Department of Mechanical Engineering

Small Scale Wind Power

Case Study: North Walls Community School

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A thesis submitted in partial fulfilment for the requirement of the degree

Master of Science

Sustainable Energy: Renewable Energy Systems and the Environment

2011

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Signed: Sarah Allardyce Date: 9th September 2011

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Abstract

This project involves a detailed look into the integration of small scale wind into schools and communities especially in rural areas. It will, in particular, look at a case study of North Walls community school on Hoy in Orkney.

North Walls already has one 6kW turbine installed and the performance of this turbine was analysed along with the potential upgrades and how they affect the site's energy demand. The optimum level of production was calculated and the recommended capacity determined for installation on site with a financial analysis to provide benefits given by FITs on the already installed turbine as well as the future possible installations.

The priorities of this project were to perform analysis on installing small scale wind on school sites; through having looked at the advantages to lessening energy demand, the problems with the installation onsite and the costs and financial incentives available. This involved the particular case study at North Walls but has the possibility to repeat the same procedure for schools all over the country.

North Walls are able to supply 7% of their yearly demand with their current turbine and by either installing a Proven 15kW turbine or two Eoltec 6kW turbines, along with the current turbine, could provide over 20% of their supply. It could also produce a yearly income of at least £12,080 from FITS and save at least £8353 from the yearly energy bill. If ground source heat pumps could be installed to generate heat, while using the wind turbine to provide the electricity needed for it, then over 35% of the school's supply can be provided by a renewable source. The ground source heat pumps will generate an additional income through the RHI of at least £1700.

Acknowledgements

I would like to thank my supervisor Dr. Andrew Grant for his assistance and guidance throughout this project. Special thanks also go to Alistair Morton of Orkney Islands Council for being able to provide me with all the data I required and his help with all my questions.

I would like to thank David Palmer for the initial information he provided for the project.

I appreciate the information given by Grace, the janitor at North Walls School, and Sarah Firth, the administrative assistant at North Walls.

I also appreciate the information provided by Annabel Bews and Tracey Jackson of Bryan J. Rendalls Electrical and Louise McLaughlin, the sales administrator, at Proven Energy.

Finally I’d like to thank my family and friends for their help and support throughout this project.

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Chapter 1: Introduction

As the country strives to become more self sufficient we need to look for more ways to supply decentralised energy instead of relying on our power stations. Currently over half of Scotland's renewable energy comes from wind farms with even more planned. However this only accounts for around 16%[1] of Scotland's energy demand.

The Scottish Government has raised its target to power 50% of Scotland's energy by 2020 from renewable sources to 100% by 2020 last year and most of this is likely to come from wind power[2]. The majority of this percentage will be made up of large scale wind farms. Construction is already underway for an additional 75 turbines to the huge Whitelee Wind Farm; whose current capacity is 322MW from its 140 turbines and planning proposed for the Clyde Wind Farm in South Lanarkshire which will have a capacity of 350MW from 152 turbines[3]. Together both these wind farms should be able to power nearly 600,000 homes. Also the UK Government wants to cut out greenhouse gas emissions by 34% by 2020 and by at least 80% by 2050. In the UK our home energy use makes up to 24% of CO_2 emissions and our public sector accounts for 12%[4]. This value can be reduced by the introduction of small scale wind and solar panels into our homes and communities. The public sector is the area identified where plans can be implemented in order to cut these carbon emissions so we can meet the UK's Kyoto commitments. These plans look to local councils to incorporate energy saving initiatives and the generation of electricity and heat from onsite renewables.

Orkney Islands Council has 1600 council buildings, including their 30 educational buildings, to maintain. They are involved in financial assistance to businesses and could use this to help them to install renewables into their buildings.

The council printed a paper in December 2009 (A Sustainable Energy Strategy for Orkney)[5] which outlines their three main aims:

- Ensure Orkney uses energy as efficiently as possible and has a secure supply that is affordable to meet the island communities' future needs.
- Add value to the renewable energy resources for the benefit of the local economy and community whilst minimising damage to the environment.
- Reduce Orkney's carbon footprint.

Orkney, as an island archipelago, is a reasonably heavy user of energy, relying on fossil fuels to help power the ferries and aircraft in order to provide transport to the mainland. The key industry is agriculture which also uses a lot of fuel in all the machinery needed for this[6]. Also, while Orkney is connected to the National Grid there is a slightly different pricing system dependent on the area. This means that fuel prices are approximately 10% higher than mainland prices. This does not help with the economic and social development of the island communities.

Energy use in the home is also high; because of the climate there is a high space heating demand so people are spending at least 10% of their income on domestic energy. Therefore being able to compensate for some of this demand through generating their own energy would be extremely beneficial. The OIC is also part of the Carbon Trust's Carbon Management Programme which commits the council to a target to reduce CO_2 by 11% by 2014 which "underpins potential financial savings" to the council of £1.6m. There are also a number of ways the community benefits from proposed projects.

These come under the headings of:

- Community benefit paid by private developer
- Council Equity participation in wind turbine projects
- Community-owned wind turbines
- Local private investor-owned wind turbines
- Council-owned wind turbine projects

1.1 Objectives

The outcome of this project will develop a potential design for the further installation of wind turbine(s) to provide heat and power to North Walls School. This will include:

- Analysing the existing half hourly demand data available from the electricity company along with the supply data from the turbine itself. The combination of these will give the overall electricity usage pattern of the school building.
- Using wind speed data to look at the potential from the site; comparing what the current turbine has generated with what the manufacturer says it should provide at certain wind speeds.
- Possible identification of scope for demand side management to match the renewable potential.
- Identifying optimal rating for a wind turbine installation based on building load and demand management. The target is to install renewable systems to offset at least 25% of electrical demand.
- Looking at the potential payback period under the current UK FIT scheme.

1.2 Scope and Methodology

The OIC and North Walls School have wanted to extend the renewable generation potential at the school since 2007 but have not been able to make a case for doing so without knowing how the current turbine is performing. The work done through this report should give them a basis for this.

The general methodology followed was:

- Consider the school’s energy load profiles
- Analyse the current turbine data
- Use Merit to look at how supply can better meet the demand
- Look at the further potential of the site
- Perform a basic financial analysis on the recommended scenario
- Draw conclusions and make recommendations

Specifications for potential turbines will be taken from manufacturer’s website with the assumption that these tend to reflect the best possible result. The power output curves will be used to provide the data needed by Merit to calculate the turbine’s performance.

Chapter 2: Background Information

2.1 Orkney

The Orkney Islands are an archipelago situated 10 miles north of the coast of Caithness, Northern Scotland. It comprises a total of around 70 islands but only 18 of these are inhabited. The area of Orkney is 989km^2 and has a population of 19960 with the largest settlement, Kirkwall on Mainland Orkney [7]. The Pentland Firth separates Orkney from mainland Scotland and is 6.5 miles wide and a key potential site in the development of tidal energy. The Islands are noted for having an absence of trees which increases its wind power potential.

The climate is cool but remains mild and steady thanks to the Gulf Stream. The average temperature is 8°C[8] and annual rainfall averages of 348-882mm[9]. There is an almost constant supply of wind, even in summer and frequently there are strong winds. This wind resource along with the potential marine resources means that Orkney will be an important region in the generation of Scotland's renewable energy. The European Marine Energy Centre, which is backed by the Scottish Government, has installed a wave and separate tidal power testing system[10]. In 2007 it was announced by the Scottish Government that there was funding available for the UK's first wave farm with a capacity of 3MW[11]. There are a number of wind turbine projects on Orkney. These range from individual single small scale turbines with as little capacity as a few hundred watts to large scale wind farms like Burgar hill which has over 17MW capacity[12].

Orkney has a school population of around 3000. It has 2 senior secondary schools, 4 junior high schools including North Walls, 17 primary schools and one hall of residence[13]. The council also encourage community use of all its schools so the buildings become a valuable community asset.

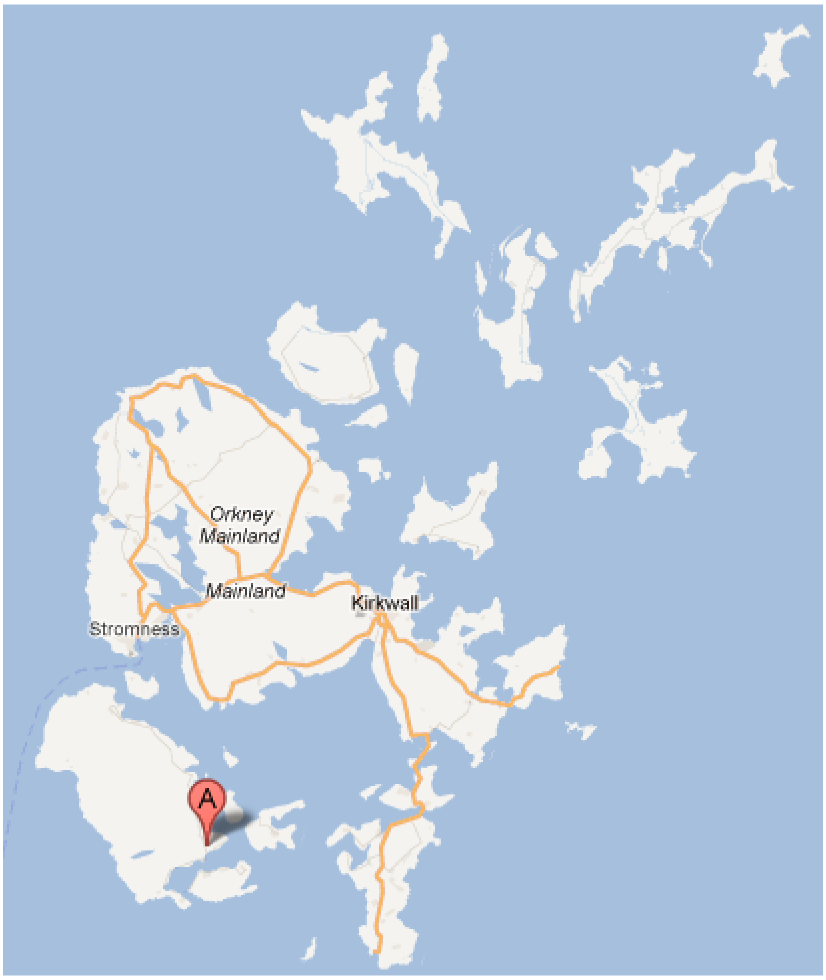


Figure 1: Map of Orkney Islands. ‘A’ indicates the position of North Walls Community School on the South East corner of Hoy. Source: Google Maps.

2.2 North Walls Community School

This school is situated on the island of Hoy. It provides education for pupils between 5 and 14[14] (up to second year of high school). As a community school they share their facilities with the community of around 400 – 500 people. They share the use of the small swimming pool, fitness room and the main hall with its community room.

The school and nursery are in use from 9am to 5pm Monday to Friday with the community hall being used by the school during the day, and by the community in the evenings and weekends. The pool and fitness suite are used all week. There are fluorescent lights throughout the building, 11 desktop computers and 20 laptops. The types of heating used are 10 large industrial storage heaters, 8 large storage heaters and 3 areas of underfloor heating, all of which are electrical and required all year round.

Figure2: North Walls school on Hoy with current installed turbine in South East corner of playing field. Source: Google Maps.

There is a 6kW wind turbine already installed, in August 2008, and there have always been plans to extend this capacity, as initially they wanted to install a 25kW turbine. All electricity generated by the turbine goes directly to the school and is used alongside electricity from the grid. System performance data are available for the school and community to view which hopefully will encourage public support for the turbine and plans for extensions. The school's energy demand comes from the constant need for heating due to Orkney's climate. The water used onsite is also heated electrically so this also increases the electricity demand. The school wishes to meet at least 25% of this demand through renewable sources.

2.3 Orkney Grid Connection

The council's vision for Orkney is that it will become a major player in the generation of renewable energy in the UK, and even globally with regards to marine energy. This will hopefully benefit all the islands' communities in terms of being self sufficient and the amount of jobs these industries will produce.

However, currently the connection between Orkney and mainland Scotland poses a problem with transmission charges and the connection to the network, as it is not strong enough to handle this influx of renewable energy generated electricity. The existing Pentland Firth link is currently at full capacity. The difficulty is there is a mismatch between the current connection procedure and the pattern of small scale renewables that are developing across Orkney which will continue to develop in the coming years. Because it is small-scale development it is harder to get guaranteed finance for a new grid investment as the critical amount for this is difficult to achieve and even more difficult to continue to guarantee. To achieve the required connection to the transmission network new developers will have to put a cable across the Pentland Firth[15]. Therefore with regards to wind power, it is likely to continue to develop small scale projects that are owned locally by groups of individual investors or the community. This will ensure the benefit of the local resources remain local. It will be the development of marine energy projects that will guarantee a new connection and the further development of large scale renewable sources on Orkney.

