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AUSTRALIA

A Feasibility Study of the Application of Integrated Solar and Wind Power Plant in the City of Victor Harbor

Victor Harbor Council
Centre for Energy Technology

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Life impact The University of Adelaide

Executive Summary

A feasibility study into the use of hybrid solar and wind systems has been undertaken by the Victor Harbor City Council. The initiative, undertaken in conjunction with the Centre for Energy Technology at The University of Adelaide, builds upon the strong support for sustainable energy development projects already implemented by the Council. The overall aim of the initiative is to develop and commission an integrated wind and solar renewable energy system that can best utilise the renewable energy resources of the region and be used to reduce the dependency of the council on mains electricity.

The system is to be devised so as to be capable of powering domestic applications and hence assist in reducing the dependency of the Civic Centre and the City's street lighting on mains electricity.

The study has been undertaken using the Victor Harbor Civic Centre as a test site. The wind and solar energy available at the Civic Centre typifies that within the council jurisdiction and therefore provides the necessary information required to identify the most suitable component types for the hybrid system.

A market evaluation of currently available wind and solar technologies has been conducted as part of the project. This evaluation has provided the project with the necessary information to approximate costs and performance for the different types of components when operating in the City of Victor harbour. Combining this information with the opinions and desires of the council members has allowed the project to recommend what is considered to be the most suitable wind and solar technology types for the integrated system concept.

The feasibility study concludes with the recommendation that the hybrid system concept be further developed. Although the concept does not largely improve the cost of both solar and wind technology, combining the two technologies increases the energy that is produced in a given area and it is this result that supports this recommendation.

The recommended system features a Savonius turbine supplemented with two solar panels. The amount of power produced by each system will depend on the size developed and its siting, but estimates can be made by considering the data presented in this report. A suggestion of this project is that one system size is developed, and that additional hybrid system devices be used when additional power to that provided by a single device is required.

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Introduction

Since 2005, Victor Harbor City Council has actively promoted "environmental awareness, sustainability and best practice land management"[1]. In continued support of these ideas, Victor Harbor City Council, in cooperation with the University of Adelaide's, has investigated the feasibility of renewable energy generation for the City Council chambers/Library complex (jointly, the Civic Centre) and the city's streetlighting. It is the intention of the council to reduce or eliminate the environmental impact of these structures' power consumption.

Currently, the Victor Harbor Civic Centre relies upon the traditional energy sources of energy such as coal and natural gas for all electrical needs. The cost of powering the City's lighting alone stands at $180,000 a year, whilst the Civic Centre consumes $80,000 of electricity per annum. Converting infrastructure to sustainable energy sources would not only set a community-wide standard of environmental responsibility, but would also reduce the fiscal burden of powering the Civic Centre. In addition to these priorities, significant scope exists to support relevant local industries associated with renewable energy by seeking there expertise in the project.

To date, over nine hundred Victor Harbor households have installed solar panels as part of the Community Purchase of Renewable Energy Program (CPREP). Home-scale PV systems cost between $14,000 and $20,000. This is by no means an insignificant sum of money, but the citizens of Victor Harbor are markedly in support of renewable energy in their community.

In light of its proven track record and the support of its citizens The Victor Harbor City Council has proposed the development and installation of hybrid solar/wind energy systems to reduce the aforementioned dependence that the Council has on traditional energy sources. The integrated systems are to feature a wind turbine supplemented by photovoltaic (PV) panels. The systems are to be such that they can be installed in a suburban area and therefore provide the scope for further installations in domestic environments. The purpose of this report is to assess the potential for such a system to be used in the region of the City of Victor Harbor and its environs and identify a suitable concept that would be most suited.

Project Scope

The scope of this project is to assess the feasibility of installing a hybrid wind/solar energy system in the city of Victor Harbour and its environs. The measure of system success is difficult, owing to the highly coupled nature of system economics to module design, location and load. Therefore this report has sought to investigate these various aspects in an isolated fashion, discussing the performance of different system options in reference to various design criteria pertinent to such systems. To assist this, the authors have engaged in brief consultation with members of the community, whilst analysing the available renewable energy potential of the Victor Harbour environs. The result of this is recommendations on types of components to incorporate into such a system, as well as measures to take in siting the devices.

Approximations relating to system cost and available energy have had to be made in order to conduct this report. These are highlighted throughout the text. The approximations have been informed decisions based on available literature, manufacturers' data and experience of the authors, and these have been necessary in order to arrive at a conceptual design for the system. Still, economic uncertainty exists in the results and the end-user of the report needs to consider this fact.

The work undertaken here is the logical *first step* in selecting a suitable concept. This conceptual design phase can then be utilised to streamline field trials and obtain more precise economic data from further decisions can be based upon.

Integrated Hybrid Wind/Solar System Concept

Cursory observations reveal that Victor Harbor is rich in renewable energy sources. Constant coastal winds are already being harnessed by industrial wind turbines in strategic locations along the South Australian coast, while the clement weather indicates that dependable sunshine may be converted to electrical energy by any scale of PV array. Attempting to harness these energy sources in a practical, economical fashion for domestic purposes is the challenge being undertaken by the City of Victor Harbor.

The majority of domestic renewable energy systems currently in use rely on solar energy to derive power. The CPREP initiative instigated by the Victor Harbor City Council is indicative of this. In such domestic systems the energy from the sun is converted into electrical energy using a Solar Array consisting of numerous PV panels. The electricity is then conditioned by a number of electrical components before being dispensed to the end user, either the residence (representing the primary load) or the grid (representing the surplus load). To ensure uninterrupted power supply batteries are incorporated into the system to provide *on-demand* energy (Figure 1).

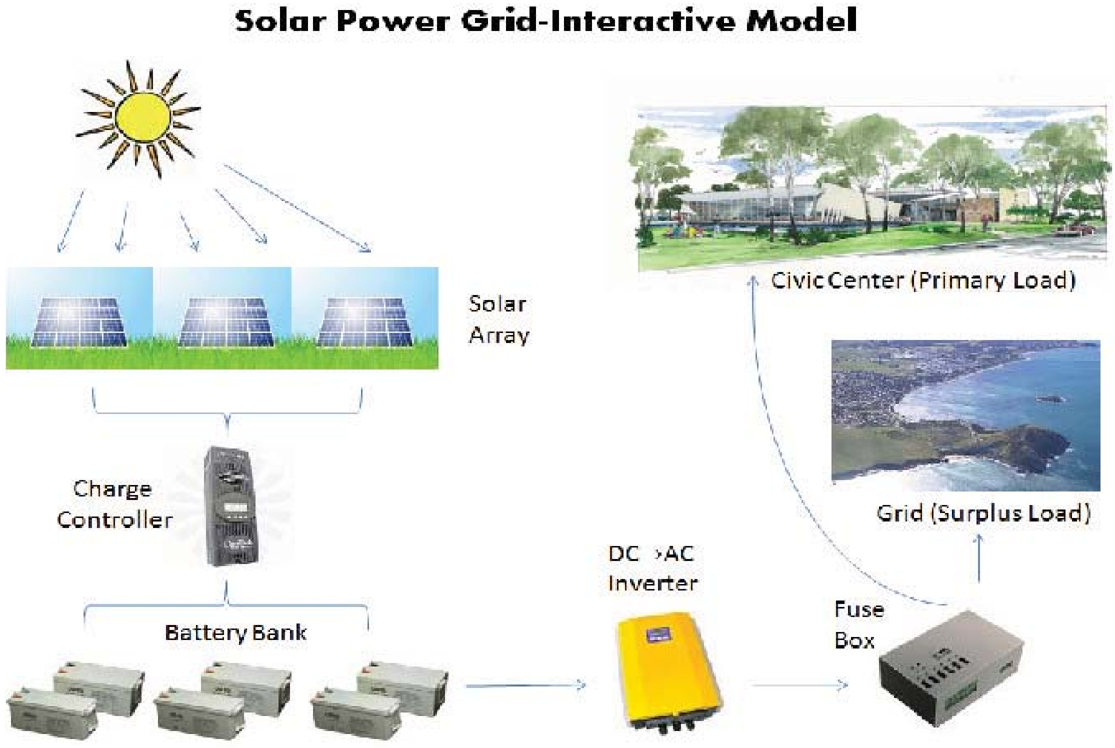


Figure 1: Energy flow diagram of a typical solar energy system as one would use for a domestic residence.

In the current economic climate domestic-sized solar energy systems are expensive. Furthermore, to develop enough energy to power a domestic residence, many panels are required, which accounts to a large amount of space. The potential to address these issues lies in the use of a hybrid wind/solar system. The energy from the sun is omnipresent in the atmosphere. Therefore where there is wind there will also be solar energy. Even if the atmosphere obscures the body of the sun and the direct beam radiation arsing from it, radiation diffused in the atmosphere as well as solar energy reflected from the Earth's surface (Albedo radiation) will be present and available for energy conversion. This means that installing a hybrid system, in lieu of a pure solar or wind device, could assist in maximising energy output from a given area and hence improve the economics of renewable energy (Figure 2).

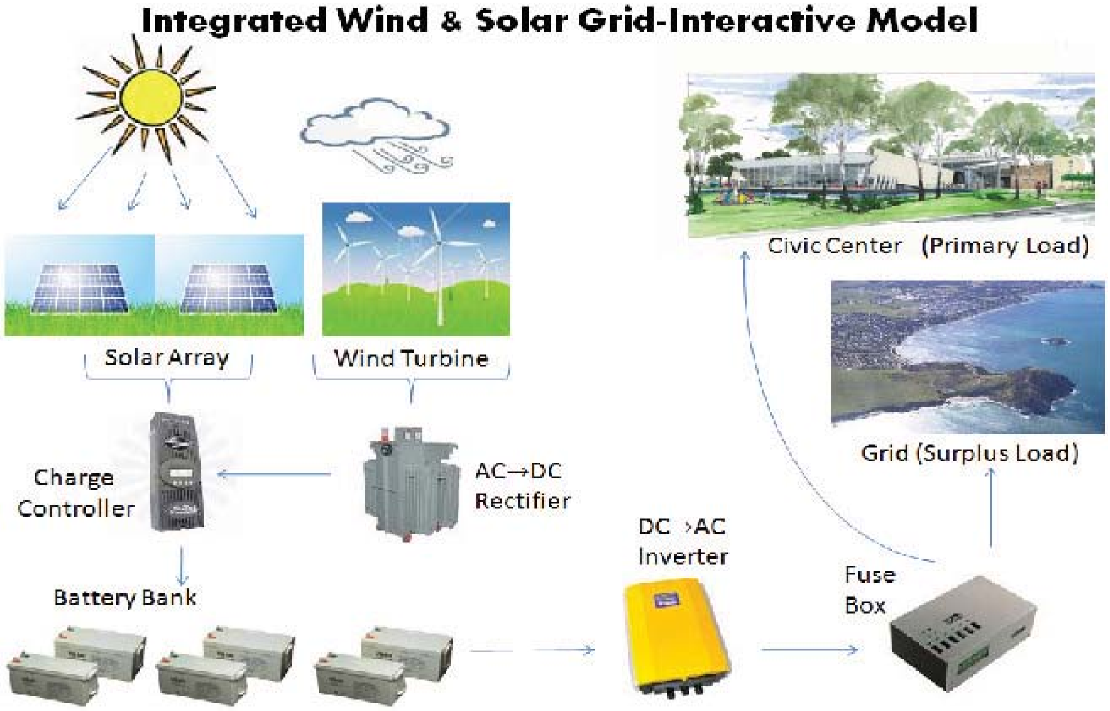


Figure 2: Energy flow diagram of the proposed hybrid wind/solar energy system as one would use for a domestic residence.

A conceptual idea of a hybrid system as originally proposed by the Victor Harbor City Council is depicted in Figure 3. The system is based on a small scale wind turbine. Solar panels are attached to the structure of the turbine thus maximising the power output of the device for its given size.

Figure 3: Hybrid System Concept - A wind turbine upon which are placed supplementary solar (PV) panels. It is hoped that the integration of the two renewable energy sources can help maximise the power output of a domestic-size, and improve the system's economics.

System Scope

The system is to be suitably sized for use in a domestic environment. The actual power output will naturally vary depending on application but typically domestic solar installations provide between 4*kW-hr* and 20*kW-hr* per day and these figures represent the bounds for which the hybrid system should fall within. The use of additional units is the suggested way to increase power output if the need exists.

The system is to help minimise the dependence of the City of Victor Harbor on traditional energy sources. This can be assisted by using a hybrid system designed for the domestic market located at the Civic Centre (Figure 4). Should the system prove viable in field trials and the council wishes to pursue further reductions in traditional energy usage, then additional units can potentially be installed at the Civic Centre site, as well as within close vicinity to the twenty-seven streetlights that the council wish to power with the hybrid system concept.

Figure 4: The Victor Harbor City Council Civic Centre - test site for the hybrid system concept.

The location, structure and environmental surroundings of the Civic Centre are typical of the Victor Harbor City environs. It therefore represents an ideal sample location from which to measure and assess wind and solar energy data for identifying the feasibility of the hybrid system concept.

Current state statutes offer no compensation for private wind power producers. In most states, home-scale producers are compensated at market rates for feeding surplus power back into the state grid infrastructure. Member for Finniss Michael Pengilly has introduced legislation supporting remuneration for home-scale wind generated power, but as of April 2010 this legislation has yet to be addressed and ratified. Thus, at this time, the hybrid system must be designed such that wind-derived technology is utilised explicitly for civic centre and street lighting purposes. Conversely, state legislation has already ratified compensation for small-scale photovoltaic array generated power. As the following data indicates, however, even this economic handicap does not seriously reduce the appeal of wind power in hybrid system over a solely solar-based array.

Considerations for Hybrid System Design

The fundamental need of the hybrid system is to provide reliable power that can be used effectively by the domestic market. However power is not the only consideration that needs to be taken into account. Given the diverse range of turbine and photovoltaic cells available considerations such as size, safety and noise need to be taken into account. This is in addition to the substantial economic considerations that need to be made.

The hybrid system represents an investment being made on behalf of the citizens of the Victor Harbor City Council. Input from these persons themselves was therefore sought so as it could be designed with their best interests in mind. For this reason a survey was distributed to citizens of the council area asking for their opinions on the matters of renewable energy and the hybrid system concept. A copy of this survey can be found in Appendix A and the average responses to each question in Appendix B.

The results of the survey show strong support for investment into renewable energy and the hybrid system concept. What is surprising is the importance that the citizens place in sustainable living over constraints such as size and cost. The citizens would be more partial to the idea of the hybrid system if it can improve the economics of renewable energy systems, but again do not appear too concerned if it the improvements are not seemingly large. The biggest concerns for the hybrid system appear to be the noise generated by a wind turbine.

The citizens of Victor Harbor City Council appear to be very receptive of renewable energy. They seem willing to tolerate the site and expense of renewable energy sources, regardless of cost. Whilst this is fantastic news for renewable energy, it is not good practice to just blindly build a system and compel the citizens to be satisfied, regardless of its performance. Therefore it is suggested that the system be designed using the concept of a weighting matrix which places appropriate weighting values for various system design aspects. Weighting matrix technique is a well-known method for decision making in complex and multi-objective problems. This matrix, whose values incorporate the results of the survey, allow the council and its engineers to exclude certain types of components from the hybrid system and ultimately realise a system concept that will be effective and economical for Victor Harbor City Council and its environs.

The two major components of the hybrid system are the wind turbine and PV panels. For each of these components, the four crucial design aspects to be considered are cost, (which is a function of power output), noise, size and aesthetics. For each of these components numerous types are available. To distinguish those most suitable, each component type can be ranked out of 100 for each aspect. These rankings can then be normalized and multiplied by the weighting matrix and the component with the highest score becoming the recommended for the system.

The weighting matrix derived for the system is presented in Table 1. It contains the four major design aspects for the project and an appropriately selected weighting value based on survey results. The biggest concern for citizens was noise levels, and the least was cost. The citizens liked the look of wind turbines and for this reason a high weighting was given to aesthetics. Although size was not a key factor for the citizens, it was given the third highest rating based on the good engineering practice of making things as small as possible. In addition, by making the system smaller, it will be able to be used in a greater number of locations.

Table 1: Design weighting matrix for the hybrid system

Design Aspect	Weighting
Low cost	10%
Low noise	40%
Small size	20%
Aesthetically pleasing	30%

Local Resource Potential

The wind power is intermittent in nature. And a stand-alone wind power system that supplies all demand is exceeded the storage capacity. This will increase the initial cost of the plant. Alternatively, a hybrid PV-wind system is expected to perform more reliably than a stand-alone wind system when appropriately designed; however its overall performance strongly depends on the local resources.

In addition to that, the cost and efficiency of each component play a determining part in a feasibility of such hybrid systems. At this time the price of photovoltaic cells is still high which makes them less competitive to the grid power. On the other hand, the price of wind turbines varies depending on their type. And selecting an appropriate type will save the cost per kilowatt power. To do that a reasonable understanding of the local wind resources is required. A right wind turbine selection involves different aspects which are the subject of this section. The design of the PV-wind systems will be discussed later in this report.

