnet alternators it equals approximately 92%

Cp- turbine efficiency; restricted by Betz limit

For the purpose of this study the complete power output equation, quoted below, is used for each turbine first of all in order to predict the probable power yield (kW) in relation to the usable wind speed range (up to 15m/s).

$P_e = 0,5 \times A \times g \times V^3 \times Cp \times Ng / 1000$

P_e- power extracted (kW)

Due to similar air conditions on both sites as well as identical wind speed range used for calculations, the dissimilarity in sizes of swept areas will account for most of the difference in the two acquired data sets. Bergey Excel 10 coefficient of performance values were used, as provided by the Bergey Windpower 2011, varying for each 0,5m/s difference in wind speed (detailed values were listed in Appendix A.4). Lack of standardized tests performed on the Ratooragh turbine limits the accuracy of this coefficient to average values obtained for similar micro scale turbines. For this exercise the value of 25% was selected.

An exemplary calculation for Bergey Excel 10 design, using its rotor diameter of 7 meters and wind speed of 4m/s, yields the value of 0,35kW as demonstrated below:

$P_e = 0,5 \times 38m^2 \times 1,22kg/m^3 \times (4m/s)^3 \times 0,92 \times 0,26 / 1000$

$P_e = 0,35$ kW

Similarly, for Hugh Piggott's 3 meter rotor diameter and wind speed of 4m/s, using the standard coefficient of performance, the same formula will yield only 0,06kW:

$$P_e = 0{,}5\times7\text{m}^2\times1{,}22\text{kg/m}^3\times(4\text{m/s})^3\times0{,}92\times0{,}25/\ 1000$$
$$P_e = 0{,}06\ \text{kW}$$

Power equation was used to complete power curves of both turbines, presenting predicted output as a function of wind speed availability, shown in figure 4.4.1. These calculated predictions are also used in the following Results section in order to compare with power measurements.

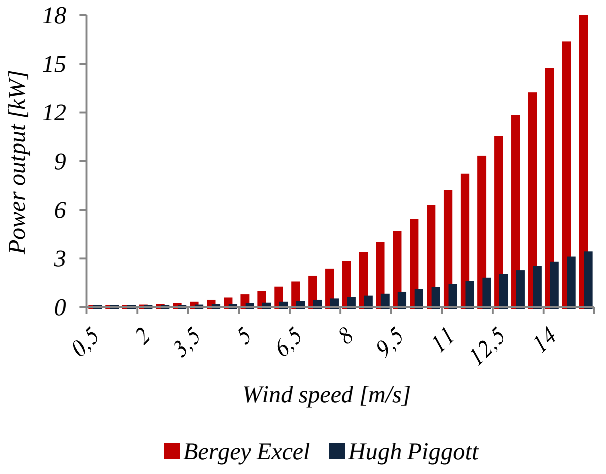

Fig. 4.4.1. Power output in relation to wind speed; Bergey Excel and Hugh Piggott design. Calculations based on the wind energy harvesting equation. Source: Ajdesigner.com

Producer's power curve

Every manufactured turbine design undergoes standardized performance tests in order to establish its power curve. This power curve identifies the most probable power output values in relation to wind speed measures. Such information gives a good understanding of turbine's efficiency as well as the most desired wind conditions needed for its optimal performance.

Field tests for Bergey Excel 10 were conducted in Bushland, Texas, on a 30 meter high tower where air density equals 1,225 kg/m^3. Results became a foundation to calculate turbines efficiency factor and obtain its power against the wind speed distribution pattern. This distribution is illustrated in figure 4.4.2. Turbine's efficiency factor stays between 20%-30% for wind speeds ranging from 3,5m/s to 13m/s and drops down significantly for wind speeds below and above those values.

Appendix A.4, based on information included in Bergey Excel Owner's Manual (Bergey Windpower 2011), includes values used in the power curve diagram placed below. The dashed line marks results calculated and discussed in the previous section.

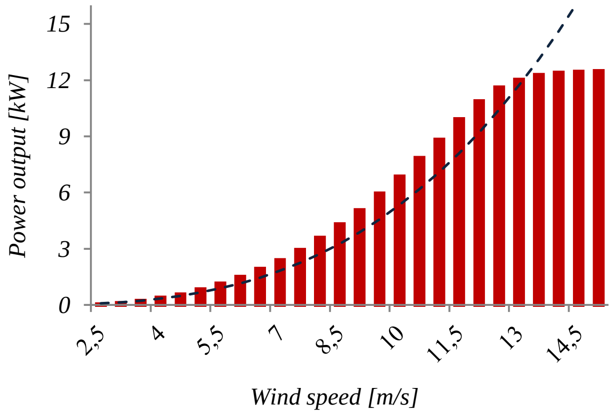

Fig. 4.4.2. Power curve, Bergey Excel 10. Source: Bergey Excel 10 Owner' Manual, Bergey Windpower, 2011

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4.5. Measurements

UCC, Excel Bergey 10

Aurora Inverter provides real time operational data, which is displayed on the interface box, as well as internally stored data, which can be retrieved by a PC. Real time operational data is displayed on the LCD screen and cycled through under normal operation. It provides information on the grid, generator (voltage, currency, frequency) and energy transmission.

Internally logged data is received from the rectifier, which connects to the inverter via an RS485 line. Two signal wires and one grounding cable feed to a RS485/RS232 converter which allows readings to be transported directly to a PC where WindBox software is installed (*APRS World LLC 2011*). Software, provided by the Aurora Company, is capable of reading and storing data from the inverter in form of energy transferred to the grid in 10 second interval. This data is further available via Ethernet to internet based monitoring software (*ResourceKraft.com 2012*).

ResourceKraft is a data storing website, which allows registered users to access data that belongs to a particular institution. For the purpose of this study a 15 minute interval was selected and energy readings were set kilowatt-hours.

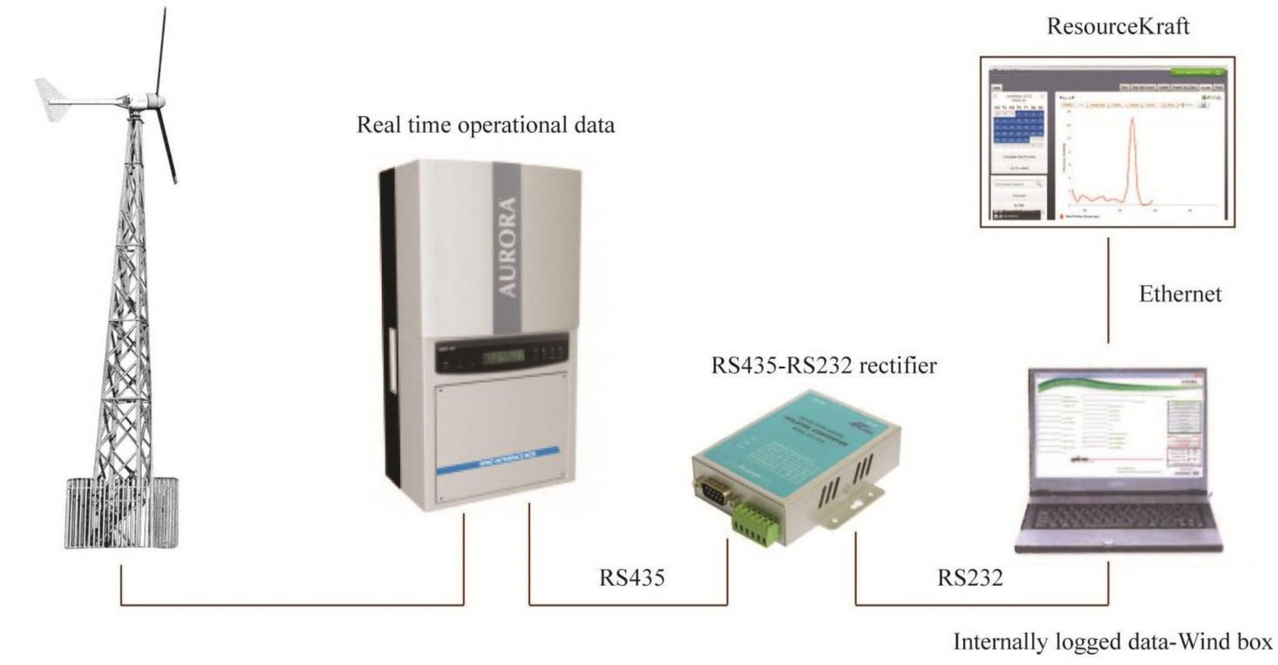

Fig. 4.5.1. Power data transmission.

Ratooragh, Hugh Piggott design

Power data from the wind turbine is recorded by the owner along with information on weather conditions from his private weather station. Monitoring system is based on the Arduino Mega which at the same time allows controlling system's output (fig.4.5.3).

Sensor circuits consist of measuring the frequency of alternating current (from which rotations per minute can be calculated) as well as Amps and Volts going into the controller and both immersion heaters. From this the support program in Java calculates and graphs power that is displayed on the home computer. This data is then uploaded to a private website every few minutes (*Choughs.net 2013*).

Power produced by the system is a sum of power calculated for both immersion heaters. It is unified to a 15 minute interval and recorded in kilowatt-hours. Wind speed measurements are integrated to the same 15 minute interval and documented in meters per second.

Information in this chapter was acquired from choughs.net website supplied by Francis Greaves.

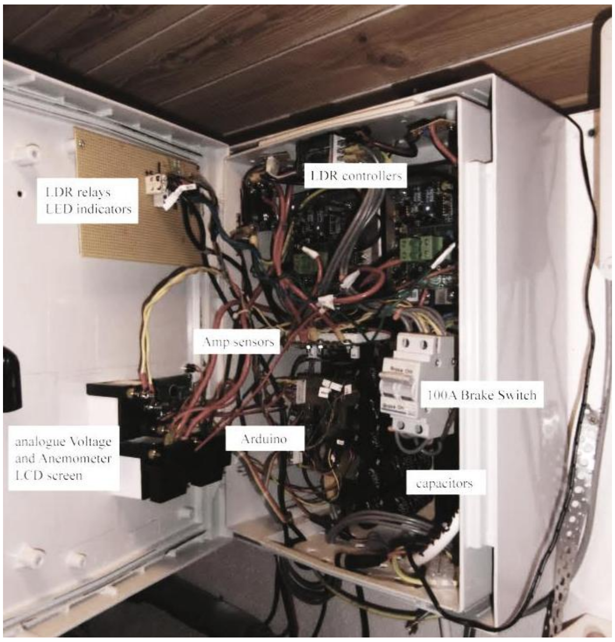

Fig. 4.5.3. Control board.

