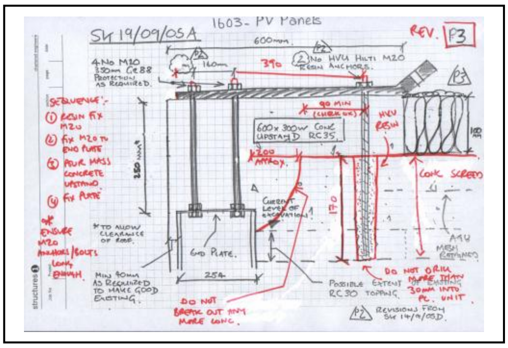
The one difficulty experienced during the installation was establishing the winch anchor points. Two were necessary, one for each turbine, to allow lowering of the units. The designers/installers did not properly investigate this matter in advance. A revised design had to be issued by the Structural Engineer. The revised detail was the main reason for cost over-run.



Final winching point

The construction period went smoothly , a Health and Safety Plan was produced that required the closure of the Innovation Centre Atrium during the short installation period. Therefore the works were co-ordinated with the college half term holiday.

Final Cost Analysis

Work stage	BRITA Budget €	Final cost 2008 €
▪ Planning consent and building Regs approval	-	7909
▪ Detailed design	8250	
▪ Supply and installation	75000	96424
▪ Specialist monitoring equipment	-	10687
▪ Health and Safety plan		1466

The reasons for the cost deviations are:

- Inflation since the BRITA Project application
- The late design of the winching point costing about €6170 extra
- The extra cost for specialist monitoring equipment
- Ancillary costs for Planning and Building Regulation approvals together with Health and Safety planning not allowed for in the original BRITA design costs

Post Installation Problems:

- Malfunctioning automatic brakes. These brakes were fitted at the suggestion of the manufacturer so the turbines would automatically stop if destabilisation occurred due to turbine blade damage. These had never been fitted before by Proven and proved very unreliable. Proven later fitted a better braking system and replaced the blades with stronger composite material at no extra cost. The sticking brakes were repaired in May 2007.
- Hand braking system difficult to operate and unreliable. The college experimented with remote braking but they proved ineffective. A better hand braking system was fitted, at no extra cost by the manufacturer, in August 2007.
- The breakdown and eventual replacement of one inverter. The replacement occurred in May 2007.
- Poor customer support from both the installer and manufacturer. Defects were slow to be rectified. They were disinterested in the poor output figures.

1.2 The monitoring period was from 1st March 2007 to 29th February 2008.

The wind turbines were fitted with the following monitoring devices:

- Both turbines are remotely linked to the college energy consumption monitoring system called Satchwell Utilities Monitoring. The meters are remotely read utilising text messaging.
- As a back up the meters were read weekly.
- The west turbine is fitted with a data logo and weather station. This provides detailed information on wind speed, wind direction and turbine output prior to the inverters. The meters read output after the data logger.

Output data from meter reading is as follows:-

<u>Combined Wind Turbine Output Analysis</u>

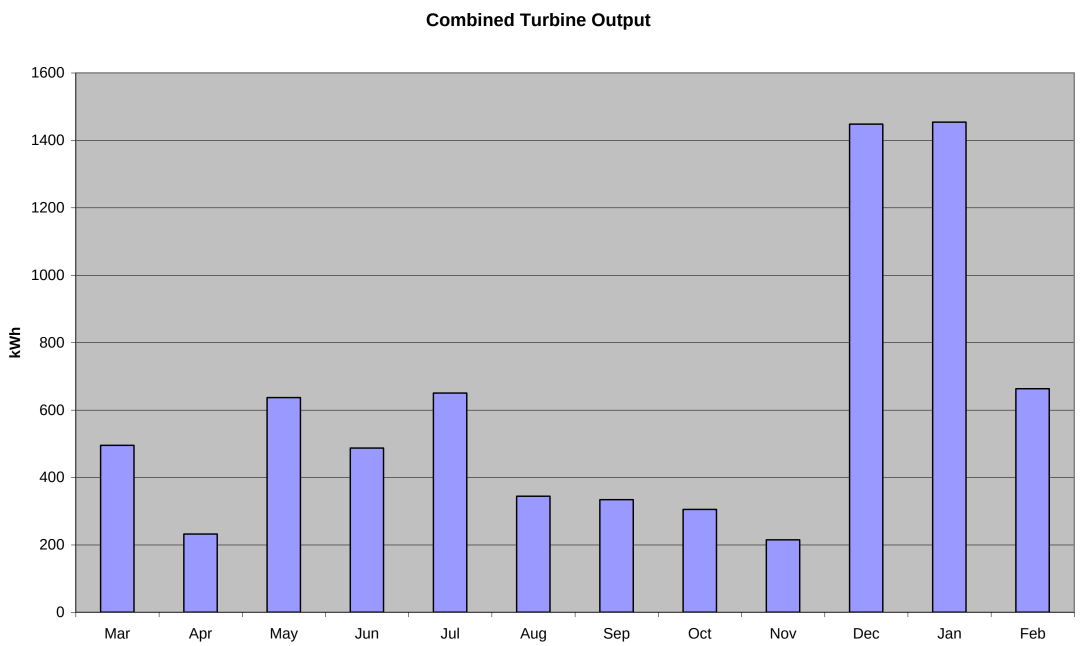
The data is collated from fixed kWh metering of the energy generated, where the meters are located after the inverters etc., therefore losses in the control gear are allowed for.