Available Wind Energy

Just because members of and visitors to the community of Victor Harbor can *perceive* that the city is *windy* does not necessarily mean that the site is well suited to wind energy harvesting. The speed, consistency and directionality of the wind together dictate the usefulness of the energy resource. Only after thorough investigation of local wind patterns one can comfortably support or object to the use of wind turbines for sustainable energy extraction.

Determining wind energy potential requires a great deal of analysis. This is because the wind source is frequently changing in behaviour. Moreover the wind source in a general region such as the city of Victor Harbor varies within the area due to changes in topography and locations of buildings, flora and infrastructure that serve to augment the behaviour of the wind.

The data utilised in this study has been obtained from the Bureau of Meteorology (BOM) operated weather station on Hindmarsh Island[2]. This data provides a base for analysing the region's historical wind frequency and direction. When compared to the data gathered by a local weather station installed on-site at the Council chambers, short-term data may be extrapolated into accurate long-term predictions about frequency, direction, speed, and embedded power. While the two data sets are theoretically identical, the important on-site variations are due to wind shading.

Wind shading is the observed effect of turbulent airflow due to roughness in terrain. "Rough terrain" is any significant natural or developed feature, including hills, escarpments, buildings, and trees. Such features disorganise the wind's flow, to the detriment of its embedded power. Broadly, any feature influencing roughness disorganises airflow in a space three times as large as is the disruptive object. Functionally, it may be generalised that rough terrain reduces accessible wind power by 60-90% in most scenarios, when it does not negate turbine potential completely.

Wind Speed Data

Wind speed is not constant for a specific location at different times of a day and varies from month to month. To perform the most reliable power analysis it is required to collect as many data samples as possible at the intended location. However, in many cases the data history is available only for a limited number of years. Moreover, most particular sites of interest do not have a legitimate meteorological record over enough long period of time.

In this case, a common strategy is either to install weather stations at the site or to interpret the available data for a neighbouring region from meteorological stations. The application of the former approach is more expensive and may not provide enough data in a dedicated project time. Although meteorological stations are not as specific as on-site data sampling, meteorological stations usually record weather data over years on an hourly or a daily basis.

To perform the wind power evaluation at the Victor Harbor civic centre, it was decided to install a weather station at the site and record as many data as possible at every half an hour (Figure 5). Finally, wind data has been gathered since January 2010 for almost more than two months. But, due to the variant nature of the wind the on-site recorded data was not enough to conduct a reliable analysis. Therefore, additional information was obtained from the BOM[2].

Figure 5: On-site data collection (from the weather station installed at the Civic Centre site)

The regional wind data used in the analysis has been obtained from the BOM-controlled Hindmarsh Island weather station[2]. This station is located at 35.52deg S, 138.82deg E and at an elevation of 11.0m. Although the hourly wind data was not available from BOM[2] for Victor Harbor, they could provide us with an hourly based annual wind speed data of Hindmarsh Island, at 16.6km east of Victor Harbor.

As Victor Harbor is an adjacent neighbour to Hindmarsh Island, it was reasonable to interpret the data of Hindmarsh Island for power estimation of our intended site in Victor Harbor. Additionally, statistical data from BOM[2] for the both regions are close to each other with an average wind speed of about 16km/h, recorded twice a day over more than ten years. To do a more specific comparison, one can investigate how similar the probability distributions are between the two sites. But, doing that requires an exact knowledge of the weather station locations, and details of their surrounding environment. This is to account the effect of wind shading on data and also to consider the alternation of wind profile within the atmospheric boundary layer. Herein, this comparison seems to be redundant as the enough data samples were not equally accessible for the both sites.

The roses of wind direction illustrated in Figure 6 and Figure 7 respectively for Hindmarsh Island and Victor Harbor. The graphs are provided by BOM[2]; and show no difference in prevailing wind directions of the two locations. So, it was decided to estimate reasonable wind data by imposing the same wind shading effect of the site on the available wind data for Hindmarsh Island.

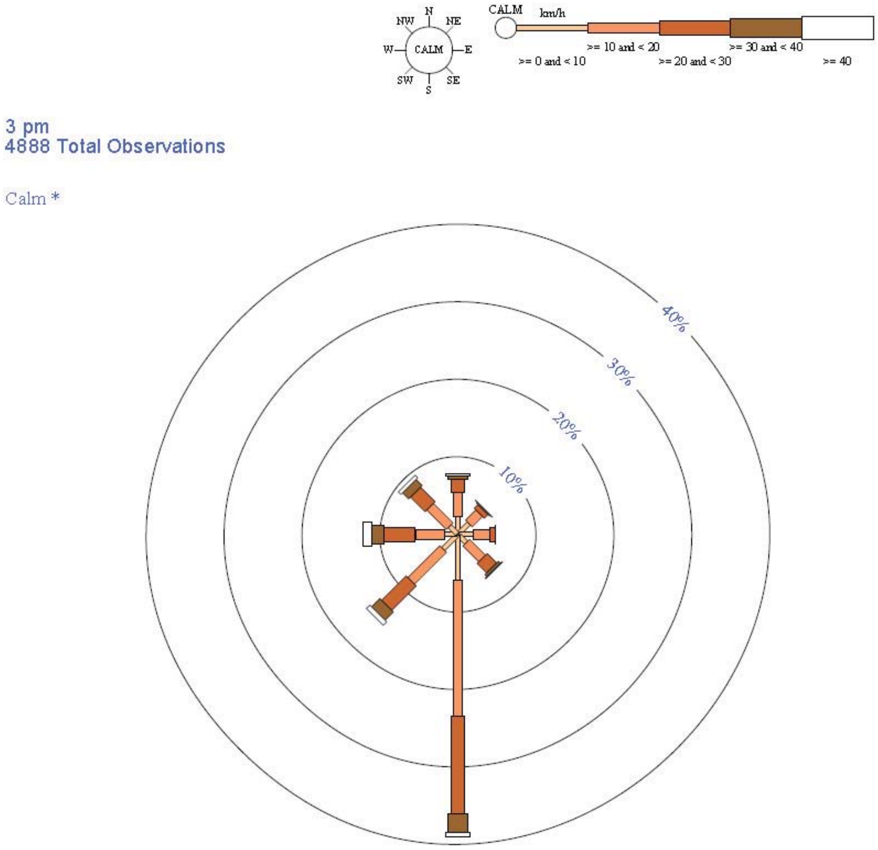


Figure 6: Rose of wind direction versus wind speed km/h for Hindmarsh Island at 3pm (01 Jun 1989 to 24 Jan 2004), (adapted from [2])

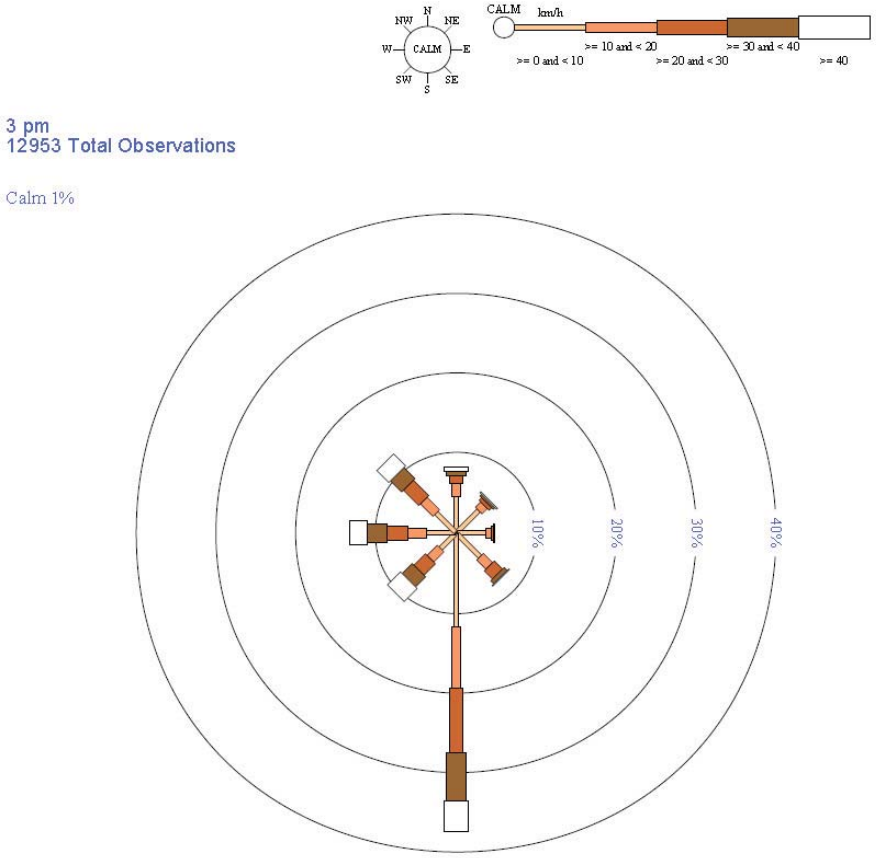


Figure 7: Rose of wind direction versus wind speed km/h for Victor Harbor at 3pm (04 Jab 1965 to 31 Mar 2002), (adapted from [2])

The wind shade at a site is a function of its circumference obstacles, their porosity and also the roughness of the terrain. The wind shading effect becomes negligible far from obstacles or when obstacles heights are incomparable to that of the turbine's hub[3]. However, the wind shade may extend to up to five times the height of the obstacle at a particular distance. According to the site specifications at Victor Harbor, the wind shade was calculated and revealed to reduce the wind speed by 50-60%. This was done based on the topology of the site and its surrounding environment. This is a conservative estimation of the wind shade effects to acquire reliable evaluation of the wind power throughout the year. It was also assumed that the BOM data were not affected by wind shade. Therefore the hourly based wind speed data for Hindmarsh Island were adjusted to encompass the wind shade presents at the Victor Harbor site. Figure 9 shows the adjusted Hindmarsh Island wind speed data provided by BOM[2] for January 2009 together with their Weibull distribution. The result is in a good agreement with the data collected from the installed weather station at the site, (Figure 8). Although for wind speed less than 2 m/s the individual figures do not follow the same trend, due to some approximations in the statistical analysis. This data was subsequently used to assess the effectiveness of different types of wind turbines hypothetically operating in Victor Harbour.

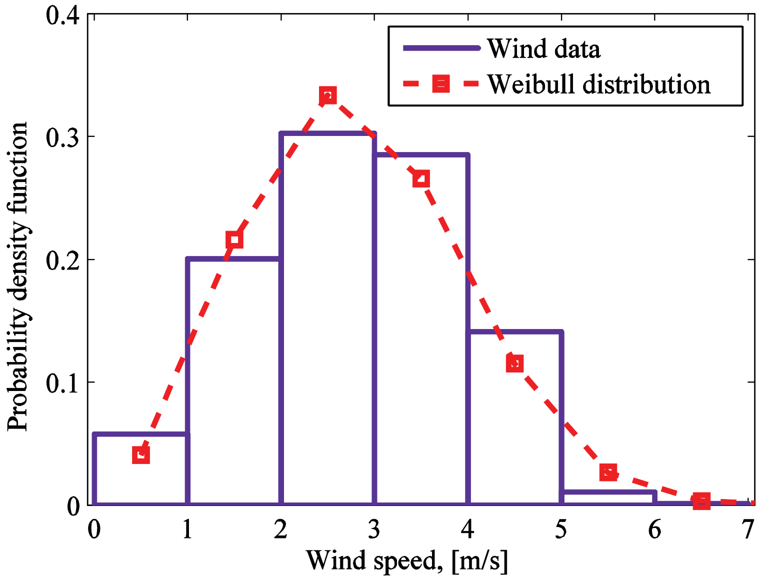


Figure 8: Adjusted wind speed distribution from the data provided by BOM for Hindmarsh Island - January 2009.

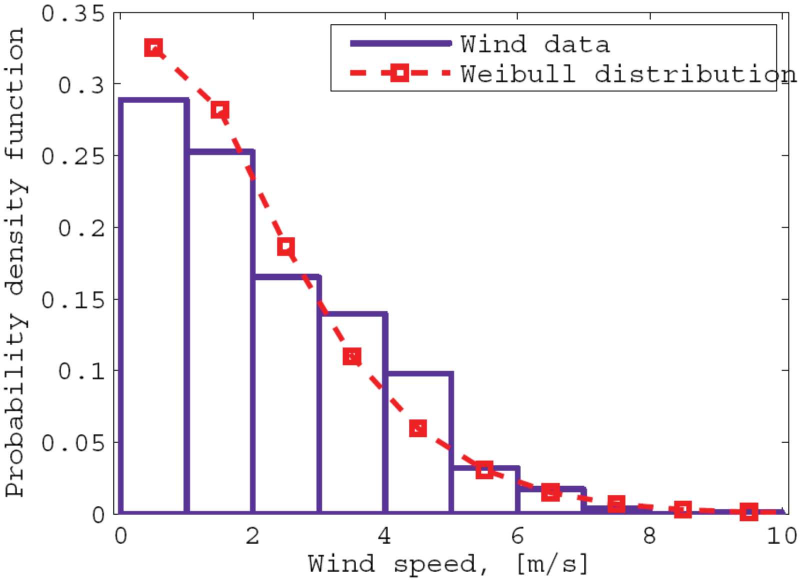


Figure 9: Wind speed data distribution from the station installed at the site - January 2010

The Weibull and Rayleigh probability density functions are widely adopted in the wind related studies. These functions provide a mathematical representation of the wind speed data for wind energy calculation purposes. The Weibull function is more versatile and the Rayleigh function is simpler to use. In the present work, it was found that the Weibull function follows the wind data more accurately than the Rayleigh function. So, the site power estimation was conducted based on the predictions of the Weibull function. The probability density function of Weibull distribution is given by Equation (1),

$$f_W = \left(\frac{k}{c}\right)\left(\frac{U}{c}\right)^{k-\text{`}} \exp\left(-\left(\frac{U}{c}\right)^{k}\right) \tag{1}$$

where k and c are respectively shape and scale factors of the Weibull distribution and *U* is the wind speed.

There are different methods to calculate the Weibull distribution parameters in the literature. Herein, shape factor was calculated using the expression given by Justus[4], Equation (2). And values of *c* were evaluated for the available data from Equation (3)[5],

$$k = \left(\frac{\sigma}{\overline{U}}\right)^{-1.086} \tag{2}$$

$$c = \frac{\overline{U}}{\Gamma\left(1 + {}^{1}\!/_{k}\right)} \tag{3}$$

σ in Equation (2), is the standard deviation of wind data, and Γ in Equation (3) is the gamma function. The turbine power was determined based on Equation (4). And, the average wind machine power can be calculated using Equation (5)[5].

$$P_W(U) = \frac{1}{2}\rho A C_P \eta U^3 \tag{4}$$

$$\overline{P_W} = \int_0^{\infty} P_W(U) f_W \, dU \tag{5}$$

In Equation (4), ρ is the air density, A is the swept area of the wind machine, η is the efficiency of the generator, and C_P is the rotor power coefficient defined by Equation (6)[5] and is ideally equals to the Betz coefficient $C_{Betz}=16/27$.

$$C_P = \frac{\text{rotor power}}{\text{power in wind}} = \frac{P_{rotor}}{\frac{1}{2}\rho A U^3} \tag{6}$$

Hence, substituting the integral in Equation (5) with summation over *N* bins gives the following relation to calculate the average wind machine power, Equation (7) [5].

$$\overline{P_W} = \sum_{i=1}^{N}\left\{\exp\left(-\left(\frac{U_{i-1}}{c}\right)^k\right) - \exp\left(-\left(\frac{U_i}{c}\right)^k\right)\right\} P_W\left(\frac{U_{i-1}+U_i}{2}\right) \tag{7}$$

In the above equation the wind turbine power is calculated at the midpoint between U_{i-1} and U_i.

Turbine Selection

There exists three commercially available wind turbine designs. All could potentially prove suitable for use in the Victor Harbor City Council. Most familiar to the public is the Horizontal Axis Wind Turbine (HAWT), a triple-bladed design used in large scale wind farms, Figure 10A. These turbines operate in much the same way as the propeller of an aircraft, utilising the lift generated by wind passing through the blades to produce a shaft rotation, ultimately converting mechanical power into electrical power. A Darrieus type turbine, Figure 10B, also uses the lift produced by the air moving past, but instead of rotating about a horizontal axis, Darrieus have two or more blades that spin about a common vertical axis. The third type, the Savonius, is also a vertical axis type turbine, where drag rotates the device as the air moves past it.

Figure 10: Wind turbine schemes: A) Horizontal axis wind turbine[6] B) Darrieus wind turbine[7] C) Helical Savonius wind turbine[8]

Each turbine performs differently over different wind speeds and levels of turbulence. Figure 11 highlights the expected power that can be extracted from typical turbines of the three types, as a function the speed ratio. It can be instantly identified that HAWT (two & three blade air screws) appear to be the most efficient and effective, whilst the Savonius is the poorest. When considering the use of wind turbines in large scale applications, this data supports the common choice of HAWT wind farms. In small scale operations, however, reality seldom reflects ideal conditions. An investor may not have the luxury of ideal topography; perhaps roughness features cannot be altered, or location choices are limited. This means a VAWT may be more favourable in a suburban environment.