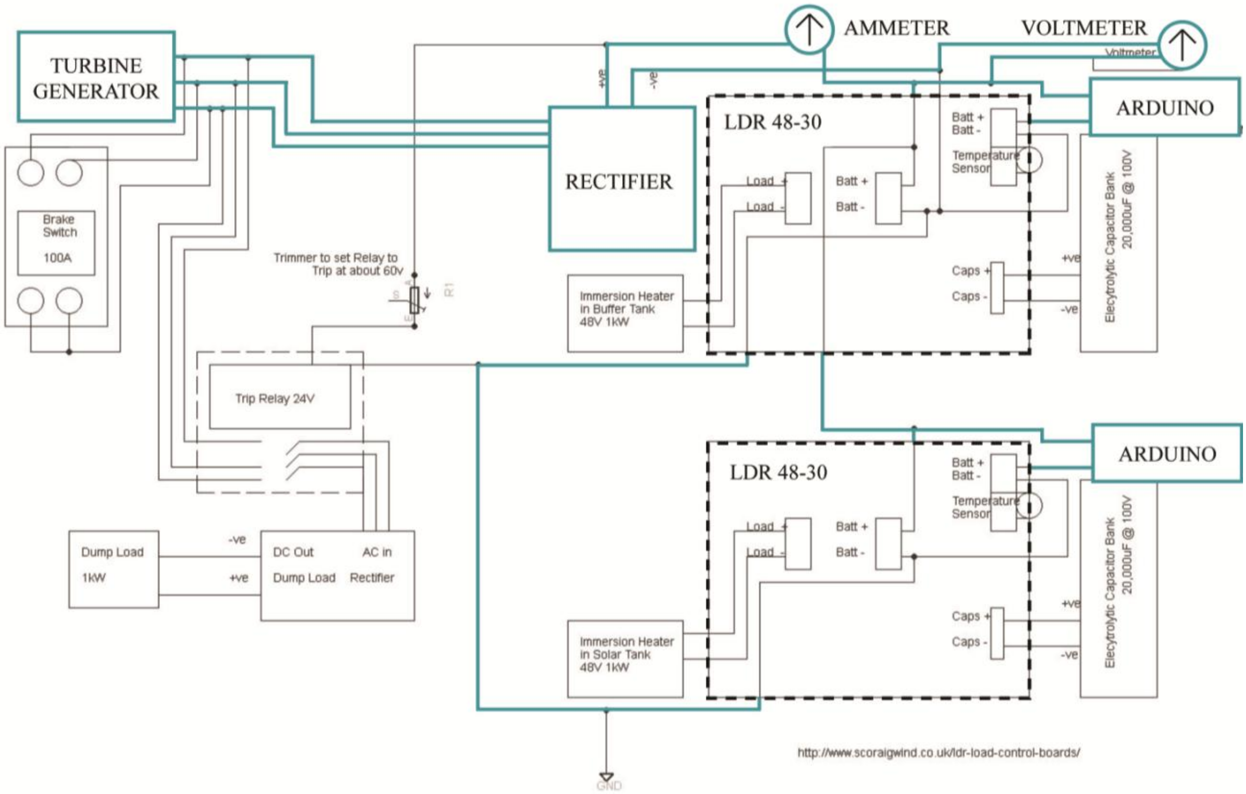

Fig. 4.5.2. Power data transmission. Source: www.choughs.net.

4.6. Results

Results are divided into two main sections, first one representing differences between two discussed systems and the second one concentrating on the assessment of the prediction methods. Calculations and results from chapter ***4.4. Power predictions*** are juxtaposed and analysed in relation to data measured on both sites.

4.6.1. Comparison of Technologies

The two systems looked into in this thesis display significant dissimilarities which affect their production and profits for the owner. In order to analyse results presented in this chapter these differences have to be borne in mind. The most important of those characteristics are reminded in table 4.6 below.

Table 4.6. Project characteristics for Bergey Excel and Hugh Piggott.

	Bergey Excel	**Hugh Piggott**
Mean wind speed	1,2 m/s	9,5 m/s
Standard deviation	1,5 m/s	4,3 m/s
Weibull shape	1	2,57
Rotor diameter	7m	3m
Swept area	38 m^2	7 m^2
Height	15m	15m
Site type	dense urban	countryside
Cost	€50.000	€5.000

Performance

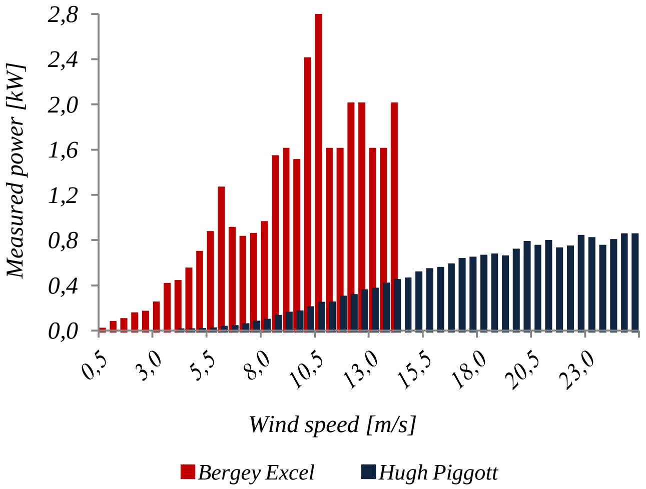

Fig. 4.6.1. Measured power plotted against measured wind speeds; Bergey Excel and Hugh Piggott.

Figure 4.6.1 illustrates the measured power output (kW) plotted against measured wind speeds for Bergey Excel 10 and Hugh Piggott design. The range of recorded wind speeds was much greater on Ratooragh site; hence the visible gap on the diagram. A less uniform curve in the power output of Bergey Excel 10 may be due to smaller amount of non-zero values recorded for this turbine in comparison with Hugh Piggott. Due to persistently low wind speeds at UCC, turbine was running approximately 4,5 times less than the one in Ratooragh, which continued production 77,5% of a time.

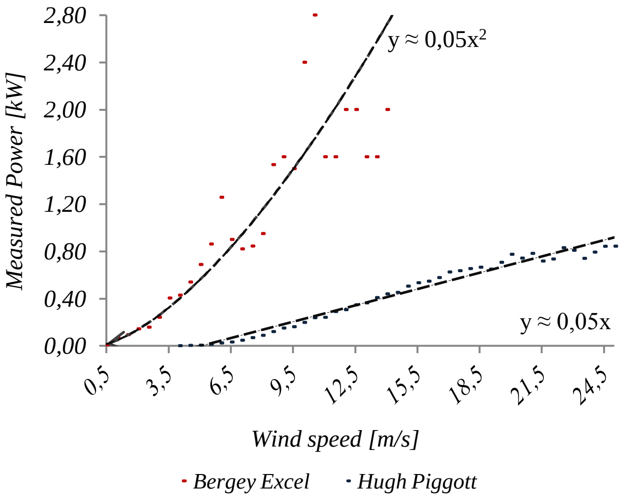

Fig. 4.6.2. Trend lines for measured power (kW) plotted against wind speeds; Bergey Excel and Hugh Piggott.

The gap between both sets is clearly visible. Trend lines in figure 4.6.2. are an approximated function of the results. While Bergey Excel turbine yields an exponential growth ($y\approx 0{,}02x^2$), Hugh Piggott is closer to a linear one with trend line function of $y\approx 0{,}02x$. The production of that second turbine does not reach 500 Watt up until comparably high wind speeds of 15m/s. This value represents the furling speed for Bergey Excel, which reaches the same production of 500 Watts already at speeds of 4,5 m/s.

On average the production from Bergey Excel for the usable wind speeds between 11m/s and 14m/s is 5 times greater than that from the other turbine; this value is closer to 10 times for the lower speeds of 7m/s - 11m/s. In order to fully evaluate this difference, however, these values have to be juxtaposed with dissimilarities in characteristics of two turbines, mainly the size of their swept area. This value, which has a great effect on the output, is more than 5 times greater for the University Campus turbine (table 4.6).

Recorded data gives a good understanding of relationship between the available wind speed and power production for each system. As established in chapter ***4.4. Power predictions***, the wind speed along with turbine geometry are the main factors affecting power available for extraction. The actual power produced from the system, however, is affected by one more important variable, the coefficient of performance. As noted before, Cp values were provided by Bergey Windpower based on exhaustive tests in idealized conditions, while Hugh Piggott design has never had an opportunity to undergo similar tests. Recorded power data, however, allows for calculation of the Cp value for both turbines under their specific conditions. This can be achieved by using a modified version of previously used formula:

$$P_e=0{,}5\times A\times g\times V^3\times Cp\times Ng \quad \Big| /0{,}5\times A\times g\times V^3\times Ng$$

Therefore:

$$Cp= P_e/0{,}5\times A\times g\times V^3\times Ng$$

Calculations using this equation were performed for both turbines and for wind speeds ranges recorded on each site (starting from 2,5 m/s). An exemplary calculation for Bergey Excel 10 and wind speed of 6m/s, for which the average power detected by the equipment was equal to 1,26kW, is presented below:

$$Cp= 1257/0{,}5\times 38\times 1{,}22\times 6^3\times 0{,}92$$
$$Cp= 0{,}273$$

In this case the coefficient of performance equals 27,3%. At the same wind speed, the same formula yields only 2,85% for the Hugh Piggott design:

$$Cp= 24/0{,}5\times 7\times 1{,}22\times 6^3\times 0{,}92$$
$$Cp= 0{,}0285$$

Results are presented in the diagram in figure 4.6.3. Values for lower wind speeds are significantly higher for the UCC turbine however around the wind speeds of 11m/s they become almost identical.

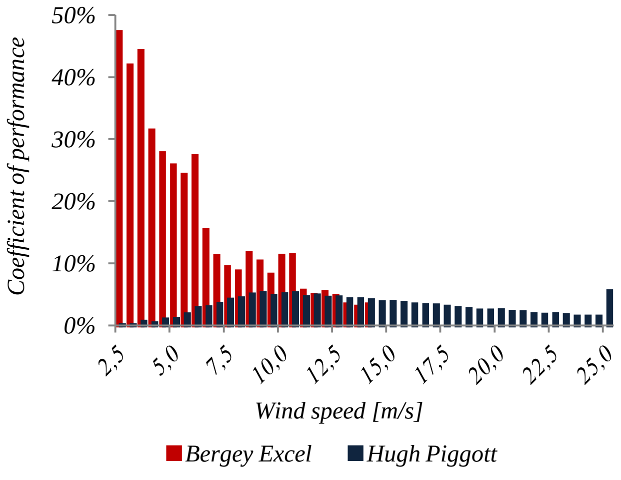

Fig. 4.6.3. Coefficient of performance for the full observed wind speed range; Bergey Excel and Hugh Piggott.

Energy production

Table 4.6. a. Daily energy production; Bergey Excel and Hugh Piggott [kWh].