2.4 Government Incentives

The advantages of producing your own energy are increasing with the introduction of schemes like ROCs, FITs and RHI.

2.4.1 FITS

The feed in tariffs are a scheme introduced in April 2010 under the Energy Act 2008 to encourage those not usually associated with the energy market to look into producing their own low carbon energy. They are a Government incentive, paid for by the energy suppliers, to help reach the UK target of 15% of energy from renewables by 2020[16]. There are 3 benefits for anyone that qualifies for FITs; these are:

- A payment for all electricity generated even if it isn't exported.
- Additional payment for any exported electricity (export tariff)
- Reduction in energy bills, offset by the electricity generated.

They are available for anyone generating up to 5MW so small-scale wind projects, like those in Orkney, are definitely eligible. However those installed before 15th July 2009 need to be registered for the Renewables Obligation (RO) to be able to receive a slightly lower FIT rate of 9.4p/kWh. Those installed from then on can join the FIT scheme and will receive payment from the 1st April 2010. Also for systems below 50kW both the equipment and the installer need to be accredited under the Microgeneration Certification Scheme (MCS). These tariffs are available for 20 years so should cover the lifetime of the installed device with regards to small scale wind. The feed in tariff should, over a number of years, be able to pay back the initial cost of installation and also be able to make a profit in time[17].

The FITs work alongside the RO which has been in place longer, and was more directed at large scale generation, and the Renewable Heat Incentive (RHI) which was implemented this year and supports the generation of heat from renewable sources at small scale only, presently.

Energy Source	Scale	Tariff (p/kWh)[*]	Duration (years)
Anaerobic digestion	≤250kW	14.0	20
Anaerobic digestion	>250kW - 500kW	13.0	20
Anaerobic digestion	>500kW	9.4	20
Hydro	≤15 kW	20.9	20
Hydro	>15 - 100kW	18.7	20
Hydro	>100kW - 2MW	11.5	20
Hydro	>2MW - 5MW	4.7	20
Micro-CHP [**]	<2 kW	10.5	10
Solar PV	≤4 kW new[***]	37.8	25
Solar PV	≤4 kW retrofit[***]	43.3	25
Solar PV	>4-10kW	37.8	25
Solar PV	>10 - 50kW	32.9	25
Solar PV	>50 - 150kW	19.0	25
Solar PV	>150 - 250kW	15.0	25
Solar PV	>250kW - 5MW	8.5	25
Solar PV	Standalone[***]	8.5	25
Wind	≤1.5kW	36.2	20
Wind	>1.5 - 15kW	28.0	20
Wind	>15 - 100kW	25.3	20
Wind	>100 - 500kW	19.7	20
Wind	>500kW - 1.5MW	9.9	20
Wind	>1.5MW - 5MW	4.7	20
Existing generators transferred from RO		9.4	to 2027

Table 1: Tariff Level Table for income from FITS for a range of renewable sources.
Source: www.fitariffs.co.uk/FITs

Notes:

[*] These tariffs will be subject to inflation based on retail price index

[**] Will be reviewed after 12000 units have been installed as is only for up to 30000 installations

[***] These terms are defined below:

- "Retrofit" means it is installed on a building with occupants.
- "New Build" means the solar panels are installed on a new building before it has occupants.
- "Stand-alone" means the solar panels are not attached to any building so are not supplying energy to any building but just for the grid.

2.4.2 RHI

Announced in March 2011, the Renewable Heat Incentive will support technologies that generate heat from a renewable source[18]. It is similar to FITS but with some differences:

- The money does not come from the energy suppliers but from the treasury.
- There is no possibility to export unused heat.

Tariff name	Eligible technology	Eligible sizes	Tariff rate (p/kWh)
Small biomass	Solid biomass; Municipal Solid Waste (incl. CHP)	Less than 200 kW	*Tier 1:* 7.9
			Tier 2: 2.0
Medium biomass		200 kW and above; less than 1000 kW	*Tier 1:* 4.9
			Tier 2: 2.0
Large biomass		1000 kW and above	2.7
Small ground source	Ground-source heat pumps; Water-source heat pumps; Deep geothermal	Less than 100 kW	4.5
Large ground source		100 kW and above	3.2
Solar thermal	Solar thermal	Less than 200 kW	8.5
Biomethane	Biomethane injection & biogas combustion, except landfill gas	Biomethane all scales; biogas < 200 kW	6.8

Table 2: Tariff Level Table for RHI payments for non-residential installations.
Source: www.rhincentive.co.uk

Tier 1 tariffs will be available until 15% of the annual rated output has been reached and then tier 2 will be used. Once registered for the RHI tariff, like the FITS it is subject to adjustment under inflation based on the retail price index and is guaranteed for 20 years.

Chapter 3: General Information

3.1 Getting Electricity from the Wind

Wind turbines produce electricity through using the wind to drive a generator. The wind turns the rotor blades which are connected to a hub that is then connected to a gearbox and generator. These are located in the nacelle, which holds all the electrical components, at the top of the tower. The diameter of the rotor blades can be up to 80m and turbines may have 1, 2 or 3 blades. The blades are constructed of fibreglass – reinforced polyester or wood-epoxy. The blades of large turbines rotate at 10 – 30 revolutions per minute, usually at a constant speed[19].

Most turbines will start to operate around 4 – 5 ms^{-1} and will reach their maximum power at about $25ms^{-1}$. The power is controlled automatically as the speed of the wind varies and the machines are switched off in very high wind speeds to protect them. The crucial part of the design, especially with regards to small scale generation, will be the length of the blades; the larger the swept area, the more energy that will be generated.

For a wind turbine to be 100% efficient it would have to stop 100% of the wind to convert into electrical energy which is just not possible. The theoretical maximum kinetic energy captured is 59%, the Betz limit. This is hardly reachable when you consider further losses in the turbine so that the actual amount of wind energy captured is between 35 and 45%. Furthermore, after taking into account the efficiencies of the generator and other parts then perhaps less than 30% of the original wind energy might actually be turned into electrical energy[20]. The power coefficient; the maximum fraction of the original wind energy that can be extracted, is given by $C_p = \frac{Power\ output\ from\ wind\ turbine}{Power\ available\ in\ wind}$. The power output can be calculated by

$P = \frac{1}{2}\rho A C_p V^3$ where ρ is the density of air, A is the swept area by the rotor blades, C_p is the power coefficient and V the speed of the wind through the rotor blades[21].

3.2 Capacity Factor

The capacity factor is the actual output from the wind turbine. The formula to calculate the capacity factor of a wind turbine is: $Capacity\ Factor = \frac{Energy\ Generated\ (kWh)}{365 days\ in\ a\ year \times 24\ hours\ in\ a\ day \times rated\ capacity\ of\ turbine (kW)}$. There are a number of reasons why a turbine wouldn’t have 100% capacity. There are a number of times the blades won’t be rotating due to the wind being below cut-in speed or above cut-out speed or switched off for maintenance purposes. Typical wind capacity factors are 20 – 40%[22]. The capacity factor is not the same as the efficiency. With regards to wind power the capacity factor can be an important quantity to estimate before installation as it can determine how good a site is by using climatic data to predict the potential.

3.3 Yawing

The ability to turn the rotor perpendicular to the direction of the wind to maximise energy captured is yawing. This is only necessary for Horizontal Axis Wind Turbines, as Vertical Axis Wind Turbines are always facing the wind. There are two categories of yawing technique; electronic or hydraulic motor to move the rotor into the wind or by using the wind itself to turn it using a tail vane. A downwind wind turbine can use its rotor to allow yawing; this is called coning. For larger diameter turbines an electronic or hydraulic motor is required; these are called yaw drives. There is a controller in the yaw drive that will activate the yaw drives when necessary[23].

3.4 Connecting Wind Power to the Grid

Wind turbines tend to be located in rural areas so sometimes the grid connection in this area is weak and the local demand may be much less than the supply. If this supply has to be added to a network that's already at capacity, it is necessary to reinforce the network or connect to a stronger part of the grid which will obviously cost more.

The supply from a turbine is also dependent on the supply from the wind which varies constantly. This will cause voltage variations on the connected local network; these must not exceed certain limits. The potential for connection to the grid needs to be determined early on in the planning stages as the cost to do so may prevent a project from proceeding. The steps for making the connection include notification of the local electricity supplier to enquire about basic connection cost, followed by a technical submission and the connection quotation. Also if it happens to be a new connection then planning permission is required and agreements must be made with the local electricity supplier for metering.

3.5 Benefits of Wind Power

Wind power has many advantages. The technology has modernised so much in the past 20 years that we can now harness the free power of the wind very effectively and much more efficiently than ever before. Once the construction and transportation is complete there are no pollutants released during energy production unlike other sources. There are also no waste products from this source unlike fossil fuels and nuclear. This reduction in our CO_2 emissions is also a good partial solution to global warming.

Wind turbines are tall but only take up a small area of land therefore can easily be installed in many different areas, i.e. on farmland where the ground below can still be used for animal grazing or in a school where the area around the turbine may be part of the playground. They are very interesting and educational so when they are in clear view they can be used for other purposes than just producing energy, for example in science classes to explore the generation of energy and how we use it. In remote areas where it’s harder to connect to the national grid they can, possibly along with solar or biomass, provide a decentralised supply of energy and because they are available in a range of sizes to allow supply to a range of demands. This means that turbines can be installed locally to provide energy as well as in large wind farms that supply the national grid. On top of all of this, using wind power to meet your energy demand can dramatically reduce energy bills with the FITs for generation and exporting. In Scotland we have a potential wind resource of 159GW[24] and our peak requirement is only 10.5GW. This untapped capacity is due to a lack of investment, planning constraints and the fact that some of the best areas of generation are areas of conservation. The installed capacity we presently have is able to supply around 16% of our electricity demand. There are a number of wind farms in their planning and construction stages which will boost this figure dramatically, like the Clyde Valley Wind Project; soon to be the largest in Europe, powering 320,000 homes. Alongside this is the potential for development of small scale turbines, either free standing on adjacent ground or urban installations on top of buildings to help reduce the reliance on the grid.

A disadvantage to the installation of wind turbines is that there is an amount of carbon released during manufacturing, construction and transportation but this can be compared to the CO_2 saved from supplying your home with clean energy. The impact they have on the surrounding environment is also a disadvantage as they tend to be opposed to because of their size and noise. There have been a number of projects rejected on Orkney due to this noise level and because they feel the turbine dominates the landscape. One example is that of the application for a community turbine to be installed at Howe in Shapinsay. The proposed turbine was to be 67m high and would have been 450m from the nearest dwelling but plans were rejected due to complaints regarding noise and landscape impact after 38 letters of complaint and one complaint report were received by the OIC[25]. Wildlife and habitat impacts are thoroughly reviewed when choosing a site and only wind farms that are situated properly with acceptable impacts gain planning permission. This accounts for more than 50% of sites entered into the planning stages being refused due to the conservation of species, landscape or the potential of unacceptable noise pollution[26]. The noise pollution from the turbine comes from the aerodynamic noise; the flow of air over the blades. The noise near a turbine is much less (35 – 45dB @ 350m) than that of a nearby truck (65dB @ 30mph @ 100m), a busy office (60dB) or a car (55dB @ 40mph @ 100m)[27] although it will obviously be a constant noise as long as the wind is blowing across the blades. This is taken into account during the planning process especially regarding small scale turbines as they tend to be in more built up areas although not all objections mean that planning will be rejected. These objections to small scale turbines are not outweighed because of positives of being able to generate electricity onsite but with no transmission losses, they are able to strengthen the grid in some places which reduces the need to upgrade[28]. Most Local Authorities now have plans that will require a percentage of any new major developments to be produced from onsite renewables[29].

3.5.1 Wind Variability

One critical issue of wind power is the variability of the supply; it cannot be predicted unlike tidal power. The wind speed can vary depending on the time of day, year, the height or location which means a good supply cannot always be guaranteed. This can also be a problem in relation with the connection to the grid as if it's not strong enough it will not be able to handle this varying supply. This is why it is necessary to monitor the supply at the site for at least a few months before installation and check the grid connection if there are plans to export any electricity generated.

3.5.2 Shadow Flicker

This is the effect caused by the wind turbine blades casting shadows over nearby houses and buildings so the shadows appear through windows. This happens very rarely in the UK as it needs specific timing for it to occur; i.e., the exact positioning of the sun behind the rotor so that it casts the shadow on the area of a building in which it will be seen. Research carried out by the DECC has only identified one case of shadow flicker in the UK[30].