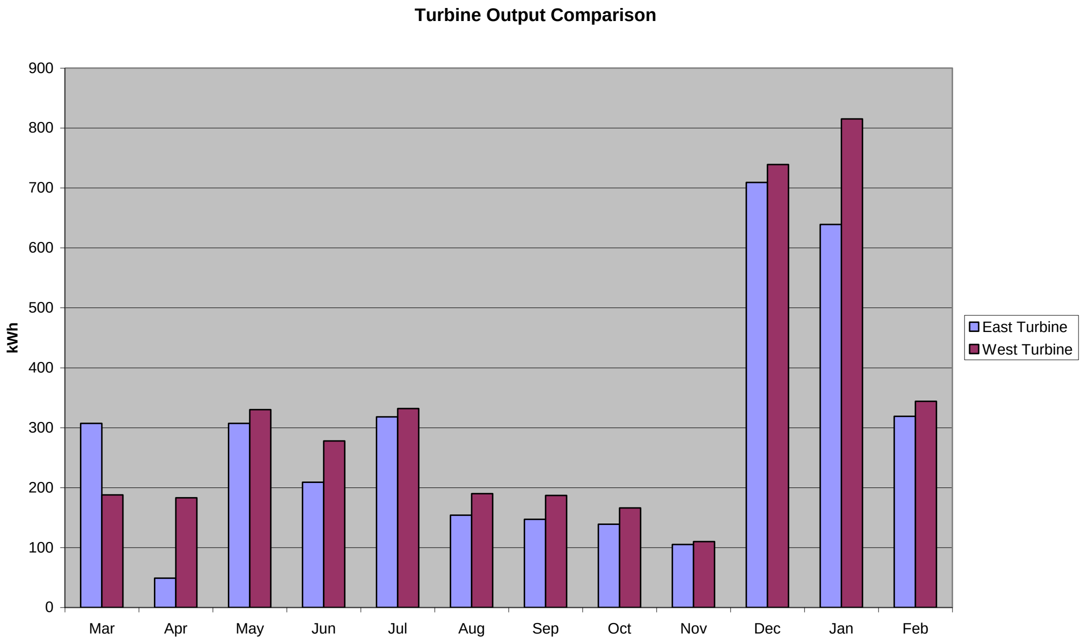
The turbine output comparison indicates generally, that the West turbine (Turbine B)has a greater generating capacity than the East. This is probably a function of the turbines relative location to the adjacent tower block building, and the incidental predominant wind direction.

This data is collected manually each day from fixed meters and will vary compared to the data logged at the turbine mast. This is because the logged data time reference is 00:00 hrs (ie the time each day that the data runs from), however the manually collected data is recorded at random times which may be as much as 10 hours or more time difference.

TOTAL CUMULATIVE POWER GENERATED

Month	Turbines A+B	Turbine A	Turbine B	Turbine B measured power generation before inverters
Mar	*495*	307	188	318
Apr	*232*	49	183	69
May	*637*	307	330	310
Jun	*487*	209	278	212
Jul	650	318	332	329
Aug	344	154	190	142
Sep	334	147	187	130
Oct	305	139	166	132
Nov	215	105	110	138
Dec	1448	709	739	745
Jan	1454	639	815	723
Feb	663	319	344	348
TOTAL (kW/h)	*7264*	3402	3862	3591




Turbine Output Comparison
kWh
900
800
700
600
500
400
300
200
100
0
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
East Turbine
West Turbine

Output data from Data Logger fitted to West Turbine

Summary for the 12 month period is provided below and the whole report can be found in Appendix A.