Date	Bergey Excel	Hugh Piggott
2012-11-01	2,30	4,39
2012-11-02	0,50	0,07
2012-11-03	1,40	11,30
2012-11-04	1,10	9,52
2012-11-05	0,60	3,35
2012-11-06	1,00	5,52
2012-11-07	1,30	5,15
2012-11-08	0,60	2,07
2012-11-09	0,90	5,43
2012-11-10	0,70	6,26
2012-11-11	0,30	2,67
2012-11-12	2,80	10,27
2012-11-13	13,00	11,09
2012-11-14	2,40	4,90
2012-11-15	0,00	0,00
2012-11-16	0,00	0,12
2012-11-17	0,70	1,66
2012-11-18	11,80	9,80
2012-11-19	18,60	10,48
2012-11-20	11,10	7,05
2012-11-21	10,80	7,94
2012-11-22	10,90	11,93
2012-11-23	0,40	1,56
2012-11-24	0,20	1,00
2012-11-25	2,90	4,09
2012-11-26	2,50	9,85
2012-11-27	2,10	10,59
2012-11-28	0,20	2,35
2012-11-29	0,00	0,06
2012-11-30	0,00	3,01
Total [kWh]	**101,10**	**165,76**

WIND STUDY has shown huge differences in wind availability at UCC campus and Ratooragh sites (the average values are reminded in Table 4.6). At the same time the ***Performance*** section revealed that coefficient of performance for the two turbines displays significant dissimilarities, especially for lower wind speeds. These two effects seem to equal each other out causing quite similar overall energy production by both systems. Table 4.6.a summarizes daily energy production for the full month of November, with total energy production yielding 101,1kWh for Bergey Excel 10 and 165,76kWh for Hugh Piggott design (summed up at the bottom of the table).

Correlation factor

Since the most important issue related to wind harvesting is its unstable nature, an understanding of fluctuations in power output as well as system's ability to respond to wind speed changes are crucial for evaluation of system's performance. Big, unpredictable jumps in power production can rarely be utilized, while even very high wind speeds, if present only for a brief time, may not trigger turbine's response. Often, when a brief raise in wind speed is recorded there is no correlated raise in the power output. In general, smaller hubs react quicker to wind speed changes thanks to their lower weight, meaning higher sensitivity to wind fluctuations. Relationship between wind speed and power output symbolizes system's responsiveness to wind conditions and can be calculated using the correlation factor formula:

$$\mathrm{Correl}\,(x,y) = \sum (x-\dot{x})\,(y-\dot{y})/\sqrt{\sum(x-\dot{x})^2\,\sum(y-\dot{y})^2}$$

$\dot{x}$, $\dot{y}$ - variables, in this case wind speed and power
x , y - average values of the set of variables

Correlation factor for the full set of data for Bergey Excel yields the value of 65% while for Hugh Piggott this result is much higher and reaches almost 93%. This means that correlation between power output and wind speed is very high for the Ratooragh system and almost all of the turbine readings are simultaneous with changes in wind speed.

Fluctuations

Table 4.6. b. Mean production of Bergey Excel and Hugh Piggott.

	Bergey Excel	Hugh Piggott
Average production	0,1kW	4,2kW
Standard deviation	0,4kW	2,5kW

Despite similarities in total energy production over the course of full month, power measurements of two systems display very different behaviour. Average power generation in relation to its standard deviation is a good indicator of output's stability. Standard deviation is relatively small when most values remain close to the mean, indicating a stable power source. Table 4.6.b. shows that standard deviation of UCC system's output is 4 times bigger than its average value. This indicates huge fluctuations in comparison to Hugh Piggott design, where standard deviation equals nearly half of its average production. Figure 4.6.4. shows how often do certain power output values occur as a fraction of all measured data, revealing big dissimilarities of both systems. Bergey Excel remains in stall 80 % of a time while 4% of its production exceeds 1000 Watt. On the other hand 77,4 % of Hugh Piggott turbine power remains between a few and 1000 Watts. It appears that the Ratooragh turbine production is evenly distributed at average levels, while Bergey Excel has a few moments of high production that make up for long hours in stall.

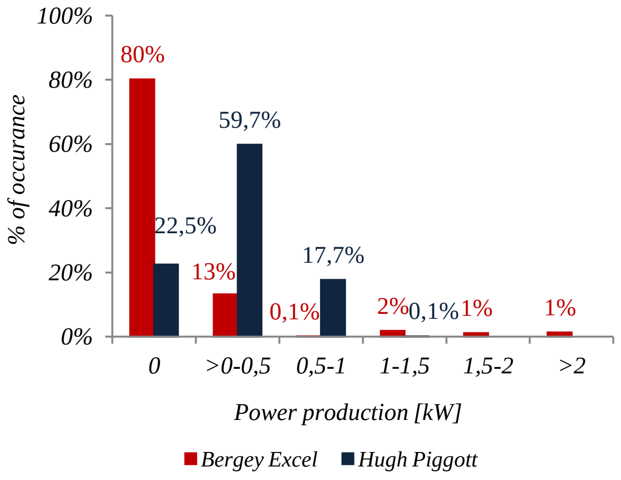

Fig. 4.6.4. Frequency of power output values.

These dissimilarities can be viewed in more detail in Appendix A.5 where power data for the full month was included.

4.6.2. Evaluation of prediction methods

Results from two prediction methods introduced in chapter 4.4 were put side by side with measured values in order to investigate their efficiency.

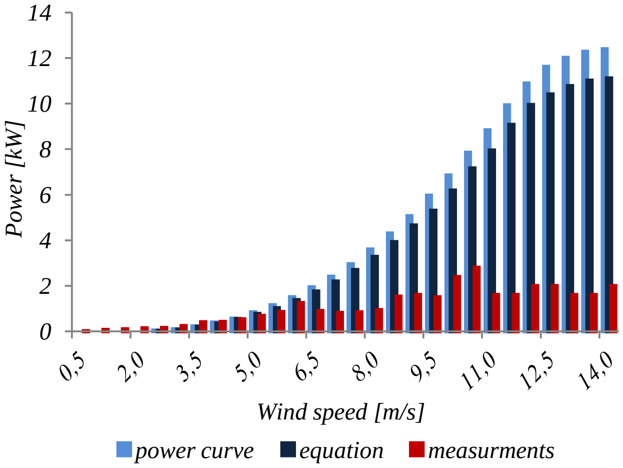

Fig. 4.6.5. Comparison of prediction methods and measured data; Bergey Excel 10.

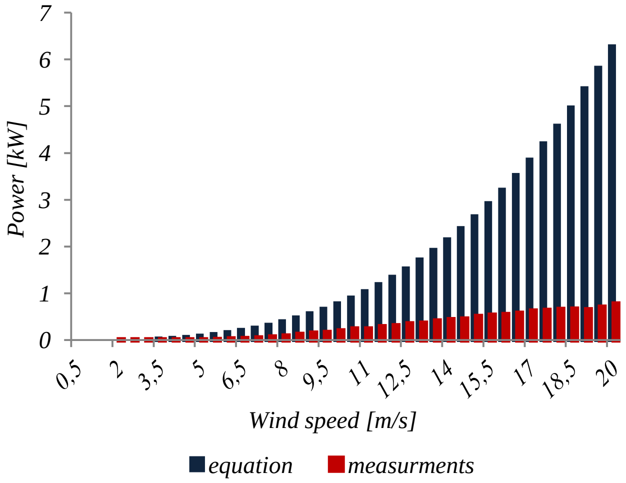

Fig. 4.6.6. Comparison of prediction methods and measured data; Hugh Piggott design.

Figures 4.6.5 and 4.6.6 display results for Bergey Excel and Hugh Piggott respectively. Interestingly, both prediction methods, the equation and power curve, yield a very similar result (fig. 4.6.5) despite differing vastly from the actual data. The expected output seems to be higher than the real one in each case, with more staggering difference for the Hugh Piggott system. This might be due to high coefficient of performance value used for calculations, which appears to be much lower than the proposed one. The difference between producer’s Cp, which seems to be overestimated especially for higher wind speeds, and the Cp calculated from measured data for Bergey Excel is shown in figure 4.6.7.

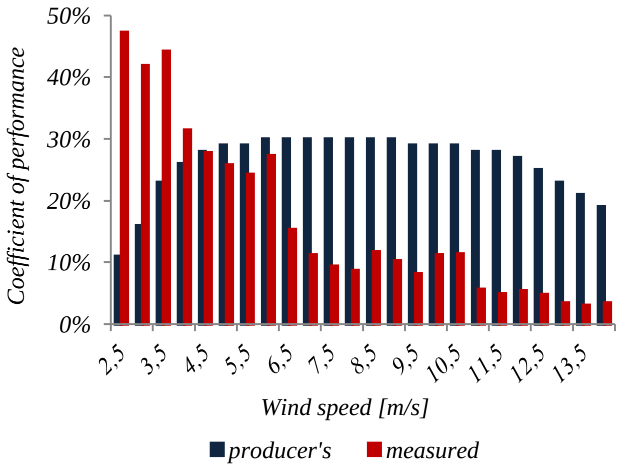

Fig. 4.6.7. Comparison of the coefficient of performance values; Bergey Excel.

Estimation of power dependence on wind speed availability in addition to wind measurements allow to calculate the full energy production for a specific site. Despite significant differences in dependence of power output on wind speed (fig.4.6.5.-4.6.6.), total energy expectations for the full month using both prediction methods are surprisingly comparable to the actual data for the Bergey Excel turbine. This derives from the fact that for wind speeds below 4m/s, the actual output is slightly higher than the predicted one. These wind speeds occur most often on the UCC site, equalling out the overestimation for high wind speeds.

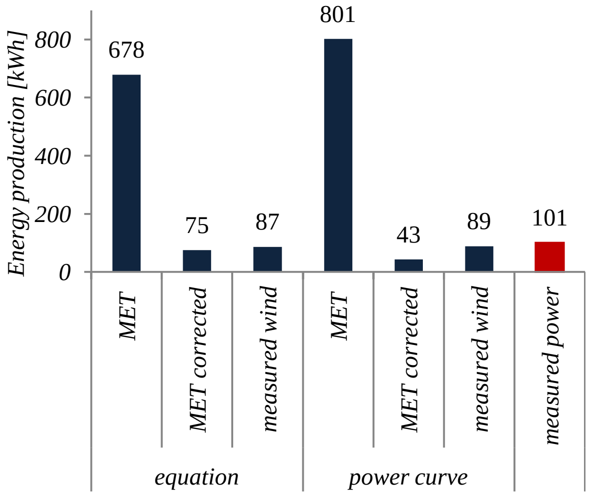

Fig. 4.6.8. Summary of prediction methods for Bergey Excel. Energy production calculated using various data inputs put side by side with the real data (highlighted).

Figure 4.6.8. summarizes those results, at the same time indicating what happens when wind data from weather stations (introduced in WIND STUDY) is used for the forecasts instead (the average wind data for November is reminded in table 4.6.c. at the end of this

section). The gap is substantial, yielding results up to almost 8 times bigger than the actual output. Corrections help to bring those results closer, although in this case the prediction is lower than measured output.