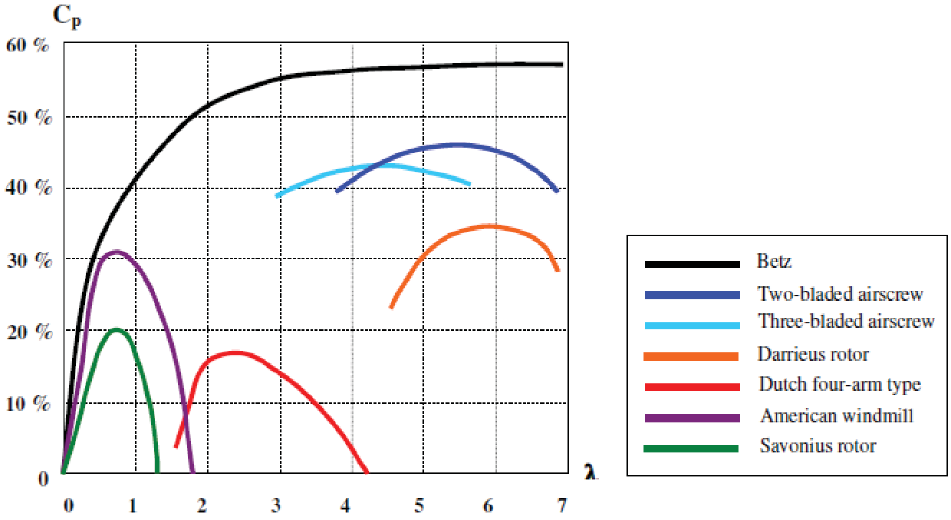


Figure 11: Performance of main conventional wind machines[9] adapted from [10]

Turbine Power Outputs

A primary focus of wind turbine technology concerns analysing how much of the wind's energy may be harnessed by a device. In addition to electrical generation, loss must be analysed from a financial perspective: what are the costs of access, both at outset and over time. To do this a trade study is of use. For the trade study a number of commercially available wind turbines were studied. A power curve like the example in Figure 12 was obtained for each turbine and the data quoted from the manufacturer used to assess how effective each turbine is if it were to be used at the Victor Harbor site. Appendix D contains a table of the turbines that feature as part of the trade study.

When used in conjunction with the monthly Probability Density Functions (PDF) arriving from the Weibull distributions for the wind data, one can determine the monthly performance. Normalising the power produced by each type against the mean cost of the respective systems then allows an estimate of the power-output per unit dollar for each system.

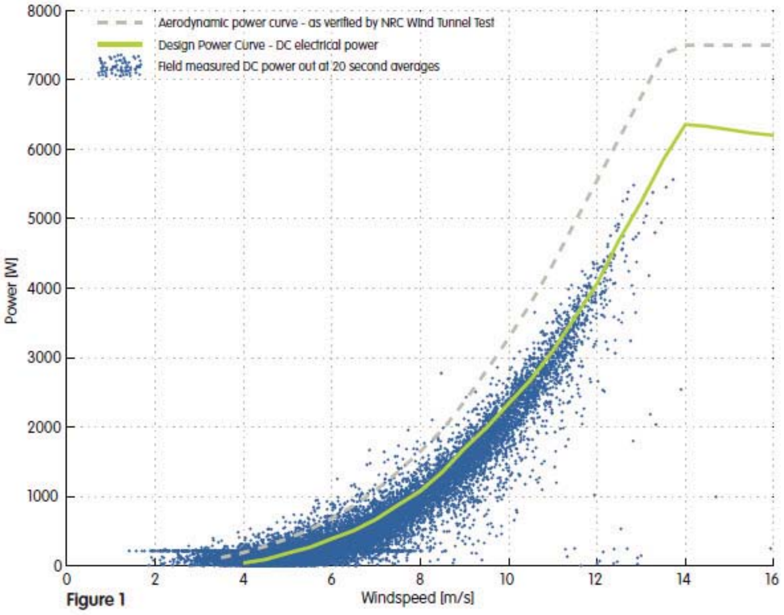


Figure 12: Power curve for the Quiet Revolution qr5 VAWT. This curve is typical of the data supplied by a turbine manufacturer[11].

Two cases have been performed for the power estimate. The first is the case for the turbines in an ideal environment. The wind data for this was derived from the HI weather station. An assessment incorporating the shading effects of suburbia was also conducted. For this case the council site data was used. The data for January to February was derived from the station itself. The remaining data for the last nine months was extrapolated by adjusting the HI data with the appropriate shading factors that Victor Harbor suburbia represents. Considering the ideal value of rotor power coefficient and the generator efficiency of 90% the average wind turbine power was evaluated by Equation (7) for each month of a year. And the results are demonstrated in Table 2 per swept area of the wind machine.

Table 2: Estimated average wind machine power in each month of a year at the site

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$\overline{P_W}\left(W/_{m^2}\right)$	10.5	13.0	9.3	7.9	3.0	5.3	9.2	10.0	11.2	12.3	10.5	9.5
$\overline{P_W}\left(kWhr/_{m^2}\right)$	7.8	8.7	6.9	5.7	2.2	3.8	6.8	7.4	8.0	9.1	7.6	7.1

According to the above calculations an average power of 81.1 $\left(kWhr/_{m^2}\right)$ can be harnessed at the site by employing an appropriate wind machine throughout a year. The Weibull distribution for each month of a year is included in Appendix C

Figure 13 represents the cumulative power per dollar of a system placed in an open environment. It clearly shows that the HAWT produces the best power per dollar performance, with the Darrieus second and the Savonius third. This ranking is reiterated in the curve for the shaded, suburban areas.

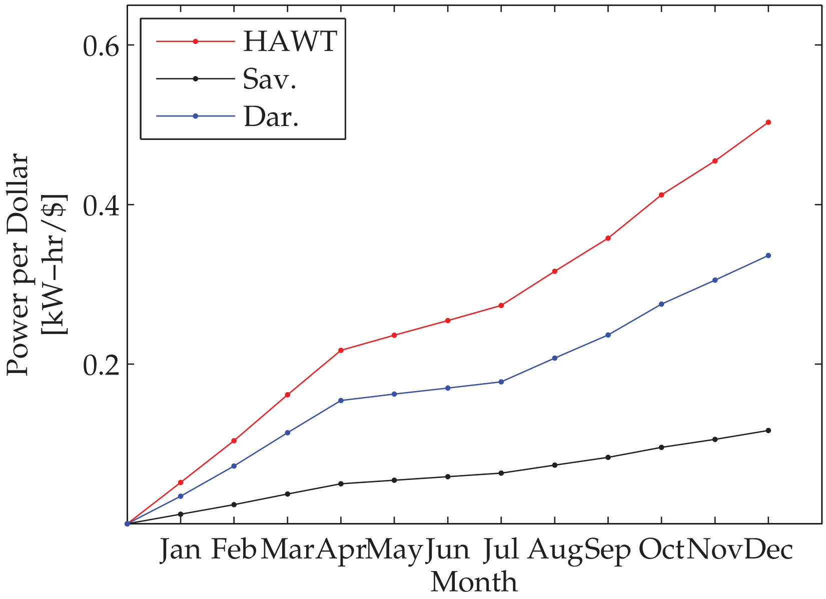


Figure 13: Cumulative power per dollar for different types of wind turbines

On the basis of the graphs resulting from the power per dollar analysis it would be easy to quickly recommend the use of a HAWT. Indeed it does produce the most power per dollar according to the graphs. However interpretation of the graph should be done so with caution. HAWT, unlike VAWT, are required to point in the direction of the wind at all times to extract maximum power. This requires additional cost for the tracking system, and system complexity. Whilst the majority of HAWTs include a device for following the wind, its performance will be dependant on the responsiveness of the system to rapid changes in direction. The direction of the wind at Victor Harbor and its environs is highly variable. Although a prevailing S/SE does exist, as the Figure 7 shows, approximately 60-70% of the time, the wind is travelling in other directions. These factors all suggest to the authors that the power output per unit cost of an HAWT will be less than that predicted by the results in Figure 13. Conversely, VAWT do not suffer from such problems, and will cope well with frequent wind direction changes and this leads to strong support for their implementation. Further supporting this is also the reduced cut-in speeds associated with Savonius types, which equates to more energy production at lower wind speeds compared with HAWTs.

Discrepancies between turbines' power per dollar estimates diminish when analysed in light of these preceding local factors. As mentioned, HAWT turbines will most likely perform worse than expected in Victor Harbor and its surroundings due to frequent changes in wind direction. In addition, VAWTs do not require the same degree of precision in manufacture as HAWTs due to simpler designs (flat plates and simple two-dimensional wings are easier to manufacture than complex propellers), meaning that manufacturing costs of new VAWTs can be cheaper.

Savonius wind turbines also emerge as superior when analysed with regard to local installation. Using the wind data extrapolated form the data collected at the Civic Centre the cumulative power per unit dollar for the three turbines in a shaded urban environment has been calculated. (Figure 14).

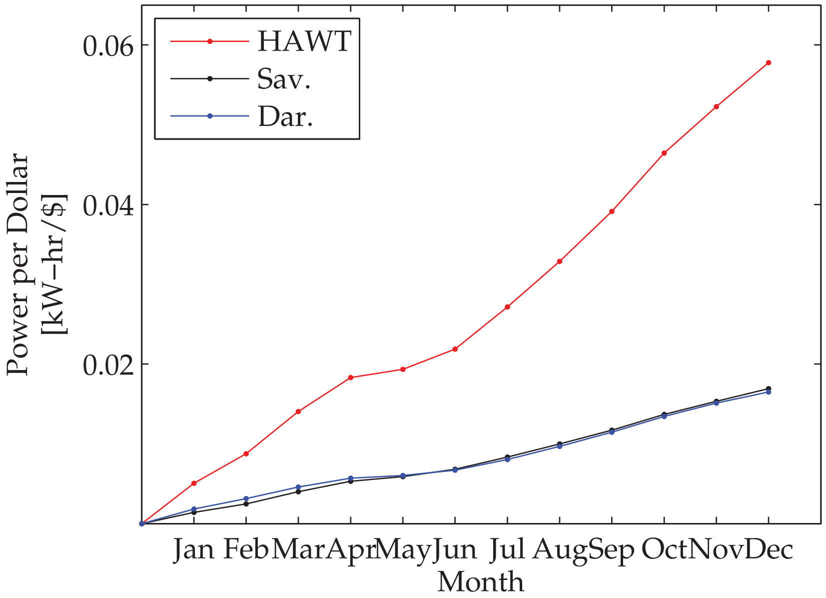


Figure 14: Projected performance of different wind machine designs.

Whilst at first it appears that the HAWT is still the better choice for producing power, wind speed over time does not provide a complete model. Significant wind shading effects surrounding the Council/Library complex describe a dramatic reduction in the power output. When one considers the percentage loss of performance due to the shading, Figure 15, Savonius turbines prove substantially less sensitive. Robust performance in the presence of significant shading allows for greater flexibility in site selection, both at the Council/Library complex and broadly throughout the Victor Harbor region.

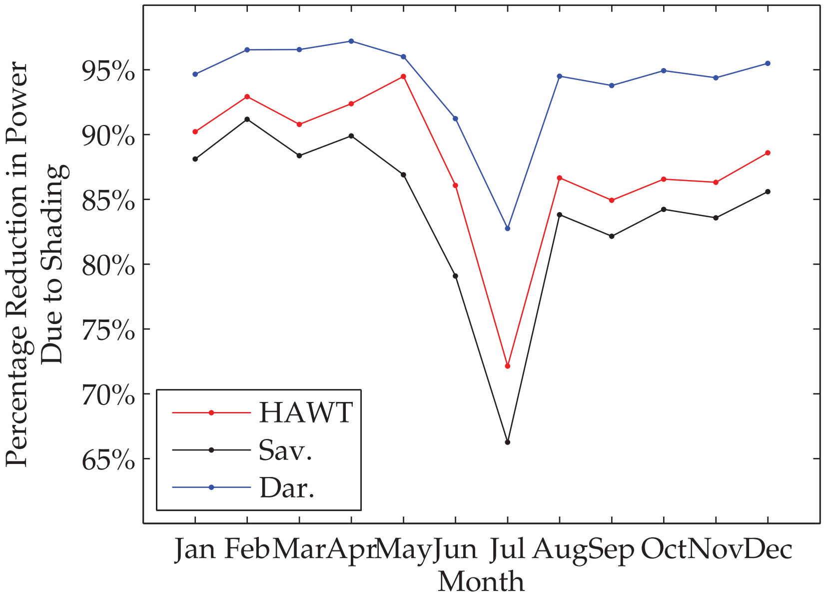


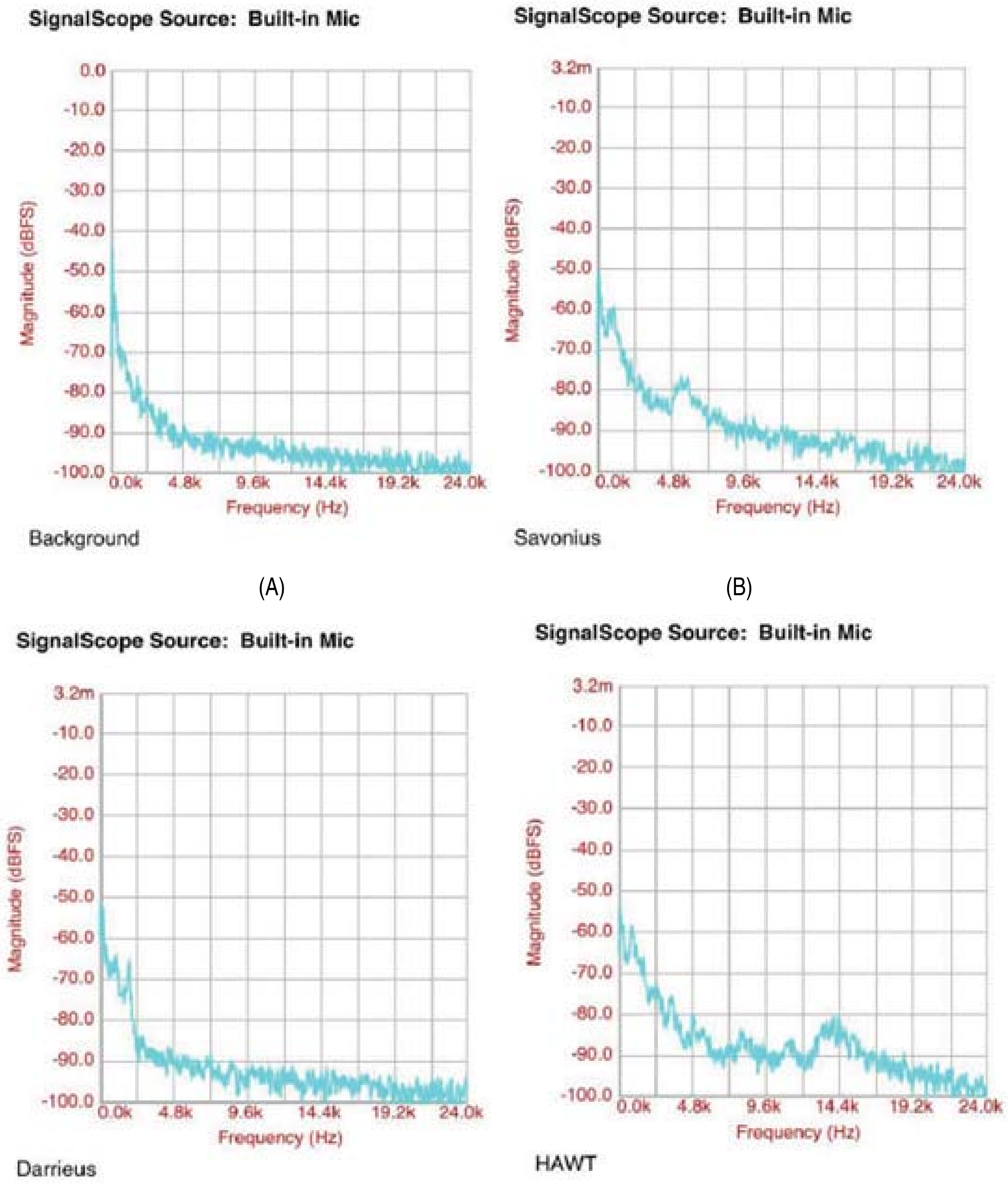
Figure 15: Effect of wind shading on power generation for different wind machine designs

In light of the preceding data, it is the conclusion of the authors of the report that projected fiscal efficiency is insufficient grounds for recommending the popular HAWT model. It may be surmised that power-per-dollar curves will change over time in favour of the VAWT; in addition the local factors suggest that the Savonius VAWT would out-perform HAWT due to dramatic wind shading.

Noise Considerations

The use of wind turbines in urban environments brings noise considerations to the forefront of system planning. Small wind turbines are renowned for the noise which they develop, notably a high whining sound. This sound is primarily related to the vortex shedding from the tips of the turbine blades, and its magnitude is directly related to the tip speed of the turbine.