14 Annual Summary and Conclusions

14.1.1 The annual wind rose for the site is shown in figure 14.1 below. The prevailing wind is predominantly from a North Westerly direction which is a little unusual for the UK, although as mentioned previously a quick look at wind atlas data for both Exeter and Burrington (Devon) shows a similar trend. Note that the average mean speed at the site for the year is just 2.8m/s.

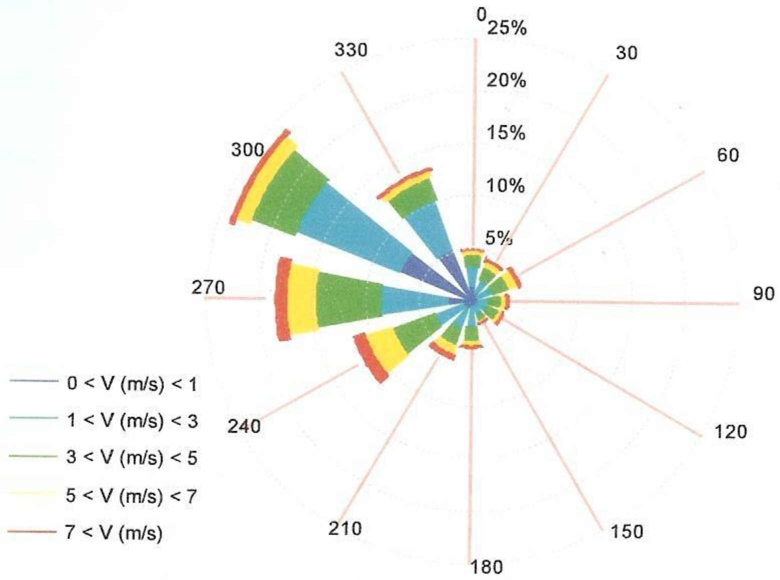


Figure 14.1; Annual wind rose for the site.

14.1.2 In the period from 01st March 2007 to 29th February 2008, the turbine yield was 3591kWh representing a capacity factor of 6.8%. In the author's experience this value of capacity factor is not unusual for a wind turbine in an urban environment, particularly so when one considers the low mean speed at the site. Without a thorough analysis of the wind speed distribution, this would indicate that there is a reasonably wide distribution of wind speeds about the mean. It is also worth noting that over 40% of the yield was obtained in a two month period from December 2007 to January 2008 when the wind speeds were significantly higher than the annual mean.

14.1.3 The data also gives no indication if the yield is typical of a 'mean' year. The only way of estimating the yield in a typical year would be to obtain both short and long term data from a nearby Met Office station and correlate the data with that from the site.

14.1.4 The final plot shown in figure 14.2 is the power curve generated from the whole dataset from March 2007 to February 2008. The black dots represent the one minute average readings (they appear as lines due to the 0.1m/s resolution of the anemometer) and the blue line is the 'mean' power curve derived by taking an average of the power readings in each wind speed interval.

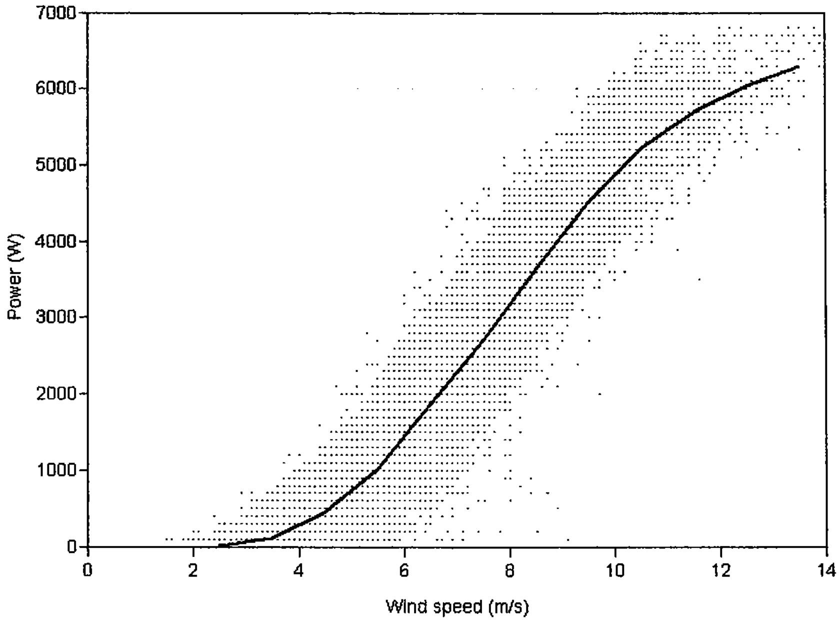


Figure 14.2; Power curve from the annual dataset.