Situation differs significantly for the Hugh Piggott turbine, where measured wind is much higher than the weather station data. High coefficient of performance makes predicted output much higher than the actual one, while low MET wind speeds cause the results to be closer to real output (figure 4.6.9).

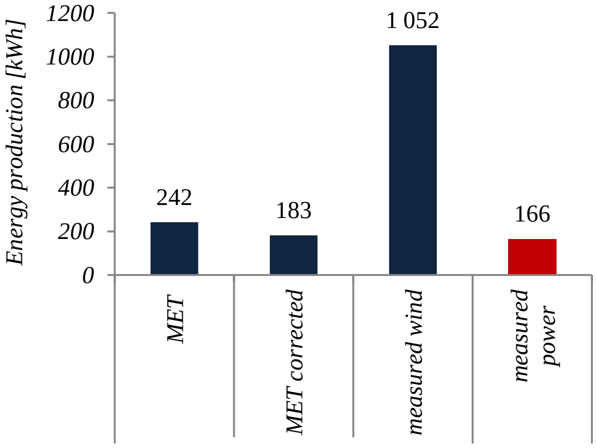

Fig. 4.6.9. Summary of prediction methods; Hugh Piggott. Energy production calculated using various data inputs put side by side with real data (highlighted).

Table 4.6.c. summarizes these findings, at the same time showing how important is not only accuracy, but also the level of detail in acquired information. Total energy output, which was initially calculated from the most detailed data that was available (15 min interval for measured records and daily MET inputs) was also performed on averaged wind speed values. Difference in estimations is dramatic, especially where average data does not reach the required 2,5 m/s (Bergey Excel).

Interestingly, in Bergey Excel calculations, MET corrected data is twice as big as the measured one, however detailed wind speeds cause the power calculations to yield opposite results. Very high average wind speeds for Ratooragh area visibly cause huge overestimation of the result.

Table 4.6.c. Prediction results for various input sources; Bergey Excel and Hugh Piggott.

		Bergey Excel			**Hugh Piggott**		
Method	**Wind source**	**Average wind speed[m/s]**	**Power [kWh] (averaged data)**	**Power [kWh] (detailed data)**	**Average wind speed[m/s]**	**Power [kWh] (averaged data)**	**Power [kWh] (detailed data)**
Equation	**MET**	4,96	466,8	678,4	6,6	810,7	242,3
	MET corr.	2,4	52,9	75,0	6,0	610,9	182,6
	Measured	1,2	6,6	86,8	9,5	2396,6	1052,1
Power curve	**MET**	4,96	610,6	801,3	-	-	-
	MET corr.	2,4	0	42,9	-	-	-
	Measured	1,2	0	88,7	-	-	-
Measured data		**101,1**			**165,76**		

4.6.3. Further predictions

The purpose of WIND STUDY was to analyse wind conditions in various urban landscapes, in order to understand wind availability in urban environment at the same time identifying best sites for wind harvesting in the area. As the ***3.5. Results*** chapter revealed, the most abundant winds are at the Blackrock Castle Observatory. This site was therefore chosen for further investigation.

Establishing power dependence on wind speed (resulting in Cp estimation) allows using wind speeds measured near BCO to predict probable power output of both studied turbines if they were placed on that site. Wind speed data was used in the same form as in the WIND STUDY, with 30 minute interval, for the full month of November. Calculated power production was then summarized on daily basis to obtain energy yield for that whole period (table 4.7.d.). That gave a staggering difference in output for Bergey Excel turbine, for which the estimated energy production is nearly 5 times higher under BCO conditions. Comparing with obtained 100 kWh, the estimated output of nearly 500 kWh is a significant power gain that could be utilized in the building. Hugh Piggott, on the other hand, performed worse than under Ratooragh conditions due to overall lower wind speeds at BCO during this particular month (the full wind data gives the opposite result).

In order to understand the relevance of measured power production as well as predictions from this section, all obtained results will be compared with power consumption from the university building introduced in the following part, BUILDING DEMANDS.

Table 4.6.d. Prediction results for Bergey Excel and Hugh Piggott.

Date	Bergey Excel	Hugh Piggott
2012-11-01	24,43	10,19
2012-11-02	21,02	4,76
2012-11-03	26,87	3,96
2012-11-04	9,54	8,46
2012-11-05	30,21	8,21
2012-11-06	21,76	7,43
2012-11-07	18,16	5,31
2012-11-08	24,45	3,20
2012-11-09	21,21	3,07
2012-11-10	14,25	7,28
2012-11-11	18,48	3,60
2012-11-12	9,46	1,28
2012-11-13	16,88	2,31
2012-11-14	7,59	0,13
2012-11-15	0,65	0,00
2012-11-16	9,24	0,47
2012-11-17	17,37	2,73
2012-11-18	16,86	2,82
2012-11-19	33,54	5,96
2012-11-20	16,48	7,01
2012-11-21	22,01	2,90
2012-11-22	24,21	6,90
2012-11-23	7,23	1,16
2012-11-24	13,67	1,89
2012-11-25	6,93	4,07
2012-11-26	1,80	15,71
2012-11-27	11,40	14,17
2012-11-28	29,38	3,37
2012-11-29	6,61	0,53
2012-11-30	10,47	0,87
Total [kWh]	**492,16**	**139,77**

5. BUILDING DEMANDS STUDY

The purpose of wind harvesting is to provide usable power to the grid, or, like in the case presented in this study, straightforwardly to the dwelling. The aim of studied wind technology is to ensure the highest possible coverage of building's demands, at the same time keeping the overproduction to minimum. In order to evaluate efficiency of a wind system it is essential to understand power consumption on the other end. For this reason, a study of the dwelling supplied by one of previously presented turbines was performed. Factors affecting building's power consumption were identified and their work was monitored to be later compared with turbine's output. Data from other buildings was used for comparison, in order to understand power consumption trends better. This allowed evaluating the actual efficacy of the system and establishing certain patterns which may be useful for future studies.

5.1. Building overview

Bergey Excel 10 was placed in the middle of Northern Campus at University College Cork. It is at the distance of approximately 50 from the building it supplies, called the Cooperage It hosts the School of Biological, Earth and Environmental Sciences and is used mainly by the academic staff and students for research in this field. The Cooperage is a one storey high, converted, listed building, with most of its area devoted to large teaching laboratories. The rest of the space contains offices for academic and technical staff, school workshop, specialist laboratories, marine and freshwater holding facilities, a post-mortem facility (for cetacean and seal studies) as well as cold rooms and storage spaces that make up the total area of 2451 m^2 (figure 5.1.1). Table 5.1 lists all of those rooms along with their floor areas, highlighting the exceptional room types with a star. Those rooms require specific, unusual conditions that are kept at all times and influence power usage of this building significantly.

Table 5.1. List of rooms in the Cooperage building.

Room type	Amount	Area [m^2]
Offices	10	288,7
Reception	1	21,6
Meeting room	1	18
Hub rooms	2	18,7
Teaching labs	4	447
Research labs	14	949,2
Museum	1	61,2
Constant temperature rooms*	3	26
Cold room*	1	6,8
Algae growth room*	1	7,9
Freezer room*	1	46
Microscope rooms*	2	26
Toilets	5	65,85
Boiler room	1	3,6
Switch room	1	9,6
Aid room	1	5,8
Circulation area	2	404,5
Total		**2451**

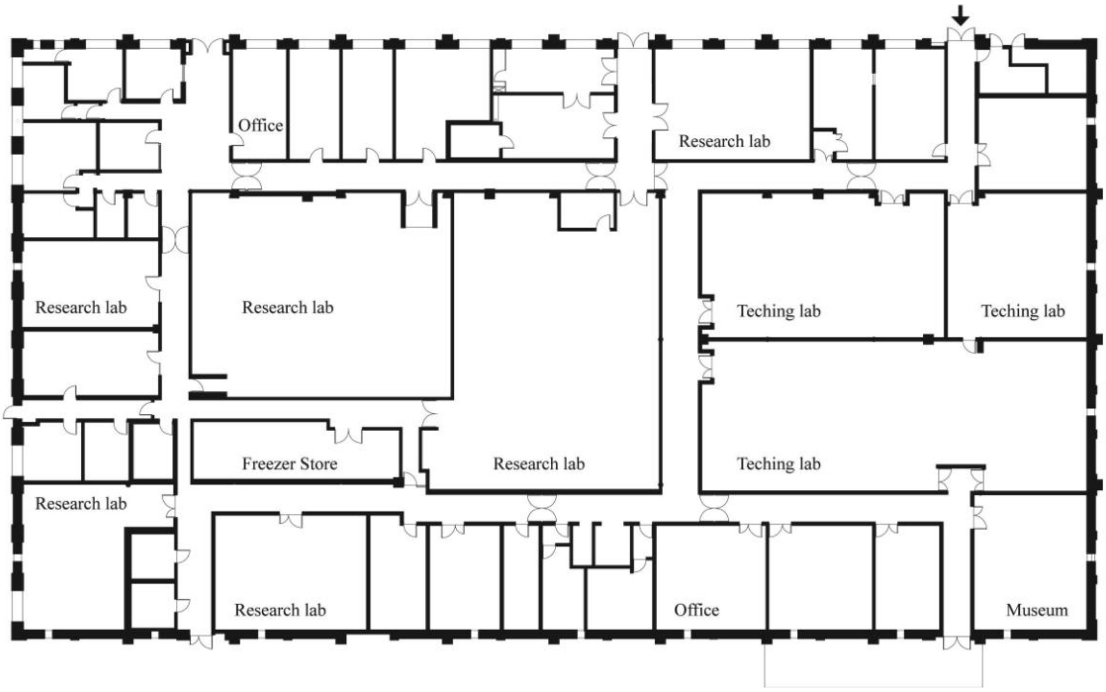

Fig. 5.1.1. Plan of Cooperage building.

5.2. Power usage

Building operates at constant, high energy demands seven days a week to supply 25-30 of its staff members along with up to 90 students at a time. It is used mainly Monday till Friday between 10 am and 6pm, although students and researchers also come during weekend days. Opening times are Monday-Sunday, 8.45 am to 5.45 pm.

Cooperage is an unusual dwelling due to its sophisticated research equipment. Fridges and freezers require constant temperature control affecting the amount of power consumed by the building significantly. They are left running over night, along with other professional equipment, which includes fume hoods and water circulation units. This is causing a much smaller difference between night and day energy consumption than in most other dwellings. This means that the risk of overproduction from a fluctuating source, which usually appears at night when human activity is reduced, is minor.

The most substantial equipment affecting energy usage is listed in table 5.2 below. Mechanical ventilation is switched off at night time; heating runs on gas. There is no automatic lighting control; lights are often left on overnight.