3.6 Classification

On a very general scale wind turbines are split into small scale and large scale. Small scale devices tend to be installed as single turbines to be used on site to address an energy demand and have a rated output ≤50kW. A large scale turbine has a capacity anywhere above this right up to the latest 7.5MW rated Enercon turbine[31] with numerous companies working on the development of a 10MW turbine. These larger turbines are grouped together to make up wind farms to supply our national grid.

3.6.1 Turbine Classes

The IEC (International Electrotechnical Commission) has defined three classes of wind turbines[32]. This is to determine the suitability of wind turbines for the wind conditions at a particular site. For example, due to the resource on Orkney a Class 1 turbine should be installed.

Wind Turbine Generator Class	**I**	**II**	**III**	**IV**
V_{ave} average wind speed at hub-height (ms^{-1})	10.0	8.5	7.5	6.0
V_{50} extreme 50-year gust (ms^{-1})	70	59.5	52.5	42.0

Table 3: The wind turbine classifications based on IEC standards.
Source: Wind Wire blog

3.7 Small Scale vs. Large Scale

The real difference, apart from the capacity, between large and small scale wind power is the way in which they are used. As discussed earlier, the large scale turbines are used in groups to form wind farms to feed our national grid and the small scale are used by homes or businesses to subsidise their energy demand and reduce their energy bill whilst bringing in a certain income from FITs. The small scale turbines are particularly suited to being used for off grid or mobile applications or combined with PV. The PV and wind combination works well to provide a good supply to a home or business. The solar input is at its maximum in summer when the wind supply may be lower and then the opposite in winter so they can provide a balanced supply.

A questionnaire by the WINEUR (Wind Energy Integration in the Urban Environment) project showed that 4% of small scale installations are installed not for financial reasons[33] but for educational and environmental reasons. There is an overall lack of experience when it comes to installing small wind turbines, especially roof mounted in urban environments, as only recently have they become widely available and with Government grants they are becoming more popular.

Chapter 4: Small Scale Turbines

Small scale machines can be as small as 100W and can be used to recharge a battery or possibly supply a small caravan. A 1 to 6kW turbine is recommended to supply a single house, with a larger community building needing the 6kW supply.

There are two different types of turbine; free standing, mast mounted or roof/building mounted. Generally mast mounted devices are used in rural or not so built up areas where there is open ground for installation. Building mounted systems are used in urban areas where there is no possibility for mast mounting. They tend to be smaller and less efficient as they are in built up areas and there may be things blocking the wind from effectively reaching the turbine. The majority of installations in urban areas are Horizontal Axis Wind Turbines (HAWT). These are the most common turbines that are seen, normally 3-bladed and need to be facing the wind. These small wind turbines normally use a wind vane to do this, so if that is blocked or not operating properly then performance is poor. Recently there has been evidence to suggest that turbines mounted on or near a building have had low cost-effectiveness[34]. Wind turbines need to have maximum exposure to be able to obtain as much power from the wind as possible but requirements to reduce the visual impact can interfere with this. More effective turbines are being designed for this urban purpose. The Vertical Axis Wind Turbine (VAWT) has the advantage over HAWTs in that they don’t need to rotate to face the wind. They are also more visually suited to being installed on top of buildings but aren’t as efficient as HAWTs. There is a cost for installing on a building which could also pose an additional problem.

4.1 Manufacturers

There are now a number of wind manufacturers and suppliers across the UK. Proven Energy is the World's largest producer of small scale wind turbines, generating power on every continent[35]. It was founded in 1980 in Scotland and was the forerunner in designing bespoke autonomous systems. The wind turbines are designed as downwind machines with controls to produce a maximum yield in a range of wind speeds. They have a number of rated capacity sizes; from 2.5kW up to 12.1kW. These have been used in a range of applications; for use on offshore oil platforms, domestic and commercial properties and even in small wind farms or crofts.

Orkney's main supplier of small wind turbines is not, however, Proven. The turbines on Orkney are supplied by a local company Bryan J. Rendalls Electrical (BJRE). It has been established in Orkney for over 20 years. They specialise in renewable energy and electrical engineering with a particular focus on wind power and marine energy[36]. They are the main UK distributors of the Eoltec turbines and also supply an 80kW turbine from Wind Energy Solutions which would be used on a farm to generate a good income. They are fully approved and accredited MCS suppliers and installers. This is now a requirement for small scale installations. They are also members of the REAL assurance scheme. Along with the MCS accreditation this allows them to deal with grant installations.

Another thing to consider when applying for revenue from turbine installations is that the turbine must also be listed on the MCS Transitional List. The 6kW Eoltec turbine supplied by BJRE is one of these turbines. It has a 5.6m diameter rotor and is known for its high efficiency and low noise. This device has the possibility to continue to operate at high wind speeds as the overspeed is controlled by the stall control[37].

4.2 Costs

The cost for wind turbines majorly depends on its location therefore individual quotes will be given but estimates can give an idea of an overall cost range. The cost for a smaller roof mounted system is normally around £2,000 including installation[38]. They can now be found online at as little as £600 though without the mounting kit or someone to carry out the installation. A larger mast mounted system can cost anywhere between £15,000 and £60,000 with installation. The turbines will also need to have yearly maintenance.

There are a number of grants available to provide funding for the installation of these projects. One of the schemes projects can apply for is the SCHRI (Scottish Community & Householder Renewable Initiative). This is funded by the Scottish Executive and controlled under the Energy Savings Trust and will provide grants for domestic and community projects in Scotland[39]. To be eligible the product and the installer must be accredited under the MCS. There is also the EDF Green Energy Fund[40]. Customers on their green tariff pay slightly more and in return EDF match this and use it to fund grants given to community and educational groups across the UK. The Government’s Low Carbon Building Programme also provided grants for around 20,000 projects across the UK between 2006 and 2010[41].

Chapter 5: Integration of Wind Power into Schools

The integration of small scale wind into our communities should be encouraged, especially within the public sector. It is becoming increasingly popular for schools to invest in onsite turbines to provide a fraction of their energy, sometimes along with a solar PV installation. This allows the school to save money on their energy bill every month. The production of renewable energy can be used as an effective teaching tool and integrated into the curriculum. Pupils should be educated on the production of energy through alternative sources, have an idea of how much they use on a daily basis and how they could save some of this through little things such as turning off lights and computers. There are a number of schools across the UK that have investigated this idea and installed their own turbines in a range of capacities dependent on location and availability.

5.1 Examples

One example is Kilmory Primary School on the Isle of Arran. They installed a Proven 6kW, 15m tall wind turbine in the southwest corner of the school grounds. The turbine is situated 80m from the school, 15m to the east of an existing tree belt with the closest residential property 120m north east of the turbine. The estimated wind turbine output is up to 15,000kWh per year which is an estimated carbon saving of 7.5 tonnes[42]. The site is on the southern coast of Arran so has a considerable wind reserve and the wind turbine is in full view of the community so will not only provide an education for the students, but for the whole community also. The planning permission for the site was obtained back in 1995 but the funds were not there to cover installation. The introduction of SCHRI at the end of 2002 allowed the project to be carried out as they funded 75% of the total project cost of £24,618 with North Ayrshire Council providing the rest[43].

Another example is Gullane Primary School in East Lothian. Their project comprised of an extension to the school using sustainable materials and the installation of a wind turbine and solar PV cells. They are used in maths and science lessons for the children and there is a display in the hall showing how much energy is being produced. This has led to the school achieving the Silver Eco Schools award with the promise to reduce electricity consumption by 25% and CO_2 emissions by 7.6 tonnes per year. The 6kW Proven turbine that was installed is estimated to produce 16,900kWh per year. The idea behind the wind turbine installation came from problems with the strength of the wind in the playground; instead of paying money to shield this problem, the turbine was installed in order to turn this into an advantage[44].

St. Andrews Primary School and Nursery in Cumbernauld have also installed their own turbine and solar panels. A third of the costs of this initiative were granted by the Scottish Power Green Energy Trust. The 6kW turbine was installed in 2003 and stands 15m high[45].

Newark Primary School in Inverclyde consolidates 3 primary schools and a nursery. The building design incorporates four micro turbines to provide power to the school. This is used as an educational aid and the pupils can view the turbines output daily. Around the same time Inverclyde Academy was built which boasts a 25m high wind turbine which can provide 15 – 20% of the school's energy. The pupils here also have access to a display system for the power output from the turbine and solar system, and also the amount of energy still being imported to the school[46].

Although most of these examples are mainland there is even more incentive for schools within the island communities. These schools are not only used during the day for teaching purposes but also tend to be used for the community in the evenings, weekends and holidays. This means power that the turbine provides will be used as a constant source of energy all year round and not just during term time. This is even more beneficial as the community schools will use more energy per head than schools just used during term time.

5.2 Turbine Site at North Walls

5.2.1 Environmental Issues

The impacts and benefits of a wind turbine are widely known or assumed, as discussed. However there are a number that will be site specific. The school is situated on the south east corner of Hoy just south of the main settlement Lyness. South of Lyness the terrain flattens out and opens up. The environmental issues that need to be considered for this area are:

- Impact visually on the landscape
- Ecological Impact
- Impact on the environment and of pollution during transportation and construction
- Noise Impact

5.2.1.1 Visual Impact

The land surrounding the school is open and is used for playground, playing field and car park areas. The current turbine was installed in the south east corner just off the playing field, approximately 70m from the community hall (the most eastern part of the school buildings). The 18m tower will be a focal point for the community, bringing an education element to the landscape.

5.2.1.2 Ecological Impact

The turbine is built on school grounds so there will be limited chances in disturbing any habitats. The tower will not be high enough to pose a big problem to birds in flight.

5.2.1.3 Construction Impacts

The school is situated on the main road, the B9047, through Hoy which is ferry – linked to mainland Orkney so transportation to the site will not be a problem. Construction can be carried out during non-term time so to cause as little disturbance as possible. The CO_2 produced during construction and transportation should be “paid back” within the first year with the savings in the grid electricity demand.

5.2.1.4 Noise Impact

As there already is a turbine in place the noise level is able to be monitored and is not seen as a problem so further installations should not face any objections. The closest buildings to the turbine are the community centre and school buildings with a number of houses, north of the school, at least 100m away from the turbine.

5.2.2 Safety Issues

It is rare for small scale wind turbines to have major safety issues but it must be considered when installing somewhere where an accident could potentially be very dangerous to a number of children. The turbine’s current location, so far from the school and off of the actual playground area, means that it will be under exceptional circumstances that an accident would occur.

An example of an accident that has occurred was during installation at a school in Norfolk. It was being installed next to the playing field and collapsed as it was being winched up and fell on top of the installer’s van. The few students on the playing field were evacuated and no-one was hurt. The reasons for the turbine collapsing are unknown as there were no strong winds or obvious problems with the turbine structure. The area around the turbine was cordoned off so the only people at risk were the installers and the accident was passed off as an embarrassing incident by the head teacher who assured everyone that “when we get to the bottom of what went wrong we will get another up”[47].

Chapter 6: Wind Potential at Site

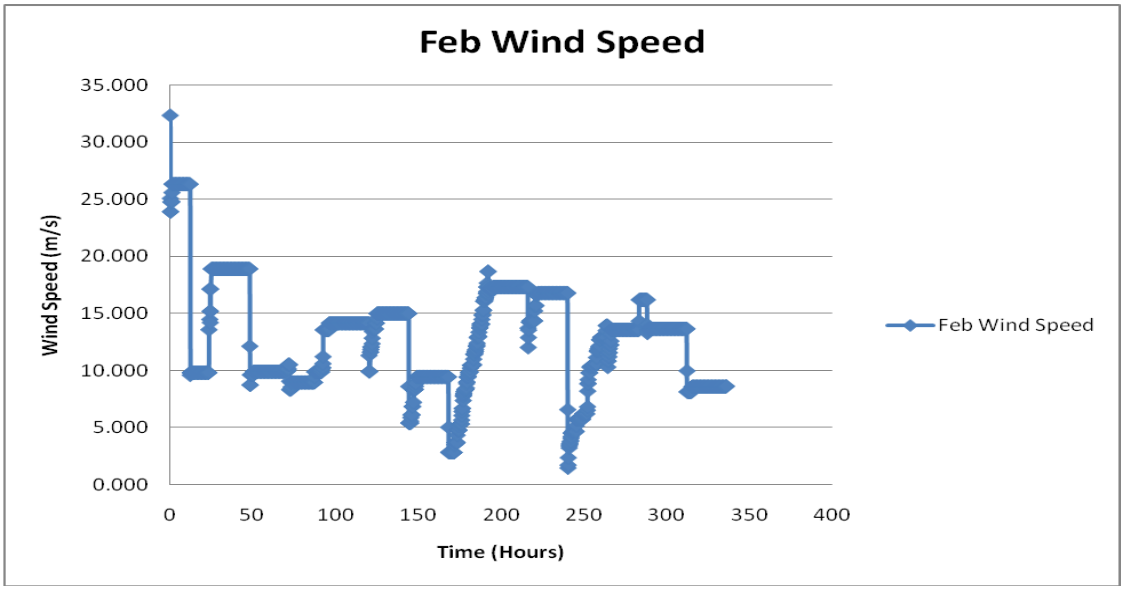
The current turbine sits away from the school with nothing blocking the wind from it. The school is situated on the South-Eastern edge of Hoy where winds coming from the South East and West and also the North West along with the relatively high wind speeds provide a good wind resource. In the past year the highest recorded wind speed at the turbine was 32.32ms^{-1} on the 4/02/2011 from a West North West direction. This is equivalent to 72.3mph and is classed as a violent storm, no. 11 on the Beaufort Scale. The wind dropped down to 26ms^{-1} soon after this although this is still considered a storm on the Beaufort Scale, therefore the turbine on site needs to have a high survival speed as it has to have the potential to withstand these large gusts. This seems to have been an exceptional circumstance as the monthly average was 12.96ms^{-1} (equivalent to 28.99mph); considered a strong breeze. The minimum wind speed was recorded in January at 0.35ms^{-1}. This speed will not allow any energy to be produced from the turbine although in the recorded data from November 2010 there are only 4 days where no energy was produced.