14.1.5 Note that the maximum power output from the turbine is around 6.8kW, which is somewhat higher than the 6kW rating of the turbine. In the authors experience this particular turbine does generate 6kW *at the point it is connected to the grid*. It is unclear from the documentation where the power readings are taken, but they may represent the raw AC power of the turbine, which will not account for the losses in the rectifiers and inverters.

1.7 Data Analysis

1.7.1 Local Meteorological Office Data

- Average annual windspeed for the Kings Road site 5m/s at 10m above ground level (Department for Business Enterprise and Regulatory Reform).
- The actual recorded wind speeds at the Plymouth Met Office Monitoring site are:-

April 07	3.9 m/s
August 07	4.5 m/s
September 07	4.2 m/s
October 07	3.7 m/s
November 07	4.1 m/s
December 07	7.0 m/s
February 08	5.4 m/s

- Wind Rose data from the Met Office Plymouth monitoring site for the 10 years 1994 to 2003 show a clear pattern of the main prevailing winds, throughout the year coming from the south west. They could not provide, at this stage, a wind rose diagram for the monitoring year.

1.7.2 Energy Generation

The annual output of only 7264 kWh/yr is very disappointing and it has been difficult to get any significant assistance from the manufacturer, Proven, to investigate the short fall.

The key issue in the monitoring year is wind speed. The lowest windspeed predicted for this roof was 5.2 m/s. The monitoring year revealed an actual average windspeed on only 2.8 m/s.

The lack of wind will have a drastic effect on output. The following quote from BWEA helps to explain the problem.

“The power available from the wind is a function of the cube of the windspeed. Therefore if the wind blows at twice the speed, its energy content will increase eight-fold. Turbines at a site where the wind speed averages 8 m/s produce around 75 to 100% more electricity than those above the average wind speed is 6 m/s”.

A private recalculation using an Open University calculation model using the actual average wind speed of 2.8 m/s predicts an output 4400 kWh/yr but the model is said to be inaccurate at such low wind speeds.

The low windspeed seems to be due primarily to micro climate effects caused by the Tower Block. The original expectation was, this should not have a profound effect since the Tower Block is situated on the north side of the turbines, i.e. the opposite side to the prevailing wind. Also the local measurements show prevailing wind coming from the

north west rather than the expected south west, reinforcing the impression of micro climate effects.
Other issues that have contributed to the low output are as follows.

- Lower than average autumn wind speeds during the monitoring year, September, October and November.
- The prevailing wind coming from the North West means the more easterly turbine output has been lower than the west turbine.
- Faulty equipment remained during the monitoring period through to and including May 2007.
- Some minor output was lost due to turning off the east turbine as a result of complaints of shadow flicker. The loss would have been minimal since this happened only during the summer months for very short periods.
- Invertor losses which seem to amount to about 10% of generated electricity. Also there is a lag in the operation of the inverters and they switch off when over generation occurs.

1.7.3 User Experience

The college's experience of owning and running wind turbines has been mixed and is summarised as follows:-

- The erection of the turbines created a great deal of media and local interest. The turbines featured briefly in news programmes both on local television and radio. Detailed enquiries arrived from local business and the public sector nationally, on average, monthly throughout 2006 and well into 2007. This interest has now subsided.
- The poor customer service from both Proven and the installers has been very frustrating. It became clear Proven had been swamped with orders due to government grants but had not expanded their workforce in response.
- The intensity of shadow flicker the turbines produce was completely unexpected. The turbines project a strobe like flickering shadow into rooms to the north of the turbines for limited periods on sunny days. The most intolerant of this effect are the college library staff during the summer months.
- The turbines cause the steel frame of the Innovation Centre to shudder during periods of strong wind. This is only a minor effect but a minority of occupiers found the effect disturbing. The complaints finally subsided by the end of 2007.
- There have been <u>no</u> formal complaint regarding noise from either college users or surrounding neighbours.

1.8 Summary

	Predicted	Obtained	Predicted total	Obtained total
Wind turbine output	5kWh/m^{2}a	1.3kWh/m^{2}a	30000kWh/a	7264 kWh/a
Measured electricity consumption 2002			650000 kWh/a	
Turbine output predicted percentage of consumption			4.6%	
Actual percentage of consumption			1.1%	

1.8.2 Overall Economic Evaluation

Cost of turbines foreseen	Cost of turbines actual	Savings foreseen	Savings actual	Payback foreseen	Payback actual
€75000	€96424	€3000	€726	25 years	133 years

It is hoped the energy production will reach 10000 kWh/a now the turbines work properly although this would still produce an excessive payback period of 96 years.