Table 5.2. List of equipment in the Cooperage building.

Equipment type	Amount
Fridges	22
Freezers	17
Water circulation units	5
Temperature control rooms	5
Light control room	1
Walk in freezer	1
Warm room	1
Fume hoods	4
Ventilation units	-
Office equipment	-
Lights	-

Fig. 5.2.1. Laboratory equipment.

Fig. 5.2.2. Water circulation units.

Fig. 5.2.3. Fume hood.

5.3. Measurements

The IO system used for monitoring power demands of the Cooperage building includes two stand-alone modules. Input and Output are connected to a RS485 wire multi drop network which feeds to RS485 to RS232 converter. They communicate using the MODBUS RTU protocol and plug directly onto an industry standard DIN rail. Personal computer in connected to network and retrieves the data via serial port (*Brainchild 2009*).

Voltage, frequency, current and power outputs are recorded in standardized 15 minute interval and documented for the purpose of this study.

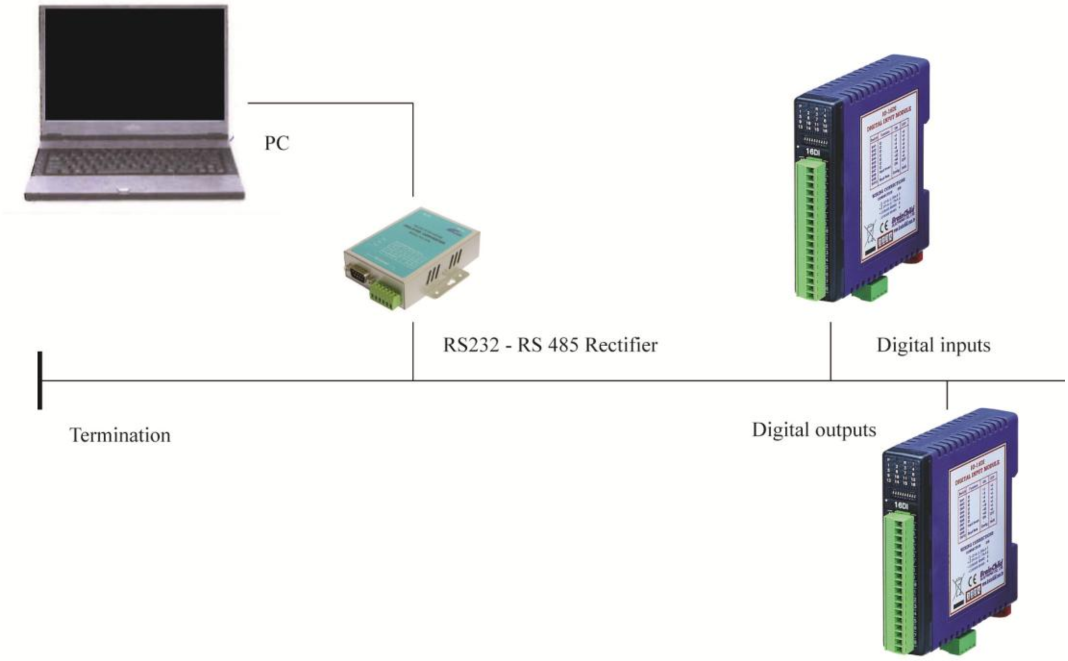

Fig. 5.3.1. Data acquisition diagram. Source: Brainchild 2009

5.4. Results

Data of power consumption obtained from the Cooperage building for the period of two weeks (15th - 30th November) is juxtaposed with power production from Bergey Excel 10 in figure 5.4.1. Diagram reveals expected patterns in the energy demands profile, showing peaks during working hours that are visibly smaller over the weekends. Night-time consumption, represented by dips on the demands line, remains quite high with values ranging between approximately 20 kW and 27 kW. This, as explained in chapter ***5.2. Power usage***, is caused by the unusual equipment, which has to be left running overnight. Consumption during the day ranges from 30 kW at weekends and almost 60 kW during the week, with peaks mostly between 10 am and 7 pm. That sums up to approximately 850 kWh daily on working days, and approximately 650 kWh at weekends.

The power production from wind turbine, included on the diagram, is significantly smaller than measured consumption. Over the full two week period it covered less than 1 % of the 12617 kWh used in total. Results are detailed in table 5.4. for each day and range between 0% and 2,3%.

Table 5.4. Bergey Excel 10 measured output and measured power demands from the Cooperage building.

Date	Building demands[kWh]	Turbine output[kWh]	% covered
2012-11-15	837,22	0,00	0,0%
2012-11-16	792,45	0,00	0,0%
2012-11-17	658,91	0,70	0,1%
2012-11-18	633,07	11,80	1,9%
2012-11-19	792,62	18,60	2,3%
2012-11-20	830,95	11,10	1,3%
2012-11-21	838,50	10,80	1,3%
2012-11-22	867,54	10,90	1,3%
2012-11-23	814,12	0,40	0,0%
2012-11-24	675,14	0,20	0,0%
2012-11-25	636,71	2,90	0,5%
2012-11-26	821,21	2,50	0,3%
2012-11-27	844,80	2,10	0,2%
2012-11-28	864,93	0,20	0,0%
2012-11-29	871,05	0,00	0,0%
2012-11-30	838,73	0,00	0,0%
Total	**12617,94**	**72,20**	**0,6%**

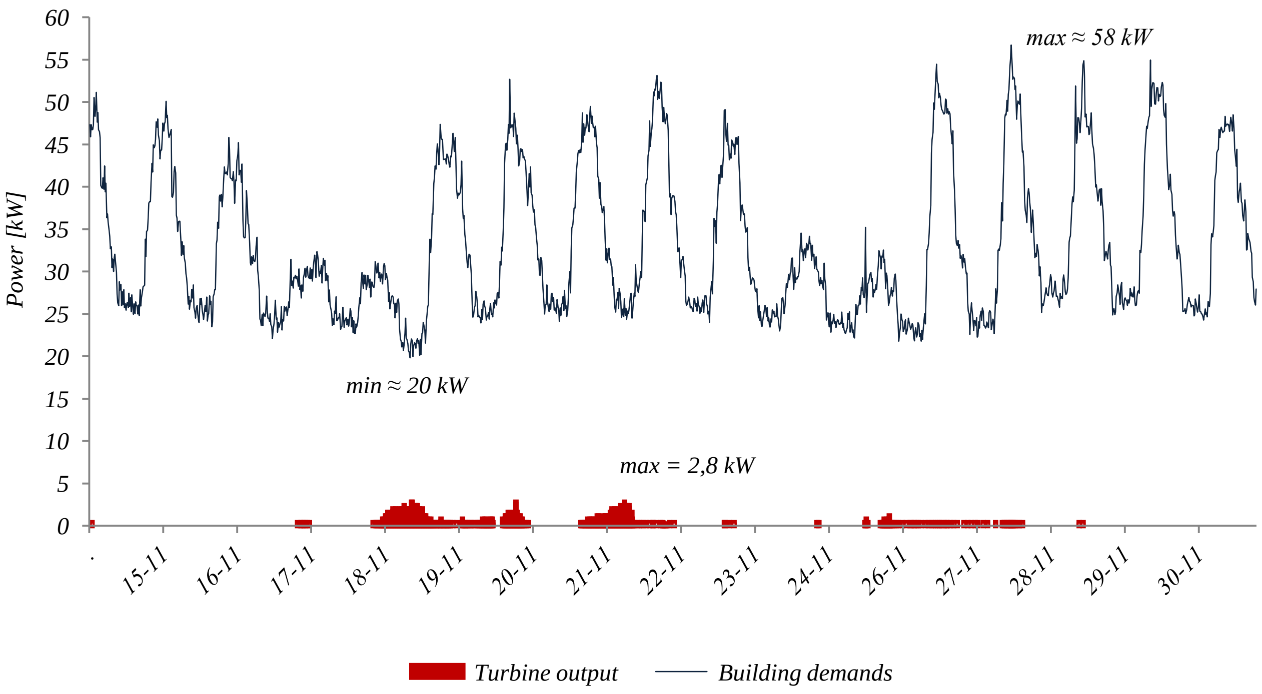

Fig. 5.4.1. Power consumption of the Cooperage building and power production of Bergey Excel 10 wind turbine, 15-30 November.

Further studies

Similar analogy was made for values calculated in ***Further predictions*** section, where estimations for the output of Bergey Excel 10 on the BCO site were performed. In this case, predicted turbine output covers 4% of building's total demands, ranging from 0,1% to 4,2% (table 5.4.a.)

Table 5.4.a. Predicted turbine output for Bergey Excel 10 at BCO site and measured power demands from the Cooperage building.

Date	Building demands[kWh]	Turbine output[kWh]	% covered
2012-11-15	837,22	0,65	0,1%
2012-11-16	792,45	9,24	1,2%
2012-11-17	658,91	17,37	2,6%
2012-11-18	633,07	16,86	2,7%
2012-11-19	792,62	33,54	4,2%
2012-11-20	830,95	16,48	2,0%
2012-11-21	838,50	22,01	2,6%
2012-11-22	867,54	24,21	2,8%
2012-11-23	814,12	7,23	0,9%
2012-11-24	675,14	13,67	2,0%
2012-11-25	636,71	6,93	1,1%
2012-11-26	821,21	1,80	0,2%
2012-11-27	844,80	11,40	1,3%
2012-11-28	864,93	29,38	3,4%
2012-11-29	871,05	6,61	0,8%
2012-11-30	838,73	10,47	1,2%
Total	**12617,94**	**492,16**	3,9%

Due to specific nature of the Cooperage building and its constant, high demands, other buildings on University Campus were studied for comparison. Selected University buildings are monitored on hourly basis with data stored online by Resource Kraft (mentioned already in ***4.3. Measurements*** chapter). Data is available to registered users and can be downloaded in form of a spread sheet. Information was obtained for the same two week period, 15-30 November, for 5 distinct buildings:

Quad East Wing (administrative offices); approx. 1200m^2: **4325 kWh**
Art Gallery; approx. 1250m2- **14877 kWh**
Geography building; approx. 1400m^2- **4270 kWh**
Cross Leigh (offices) ; approx. 550m^2- **1463 kWh**
Aula Maxima (conference room); approx. 280m^2- **19542 kWh**

Table 5.4.b. includes a matrix, which shows how much of each building's power demands would be covered from Bergey Excel 10 production measured. First column represents values obtained from current site, second one values that were predicted for BCO site.

Table 5.4.b. Percentage of buildings' power consumption covered by Bergey Excel 10 power production; current and investigated site.

	Bergey Excel	
	Northern Campus (current)	**BCO (predicted)**
Cooperage	1%	4%
Quad East Wing	2%	11%
Art Gallery	0%	3%
Geography	2%	12%
Cross Leigh	5%	34%
Aula Maxima	0%	3%

It is clear that BCO site conditions make a distinct difference and, if placed there, turbine could cover a significant fraction of some buildings' demands. On current site, however, it remains quite inefficient, reaching the maximum of 5%.