Month	December	January	February	March	April	May	June
Min. Wind Speed (ms^{-1})	2.415	0.35	1.44	2.51	0.87	0.73	1.29
Max. Wind Speed (ms^{-1})	19.86	18.79	32.32	19.91	19.83	13.74	14.68
Median Wind Speed (ms^{-1})	11.26	8.15	13.54	9.92	9.66	9.96	7.92
Mean Wind Speed (ms^{-1})	11.38	9.82	12.96	10.35	9.95	9.28	8.38

Table 4: Typical wind speeds recorded at turbine hub height for each monitored month.

The Mean and Medium are slightly different types of average for the monthly wind speed. The Mean gives an approximation of the most typical value or norm for a range of values. The Median gives ‘the middle number’; this is the value where 50% of the time the wind speed will be lower than this value and 50% of the time the wind speed will be stronger.

As can be seen in the table above the monthly averages for the monitored wind turbine data range between 8 and 13ms^{-1} (17.9 to 29.1mph) ranging from a fresh breeze to strong breeze.



Graph 1: Change in Wind Speeds for fortnight in February.

The graph shows how the wind changes over time as it builds up and remains constant for a period of time. This constant wind speed of at least 8ms^{-1} coming from the South East and West will provide a continuous supply of wind for the turbine to generate electricity from.

Chapter 7: Analysis of Current Onsite Wind Turbine

7.1 The Turbine

The current installed turbine is an Eoltec Scirocco E5.6 – 6. It has a double bladed, 5.6m diameter rotor and is recognised for its high efficiency and low noise. At high wind speeds, which Orkney is known for, the wind turbine has the ability to continue to operate. Below are the detailed specifications courtesy of Bryan J. Rendalls Electrical.

Figure 3: The Eoltec Scirocco E5.6-6 provided on Orkney by Bryan J. Rendall Electrical.
Picture provided by Eoltec.

7.1.1 Performance

Rated output power: 6.0kW @ 12ms^{-1}
Cut in wind speed: 2.7ms^{-1}
Cut out wind speed: None
Survival wind speed: 60ms^{-1} (design according to IEC 61400-1, class 2 wind site)

Wind Speed at hub height (ms^{-1})	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Output Power (kW)	*0.14*	*0.343*	*0.665*	*1.16*	*1.81*	*2.71*	*3.82*	*5.05*	*5.7*

Table 5: The output power for different wind speeds at the hub height.

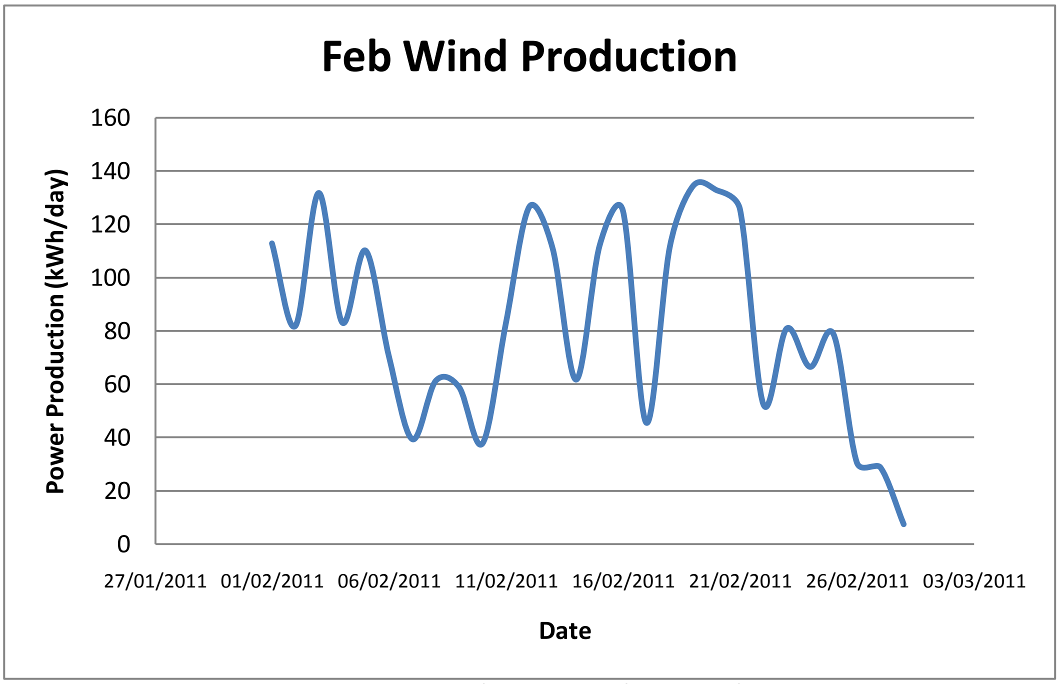
Average wind speed (ms^{-1} @ 10m)	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Average power (kW)	*0.3*	*0.69*	*1.23*	*1.81*	*2.38*	*2.87*	*3.29*
Daily energy production (kWh)	*7.1*	*16.6*	*29.4*	*43.5*	*57.0*	*69.0*	*78.9*
Monthly energy production (kWh)	*215*	*504*	*895*	*1323*	*1734*	*2098*	*2398*
Yearly energy production (MWh)	*2.58*	*6.05*	*10.74*	*15.88*	*20.81*	*25.17*	*28.78*

Estimated for inland site, altitude 300m, Rayleigh distribution (k=2), 18m tower, shear ratio 0.143, turbulence factor 10%

Table 6: The expected performance of the turbine for a range of wind speeds.
Source: Eoltec Scirocco E5.6-6 Performance and Specifications, BJRE

7.2 Current Contribution to Electricity Demand

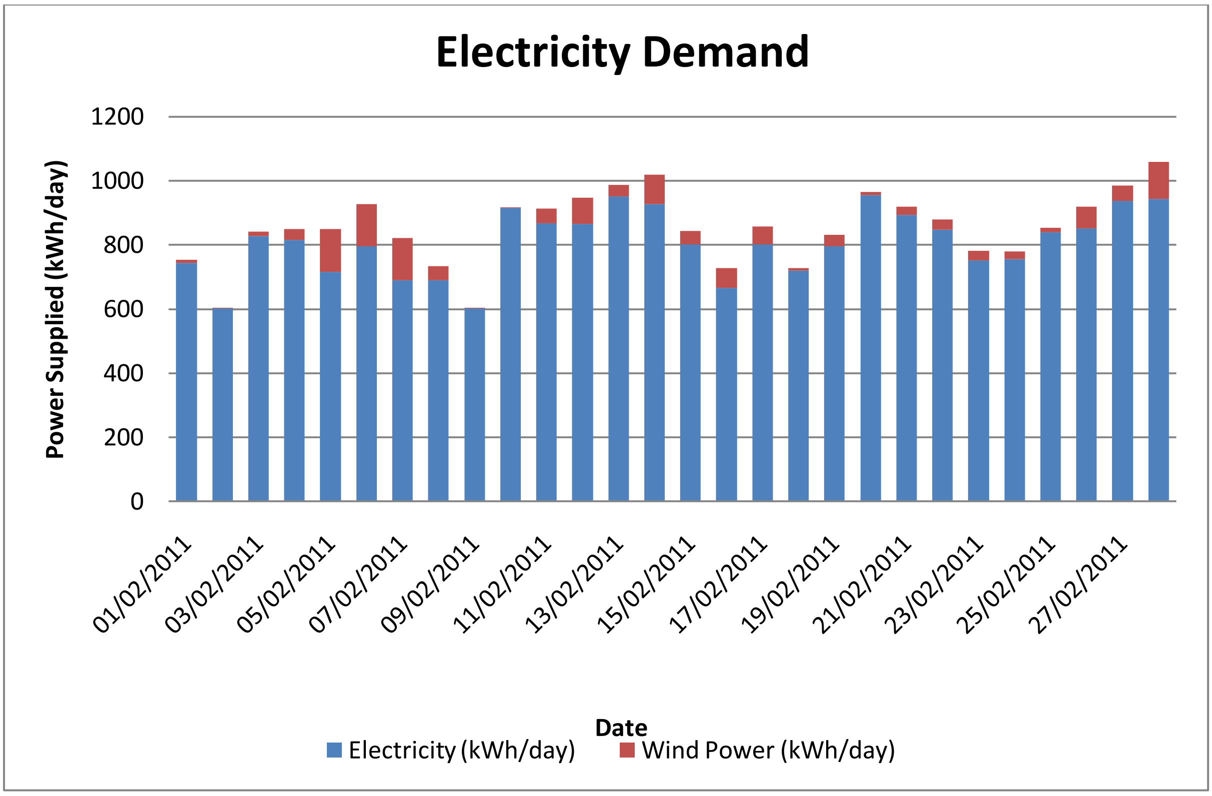
The wind turbine performance has been monitored in 10 minute intervals since November 2010. The highest daily energy production was on 19/02/2011 of 134.38kWh. February was also the month that produced the most power at a value of 4600kW (2300kWh). As is indicated in the table above the turbine is performing as well as is suggested at a speed of 9ms^{-1} @ 10m.



Graph 2: The energy produced each day from the wind for month of February.

From November last year the turbine has produced 10650 kWh of energy. The school’s electricity demand during this period was 177000 kWh therefore the turbine was able to supply 6% of the school’s energy over this time.

The contribution from the turbine is more evident in the graph below.



Graph 3: Shows the electricity demand for the school for the month of February

7.3 Performance Comparison

The graph shows the estimated performance of the turbine against the actual performance. It is evident that the wind turbine is working reasonably close to estimated performance making 70.7% of its estimated production calculated through Merit, a programme used for supply and demand matching. It already has a number of turbine profiles programmed into it but also has the potential to create new profiles from turbine output power curves given in manufacturer's specifications.

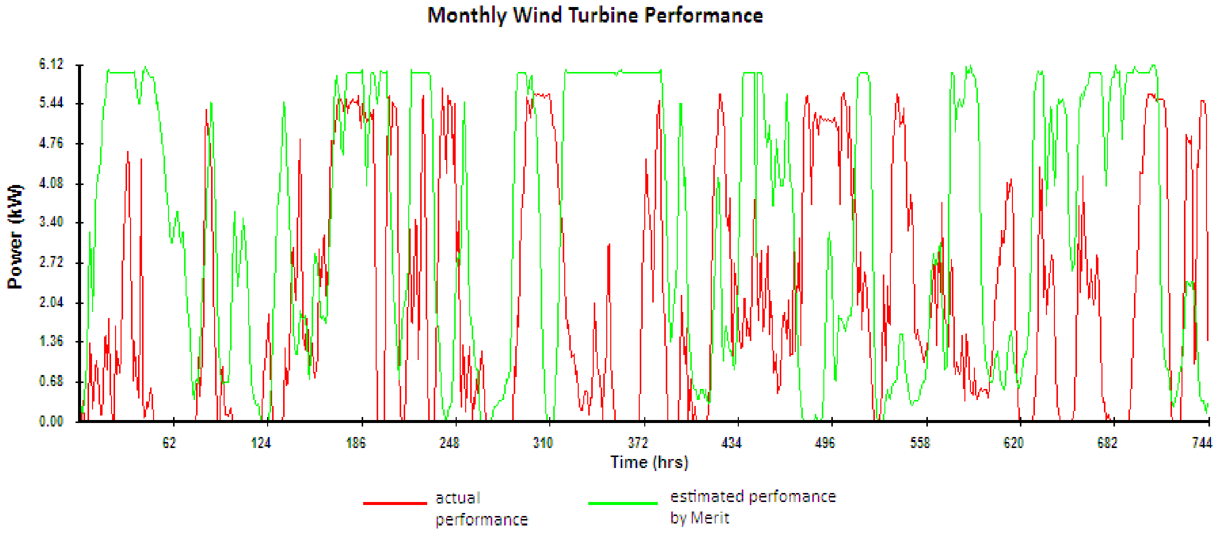


Figure 4: The estimated performance by Merit compared to the actual performance.