There is much conjectural evidence and hearsay surrounding the noise produced by wind turbines. It is widely acknowledged that VAWT produce less noise than HAWT devices. This is due to the fact that VAWTs produce lower axial speeds than HAWT. Given the relationship between tip speed and noise, it follows that VAWTs are quieter. Quantitative support comparing the noise signatures of the three different types of turbines, HAWT, Savonius and Darrieus is found in the work performed by the university. A comparison of the noise produced by three domestic-sized wind turbines developed at the University reveals this to be true[12]. Whilst the sound-pressure level of all three was imperceptibly higher than background noise, it was the frequency component which was obvious. Figure 16B through Figure 16D show the three frequency spectra for the turbines. Note that the spectrum for the Savonius differs only slightly to that of background noise. The low frequency peak is attributed to an isolated incident defect in a bearing component and hence can be discounted as a trend, essentially the same as background noise. The Savonius has a small peak at a moderate frequency; the HAWT has a powerful peak at a higher frequency. This noise was clearly audible to the researchers, who noted the discomfort it produced. Of course the high frequency is associated with the high tip speeds of the HAWT design. One can conclude then that a VAWT is better for suburban environments, with the Savonius type being the least disruptive to daily life.



(A) (B)

(C) (D)

Figure 16: Noise frequency spectra for the three wind turbine types and the background noise measured during experiments conducted at the University of Adelaide[12]

Size

System space is another key factor to be considered for home-scale hybrid system design. Of the systems studied in the statistical analysis, Savonius turbines are the most compact due to reduced turbine diameters. The vertical corkscrew rotation is also the least noticeable turbine blade movement and also arguably the most attractive. The poorest is the Darrieus type, which requires large rotational diameters and heights.

Aesthetics

Aesthetics are a difficult thing to judge given the fact that beauty is not a universally accepted quantity. HAWT turbines have been the most widely used to date and therefore arguably the most acceptable aesthetically. However, the new range of Darrieus and Savonius turbines on the market may gain aesthetic favour for their modern looks and fresh appearances.

Other Considerations

Characteristics of common HAWTs and VAWTs are discussed in the previous sections. In concluding this, it is important to know reliability and maintenance issues associated with each type.

Tall tower base of HAWT allows access to stronger winds and consequently an increase in output power. Efficiency of HAWTs is higher than that of VAWTs as they are rotating perpendicular to the wind. However, they require an additional yaw control mechanism to face the blades towards the wind. This leads to cyclic stress and vibrations that might damage the blades. And to avoid the turbine spinning and damaging itself, a braking system is also required.

High towers of HAWTs disrupt the appearance of local landscapes and make it difficult to lift and install the components on top of the tower. The tower should also be strong enough to support the weight of the blades, gearbox, braking and yaw control mechanisms, and also the generator. The noise accompanied with HAWTs is an important matter in urban areas. In addition, a tower for a HAWT needs to resist the off-axis load produced by wind and weight of the turbine, which makes the basement and shaft more expensive in comparison with a vertical axis turbine, where the loads are aligned with the axis.

Also a HAWT, in which the sharp blades rotate at high rotational speed is a potential danger in case of a any mechanical failure for the surrounding area and people living in the vicinity of turbine while such a danger does not exist in case of VAWT. This factor, in general, has large effect on the perception of small scale wind turbines by the community.

In addition, VAWTs are not sensitive to the wind direction. This reduces the number of components needed; and reduces the initial and maintenance costs subsequently. Moreover, the tower is not required to support the electronic components, allowing them to be placed near the ground. This means that the parts are more accessible, which in turn makes maintenance of VAWTs easier than that of HAWTs. One drawback however is that the average efficiency of most VAWTs is lower than HAWTs.

Nevertheless, the efficiency can be improved for rooftop mounted VAWTs. It is recommended that the height of the rooftop mounted turbine tower be approximately half of the building height for the maximum wind energy[13]. Amongst VAWTs, Savonius turbines are most reliable in areas with turbulent winds. And despite typical Darrieus turbines they are self starting and do not need external supporting structures (i.e. guy wires). The Cut-in wind speed of the Savonius turbines is less than other common types of wind machine. This makes them a good choice for sites suffering from the wind shading effects.

Available Solar Energy

The sun is a stable, effectively infinite source of energy. It has a well defined position relative to the Earth and its energy is also consistent. Thus, it is rather straightforward to calculate the quantity of solar radiation which will travel to any specific place on Earth's surface, given the relative position of the sun at the particular time of year. This data may be quantified analytically or measured empirically.

The Bureau of Meteorology records average daily solar irradiation data for the weather station at Victor Harbor throughout the year. Solar irradiation data is neither site specific nor temporal over time as is wind data, and thus the values measured at the station can be taken as the value incident on Victor Harbor City and its environs annually (Table 3).

Table 3: Average daily irradiation at Victor Harbor (courtesy of the *Bureau of Meteorology*[2])

Month	Average Daily Irradiation [MJ/m²/day]
January	26.5
February	23.4
March	18.8
April	13.1
May	9.1
June	7.5
July	8.4
August	11.6
September	15.9
October	20.1
November	24.2
December	25.6

In theory, the solar irradiation data presented in Table 3 can be considered constant across the entire city of Victor Harbor. However, shading effects caused by objects obstructing the solar radiation significantly diminish solar irradiation levels at particular locations. Light shading may be caused by significant trees, buildings and other opaque structures, and will have a significant effect on the irradiation levels of a site. This needs to be considered when establishing a renewable energy system that relies on solar energy.

The hybrid system intends to convert the energy of the sun into usable electricity through the use of photovoltaic panels (PVs), also referred to as solar panels or solar cells. PVs utilise the photoreactive element *silicon* within small *cells*. This photosensitive substrate converts the solar energy into a voltage potential, which when appropriately conditioned, can be exploited for electrical energy.

A typical solar panel system requires a number of components to harvest the solar energy and convert it usable electrical power. Not only does each component add complexity but also significant expense. In Section 2 an energy flow chart was shown detailing the conversion of solar energy into electricity using PVs. This diagram is shown in Figure 17. When considering this flow diagram it can be seen that the PV panel utilises the solar energy to produce a DC electrical output. This DC output requires AC inversion in order to be consumed by a residence or fed back to the mains power grid. Supplying power to the mains grid requires junction boxes, which add expense to the system. Further expense is added if the residence is wishing to store the developed energy through the use of battery arrays. In addition to the added expense, the extra components also diminish the overall efficiency of the system.

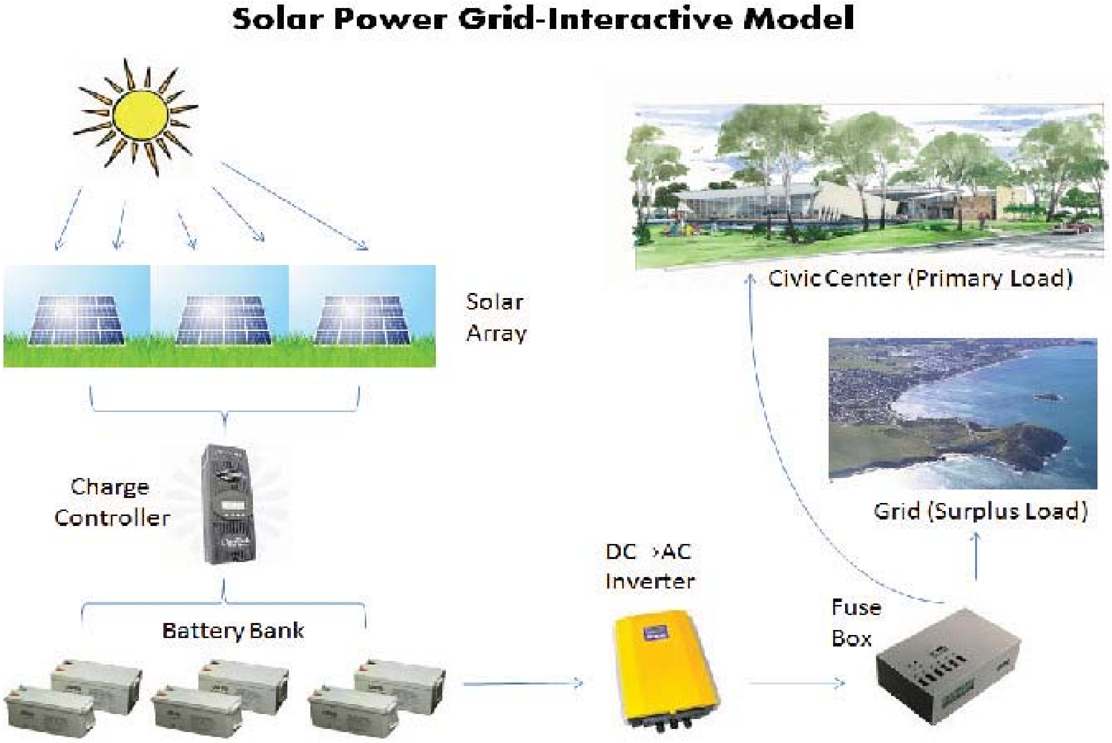


Figure 17: Energy flow diagram of a typical solar energy system as one would use for a domestic residence

When trying to ascertain the contribution solar panels should make to the hybrid system the methodology employed has focussed on the most fundamental system. That is a solar system that includes no charging provisions or capability to contribute to the mains grid. Studying such a basic system, which includes just a PV array an inverter, provides the purest details of the energy potential of a PV system, whilst providing a starting point from which economic improvements to the system can be explored. It is for this reason that when assessing the solar-derived energy potential of Victor Harbor a simplified system such as the one discussed has been considered.

To evaluate the amount of power expected to be produced by a simplified solar panel system in the Victor Harbor City area, a similar approach to that used for the wind turbine analysis. Three main types of PV panels exist, differing in substrate design, cost and efficiency. The performance of these has been approximated from the results of a market evaluation. These have then been mated to an average solar inverter and then the cumulative annual power generation for each type has been calculated using the solar irradiation data presented in Table 3.

Photovoltaic Types

The three main types of PV cells are Monocrystalline, Polycrystalline and Amorphous. The three categories utilise similar principals for energy development and each have similar panel sizes of approximately 1.3m^2 per panel, but they differ in PV substrate structure, efficiency and cost. Table 4 contains details of readily available PV cells. The data in this table has been used to estimate the expected performance of the three types of panels, thus allowing a recommendation of the most suitable PV cell type to use.

Table 4: Solar panels used for market evaluation

Type	Brand	Max. Power	Max. Efficiency	Approx. Cost [$AUD]
Monocrystalline	Sunpower	300W	18%	$2530[14]
Monocrystalline	Sunpower	230W	18%	$1900[14]
Monocrystalline	Sunpower	225W	18%	$1850[14]
Monocrystalline	Sunpower	210W	18%	$1725[14]
Monocrystalline	Sharp	180W	18%	$1668[15]
Polycrystalline	Kyocera	210W	14%	$1593[16]
Polycrystalline	Sharp	180W	14%	$1668[16]
Amorphous	Sanyo	205W	15%	$1800[14]
Amorphous	Sanyo	200W	15%	$1742[14]

Inverters

The approximate system has had to include an inverter component to augment the DC electrical output of the PV cells to usable AC electricity. Two suitable inverters found in the market are the Sunny Island 5048[17] and Outback FX2348[18]. If these are taken as possessing typical inverter performance, then it can be assumed that the inverter will have an efficiency of 95%, capable of handling 2500W, and cost approximately $4000. These are the figures that have been utilised in the study.

Photovoltaic Performance

The question of which type of solar panel to use has been answered by studying the average electrical outputs per dollar of one of each type of panel. Using the solar radiation data for Victor Harbor, and adding an inverter to each panel system, the cumulative power developed by each type per dollar over the course of a year has been calculated. Figure 18 reveals that the output per dollar for each type is approximately equal. This means that there is no real benefit in picking a more efficient PV as the added cost negates the power output benefit.

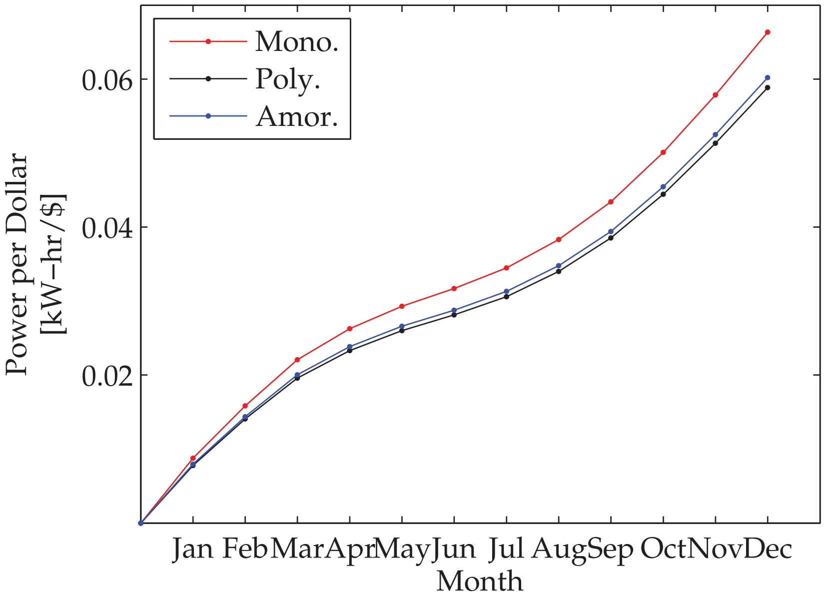


Figure 18: Cumulative power output per dollar for the three types of PV panels if used in Victor Harbor

Having established that any type of panel will work well at the site, the next question is what contribution of the energy from the hybrid should be solar derived. If one panel is used, then the output per dollar significantly favours wind. However, as the panel number increases, PV technology becomes competitive with wind data, particularly in shaded environments as can be seen in Figure 19. This is due to the fact that a common inverter can be used for approximately 6 panels, which minimises capital outlay for the system.

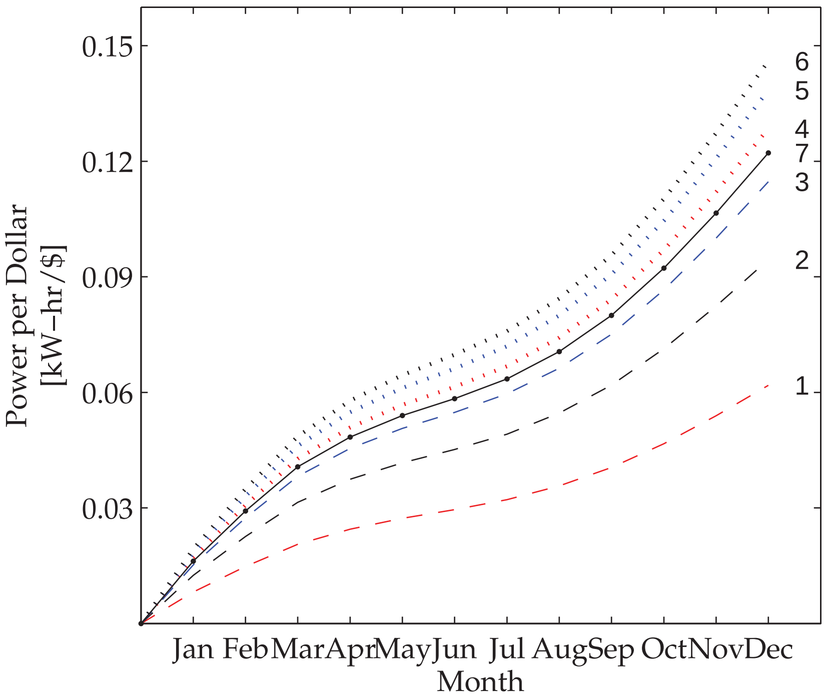


Figure 19: Benefits of value adding. Typical inverters can host up to 6 panels, meaning that system output per dollar improves with an increased number of panels.

In the presence of the context of the present study a hybrid system can at best host one or two solar panels which equates to approximate 400W of solar power. However if hybrid systems are placed in close proximity to each other, PV system components can be shared and thus help improve the economics of the system.

Shading Considerations

Shading has a significant impact on PV performance by reducing the amount of irradiation on the devices. Clearly, less solar energy will yield less power from an array. However the impact of shading is much more dramatic than a linear expression of irradiance would suggest. Photovoltaic panels' circuits are extraordinarily sensitive to shading. Due to the series circuits used in panels, one shaded cell will result in current drops of 50% at minimum or even act as a resistive load. Should a critical bypass diode be shaded, eventual overheating will cause system failure. Although a thorough exploration of photovoltaic systems' behaviour is beyond the scope of this feasibility study, Due to the non-linear dependence of PV output to shading, it is essential that the shading effects of a suburban environment be accurately predicted through a shading analysis. This can be achieved by using a tool such as the Solar Pathfinder (Figure 20). The Pathfinder operates on a reflective principle, indicating on an azimuth-accurate grid the times and amount of available irradiation throughout the year. The reflection is traced onto the grid for an exact image of shading objects and the hours of their interference (see example grid Figure 21).

Figure 20: A Solar Pathfinder system that can be used to assess shading effects at PV possible installation sites.