Time patterns

Interesting time patterns that were revealed in the WIND STUDY were looked into in relation to power consumption. Figure 5.4.2 demonstrates relationship between hourly patterns in power production and power consumption at UCC. Both show similar raise during midday hours, although turbine's output displays a less even distribution. The next diagram (fig. 5.4.3.) compares this situation to wind patterns from all other studied sites, which express an even bigger correlation to building demands. It can be seen that out of all investigated sites, winds at UCC are most scattered throughout a day.

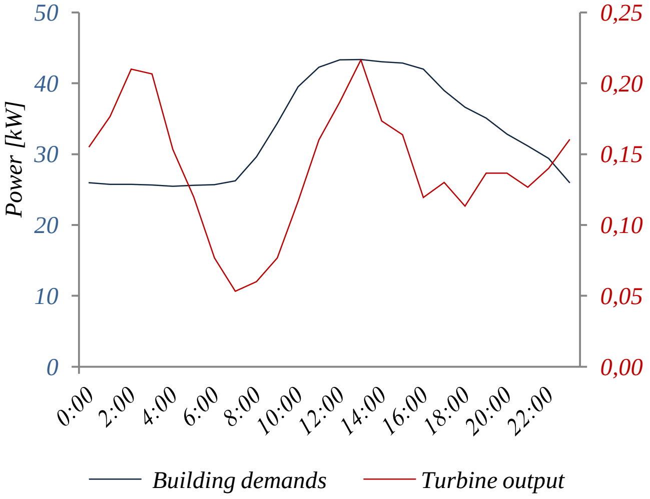

Fig. 5.4.2. Power production and power demands within the day; Bergey Excel 10 and the Cooperage.

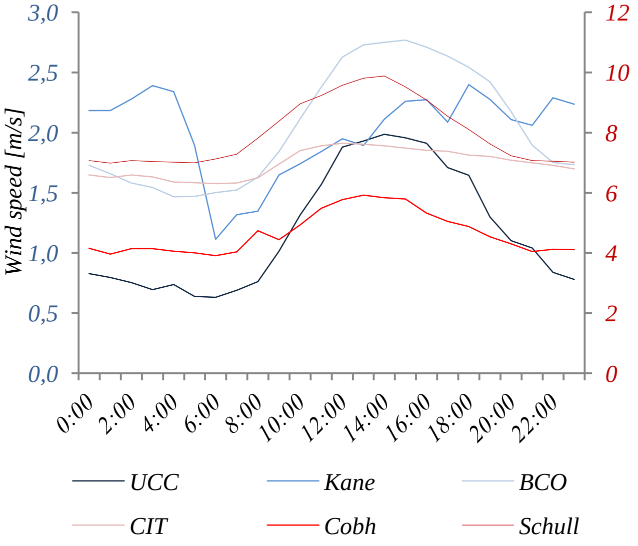

Fig. 5.4.3.Wind patterns within the day; UCC, Kane, BCO, CIT, Cobh, and Schull.

Figure 5.4.4. presents the same type of analysis of other university buildings introduced in previous chapter. They display a more distinct raise in energy demands during the day when compared with the Cooperage.

This study shows that winds in southern parts of county Cork overall display patterns within the day which are similar to energy needs. On sites where wind speeds are high enough for wind generation this becomes a very favourable situation which can be utilized in power usage planning.

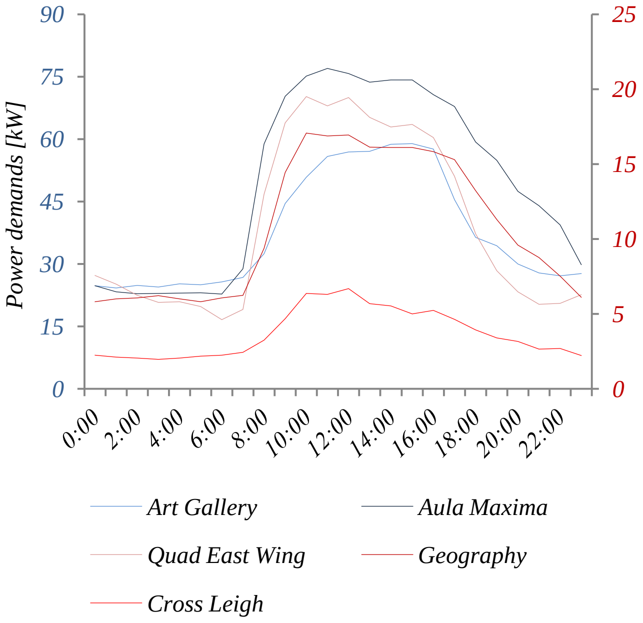

Fig. 5.4.4. Power consumption within the day; University buildings.

6. CONCLUSIONS

The most important conclusions from this thesis can be identified as follows:

- Average wind speed values are significantly smaller on the most obstructed sites; other values, however, do not seem to fully correlate to identified landscape categories; Cobh site displays much lower average wind speed than expected, while suburban Blackrock Castle Observatory site, with anemometer placed relatively low comparing to surrounding buildings, has the most abundant winds.

- Compared to wind speeds obtained from meteorological stations (MET), measured wind speeds are overall lower on most obstructed sites and greater in the suburban areas; correction factors bring the MET values down and increase the gap between predicted and measured values in 3 out of 6 sites; corrections work only for densely blocked areas, where measured winds are much lower than values obtained from meteorological stations.

- Weibull distributions for MET wind data are within favourable range; recorded wind data does not display such even distribution, resulting in quite low Weibull shape parameters.

- Timely distribution displays clear patterns on all sites; values increase during daytime, mainly between 8am and 8 pm.

- Manufactured Bergey Excel 10 displays much higher power production than home-made Hugh Piggott turbine for lower wind speeds, although this difference might be caused by bigger swept area of the first turbine; trend lines for power production dependence on wind availability follow an exponential growth for the Bergey Excel turbine and linear one for Hugh Piggott design.

- Calculated coefficient of performance for Bergey Excel 10 is much higher than the one for the other turbine at very low wind speeds; these values become very similar at wind speeds over 11 m/s.

- Total production of both turbines is fairly similar throughout the month despite big differences in efficiency; much higher wind availability in Ratooragh causes smaller fluctuations in power output; Hugh Piggott turbine continues operating for most of the time at low output levels while Bergey Excel experiences very long hours of stall followed by high power outputs for brief moments of time.

- Predicted efficiency for both turbines using provided formula is much higher than the recorded dependence on wind speeds; coefficient of performance provided by producer for Bergey Excel 10 is bigger for higher wind speeds comparing with the one calculated from recorded output.

- Averaged information used for predictions causes huge over- and underestimations when compared with measured data; detailed information yields results much closer to real output.

- Energy demands of the university building exceed power output from the turbine considerably; turbine covers only 0,6% of building’s total power consumption over the measured period.

- Based on measured data, predictions made for site with the most abundant winds yield quite promising predictions for power production.

- Wind fluctuations within the day match power usage variations in buildings; the biggest raise in both power production and power needs happens during working hours.

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Appendix

A.1: MET, wind study.