Using the information provided in the manufacturer's specification the efficiency of the turbine can be plotted for a range of wind speeds. Using interpolation, the C_p values can be calculated for the monthly average wind speeds given in the table below. The Capacity Factor is calculated using the equation:

$$Capacity\ Factor = \frac{Wind\ Production\ (kWh)}{Days\ in\ month \times 24 \times 6kW\ turbine}.$$

Month	Actual Wind Production (kWh)	Monthly average wind speed (m/s)	Capacity Factor	Cp
Dec	1304.83	11.38	29.2%	26.3%
Jan	1312.97	9.82	29.4%	33.3%
Feb	2300.09	12.96	57.0%	18.2%
March	1557.73	10.35	34.9%	31.3%
April	1028.12	9.95	23.8%	33.1%
May	1876.12	9.28	42.0%	34.2%

Table 7: The C_p and capacity factor values for 6 months of data.

The capacity factor gives a good indication of the wind availability and the power available from it, and the efficiency as to how the turbine is performing.

7.4 Application of FITs

The turbine was registered for the older RO scheme so is eligible for the FIT scheme at 9.4p per kWh. This means over the 7 monitored months they will have earned £1000 through FITs and saved £1597 from their electricity bill (assuming 15p/kWh). Over an entire year the turbine should be able to produce approximately £1738 through FITs and save £2773 from their electricity bill. This will help pay back the initial cost of the installation, any maintenance or work required or to be used to put towards further projects for the school and community.

7.5 CO_2 Saving

Grid electricity is estimated to have produced 0.54522kg of CO_2 /kWh (Carbon Trust) of non-renewable generated energy. Therefore in the monitored time period the turbine is able to displace 5800kg (5.8tonnes) of CO_2. Therefore over an entire year it should be able to displace, approximately, 10136kg (10.1tonnes) of CO_2

Chapter 8: Analysis of Potential Development

The turbine onsite is only able to supply approximately 7.1% of the current electricity demand. However the school and council wish to produce 25% of its electricity demand through renewable sources. This would suggest further development onsite to increase the renewable energy generation. This would be done by adding another turbine onsite at an increased capacity to supply around 15 - 20% of the school's demand. This has to be considered carefully as it may be more financially sensible to install a smaller capacity turbine if the larger becomes too expensive to transport and install, possibly due to the location of the site. A balance must be reached between the wind generation capacity and installed cost. The grid demand for the school currently is 241.5MWh for the year. Therefore to supply 20% of this the turbine would have to produce around 48.3MWh for the year. Working with the previous average capacity factor of 0.36, this gives an estimated required capacity of 15.3kW. As this value has been approximated, capacities above and below this should be considered.

For the purpose of this project turbines at 6kW, 10kW, 15kW and 20kW have been considered with the possibility of having multiple turbines installed. The installed turbine cost just under £50,000 and is only supplying 6% of the school's demand. The larger the turbine the cheaper they become per installed kW. On average an SCHRI grant will provide 50% of the cost of the installation and the council, individual group, fund raising initiative or loan being proposed to fund the rest.

8.1 Merit Analysis

As mentioned above a range of turbines have been considered, these include the currently installed Scirocco E5.6-6, the very well-known Proven 6kW and 15kW turbines and the 10kW and 20kW Westwind turbines, manufactured in Ireland and already installed in the more northerly Shetland Islands by Shetland Wind Power Ltd[48]. The Proven turbines are installed on Orkney by Orkney Business Ring Renewables Ltd and the 6kW Eoltec installed by Bryan J. Rendall Electricals. The technical specifications for each of the turbines considered are featured in the table below. Merit uses the manufacturer's specifications for the estimated output power at a certain wind speed to produce its own power output curve in which it can determine the output from the turbine for the particular location.

Turbine	**Scirocco E5.6-6**	**Proven 11**	**Proven 35**	**Westwind 10**	**Westwind 20**
Rated Power	6 kW @ 11.5m/s	5.2 kW @ 11m/s	12.1 kW @ 11m/s	10 kW @ 14m/s	20 kW @ 14m/s
Peak Power	6 kW	6.1 kW	13.7 kW	10.3 kW	20.1 kW
Rotor Diameter	5.6 m	5.5 m	8.5 m	6.2 m	10.4 m
Swept Area	24.6 m2	23.8 m2	56.7 m2	30.2 m2	84.9 m2
Tower Height	12 m	15 m	15 m	15m	18 m
Cut-in speed	2.7 m/s	3.5 m/s	3.5 m/s	3 m/s	3 m/s
Cut-out speed	None	none	none	None	None
Survival Speed	60 m/s	70 m/s	54 m/s	50 m/s	50 m/s

Table 8: Technical Specs. for turbines considered in Merit.
Sourced from respective turbine manufacturer specifications.

The Scirocco E5.6-6 and both Proven turbines are MCS accredited.

For newly installed turbines registered for FITS the generation tariff is 28p/kWh therefore this turbine will be able to generate a reasonable amount through this. Very rough estimates are given for the installation and groundwork costs which can give an indication for the payback period for each turbine. The calculated supply through merit can be seen in the table below.

Turbine	**Capacity (kW)**	**Supply (kWh)**	**Percentage of Demand (%)**
Scirocco E5.6-6	6	25510	10.6
Proven 35	15	71550	29.6
Generic	10	42670	17.7
Proven 11	6	28730	11.9
Proven 11 and 35	15 and 6	100280	41.5
Generic	2 x 10	85340	35.3
Scirocco E5.6-6	2 x 6	51020	21.1
Proven 11	2 x 6	59770	24.8
Westwind	20	74950	31.0
Westwind	10	33740	14.0

Table 9: Merit calculated supply from range of capacities

Using the current value for FITS and the assumed saving of 15p/kWh of displaced grid energy, the overall net benefit of installing the turbine can be calculated and used to give the estimated payback period. The values calculated through Merit were used to generate the values for this benefit.

Turbine	**Capacity (kW)**	**Supply (kWh)**	**FITS (£)**	**Bill Saving (£)**	**Total Benefit (£)**	**Initial Cost(£)**	**Extra Costs**	**Estimated Payback Period**
Scirocco E5.6-6	6	25510	7142.8	3826.5	10969.3	48597.6*	-	4.4
Proven 35	15	71550	20034	10732.5	30766.5	58000	2000	2.0
Generic	10	42670	11947.6	6400.5	18348.1	39000	2000	2.2
Proven 11	6	28730	8044.4	4309.5	12353.9	25000	2000	2.2
Proven 11 and 35	15 and 6	100280	28078.4	15042	43120.4	83000	2000	2.0
Generic	2 x 10	85340	23895.2	12801	36696.2	78000	2000	2.2
Scirocco E5.6-6	2 x 6	51020	14285.6	7653	21938.6	97195.2	-	4.4
Proven 11	2 x 6	59770	16735.6	8965.5	25701.1	50000	2000	2.0
Westwind	20	74950	20986	11242.5	32228.5	72000	2000	2.3
Westwind	10	33740	9447.2	5061	14508.2	42000	2000	3.0

Table 10: FITS and bill saving calculations for each turbine with payback periods for Merit results.
* The value given here is what the turbine cost to install at North Walls in 2008
The other costs were taken from the manufacturers or installers as a rough guide to what it may cost to install.

The extra costs in the table represent possible costs for groundwork and transportation and may increase due to the location of this project. The table suggests that the shortest payback period comes from the Proven turbines; either from the 15kW by itself, the 15kW and 6kW together or two 6kW turbines. This would give an overall onsite capacity between 18kW and 27kW. The deciding factors between these turbines are the availability of funding for the project and also the possibility of the multiple installations.

The other element to consider is the CO_2 reduction. This was calculated using the same value as before of 0.54522kg of CO_2 per kWh. The results can be seen in the table below.

Turbine	**Capacity (kW)**	**Potential CO2 Saving (tonnes/year)**
Scirocco E5.6-6	6	13908.6
Proven 35	15	39010.5
Generic	10	23264.5
Proven 11	6	15664.2
Proven 11 and 35	15 and 6	54674.7
Generic	2 x 10	46529.1
Scirocco E5.6-6	2 x 6	27817.1
Proven 11	2 x 6	32587.8
Westwind	20	40864.2
Westwind	10	18395.7

Table 11:The potential CO_2 savings calculated from Merit results.

Obviously the more energy that is generated and used on site the greater the CO_2 saving is. This is another reason for installing the highest capacity turbine that is financially sensible.

8.2 Results Analysis

For further analysis we will consider the Proven 35, a 15kW turbine that could provide up to 29% of the school's demand and the multiple installation of the current turbine, which could provide a further 15% of the demand. The site has very good wind availability so the capacity factor is taken as 35%. We assume that all electricity generated will be used onsite to displace a proportion of the grid demand. The FIT rate applicable is 28p/kWh and the grid rate at 15p/kWh therefore the total value of energy generated and consumed onsite is equal to 43p/kWh. We assume that the turbine would be in operation 97% of the time and operation and maintenance costs are initially 1.5% of the capital cost. The inflation rates are assumed to be:

- 2% for operation and maintenance costs
- 2% for the FITS rate
- 3% for grid electricity price.

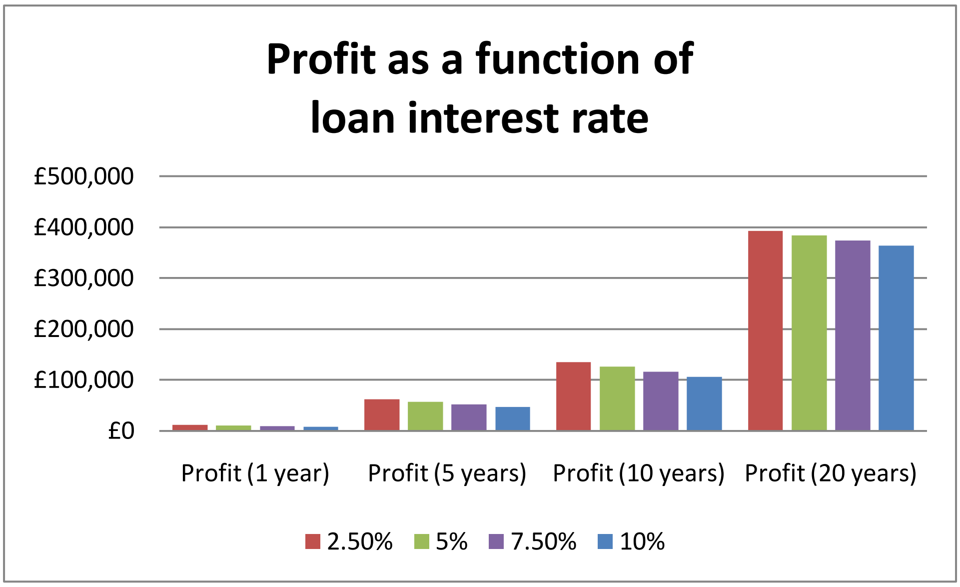
For the purpose of this financial analysis we will assume the council fund the project with a loan for the entire amount. We will consider three situations for the financial analysis; changing the loan interest rate, the loan payback period and the cost/kW of the turbine(s). We will also consider how a change in capacity factor will affect the overall profit and payback period.

8.2.1 Proven 35

The capital cost is taken at £58,000 plus groundwork costs. Using the capacity factor of 35% the supply from the turbine is calculated at 45990kWh; this would be 19% of the school's demand and along with the current turbine supply 6% this would give the desired 25% reduction. This new turbine would give a total value to the energy it can generate of just under £20,000 a year.

8.2.1.1 Loan Interest Rate

Assuming the loan repayment period is 10 years, we looked at four loan interest periods from 2.5% to 10%. The payback period increases from 4 years at 2.5% to 6 years at 10%; this is an increase of 50%.



Graph 4: How the loan interest rate affects the profit for 15kW turbine.

As can be seen from the graph the change in interest rate does not seem to cause a dramatic change in the profit but the difference between 2.5% and 10% at 20 years is a considerable £29092.