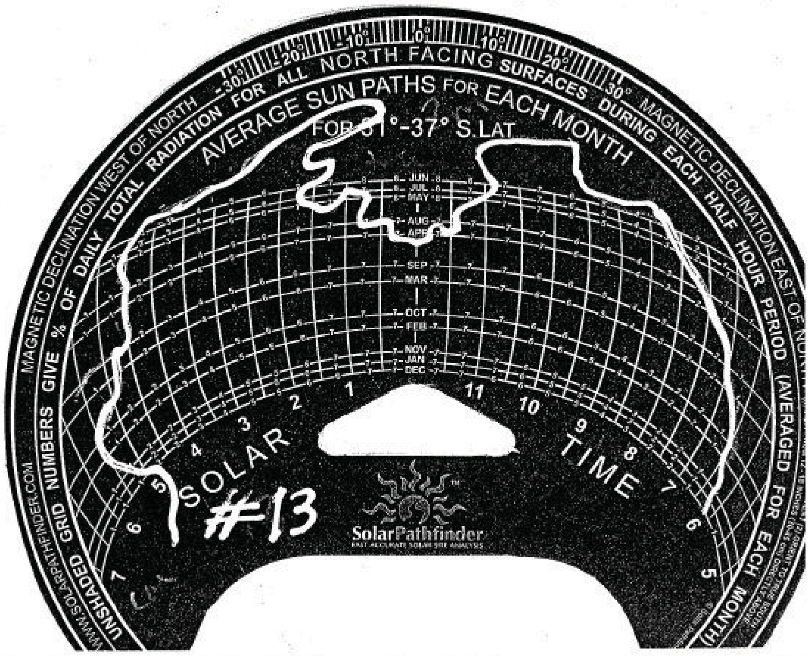


Figure 21: A typical example of a solar path affected by the shadow of a nearby object. The object has the effect of projecting over the solar path, thereby diminishing the amount of solar irradiation at the site. Through appropriate analysis, the effect can be expressed as a percentage loss of the practical maximum. Shadowing effects are site specific, and as such a Solar Pathfinder analysis should be conducted at any possible site for a PV system.

Given the highly specific nature of solar shading, it is difficult to incorporate shading effects into an economic trade study like that performed for the wind energy. For the Victor Harbor Civic Centre site, this is found to vary between 23% and 100% depending on the time of year and the site, but these results are not necessarily indicative of other locations around the area. However, using a tool like the Solar Pathfinder provides a very quick and effective way to assess shading effects at a site. It is therefore recommended that such shading analysis be conducted at any possible location before system installation to locate ideal locations as it provides a more effective means than a mathematically-based, theoretical approach.

Recommended System Concept

To proceed with the integrated system concept is has to be made clear that the idea is sensible to pursue. Normally strong financial justification can be used to support the idea. However, because of the different manner in which solar and wind technologies develop power, few components can be shared. This means that little direct financial benefit will be realised by simply supplementing a wind turbine with some solar panels. Then why should the concept be pursued further? The answer to this lies in the fact that a hybrid system can extract solar and wind energy simultaneously from a particular area. This means that the amount of electricity that can be harvested from a given area is increased through the use of an integrated system if it is designed so as the components do not interfere with eachother (ie shade one another). It is for this reason that it is recommended to further develop the integrated system concept.

To illustrate this notion of improving energy output from a given area using the hybrid concept, consider a system that uses an Environ Engines 5kW turbine and two Sharp 180W Monocrystalline solar panels. The turbine alone if used in Victor Harbor would generate approximately 1000kW-hr per annum over an area of approximately 14.3m^2. By adding the two photovoltaic panels, the area should not drastically change but energy production would increase by up to 80% if used in an unshaded site. This significant power increase shows the potential for the integrated system concept.

Having assessed the renewable energy potential of Victor Harbor, a decision on a proposed hybrid system concept can be made. Conceptually this involves selecting an appropriate wind turbine type and PV panel arrangement, and both of these decisions can be achieved through use of the weighting matrix concept.

After selecting the conceptual system, the location for installation at the test site needs to be made. This, as discussed has been made on the basis of solar radiation shading effects caused by site specific objects.

Turbine Selection

Turbine selection has been based on the weighting matrix principle. The three types of turbine have been ranked in terms of their cost, noise, size and aesthetics and then multiplied by the weighting matrix to determine the appropriate choice. Noise, size and aesthetics ranking was straight forward, but the cost consideration was a little more involved. The three turbines were ranked based on their sensitivity to shading, but were given normalized scores for cumulative power per dollar for both shaded and unshaded conditions. Summing up these three scores and then dividing through by the maximum possible score then allowed an appropriate normalised value to be assigned to each. Table 5 contains the results of this decision analysis.

Table 5: Results of turbine decision process

Aspect	HAWT	Savonius	Darrieus
Normalised Power/Cost Consideration	0.75	0.50	0.43
Noise	0.33	1	0.67
Size	0.67	1	0.35
Aesthetics	0.5	0.75	0.75
Weighted TOTAL	**0.563**	**0.813**	**0.55**

The results reveal that the Savonius type turbine is the turbine of choice. This is the best choice as it is the quietest and most compact. Although it has the poorest performance in terms of outright power generation per dollar according to the power analysis there are a few beneficial points pertaining to Savonius turbines that the authors would like to address. Firstly the Savonius turbine is the simplest in design. With few moving parts it would be the cheapest and easiest to maintain. Secondly, the Savonius works in wind coming from any direction and needs no complicated tracking system like a HAWT. The turbine is self starting unlike a Darrieus. Also, as more Savonius wind turbines enter the market and are consumed, the prices are expected to reduce in the future, which will ultimately improve the cost of the system. Although these economic considerations were not accounted for directly in the power analysis, it is believed that a Savonius wind turbine will produce improved performance per dollar than what is reflected in this report, whereas HAWT and Darrieus turbines will produce poorer performance than what is reflected in this report.

PV Panel Selection

Because of the nature of PV derived energy, the addition of solar panels to the wind turbine will have little direct benefit to either system. This is because both require differing components in order to work wit one another. However turbine structure does provide region for mounting PV cells and so if the funds the structure can be exploited for mounting PV panels.

The results of the solar energy analysis show that the power per dollar of a PV panel is essentially independent of its type. Moreover the dimensions are similar so no special decision needs to be made regarding the type of panel to select. The authors suggest that the most readily available be used.

The number of panels that a wind turbine structure can host will dictate the number of panels that the hybrid system should incorporate. PV panels have an average size of around 1.3m^2 meaning that a domestic-size turbine can realistically host two panels. This does not present the best result economically given that a typical inverter can host up to 6 panels, but this can be overcome if three such turbines are placed in vicinity of one another and hooked up so as to share the results of the inverter.

Hybrid System Additional Benefits

It is the belief of the authors of this report that some small performance gains can be used if PV panels are correctly placed in relation to the wind turbine. If the PV cells are placed above the wind turbine, then the support for the cells could be designed so as to provide a fence for the Savonius wind turbine. According to Saha et al (2008)[19] a circular fence that is 10% larger than the diameter of the turbine itself provides the optimal power output for a Savonius wind turbine. Thus if the base of the PV panel support becomes this fence a slight performance improvement may be attained.

In addition to the benefits of the fence to the performance of the turbine, it may also provide slight improvements to the solar panel. The performance of a solar panel diminishes as the panel increases in temperature as can be seen in Figure 22. Thus the fence may provide a very slight heat transfer effect that would maintain the keep the PV panels cooler and more efficient.

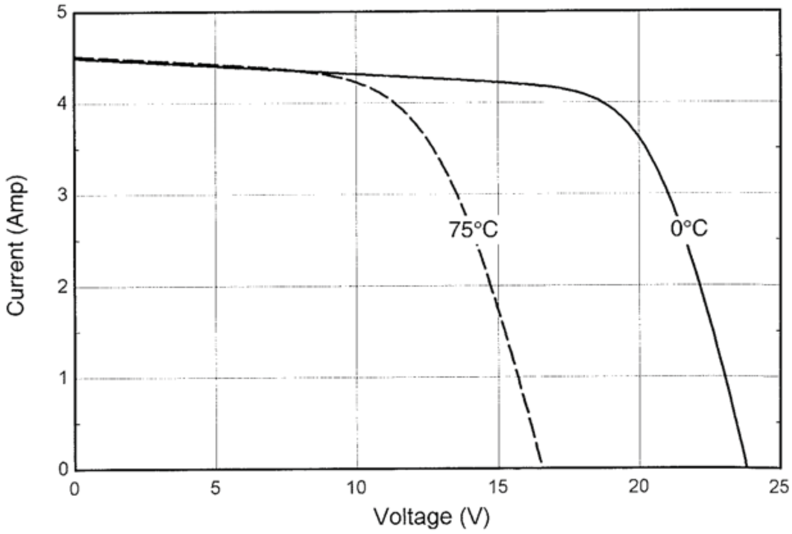


Figure 22: Effect of temperature on PV cell performance. Power output decreases as temperature increases[20].

The concept proposed by the authors would look similar to that shown in Figure 23. As can be seen, the hybrid system has a Savonius turbine upon which is placed the PV cell(s). The endplate would be such that it rotates with the turbine to improve performance.

Figure 23: The recommended hybrid system concept. A Savonius wind turbine upon which are placed one or two PV panels. The panels help to improve the efficiency of the turbine and vice versa through clever sizing and design of the panel support structure.

As alluded to previously, sharing inverter components amongst a number of turbines increases economic benefits. This would improve the output per dollar for the PV cells arranged. Such a system would look like that shown in Figure 24.

Figure 24: The use of multiple hybrid systems not only improves power output but also system cost by allowing the systems to share electronic componentry.

Siting of the System

The initial prototype system being placed at the civic centre will benefit most by placing it in the region that receives the most direct sunshine. To determine the best locations, a Solar Pathfinder was utilised in thirteen predetermined locations adjacent to the Council/Library complex (Figure 25).

Appendix E contains the solar path diagrams recorded during the siting analysis. Through appropriate analysis, the monthly and annual percentage of available irradiation befalling on each site could be calculated. The results can be found in Table 6. These results do not include the measurements for sites 1 & 8 as they were deemed unfeasible due to existing power lines. In addition sites 2, 3 & 12 were not considered as assessment of the building on site revealed that it would be impractical to erect a hybrid system on top of the Civic Centre.

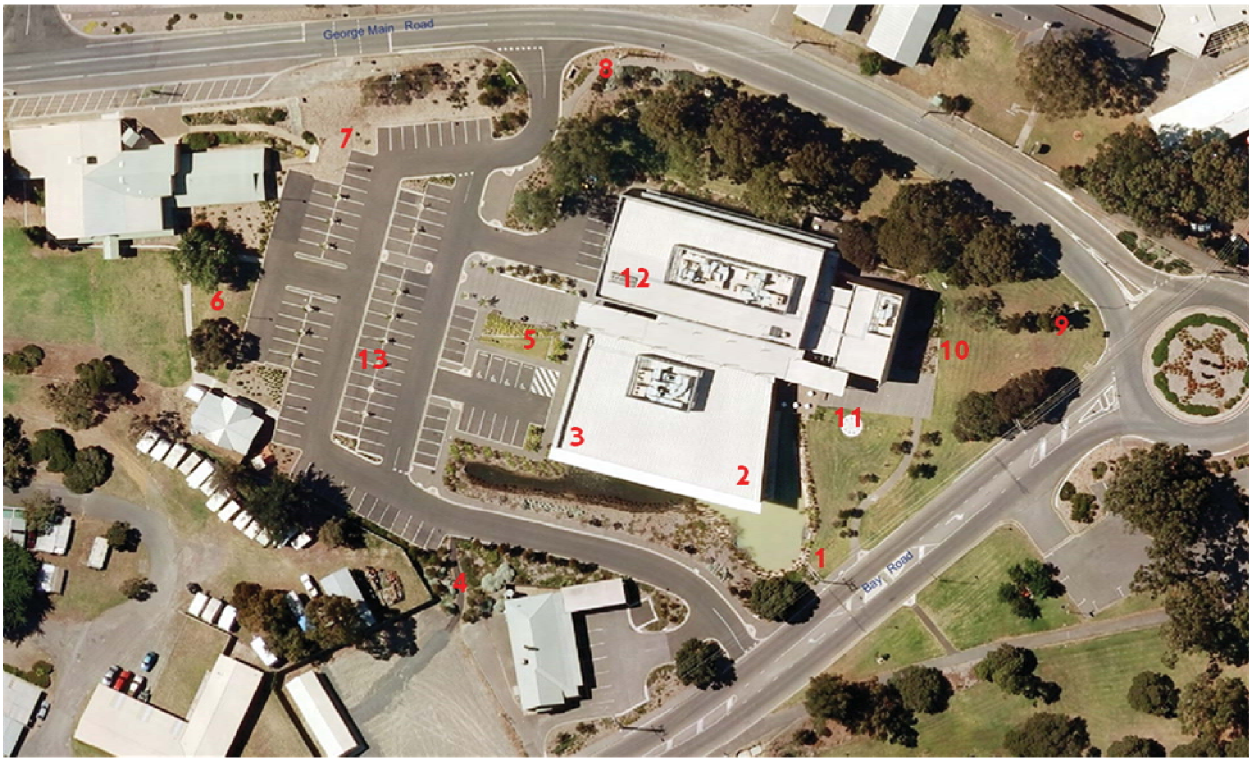


Figure 25: System siting selection. Possible locations at the Civic Centre. Note Sites 1 & 8 were deemed unfeasible due to power lines.

Table 6: Solar siting results taking into consideration shading effect of nearby objects.

Site #	**Percentage Solar Irradiation**												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Ann**
4	91	76	76	82	94	93	94	85	76	80	91	91	86
5	96	95	94	94	82	78	82	89	94	95	96	95	91
6	100	100	72	52	27	25	25	52	65	100	100	100	68
7	99	100	96	98	76	71	69	96	98	98	99	98	92
9	100	100	98	58	38	24	35	56	98	99	100	100	76
10	92	95	92	82	50	23	29	82	91	95	94	90	76
11	98	98	92	94	61	47	60	90	92	96	97	96	85
13	97	100	98	82	66	41	59	73	96	100	98	96	84

From the results of the solar siting, sites 5 & 7 are recommended as priority sites for the hybrid system as they provide maximum solar exposure throughout the year. Site 8 is also considered favourable due to the fact that the shading is due only to a small sapling near the site. If this sapling were to be removed, the annual irradiation befalling upon the site would be expected to increase to approximately 95% of the theoretical maximum.

Further Considerations

Even the most fully optimised renewable energy generation device is limited by the efficiency of the system it serves. It is essential for the Civic Centre staff to adopt an attitude of conservation. A comprehensive energy audit of the Civic Centre is recommended in the interest of understanding the directions of energy consumption.

Summary and Further Recommendations

As part of the on-going renewable energy initiatives of the City of Victor Harbor, a feasibility study focusing on the available wind and solar energy of the region has been undertaken. This study represents the first stage of the project to develop and implement integrated hybrid energy systems to power various domestic sites within the area. The hybrid systems are to utilise both solar and wind energy and initial use of the devices will be to reduce the dependency of the City's Civic Centre and street lighting on traditionally derived, mains electricity.

The feasibility study has attempted to assess the economics of such systems being used within Victor Harbour City and its surroundings. This has required assessing not only meteorological data, but also the opinions and attitudes of the region's citizens, which were obtained from a distributed survey. Meteorological data was acquired from governmental departments as well as an installed weather station at the Civic Centre test site. This data allowed for solar and wind energy output assessments for the area to be made, for various types of wind and solar systems. The results of the survey were then used to identify the most feasible system for the area.

Analysis of the information obtained throughout the project shows that hybrid system designed for domestic applications will be effective in producing electricity within the area. To identify the most suitable, the City will need to clarify its energy needs and the amount of money it wishes to spend. It is clear from the analysis that a system incorporating a Horizontal Axis Wind Turbine should produce the most energy per dollar spent on the system. This is irrespective of the types of solar panels used. The power output directly relates to the cost of the system, since power outputs of different system types can be matched simply by building extra or fewer system units. According to citizens of Victor Harbor, cost should not be the major driving factor, and consequently the hybrid system proposed by the feasibility study differs to what one might expect if basing decision purely on cost.

The integrate hybrid system proposed by the feasibility study incorporates a single wind turbine. This recommended turbine is a Savonius type, a Vertical Axis device. This type does not produce the most power per dollar but has other attributes that make it the most suited. The attributes include quiet operation and robustness to changes in wind direction.

The study has concluded that any of the three major types of photovoltaic panel will function well. All three types were found to have very similar performance per cost and as such the type that is recommended is the one that is most easily to acquire. The number of panels that should be incorporated into the hybrid system is realistically limited by the structure of the turbine. The study recommends that one or two panels be incorporated into the hybrid system and that additional hybrid system devices be used when power in addition to that provided by one system is required.

It has been established that the hybrid system will not result in a drastic improvement in the economics of both solar and wind energy. This is largely due to the different operation and power generation of the two technologies. The one major advantage of developing a hybrid system is the ability for the device to generate an increased amount of electricity for a given area. As the example given shows, this could amount to an increase of 80% for a given area. For this reason it is recommended that the development of the hybrid system concept is continued.