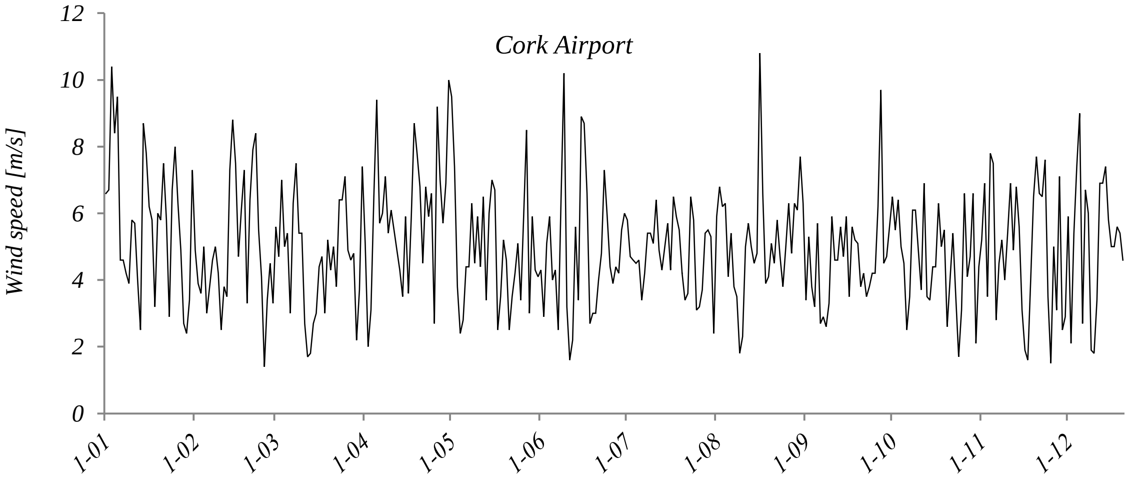

Fig. a.1.Wind data for full measurement period; Cork Airport

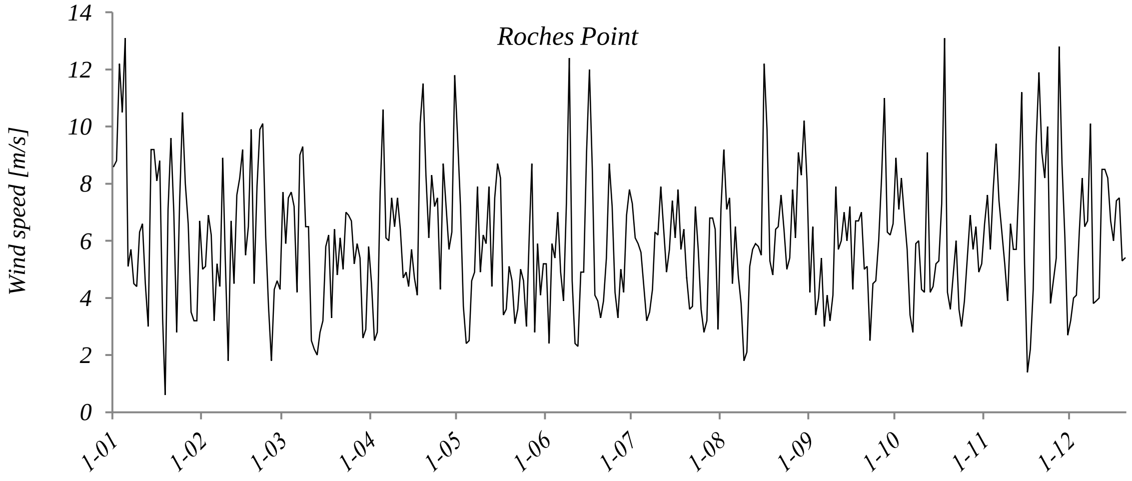

Fig. a.2.Wind data for full measurement period; Roches Point

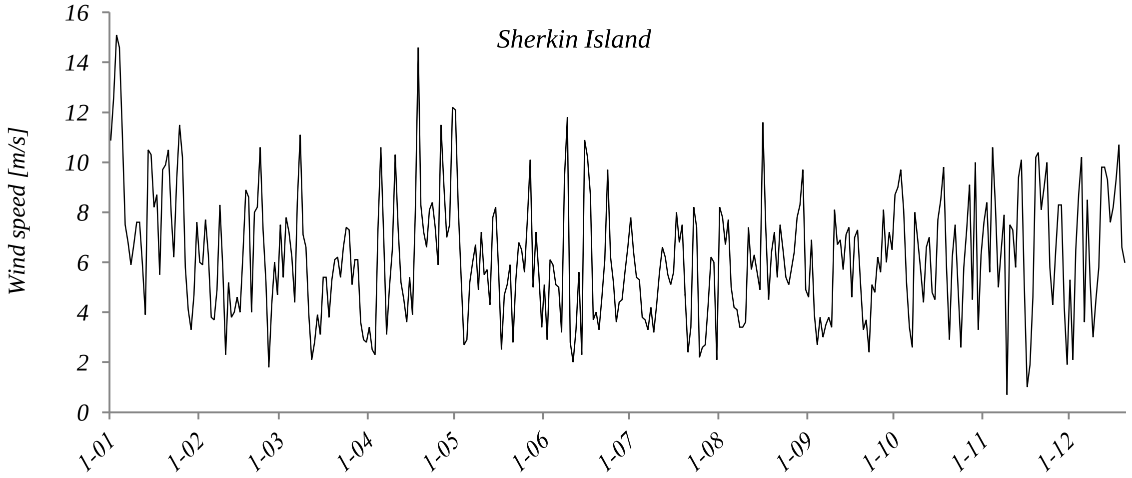

Fig. a.3.Wind data for full measurement period; Scherkin Island

A.2: Landscape categories and correction factors.

Fig. a.4.Category 1. Flat grassland. Source: MIS3003, DEEC, 2008.

Fig. a.5.Category 2. Countryside. Source: MIS3003, DEEC, 2008.

Fig. a.6.Category 3. Farmland. Source: MIS3003, DEEC, 2008.

Fig. a.7.Category 4. Suburban. Source: MIS3003, DEEC, 2008.

Fig. a.8.Category 5. Dense urban. Source: MIS3003, DEEC, 2008.

Table a.1. Correction factors. Source: MIS3003, DEEC, 2008.

	Terrain categories				
h_c	**1**	**2**	**3**	**4**	**5**
1	0.74	0.60	0.43	0.24	0.05
1.5	0.80	0.67	0.51	0.33	0.14
2	0.85	0.72	0.56	0.39	0.20
2.5	0.89	0.76	0.60	0.43	0.25
3	0.92	0.79	0.64	0.47	0.29
3.5	0.94	0.82	0.67	0.50	0.33
4	0.96	0.84	0.69	0.53	0.35
4.5	0.98	0.86	0.71	0.55	0.38
5	1.00	0.88	0.73	0.57	0.40
6	1.03	0.91	0.77	0.61	0.44
7	1.05	0.94	0.80	0.64	0.48
8	1.08	0.96	0.82	0.67	0.51
9	1.09	0.99	0.84	0.69	0.53
10	1.11	1.00	0.86	0.71	0.56
11	1.13	1.02	0.88	0.73	0.58
12	1.14	1.04	0.90	0.75	0.60
13	1.16	1.05	0.92	0.77	0.62
14	1.17	1.06	0.93	0.78	0.63
15	1.18	1.08	0.94	0.80	0.65
16	1.19	1.09	0.96	0.81	0.66
17	1.20	1.10	0.97	0.83	0.68
18	1.21	1.11	0.98	0.84	0.69
19	1.22	1.12	0.99	0.85	0.70
20	1.23	1.13	1.00	0.86	0.71
25	1.24	1.14	1.01	0.87	0.72
30	1.24	1.14	1.02	0.88	0.74
35	1.25	1.15	1.03	0.89	0.75
40	1.26	1.16	1.03	0.90	0.76
45	1.26	1.17	1.04	0.91	0.76
50	1.27	1.17	1.05	0.91	0.77
60	1.28	1.18	1.06	0.92	0.78
70	1.28	1.19	1.06	0.93	0.79
80	1.29	1.19	1.07	0.94	0.80

A.3: Sites; wind study.

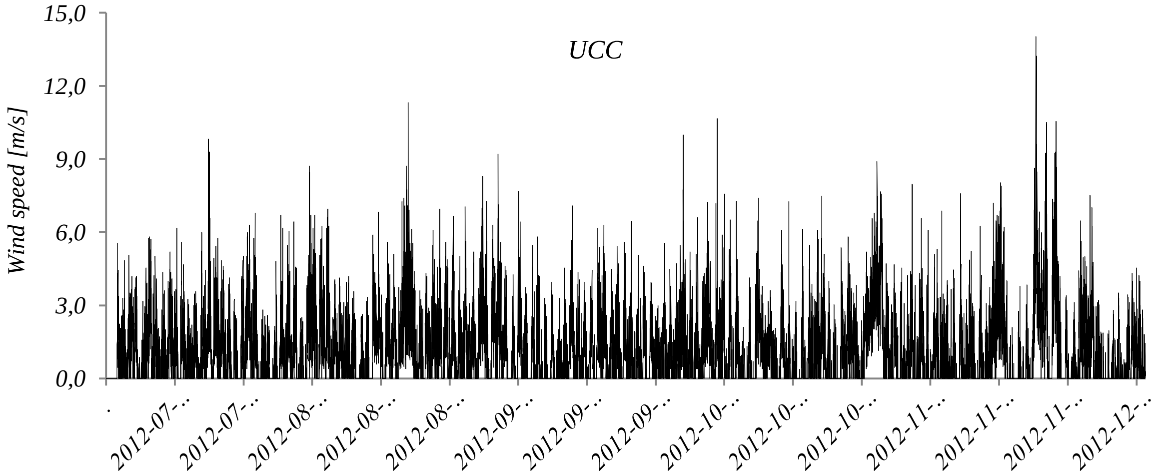

Fig. a.9.Wind data for full measurement period; UCC.

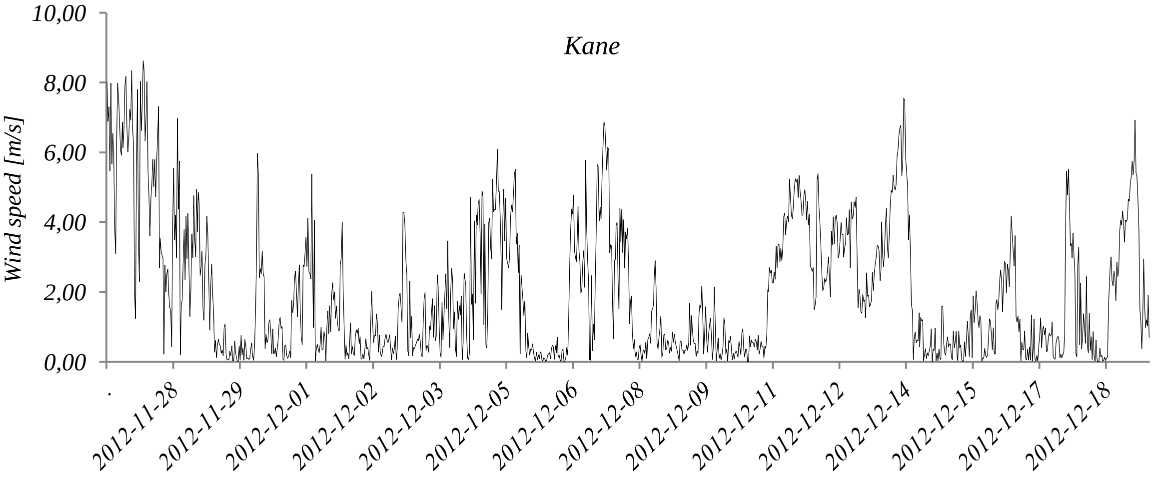

Fig. a.10.Wind data for full measurement period; Kane.

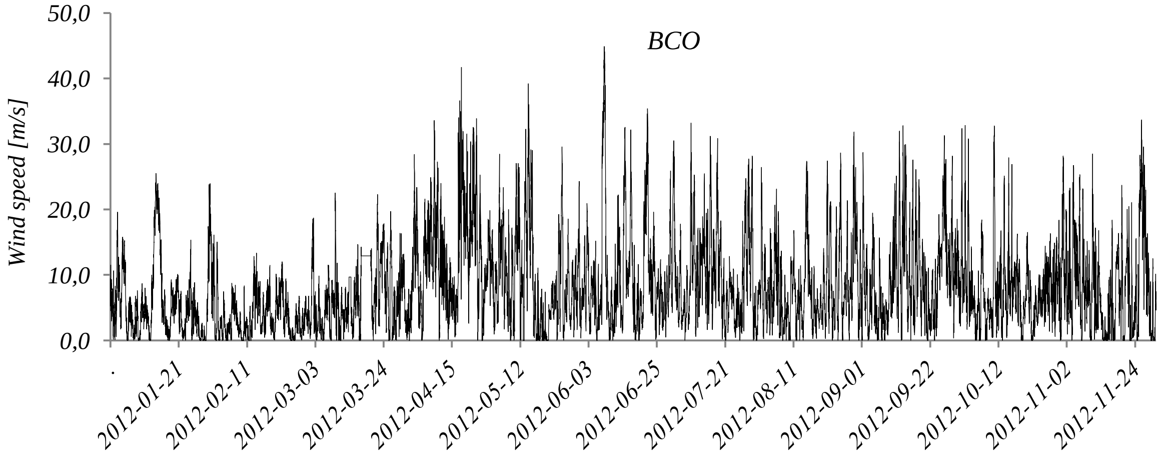

Fig. a.11.Wind data for full measurement period; BCO.