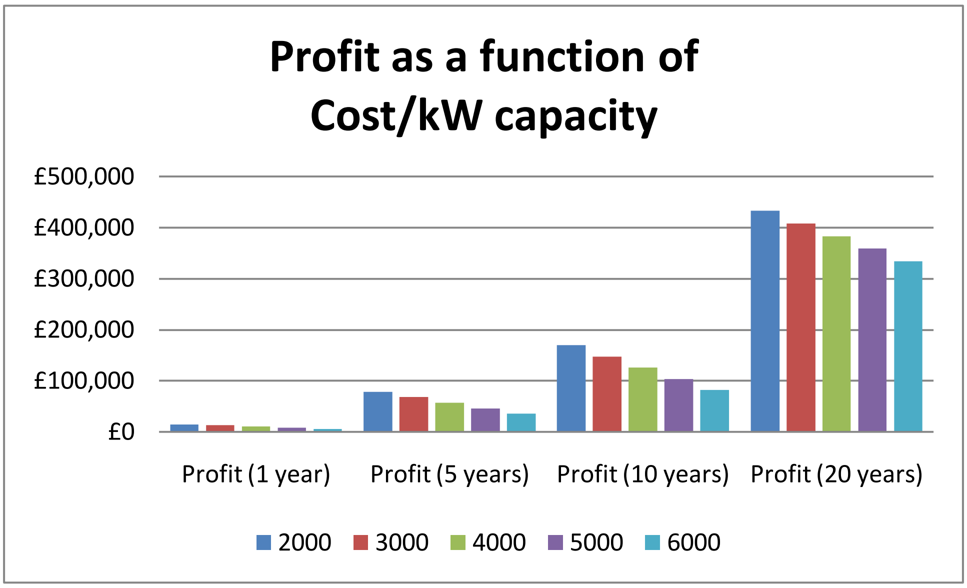
Therefore both these factors mean a lower interest rate increases the turbines profit by a significant amount.

8.2.1.2 Loan Repayment Period

Changing the period of loan repayment does not affect the payback period; however it does affect the positive cash flow and to make sure the cash flow remains positive then the loan should be taken over a period of at least 4 years.

8.2.1.3 Cost/kW

The loan interest rate is assumed to be 5% and the repayment period of 10 years. The cost/kW ranges from £2000 to £6000. The payback period is a maximum of 8 years at £6000/kW; this is nearly triple the payback at £2000/kW of 3 years which explains the major difference in the profit for each of these different values as is obvious from the graph below, with a maximum difference in profit of £99570 after 20 years.

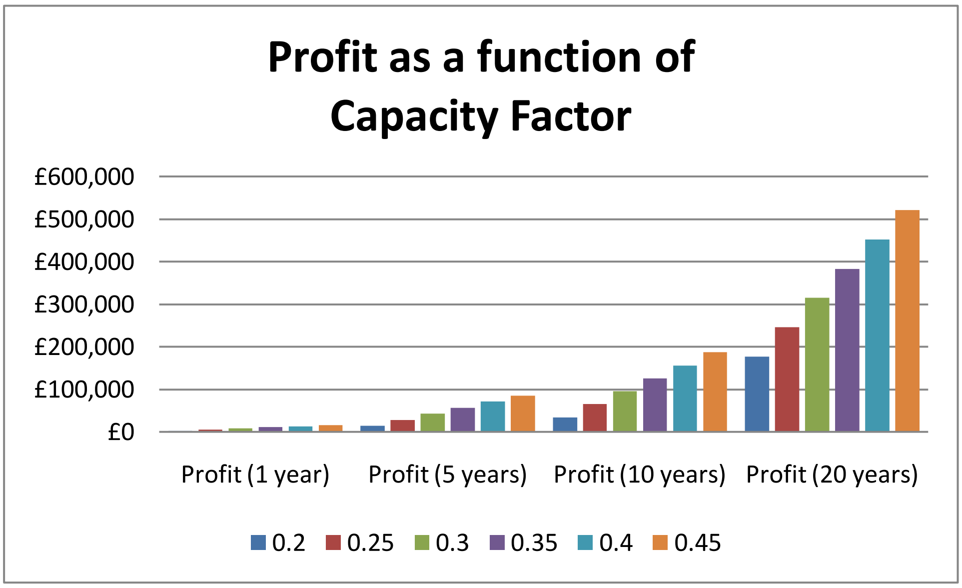


Graph 5: The difference in profit depending on the cost/kW.

8.2.1.4 Capacity Factor

The site on Orkney has what is considered a very high capacity factor, as it can be as low as 20% in built up areas. This scenario considers the difference the capacity factor can make and shows why this site is so good.

The payback period reduces from 9 years at 20% to only 4 years at 45% and there is an incredible £345214 difference between the profits at 20 years over the range of capacity factors. The increasing difference in profit due to the capacity factor can be seen in the graph below.



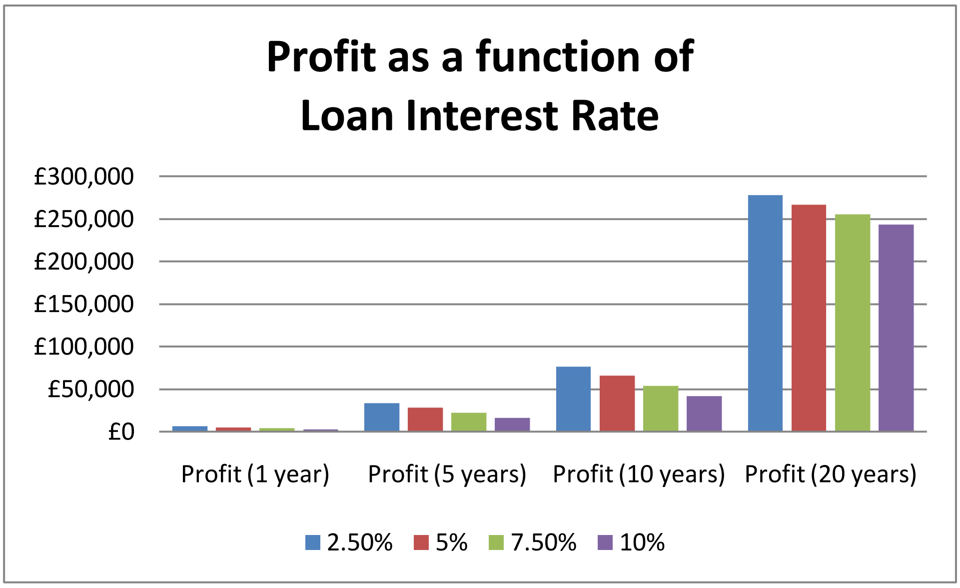
Graph 6: The difference that capacity factor makes to the profit.

8.2.2 Scirocco E5.6-6

The capital cost is taken at £35,000 for one turbine. Using the capacity factor of 35% the supply from the two new turbines is calculated at 35688kWh; this would be 14.8% of the school's demand and along with the current turbine supply 6% this would give over 20% reduction. This new turbine would give a total value to the energy it can generate of just over £15,000 a year.

8.2.2.1 Loan Interest Rate

Assuming the loan repayment period is 10 years, we looked at four loan interest periods from 2.5% to 10%. The payback period increases from 7 years at 2.5% to 9 years at 10%.



Graph 7: How the loan interest rate affects the profit for 12kW turbines.

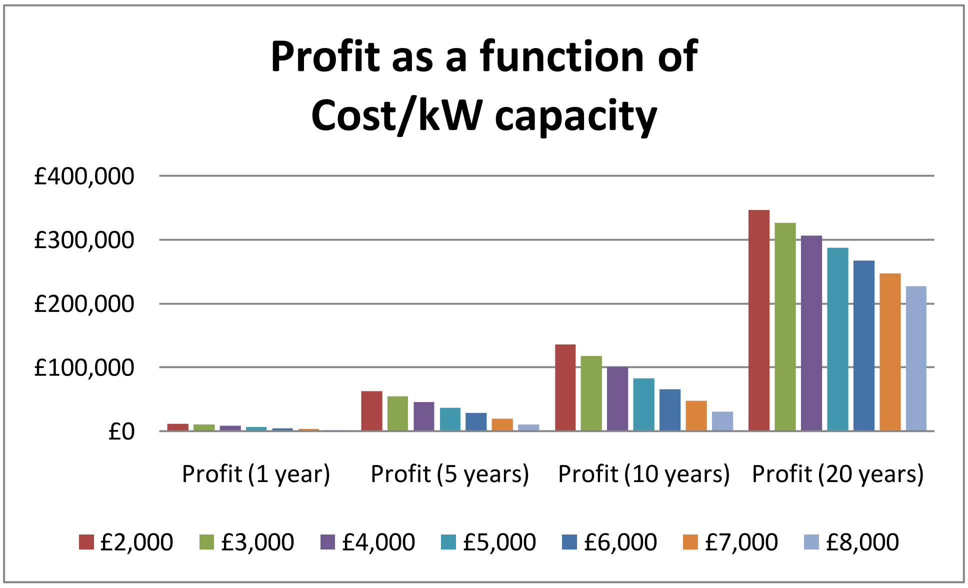
The change in the profit is more apparent at this capacity with the difference between 2.5% and 10% at 20 years almost £35,000; nearly the cost of another 6kW turbine.

8.2.2.2 Loan Repayment

The loan interest rate is also assumed to be 5% for this case and the loan repayment years ranging from 5 to 15 years. The payback period changes only from 7 to 8 years in this range; however the cash flow doesn't become positive till the 6th year with a 5 year loan. Therefore a loan of at least 6 years will allow for a continuous positive cash flow.

8.2.2.3 Cost/kW

The loan interest rate is again assumed to be 5% and the repayment period of 10 years. The cost/kW ranges from £2000 to £8000. The payback period is a maximum of 10 years at £8000/kW; this is over triple the payback at £2000/kW of 3 years which explains the major difference in the profit for each of these different values, with a maximum difference in profit of just under £120,000 after 20 years.



Graph 8: The difference in profit depending on the cost/kW for 12kW turbines.

8.2.2.4 Capacity Factor

The influence of the capacity factor was also considered for this case as there is a slightly lower capacity and also a higher capital cost. It shows even more how the right site is essential as with a capacity factor of only 20% the cash flow doesn't become positive till the 11th year of operation.

Both these simulations assume that the turbine will be in operation for the next 20 years and should they have any serious problems or break downs then a large fraction of the profit could be lost as FITS is in operation for the full 20 years.

8.3 Financial Conclusions for this site

- The capacity factor for this site provides a good basis for any wind developments.
- Even with a high capital cost/kW the payback period is still less than or equal to 10 years.
- With the right capital cost and loan agreement the payback period can be less than 5 years.
- Preferably the capital cost should be around £5000/kW (although the current installed turbine was more expensive) or less.
- The loan interest rate should be kept as close to 5% or lower if possible.

Chapter 9: Turbine Recommendations

When deciding between the two options above there are a few things to take into consideration.

Proven 35	**Scirocco E5.6-6**
3 blades	2 blades
15/20m tower	18/24/30m tower
Direct Drive Generator	PM Synchronous Generator
No Gearbox	Gearbox

Table 12: Some of the differences between the optioned turbines

9.1 Number of Blades: 3 blades vs. 2 blades

- Two bladed machines are thought to be 2-3% less efficient than the 3-bladed turbine. Increasing the rotor size by an equivalent 2-3% can compensate for this[49].
- A two bladed turbine has fewer parts so is lighter to ship and transport so can save money in manufacturing and transport costs.
- This also means there are fewer crane lifts needed to construct the turbine.
- Shadow flicker can be reduced by one third.

However,

- The 2 bladed turbine needs to operate at a higher rpm to produce the same power output of the 3 bladed.
- There is a dynamic imbalance as when the top blade is upright and in the wind stream the bottom blade is shaded by the tower which could cause problems with yawing and put extra stress on the bearings[50].
- Less suitable in some high wind areas.
- To resolve this 2 blade machines should allow for a ‘teetering hub’ so blades can adjust the load across the rotor to avoid turbulence, shear or tower shadow.

9.2 The Gearbox

- Direct drive machines have no gearbox so have no high speed mechanical or electrical elements. This allows them to operate much more quietly.
- Gearboxes don’t tend to have such long lifetimes as the turbine so need to be replaced within the turbine’s lifetime.
- By increasing the number of poles in the generator, the gearing ratio becomes lower and there is no need for the gearbox[51].
- This however means that the generator becomes more bulky and heavier as it has to operate at the same speed as the turbine blades.

9.3 Manufacturer Issues

The company that installs the Eoltec turbine at the school no longer install Proven turbines in Orkney. They don’t have faith in the performance of these machines. This is not uncommon with the Proven 15kW turbine as there are a number of forums discussing the reliability of this machine with a high percentage of comments suggesting they don’t perform as well as the company hopes they would[52]. This was apparent back in 2007 when all machines were shut down because of a problem with the structure which caused unacceptable levels of noise[53]. The turbine has been re-designed a number of times and the company assure their customers that it performs as expected and has MCS accreditation.