The performance of a hybrid system is challenging to predict owing to the complex coupling of the numerous parameters that dictate power output. For this reason much care needs to be given to the siting and energy resources available to any hybrid system. The feasibility study introduces the concept of siting and how to overcome solar and wind shading. It is expected that the representatives of the City of Victor Harbor consider these points when further continuing the project. In addition, it is expected that the representatives will regard the costing information presented in this report when making a final decision on the concept to pursue and make augmentations to the conceptual design where appropriate.

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Appendix A – Renewable Energy Survey

The Survey presented on the following pages was issued to ratepayers of Victor Harbor City Council. The objective of the survey was to receive feedback from members of the community on their ideas and concerns related to renewable energy systems, in particular opinions surrounding the hybrid system concept.

Section 1: Renewable Energy

1	**I strongly disagree**
2	**I disagree**
3	**No opinion either way**
4	**I agree**
5	**I strongly agree**

For each question below, circle the number to the right that best fits YOUR OPINION on the importance of the issue. Use the scale above to match your opinion.

Question	**Scale**				
1. I value the environment and am concerned with living in a sustainable fashion.	**1**	**2**	**3**	**4**	**5**
2. I consider the development of renewable energy technology to be vital for a sustainable existence.	**1**	**2**	**3**	**4**	**5**
3. I would like to see the City of Victor Harbor become less dependent on traditional energy sources such as fossil fuels.	**1**	**2**	**3**	**4**	**5**
4. The development of sustainable technology is a worthwhile investment.	**1**	**2**	**3**	**4**	**5**
5. I am aware of other wind and/or solar electricity plants in South Australia.	**1**	**2**	**3**	**4**	**5**
6. I object to the sight of renewable energy sources.	**1**	**2**	**3**	**4**	**5**
7. I would like renewable energy for my own home	**1**	**2**	**3**	**4**	**5**
8. I support the City of Victor Harbor Council in financing renewable energy research and development.	**1**	**2**	**3**	**4**	**5**

9. I support the City of Victor Harbor installing hybrid wind/solar electricity systems to power council buildings and infrastructure	1	2	3	4	5
10. I am concerned about seeing renewable energy systems in the Victor Harbor community.	1	2	3	4	5

Section 2: Solar Panel Installations

1	**I strongly disagree**
2	**I disagree**
3	**No opinion either way**
4	**I agree**
5	**I strongly agree**

For each question below, circle the number to the right that best represents how you feel suits THE IMPORTANCE that you place on the importance of the issue. Use the scale above to match your opinion.

Question	**Scale**				
1. I support the use of solar panels to generate electricity	**1**	**2**	**3**	**4**	**5**
2. The sight of any solar panels concerns me.	**1**	**2**	**3**	**4**	**5**
3. The sight of large arrays of solar panels concerns me.	**1**	**2**	**3**	**4**	**5**
4. I am concerned with the cost of this technology					
5. I would be willing to use solar panels to reduce my reliance on coal-derived electricity.	**1**	**2**	**3**	**4**	**5**
6. I would be more supportive of installing a solar panel array if it could be made SMALLER if used in conjunction with a wind turbine.	**1**	**2**	**3**	**4**	**5**
7. I would be more supportive of installing a solar panel array if it could be made more ECONOMICAL if used in conjunction with a wind turbine.	**1**	**2**	**3**	**4**	**5**

Section 3: Wind Turbine Installations

1	I strongly disagree
2	I disagree
3	No opinion either way
4	I agree
5	I strongly agree

For each question below, circle the number to the right that best represents how you feel suits THE IMPORTANCE that you place on the importance of the issue. Use the scale above to match your opinion.

Question	Scale				
1. I support the use wind turbines to generate electricity	1	2	3	4	5
2. The sight of wind turbines concerns me.	1	2	3	4	5
3. The sight of large wind turbine concerns me.	1	2	3	4	5
4. I find wind turbines aesthetically pleasing, and think that they appear as a sign of technological progress.	1	2	3	4	5
5. Noise generated by wind turbines is a concern.	1	2	3	4	5
6. I would be willing to use a wind turbine system to reduce my reliance on coal-derived electricity.	1	2	3	4	5
7. I would be more supportive of installing a wind turbine if it could be made smaller by using solar panels in conjunction with the turbine.	1	2	3	4	5
8. The fact that a conventional wind turbine comprises blades rotating at high speed in vertical plane worries me.	1	2	3	4	5

9. A vertical turbine that is silent and designed for the domestic environment might be an suitable alternative.	**1**	**2**	**3**	**4**	**5**

Appendix B – Results of Survey

This section represents the results of the survey distributed to citizens of Victor Harbor City Council. The results are the averages of the responses to the questions based on the Likert ratings presented in Table 7.

The results for Sections 1, 2 and 3 of the survey are presented in Tables respectively.

Table 7: Likert ratings as used in the survey distributed to council area citizens.

1	**I strongly disagree**
2	**I disagree**
3	**No opinion either way**
4	**I agree**
5	**I strongly agree**

Table 8: Survey results for Section 1: Renewable Energy

Section 1: Renewable Energy	
1. I value the environment and am concerned with living in a sustainable fashion.	**5**
2. I consider the development of renewable energy technology to be vital for a sustainable existence.	**5**
3. I would like to see the City of Victor Harbor become less dependent on traditional energy sources such as fossil fuels.	**5**
4. The development of sustainable technology is a worthwhile investment	**4**
5. I am aware of other wind and/or solar electricity plants in South Australia.	**4**
6. I object to the sight of renewable energy sources.	**2**
7. I would like renewable energy for my own home	**4**
8. I support the City of Victor Harbor Council in financing renewable energy research and development.	**4**
9. I support the City of Victor Harbor installing hybrid wind/solar electricity systems to power council buildings and infrastructure	**5**
10. I am concerned about seeing renewable energy systems in the Victor Harbor community.	**2**

Table 9: Survey results for Section 2: Solar Panel Installations

Section 2: Solar Panel Installations	
1. I support the use of solar panels to generate electricity	**5**
2. The sight of any solar panels concerns me.	**2**
3. The sight of large arrays of solar panels concerns me.	**2**
4. I am concerned with the cost of this technology	**0**
5. I would be willing to use solar panels to reduce my reliance on coal-derived electricity.	**4**
6. I would be more supportive of installing a solar panel array if it could be made SMALLER if used in conjunction with a wind turbine.	**3**
7. I would be more supportive of installing a solar panel array if it could be made more ECONOMICAL if used in conjunction with a wind turbine.	**4**

Table 10: Survey results for Section 3: Wind Turbine Installations

Section 3: Wind Turbine Installations	
1. I support the use wind turbines to generate electricity	4
2. The sight of wind turbines concerns me.	2
3. The sight of large wind turbine concerns me.	2
4. I find wind turbines aesthetically pleasing, and think that they appear as a sign of technological progress.	4
5. Noise generated by wind turbines is a concern.	3
6. I would be willing to use a wind turbine system to reduce my reliance on coal-derived electricity.	4
7. I would be more supportive of installing a wind turbine if it could be made smaller by using solar panels in conjunction with the turbine.	3
8. The fact that a conventional wind turbine comprises blades rotating at high speed in vertical plane worries me.	2
9. A vertical turbine that is silent and designed for the domestic environment might be an suitable alternative.	4

Appendix C – Weibull Data

The Weibull function was used to evaluate the amount of wind power potentially available at the site. To do that, statistical distributions of the onsite measured data and the original and adjusted wind speed data from Hindmarsh Island are presented in this section. Figures Figure **26** to Figure **37** show probability density functions for data from Hindmarsh Island over months of 2009.

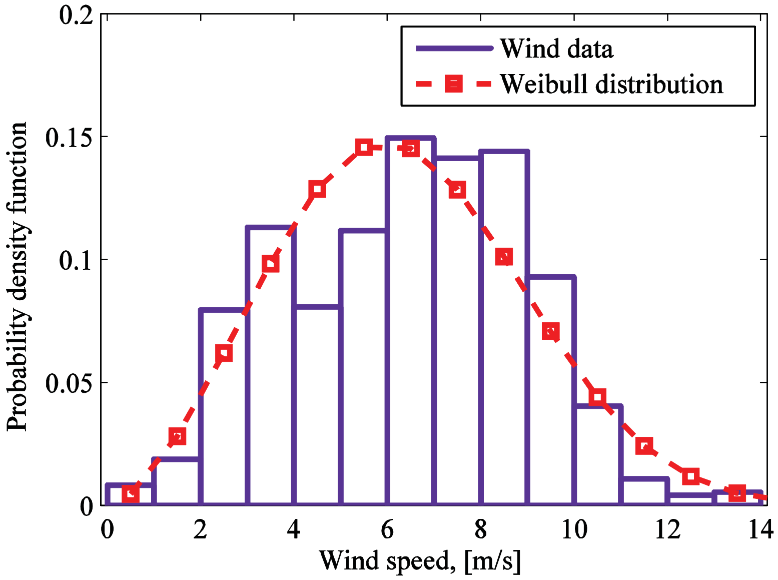

Figure 26: Probability distribution of Hindmarsh Island wind speed data, January 2009

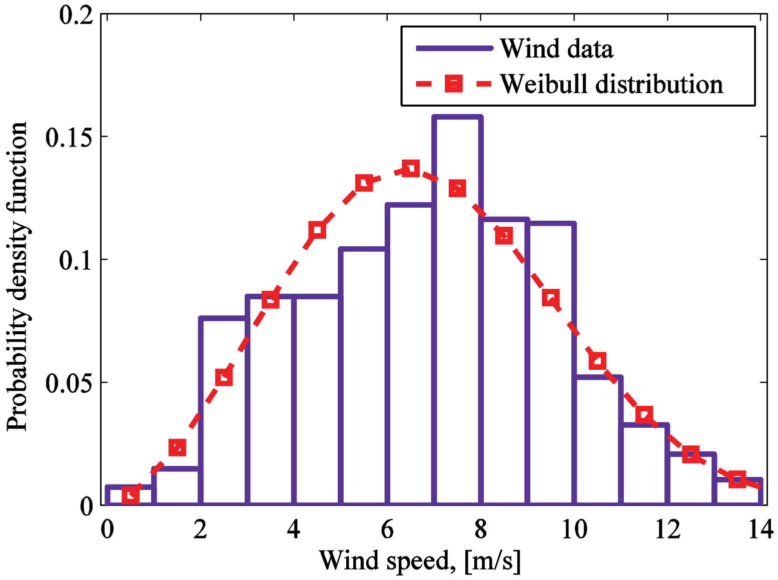

Figure 27: Probability distribution of Hindmarsh Island wind speed data, February 2009

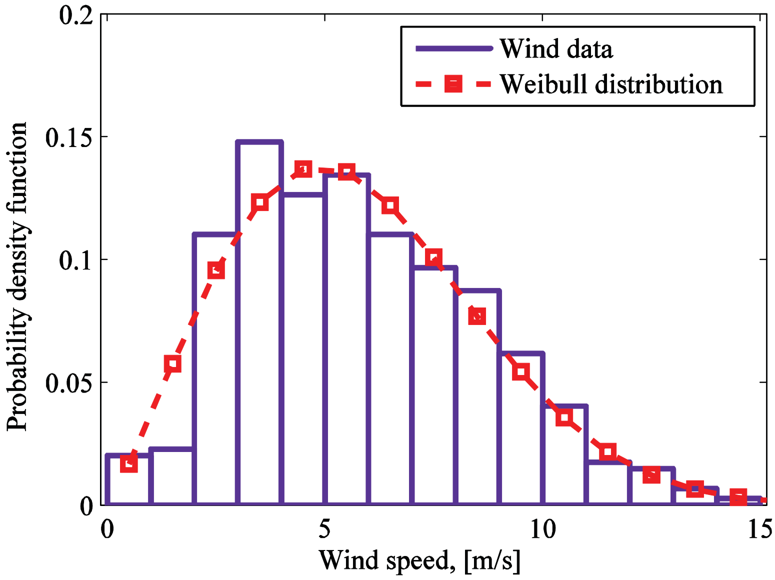

Figure 28: Probability distribution of Hindmarsh Island wind speed data, March 2009

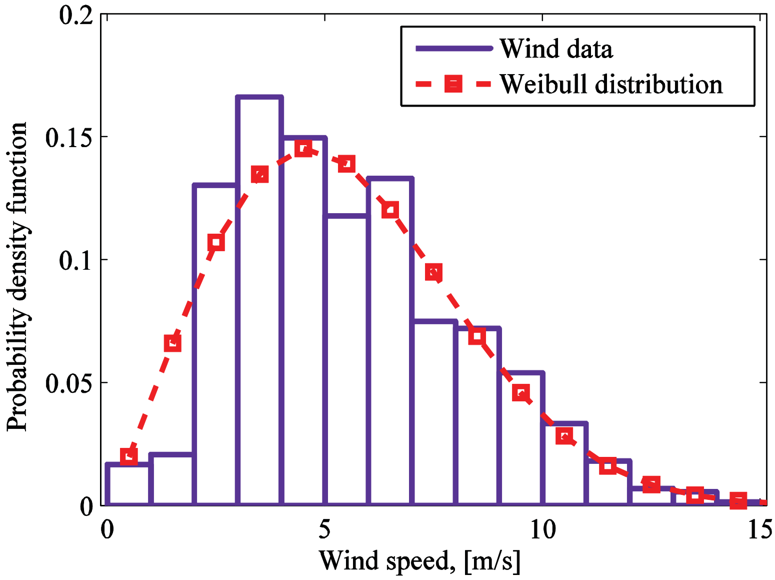

Figure 29: Probability distribution of Hindmarsh Island wind speed data, April 2009

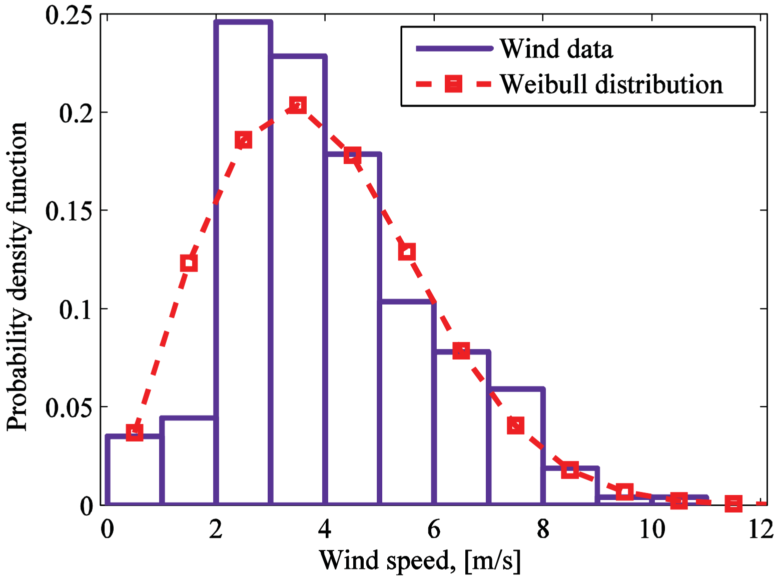

Figure 30: Probability distribution of Hindmarsh Island wind speed data, May 2009

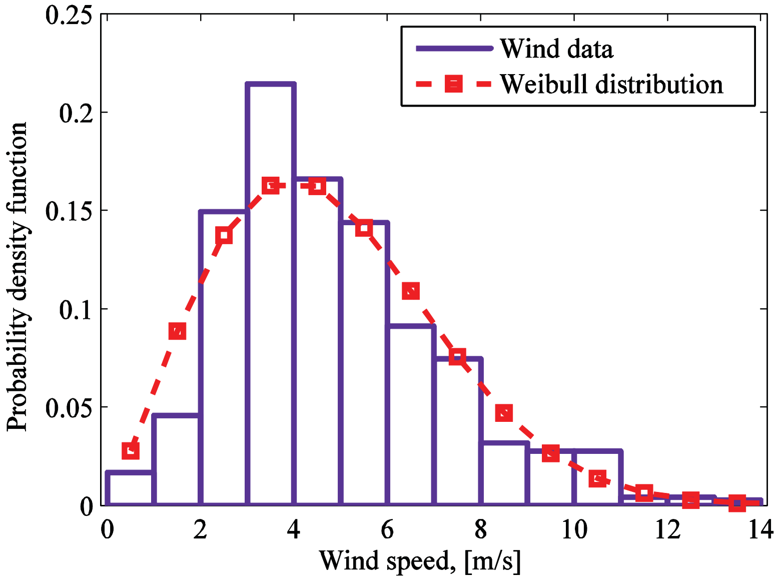

Figure 31: Probability distribution of Hindmarsh Island wind speed data, June 2009