1.9 Lessons Learned

1.9.1 Wind Turbines

- The most important issue, for those considering a wind turbine is to do a year of wind speed monitoring before making the decision to purchase. DO NOT rely on existing wind speed data bases. The key factor in the performance of the turbines at this College is the very low average wind speed of 2.8 m/s caused by the presence of the Tower Block.
- It is essential that a local installer is used who takes full legal responsibility for the units they supply. Problems will arise and a local supplier is much more likely to be responsive.
- The installer must be instructed to fully consider all design issues before starting work. Otherwise the risk of unforeseen expenditure increases greatly. The winching points at the college should not have needed re-design at a late stage in the project.
- An installer with proper experience of installing wind turbines is essential. This will mean taking up references before making an appointment. The college used their installer due to previous experience and their success at winning grants. But it was then discovered they had very limited experience of wind turbines.
- The effects of shadow flicker must not be underestimated. This is much more than moving shadows. It is a strobe lighting effect that is caused by the sunlight projecting through the moving turbine blades into adjacent parts of the building. This means predicting

the route of turbine shadows through the year to assess and identify problem areas.

- Vibration has been an issue for the college. The Innovation Centre is a steel frame building but the dampening under the turbines' support structures is very basic. The designer was challenged to consider this more prior to installation but he stated it was somewhat experimental. The shuddering the building experiences only occurs during strong wind speeds. It is a minor shuddering but has caused some concern among occupants. Signs have been put up around the upper floor rooms explaining the vibration. This movement is less than would be induced by bus on tick-over next to the building or the vibration that can be caused by heavy trolleys.

must be available otherwise the structural investigations to establish suitability of the building would be cost prohibitive. It is presumed a reinforced concrete structure would transmit less vibration than a steel structure.

- The inverters to rectify the turbines' power output to the electrical supply of the building caused a power loss of up to 10%. This is made worse by time lag for the in-line inverters to become active when the power output trigger points are reached. What is worse, when the turbines over generate, the inverters automatically tripout. The selection of the inverters and their programming needs to be carefully considered at the design stage.
- In windy weather the noise from the turbines is more significant because it can be experienced directly underneath the turbines adjacent to the building. The noise at worst, is like the cutting of the air, helicopter blades will produce although there is no loud engine

noise. But when they are at their noisiest so are background noise levels due to the high wind conditions. No actual complaints have been received from users of the site, occupiers of the building or neighbours. Noise is not a problem.

- The local planning office was quite supportive so planning consent was easy to obtain although it had to include an environment impact assessment. Building Regulations Approval was straight forward. Installation was quick and easy although a proper Health and Safety risk assessment and method statement must be prepared.

1.9.2 General lessons learnt during the Tower Block design process.

- Untested opinions and ideas are critical to the creative process, however the modelling of these ideas are essential. Time needs to be built in to the programme to facilitate sufficient analysis and testing of ideas, particularly when dealing with the constraints offered by an existing building.

- It is important to establish a model of the building to allow the rapid testing of ideas, as the most obvious concepts do not always offer the greatest benefit. For example the proposed vertical brise soliel under the PV array to the west elevation. Modelling showed a good saving from solar gain but the additional cost was unacceptable to the client
- The long payback period discourages the choice of low energy technologies unless grant funding is available to support investment.

- Alternative and more adventurous solutions should always be considered as they can have positive benefits if properly researched, proved and implemented.

- It is possible to integrate technologies to serve dual purposes. In the case of this building the PV arrays would also serve as solar shading. Careful consideration of all aspects of a project at the outset will permit such integration.

- The goal for all designers is that the services concepts should always start from a desire to consume zero energy and only add what is required to make the building function. It is not acceptable to use established benchmarks as a starting point as this can stifle innovation and lead to tried and tested solutions coming to the fore. This should apply to all projects and not just those seeking to be specifically energy saving.

- Better control of services can save considerable quantities of energy. This should be coupled with high quality commissioning procedures and concise training of the Client in the best use of the systems. Poorly trained people will not use systems effectively and energy consumption will suffer as a result.

- The introduction of thorough sub-metering linked to the BMS is essential to allow for efficient management of utilities. There is an education process required at the handover stage to ensure that building users understand the advantages and/or limitations of any installed systems.

- There may be an expectation that the systems will perform functions or provide results that are outside of design parameters. This needs to be clearly explained such that the end users are "bought in" to the processes at an early stage. Close liaison with the Client and end users through the design process is a great advantage.

- Many low energy technologies are currently produced by small businesses. These businesses struggle to provide good customer service when experiencing high demand. The use of businesses within the same region as the development is recommended.

Appendix A – separate document