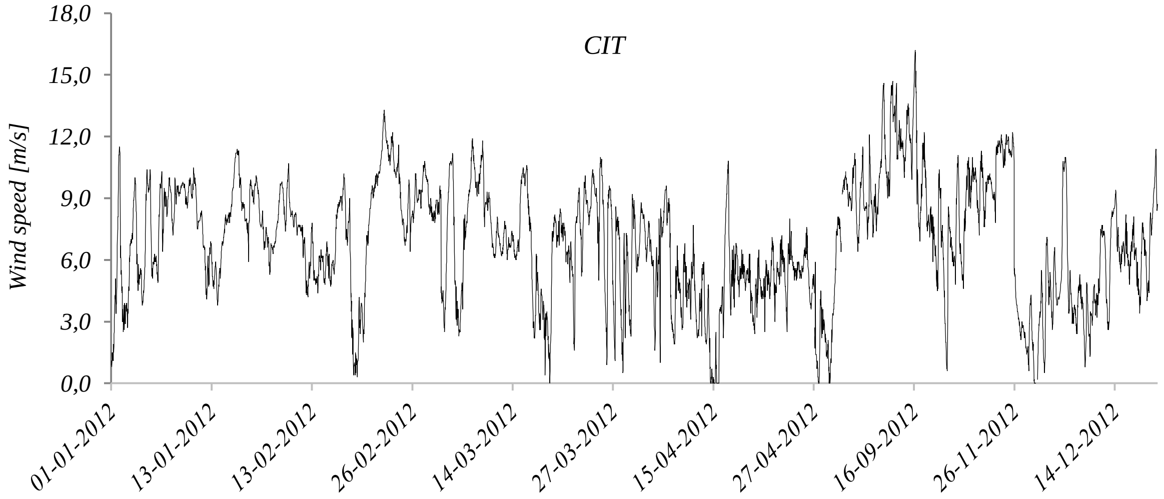

Fig. a.12.Wind data for full measurement period; CIT.

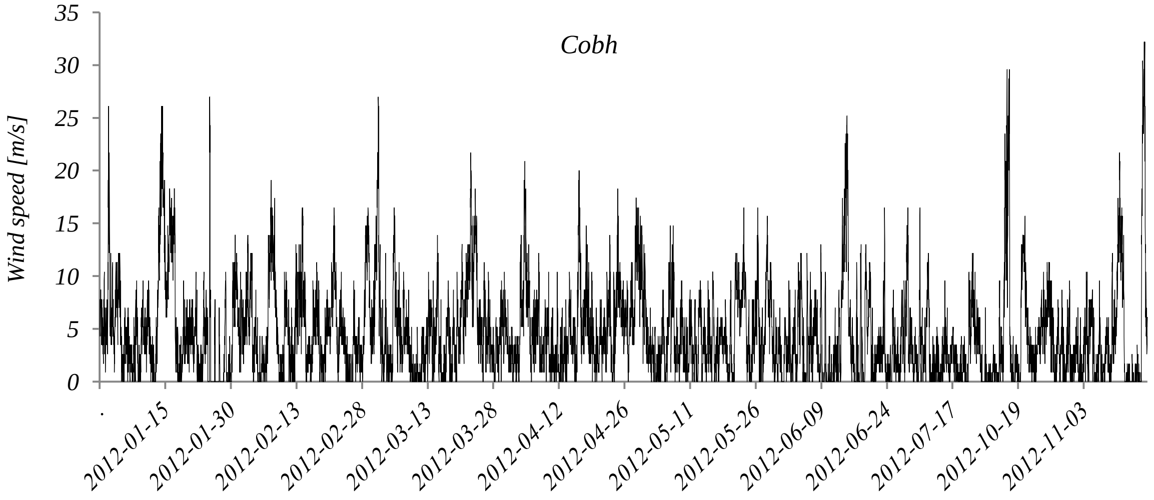

Fig. a.13.Wind data for full measurement period; Cobh.

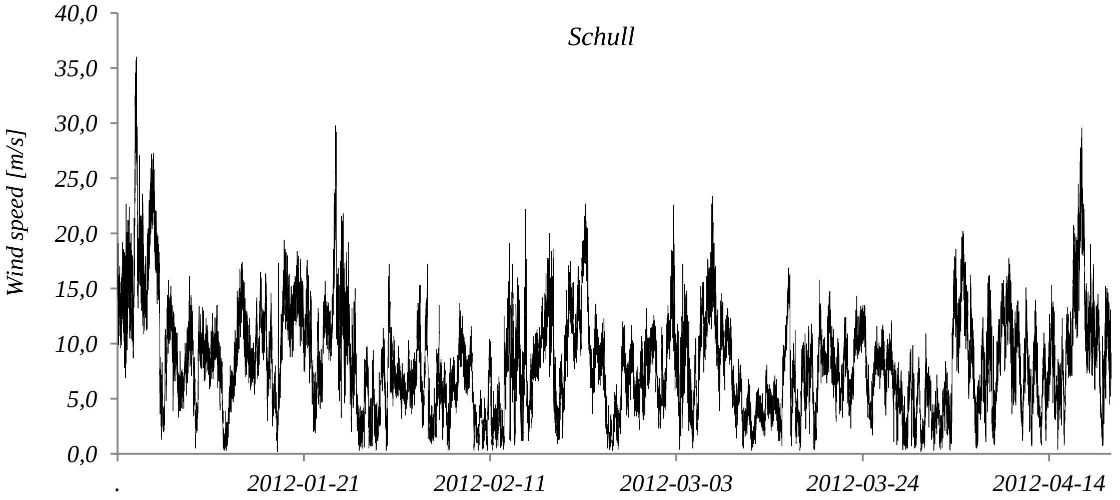

Fig. a.14.Wind data for full measurement period; Schull.

A.4: Coefficient of performance for Bergey Excel 10 (Bergey Windpower 2011)

Table a.2. Coefficient of performance. Source: Bergey Excel 10 Owner's Manual, Bergey Windpower 2011.

Wind speed [m/s]	Power output [kW]	Coefficient of performance
0,5	-	-
1	-	-
1,5	-	-
2	-	-
2,5	0,039	11%
3	0,102	16%
3,5	0,229	23%
4	0,399	26%
4,5	0,569	28%
5	0,848	29%
5,5	1,151	29%
6	1,51	30%
6,5	1,938	30%
7	2,403	30%
7,5	2,949	30%
8	3,602	30%
8,5	4,306	30%
9	5,071	30%
9,5	5,96	29%
10	6,856	29%
10,5	7,849	29%
11	8,836	28%
11,5	9,928	28%
12	10,885	27%
12,5	11,619	25%
13	12,019	23%
13,5	12,276	21%
14	12,395	19%
14,5	12,449	17%
15	12,495	16%
15,5	12,508	14%
16	12,546	13%
16,5	12,555	12%
17	12,503	11%
17,5	12,528	10%
18	12,442	9%
18,5	12,396	8%
19	12,208	8%
19,5	11,878	7%

A.5: Power data.

Bergey Excel 10, UCC

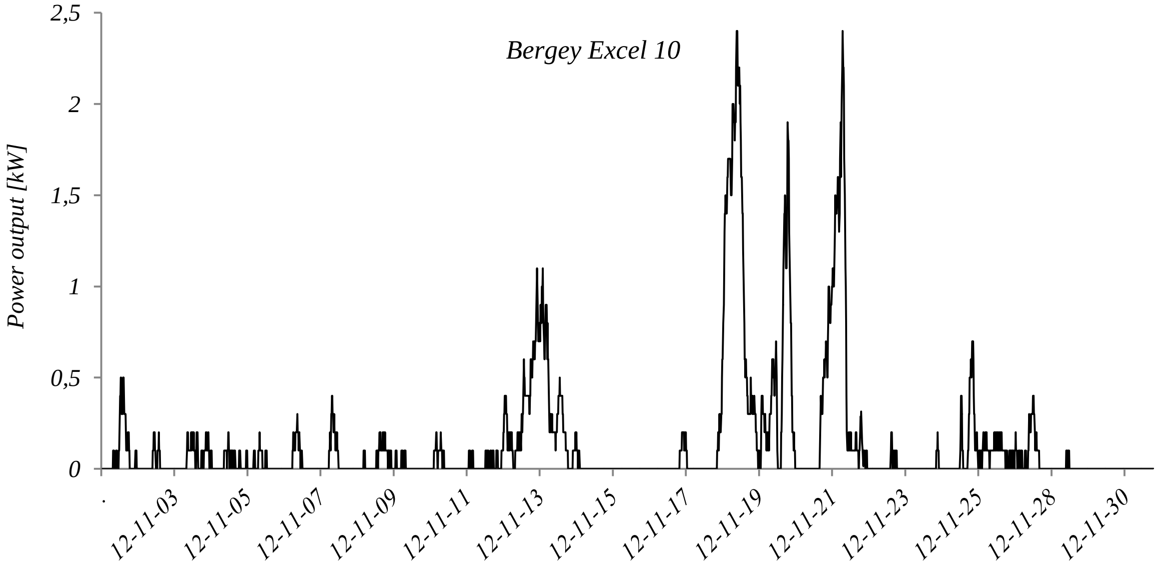

Fig. a.15.Power data for full measurement period; Bergey Excel 10.

Hugh Piggott design, Ratooragh

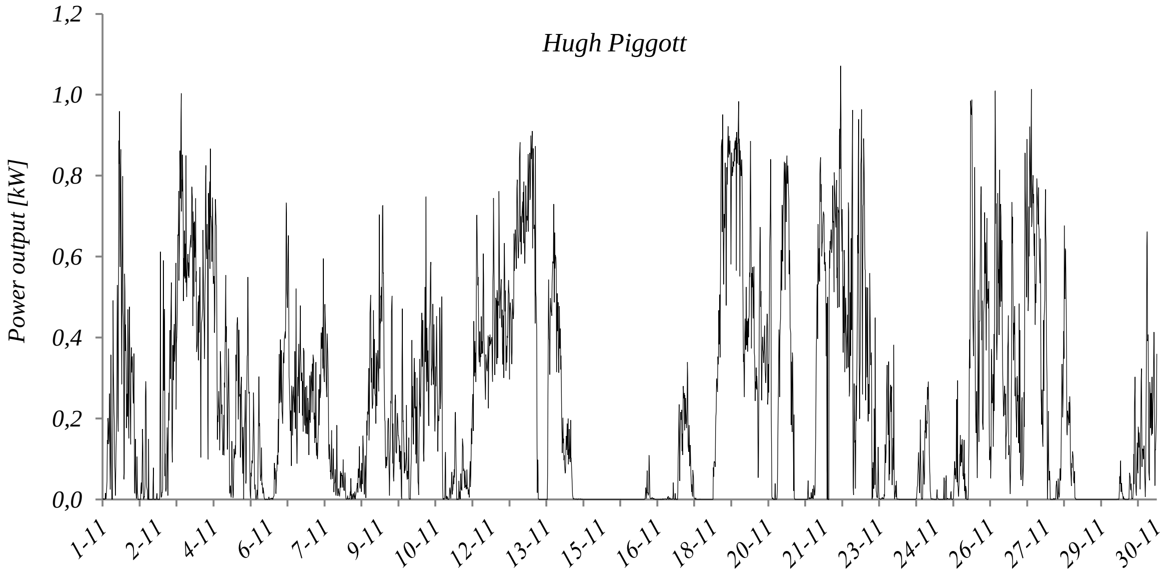

Fig. a.16. Power data for full measurement period; Hugh Piggott design.