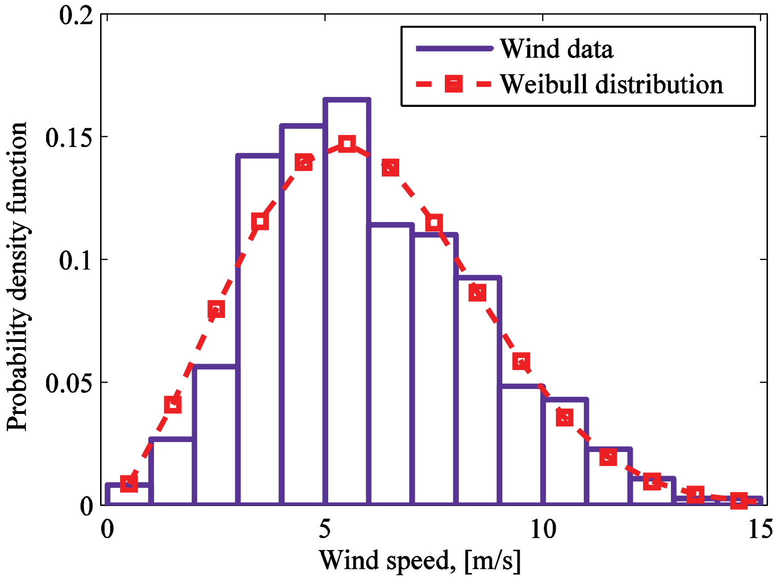

Figure 32: Probability distribution of Hindmarsh Island wind speed data, July 2009

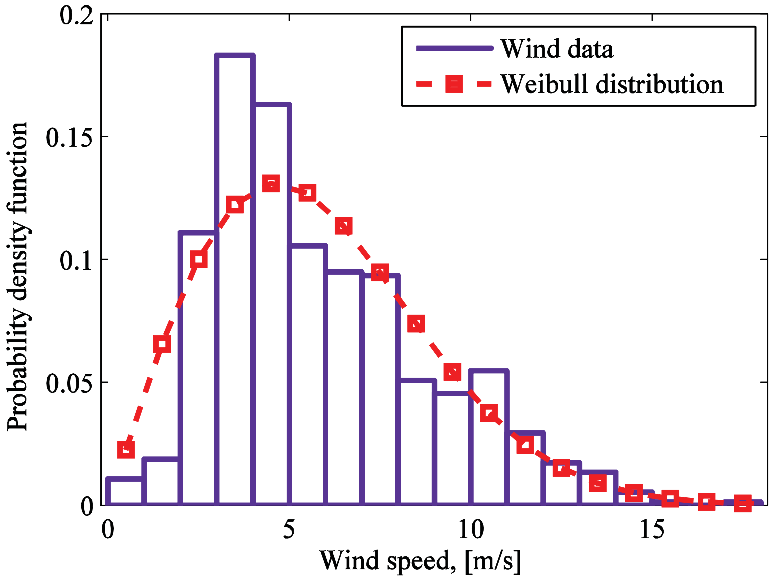

Figure 33: Probability distribution of Hindmarsh Island wind speed data, August 2009

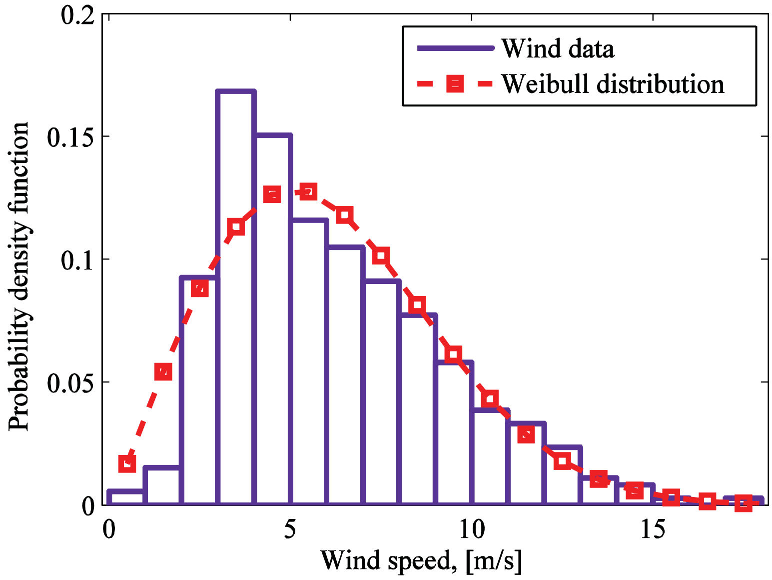

Figure 34: Probability distribution of Hindmarsh Island wind speed data, September 2009

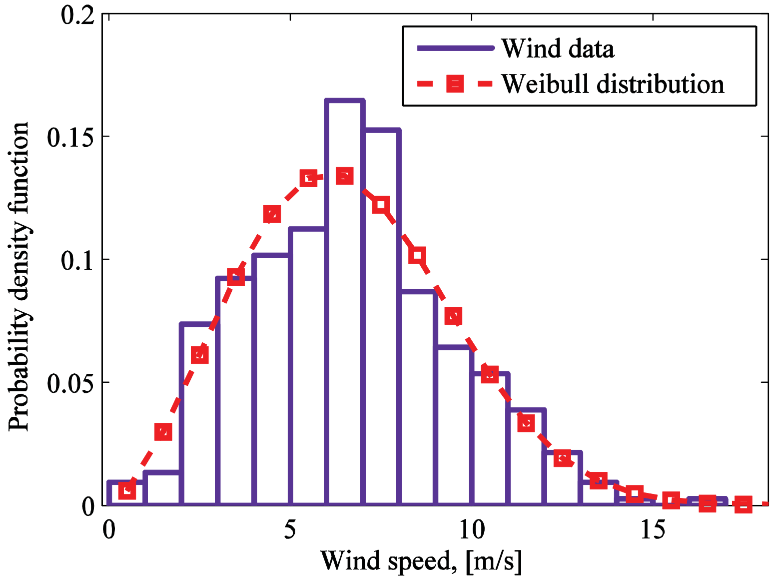

Figure 35: Probability distribution of Hindmarsh Island wind speed data, October 2009

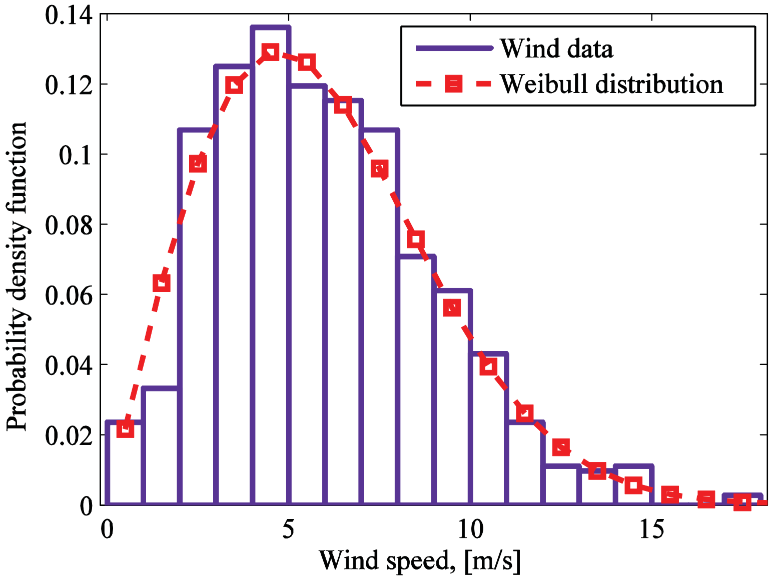

Figure 36: Probability distribution of Hindmarsh Island wind speed data, November 2009

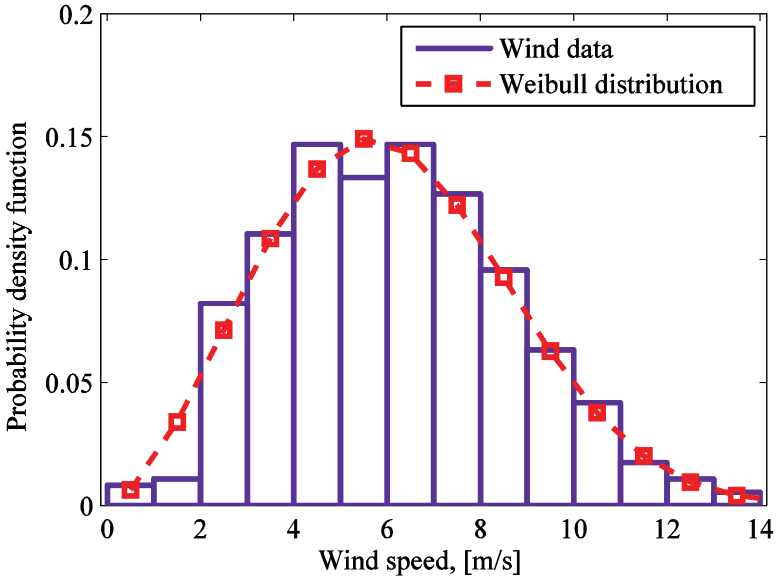

Figure 37: Probability distribution of Hindmarsh Island wind speed data, December 2009

Weibull cumulative density distribution based on Hindmarsh Island data are illustrated in Figures Figure **38** to Figure **49**.

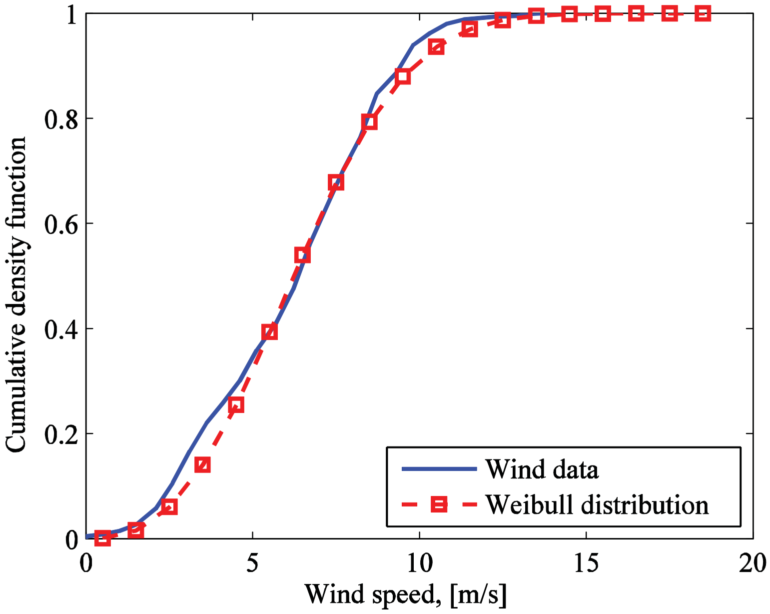

Figure 38: Cumulative distribution of Hindmarsh Island wind speed data, January 2009

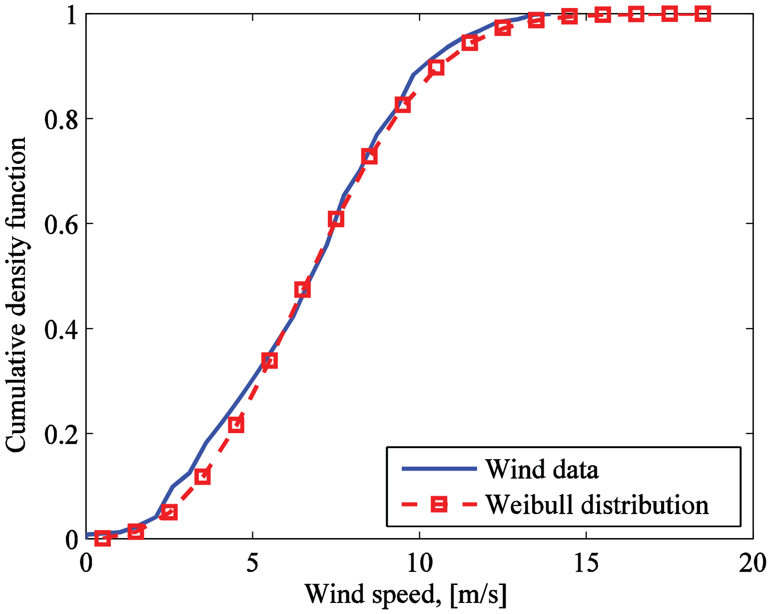

Figure 39 Cumulative distribution of Hindmarsh Island wind speed data, February 2009

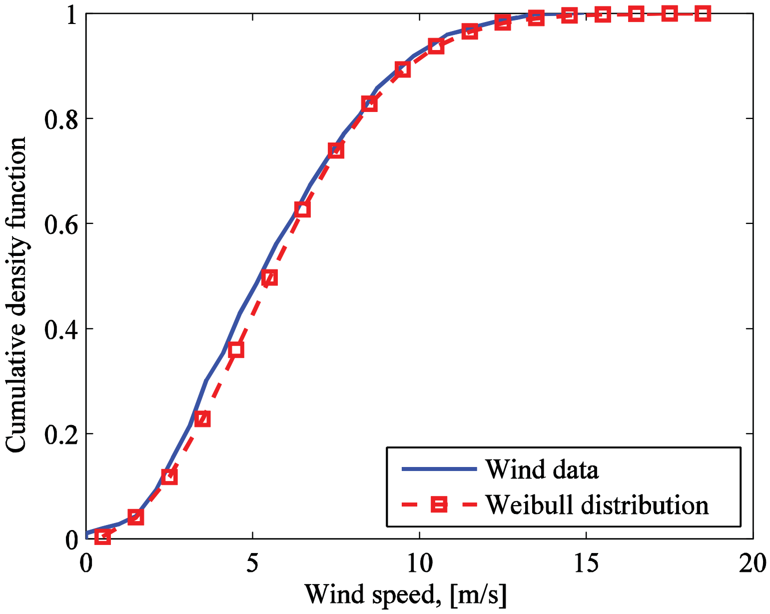

Figure 40: Cumulative distribution of Hindmarsh Island wind speed data, March 2009

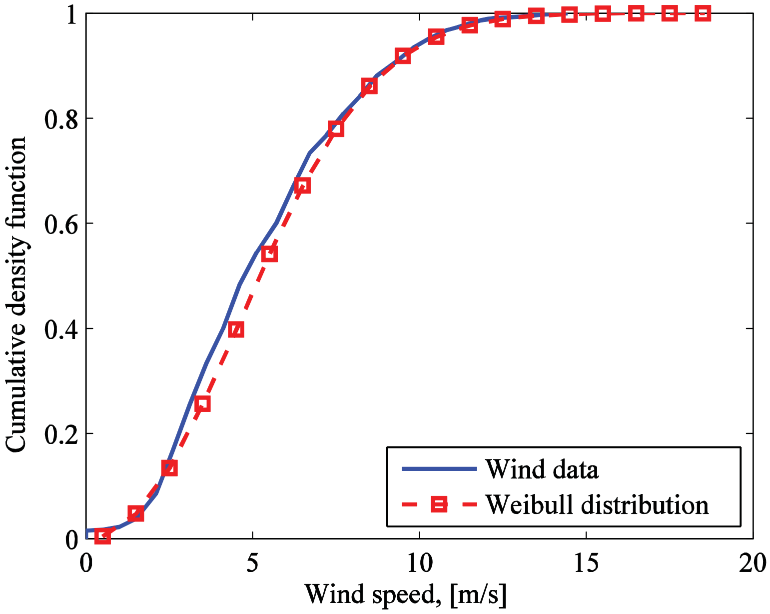

Figure 41: Cumulative distribution of Hindmarsh Island wind speed data, April 2009

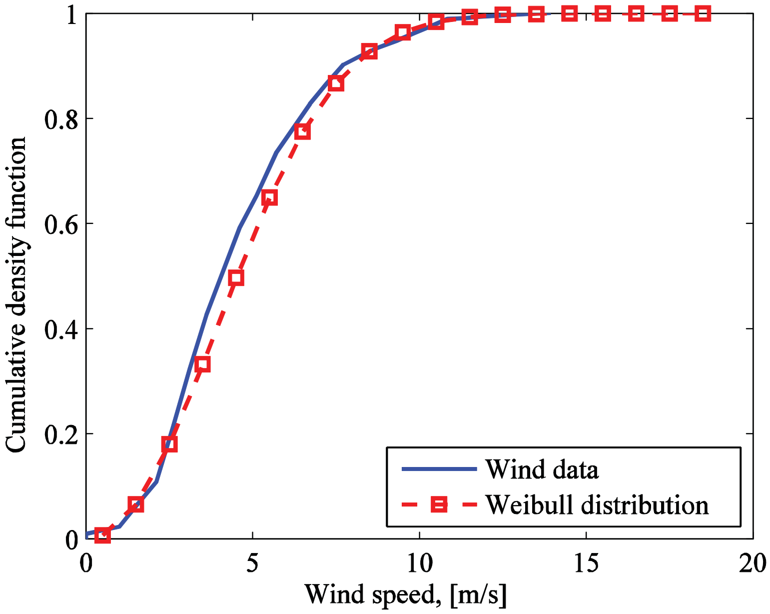

Figure 42: Cumulative distribution of Hindmarsh Island wind speed data, May 2009

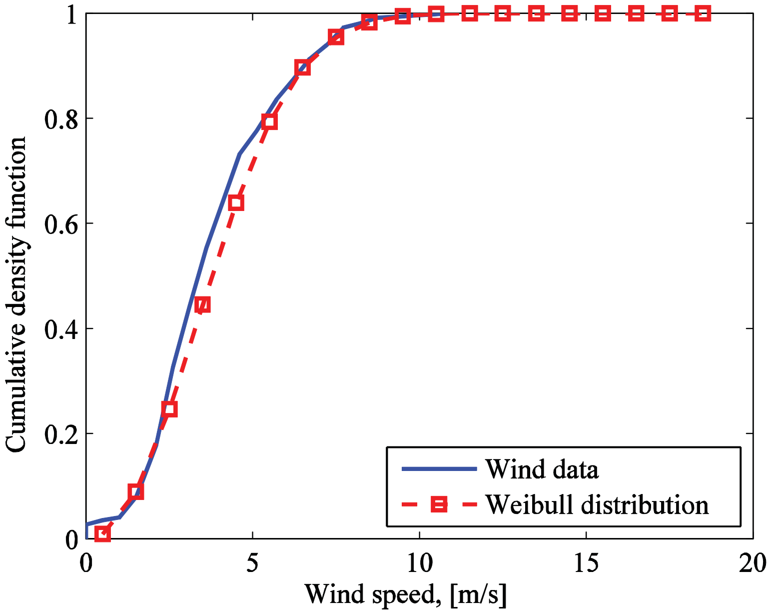

Figure 43: Cumulative distribution of Hindmarsh Island wind speed data, June 2009