The Eoltec 6kW turbine was co-developed by BJRE from Orkney. It is the first small-scale turbine of this capacity to meet Class 1 standards under the MCS. This means it can withstand the extremely high winds speeds that occur in the North of Scotland and has been certified to be able to produce” 10% more electricity than its nearest rival”[54]. This, alongside the higher hub height than other 6kW turbines means that the Scirocco has a slightly higher capital cost. This can be made back through the generation potential this turbine has at the nominated site.

9.4 Recommendation

Taking all these factors into account it seems to suggest that the recommended solution for North Walls is multiple 6kW turbines. These would follow the same manufacture and installation process as the already installed unit and the knowledge of how their current turbine operates gives a convincing argument for the continued installation of this turbine. The relationship the school and council already have with the installer company will mean a consistent and reliable service. The 3 turbines onsite should be able to provide 55.8MWh of electricity for the school. This would be around 21.5% of the school's demand if the additional turbines perform in the same manner as the current turbine.

9.5 Other Considerations

Something that will have to be taken into account when installing multiple turbines in a smaller area is the wake effect. This occurs downstream of the turbine and reduces the wind speed. As it gets further downstream it spreads and returns to the same speed as the non-affected winds. This effect on the turbines will be controlled through the positioning of the new turbines so any possible wake effects are reduced.

The cost/kW increases the smaller the capacity of the turbine. If funding is possible, it may be better to install a larger 50-80kW to supply almost the entire school demand. This would also have the potential for the export tariff on top of the generation tariff and the saving on the bill. The other problem, apart from finding possible funding, may be planning permission for such a large turbine on the school's site. The financial and energy yield outlook for a larger turbine can be found in the appendix.

Chapter 10: Conclusions and Recommendations

10.1 Energy Saving from Current Turbine

The current turbine operates with an average capacity factor of 36%, 98% of the time. Over the course of an entire year this allows for 18.5MWh to be generated which provides 7.1% of the school’s energy demand. The remaining 241.3MWh are currently supplied by the national grid.

10.2 Current Income from FITS

Currently the FITS rate for this turbine sits at 9.4p/kWh as the turbine was installed before 2009 but was registered for ROCS. Assuming the electricity grid rate is 15p/kWh as Orkney is on a higher tariff due to its location then the saving for the turbine becomes 24p/kWh with all electricity generated being used onsite. Generating 18.5MWh gives an income through FITS and offsetting the electricity of £4440. This also provides an equivalent CO_2 saving of over 10000kg (10tonnes).

10.3 Options for Increased Wind Potential

There are two options for a small-scale upgrade for this site using a MCS accredited Orkney installation company. FITS and electricity displacement should initially be 43p/kWh of electricity generated; 28p/kWh from generation of electricity and 15p/kWh from displacing grid electricity. This value should rise due to inflation of both the FIT rate and the cost of grid electricity. The FIT rate is guaranteed for the next 20 years.

10.3.1 Option 1: Proven 15kW turbine

This turbine would be installed by Orkney Business Ring Renewables Ltd. who are Proven’s reseller in Orkney but were not the previous installation company. With a 36% capacity factor the 15kW turbine should be able to generate 46.5MWh of electricity. This makes up 17.9% of the school's demand and along with the current 6kW turbine should be able to meet the councils 25% target.

This turbine should have a payback period of equal to or less than 5 years and can generate almost £20,000 through FITS and the potential displacement of grid electricity. It should also be able to offset 25.4tonnes of CO_2 each year.

10.3.2 Option 2: Two 6kW Eoltec Scirocco turbines

These turbines would be installed by Bryan J. Rendall Electricals who already have a relationship with the school after installing the first turbine. With the same 36% capacity factor the two 6kW turbines should be able to generate 37.2MWh of electricity. This makes up 14.4% of the school's demand and along with the current turbine totals 21.5% of the total energy demand of the school.

The Eoltec turbines have a higher rate of cost/kW so the payback period would be 7-8 years. The turbines should be able to generate £16,000 and offset over 20 tonnes of CO_2 each year.

10.4 Wind Installation Procedure

With the saving in electricity, the income generated and the environmental benefits from the installation of a wind turbine then schools over the country may wish to follow this example if they have not already. The procedure below gives an idea of what the process involves.

- Identify possible renewable energy options; solar is the most popular installation in schools but in areas, like Orkney, with such a good wind resource then wind power is the obvious choice.
- Evaluate the energy yield at the chosen site from renewable sources. This can be calculated using an estimated capacity factor for the site.
- This will allow the identification of the capacity range for the chosen renewable to provide x% of the demand.

- Identify local accredited installers that will be able to properly size and maintain the chosen renewable system. This will involve looking at the companies' previous projects.
- Identify grants and finance options after calculating the potential FITS income and payback periods; this can usually be carried out by the company providing the installation.

10.5 Other Renewable Energy Systems Potential

Solar power is a popular installation for schools. It takes up no ground space as it is installed on the roof of the buildings. There are a number of schemes that will fund projects in schools across the UK like the Eco-Schools Solar Programme in England[55]. They guarantee zero installation and maintenance costs. All electricity generated goes to the school and there will be a display system installed so staff and pupils can see the electricity generated.

Another renewable system installed in schools and colleges is biomass heating. An example of this is John Wheatley College in the East End of Glasgow[56]. It burns wood chip to generate heat that can supply almost 75% of the college's heating demand with a gas boiler providing the rest. The college has a number of sustainable features including the biomass boiler, PV systems and air-sourced heat pumps which means it obtained an A rated Energy Performance Certificate back in 2009.

Air source and Ground source heat pumps absorb heat from the outside air and the ground to use in radiators or underfloor heating systems. These both need electricity to run; this electricity could be generated through another renewable system operating at the school. An example of this is Morgan Academy, Dundee[57] who use a solar system to power the ground source heat pumps that provide heat to their atrium and assembly hall.

Chapter 11: Demand Side Management

Demand Management involves changing how we use energy so we can decrease our peak demand on the grid. This can be through encouraging the use of some utilities only when a good source of energy is available. This is usually when there are renewable sources onsite and there has to be planning in place so highest demand is met by peak production periods. Another option is to reduce the total amount of energy we use. This can be done through the education of the community about reducing lighting demand, switching off computers, T.V.s, etc and through better heating controls. The heating/cooling demand can also be reduced by adding shading or changing the layout of the building so natural light is used as much as possible. This should result in reduced energy costs and a better use of any capacity supplied by a renewable source. Along with a decrease in cost it should also mean a reduction in emissions which will improve the buildings energy rating.

The main types of demand side management[58] are:

- An Energy Reduction Programme - this reduces demand through more efficient buildings and equipment.
- A Load Management Programme – the spread out use of utilities to decrease demand at peak times.

The two main areas that energy demand can be reduced are:

11.1 Lighting

Lighting can amount to 50% of electricity demand. This can be reduced by:

- Using energy efficient bulbs
- Using appropriate lighting depending on the area
- Use natural light where possible. This includes installing roof panels or skylights.
- Light coloured walls and ceilings will reflect light and reduce need for lighting.

11.2 The Building

There can be large savings available at a low cost by initially evaluating what can be done by simple energy saving methods like:

- Improving sealing and insulation in:
    - Floors, walls, ceilings and roof spaces
    - Through cracks in windows and doors
    - Fireplaces
- Run electrical equipment only when needed, i.e. washing machines and dishwashers only run with full load.
- Space heating and cooling – use blinds or curtains to keep the sun out if it's too warm or to allow the sun in if it's cold. They will also help keep the building insulated at night.
- Replace older equipment with newer, more efficient machines.

11.3 North Walls

North Walls is a new school so has the insulation needed to meet energy standards. Therefore there is limited heat lost to the surroundings as the building is properly insulated. Because of the climate there is a much higher heating demand than needed for cooling. Any source that could provide additional heating power could dramatically reduce the electricity demand used to heat the school.

One option for this is the ground source heat pump. A ground source heat pump will extract the heat from the ground surrounding the school, compress it to raise the temperature and then a heat exchanger takes this heat and uses it through the heating system to radiators and underfloor heating or to provide hot water[59]. The ground source heat pump needs electricity to run. A 9kW heat pump requires 21.55MWh per year to run but can supply 77.76MWh of heating throughout the year. This is almost 30% of the school's entire electricity demand. This 21.55MWh would need to use the entire supply from one 6kW turbine to power it however will be able to reduce grid demand overall. A number of capacity ground source heat pumps were considered as an additional option for this site for both the solutions suggested.

11.3.1 Option 1: Proven 15kW Turbine

Heat Pump Capacity	School Demand (MWh)	Heat Pump Demand (MWh)	Total Demand (MWh)	Current Turbine Supply (MWh)	New Turbine Supply (MWh)	Turbine Supply Percentage	Heat Pump Supply (MWh)	Heat Pump Percentage	Total Renewable Percentage	Grid Supply Required (MWh)
4.5kW	259.7645	10.675	270.4395	18.49	46.5	24.0%	38.26	14.1%	38.2%	167.190
9kW	259.7645	21.745	281.5095	18.49	46.5	23.1%	77.76	27.6%	50.7%	138.760
12kW	259.7645	29.455	289.2195	18.49	46.5	22.5%	105.87	36.6%	59.1%	118.360

Table 13: Potential for renewable generation with 3 different capacities of GSHP along with the 15kW turbine.

11.3.2 Option 2: Two Scirocco 6kW Turbines

Heat Pump Capacity	School Demand (MWh)	Heat Pump Demand (MWh)	Total Demand (MWh)	Current Turbine Supply (MWh)	New Turbine Supply (MWh)	Turbine Supply Percentage	Heat Pump Supply (MWh)	Heat Pump Percentage	Total Renewable Percentage	Grid Supply Required (MWh)
4.5kW	259.7645	10.675	270.4395	18.49	37.200	20.6%	38.26	14.1%	34.7%	176.490
9kW	259.7645	21.745	281.5095	18.49	37.200	19.8%	77.76	27.6%	47.4%	148.060
12kW	259.7645	29.455	289.2195	18.49	37.200	19.3%	105.87	36.6%	55.9%	127.660

Table 14: Potential for renewable generation with 3 different capacities of GSHP along with the two 6kW turbines using data from Merit to give GSHP demand and the supply it may provide.

Therefore with the additional of a ground source heat pump the renewable sources onsite would be able to supply between 35 and 60% of the school's demand. This will allow for a substantial saving in CO_2 emissions and will be eligible for an RHI income for every kWh generated. The current rate for RHI below 100kW is 4.5p/kWh.

Taking the cost of a ground source heat pump to be £1200/kW, the payback period from just the RHI potential is given in the table below.

Capacity (kW)	Estimated Capital Cost (£)	Potential RHI Income	Payback Period (years)
4.5	£5400	£1,721.70	3.1
9.0	£10800	£3,499.20	3.1
12.0	£14400	£4,764.15	3.0

Table 15: The potential payback period for the three different capacities of GSHP

This means that the payback period for the turbines will not be affected as the same FITS generation income will go to paying back the turbine. The Ground Source Heat Pumps used in this analysis were Calorex models and are MCS approved[60].

Therefore if the possibility of ground source heat pumps is available on this site then they would greatly increase the renewable supply to the school and allow for a much greater potential income from these.

Final Conclusions

The further installation for turbines on this site is definitely recommended. Through this study I have recommended the installation of one 15kW turbine or, if possible, another two 6kW turbines. I also recommend the installation of Ground Source Heat Pumps to displace some of the heating demand that currently is supplied by electricity from the turbine and the grid. This would mean at least 35% from renewable sources and a generation income from both FITS and RHI. If the GSHP is not available then the turbines would still be able to supply 20 – 25% of the school's demand.

Further Work

Although the aim was to supply around 25% of the school's demand, there is the possibility to supply 60-100% by installing a 50 or 80kW turbine. The initial financial calculations can be seen for these capacity turbines in the appendix. What would be the issue is the funding for a turbine this size; although it has a lower cost/kW, it will have a much higher capital cost so funding may not be guaranteed even with the return from the FITS payments and the potential bill saving.

Also with a larger turbine some of the electricity generated may be more likely to be fed back to the grid. Therefore, although the grid connection is already there, it will be subject to review to make sure it can handle electricity being fed back into it from the school. This would also encourage a battery storage system to be put in place to store the surplus from one of these larger turbines.

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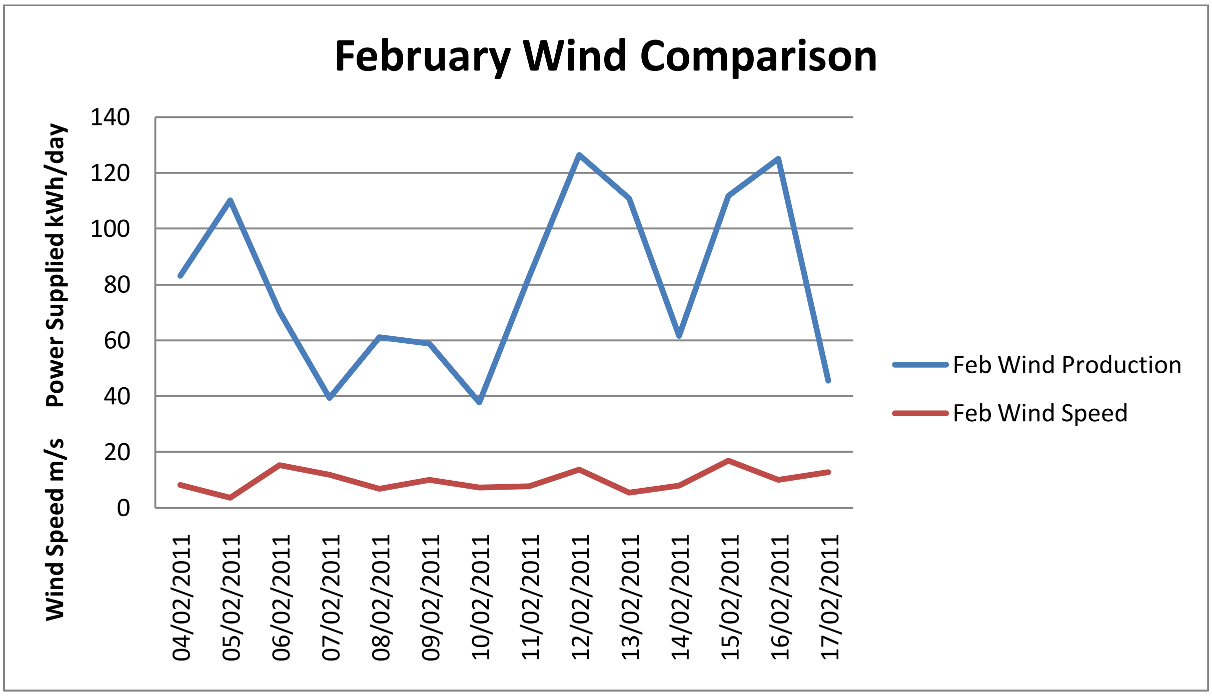
Appendices

Appendix 1: February Wind Comparison

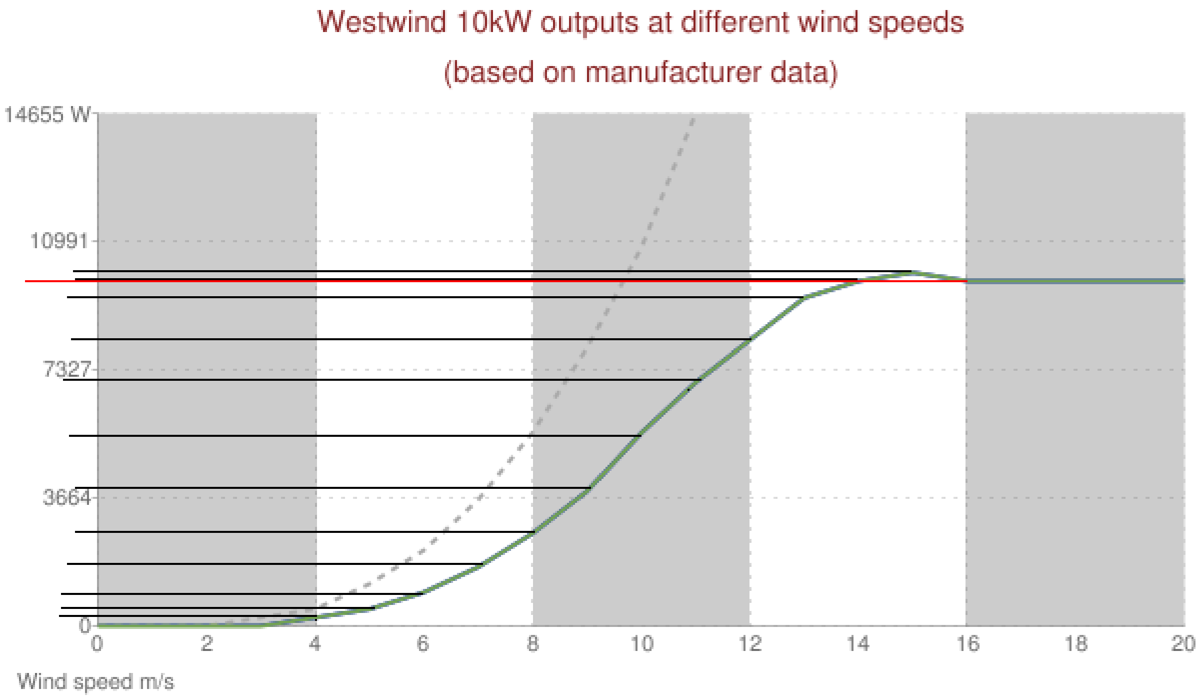


Graph to show lower wind speed does not mean lower power production.

This gives indication of best wind direction.

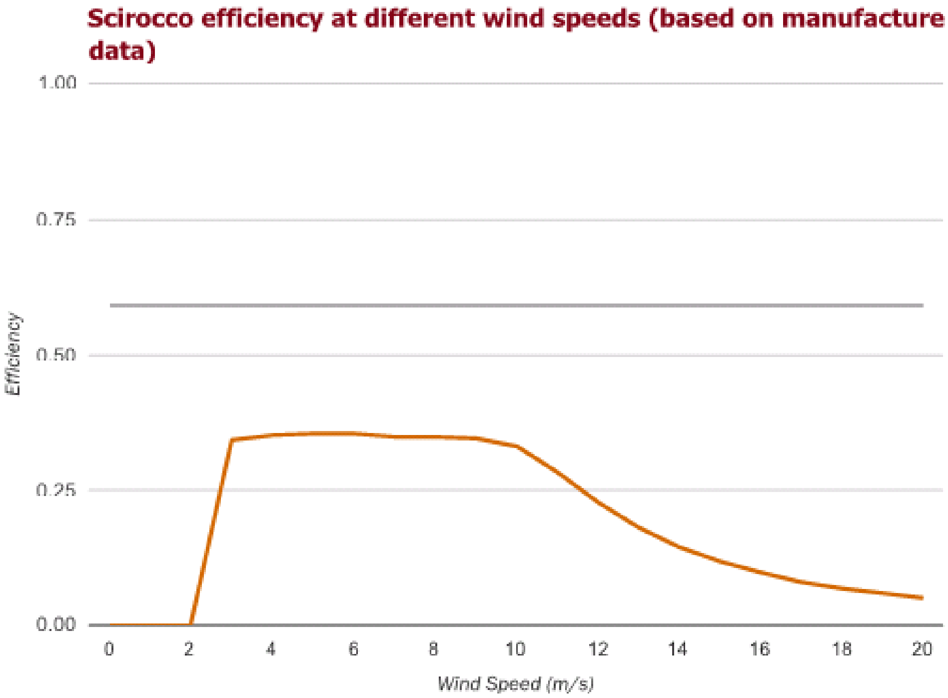
Appendix 2: Power Output Curves for additional Merit turbine analysis

Output curve for Westwind 20kW turbine used in Merit.
Source: Better Generation



Output curve for Westwind 10kW turbine used in Merit.
Source: Better Generation

Appendix 3: Eoltec Scirocco E5.6-6 Efficiency Curve



The efficiency curve for the installed turbine; this allowed the C_p values to be calculated for the wind speeds at the site in Orkney.

Source: Better Generation

Appendix 4: Financial Analysis Tables

15kW Proven Turbine

Loan Rate	Payback period	Profit (1 year)	Profit (5 years)	Profit (10 years)	Profit (20 years)
2.50%	4	£11,427	£61,568	£135,072	£392,877
5%	5	£10,512	£56,994	£125,925	£383,729
7.50%	6	£9,541	£52,140	£116,216	£374,020
10%	6	£8,518	£47,022	£105,980	£363,785

Loan Period	Payback period	Profit (1 year)	Profit (5 years)	Profit (10 years)	Profit (20 years)
2	5	-£13,986	£31,309	£139,091	£396,896
4	5	£1,362	£28,163	£135,945	£393,750
6	5	£6,461	£36,740	£132,701	£390,506
8	5	£8,999	£49,429	£129,361	£387,165
10	5	£10,512	£56,994	£125,925	£383,729

Cost/kW	Payback period	Profit (1 year)	Profit (5 years)	Profit (10 years)	Profit (20 years)
2000	3	£14,847	£78,762	£169,704	£433,514
3000	4	£12,680	£67,878	£147,814	£408,622
4000	5	£10,512	£56,994	£125,925	£383,729
5000	7	£8,345	£46,110	£104,035	£358,837
6000	8	£6,177	£35,226	£82,146	£333,944

Capacity Factor	Payback period	Profit (1 year)	Profit (5 years)	Profit (10 years)	Profit (20 years)
0.2	9	£2,291	£13,910	£34,432	£176,601
0.25	7	£5,031	£28,271	£64,930	£245,644
0.3	6	£7,771	£42,633	£95,428	£314,686
0.35	5	£10,512	£56,994	£125,925	£383,729
0.4	5	£13,252	£71,355	£156,422	£452,772
0.45	4	£15,992	£85,717	£186,920	£521,815

Two 6kW Eoltec Turbines

Loan Rate	Payback period	Profit (1 year)	Profit (5 years)	Profit (10 years)	Profit (20 years)
2.50%	7	£6,039	£33,670	£76,694	£278,132
5%	8	£4,942	£28,181	£65,717	£267,155
7.50%	8	£3,777	£22,356	£54,067	£255,505
10%	9	£2,548	£16,215	£41,784	£243,222

Loan Period	Payback period	Profit (1 year)	Profit (5 years)	Profit (10 years)	Profit (20 years)
5	7	-£2,364	-£8,348	£75,810	£277,247
7	8	£1,823	£12,588	£71,859	£273,298
10	8	£4,942	£28,181	£65,717	£267,155
12	8	£6,143	£34,186	£77,726	£262,917
15	8	£7,329	£40,120	£89,594	£256,349

Cost/kW	Payback period	Profit (1 year)	Profit (5 years)	Profit (10 years)	Profit (20 years)
£2,000	3	£11,878	£63,010	£135,763	£346,812
£3,000	4	£10,144	£54,303	£118,252	£326,898
£4,000	5	£8,410	£45,595	£100,740	£306,984
£5,000	7	£6,675	£36,888	£83,228	£287,070
£6,000	8	£4,942	£28,181	£65,717	£267,155
£7,000	9	£3,208	£19,474	£48,206	£247,241
£8,000	10	£1,474	£10,767	£30,694	£227,327

Capacity Factor	Payback period	Profit (1 year)	Profit (5 years)	Profit (10 years)	Profit (20 years)
0.2	12	-£1,635	-£6,286	-£7,477	£101,453
0.25	10	£557	£5,203	£16,921	£156,687
0.3	9	£2,749	£16,692	£41,319	£211,921
0.35	8	£4,942	£28,181	£65,717	£267,155
0.4	7	£7,134	£39,670	£90,115	£322,390
0.45	6	£9,326	£51,160	£114,513	£377,624

Appendix 5: 50kW and 80kW Turbine Analysis

The analysis is based on the Polaris 50kW turbine and the 80kW Wind Energy Solutions turbine. The supply was calculated using the capacity factor equation with the value of 0.35 taken as the capacity factor. The capital cost for the 50kW turbine was taken from the manufacturer details and was provided by BJRE for the 80kW turbine. A similar analysis as above was carried out to provide overall figures for payback and profits.

Capacity	**Supply**	**Total Loan Cost**	**Payback period**	**Profit (1 year)**	**Profit (5 years)**	**Profit (10 years)**	**Profit (20 years)**
50kW Turbine	149MWh/ year	£194,257	5	£38,251	£205,366	£448,753	£1,264,522
80kW Turbine	238MWh/ year	£310,810	5	£61,201	£328,586	£718,005	£2,023,235

Table 16: projected profit over 20 years for both medium size turbines.

Turbine	**WES18**	**Polaris P17-50kW**
Rated Power	80kW @ 12.5m/s	53kW @ 11m/s
Peak Power	80kW	53kW
Rotor Diameter	18m	16.5m
Swept Area	254.5m2	213.8m
Tower Height	18m	18m
Cut-in speed	2.7 m/s	2.7 m/s
Cut-out speed	25 m/s	25 m/s
Survival Speed	60 m/s	59 m/s
Max. Year Supply (kWh)	252288	157680
Percentage Supplied	97.12%	60.70%
with current turbine	104.24%	67.82%

Table 17 gives the specifications for each larger turbine. It also shows the calculated supply with the onsite value of capacity factor of 0.36. This value was used to calculate the possible percentage of the school's demand this turbine could supply, on its own, and with the current installation.