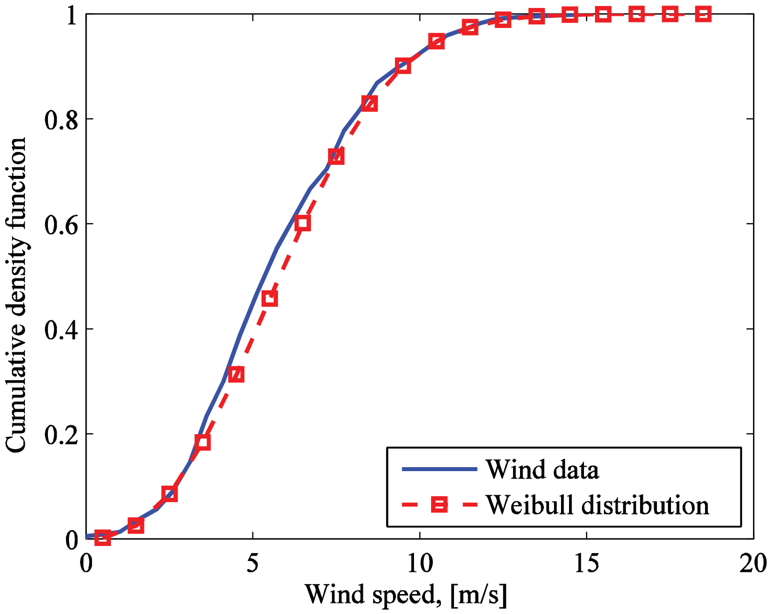

Figure 44: Cumulative distribution of Hindmarsh Island wind speed data, July 2009

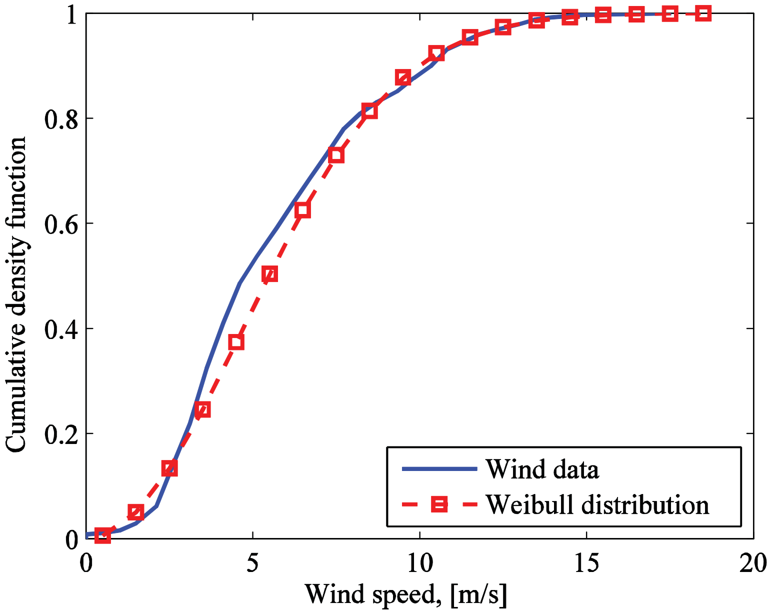

Figure 45: Cumulative distribution of Hindmarsh Island wind speed data, August 2009

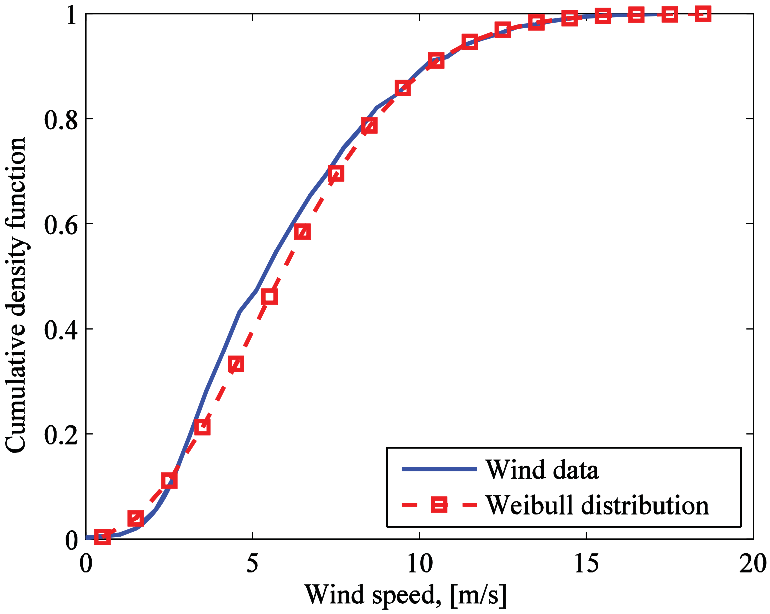

Figure 46: Cumulative distribution of Hindmarsh Island wind speed data, September 2009

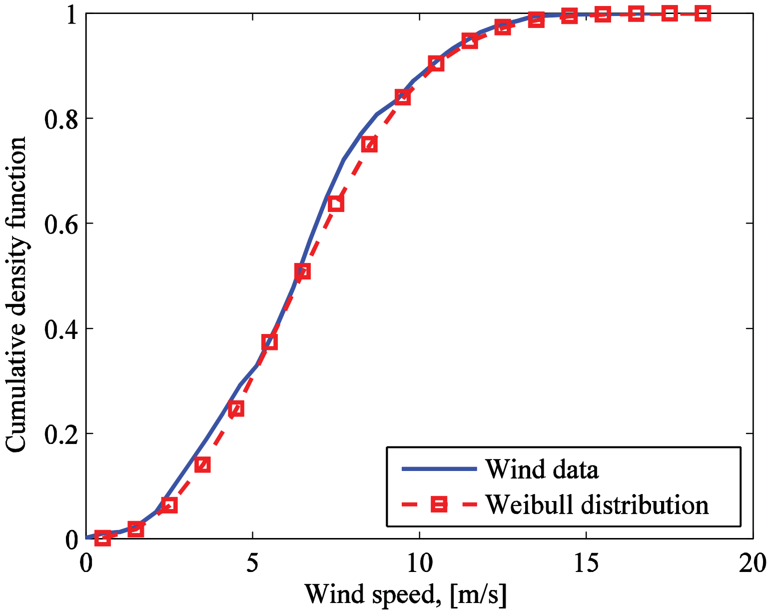

Figure 47: Cumulative distribution of Hindmarsh Island wind speed data, October 2009

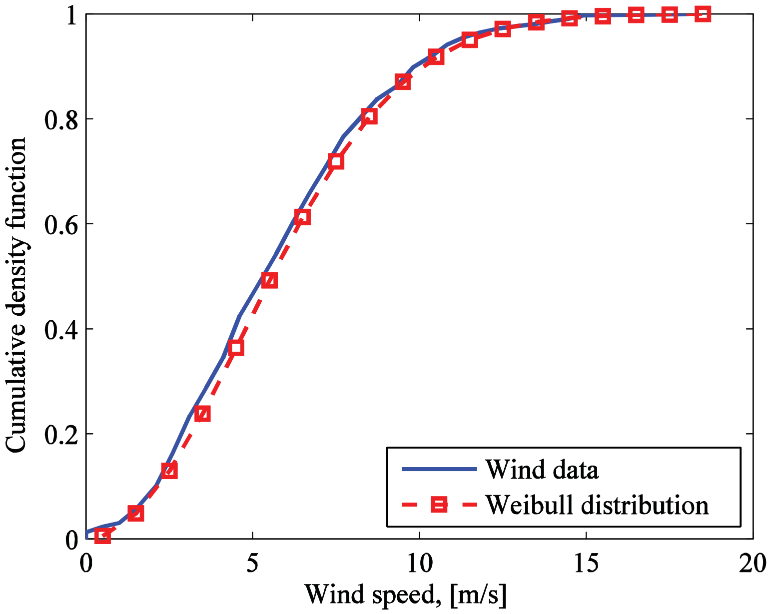

Figure 48: Cumulative distribution of Hindmarsh Island wind speed data, November 2009

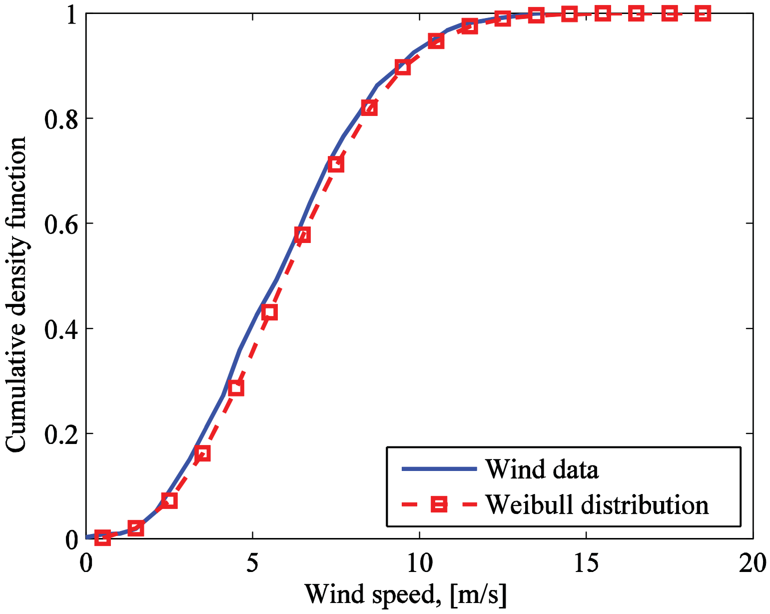

Figure 49: Cumulative distribution of Hindmarsh Island wind speed data, December 2009

Figures Figure **50** to Figure **61** depict the Hindmarsh Island adjusted probability distributions to be used for the Victor Harbour site.

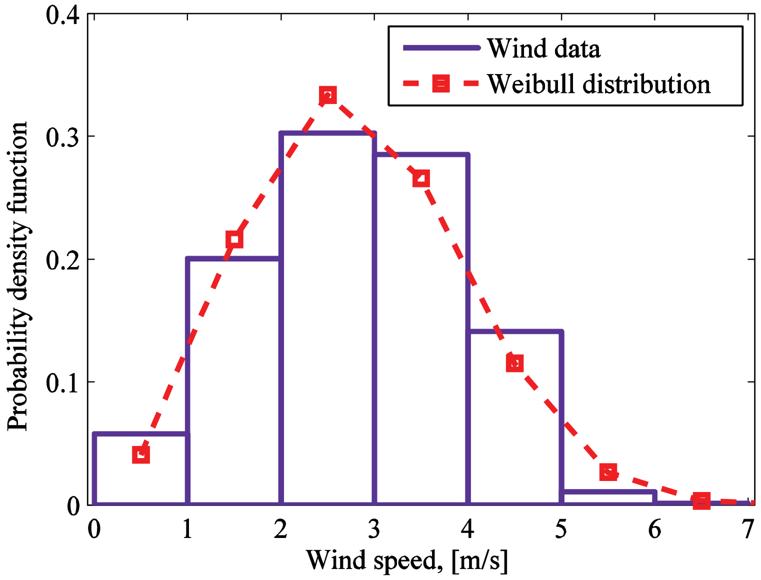

Figure 50: Adjusted probability distribution of Hindmarsh Island wind speed data, January 2009

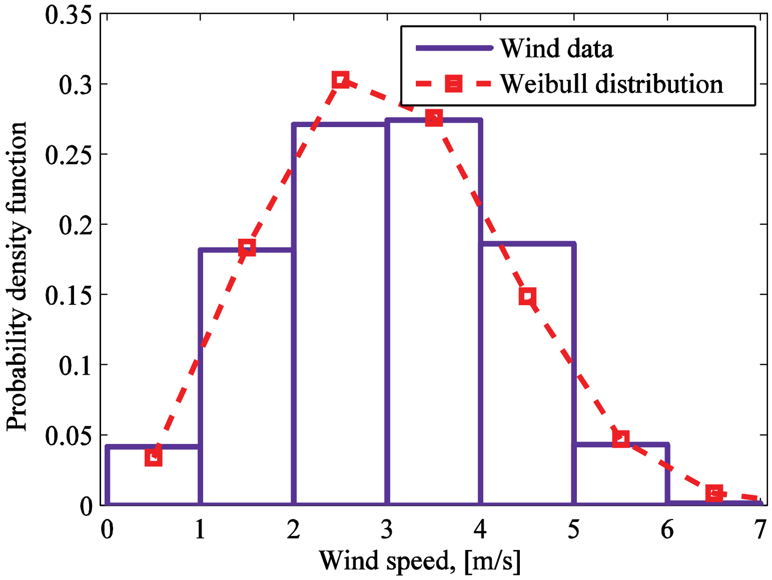

Figure 51: Adjusted probability distribution of Hindmarsh Island wind speed data, February 2009

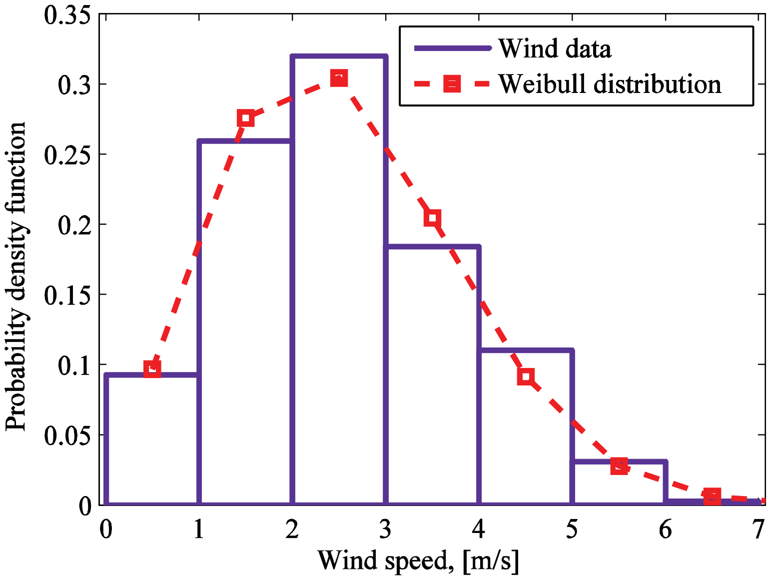

Figure 52: Adjusted probability distribution of Hindmarsh Island wind speed data, March 2009

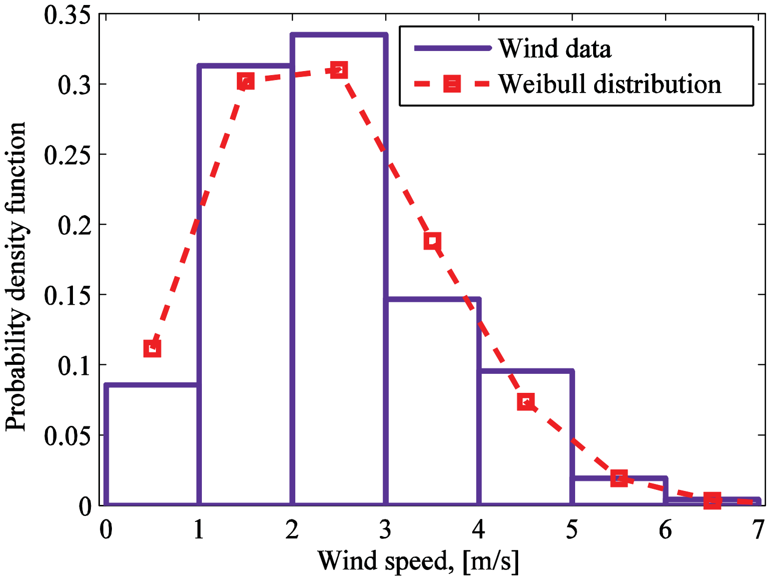

Figure 53: Adjusted probability distribution of Hindmarsh Island wind speed data, April 2009

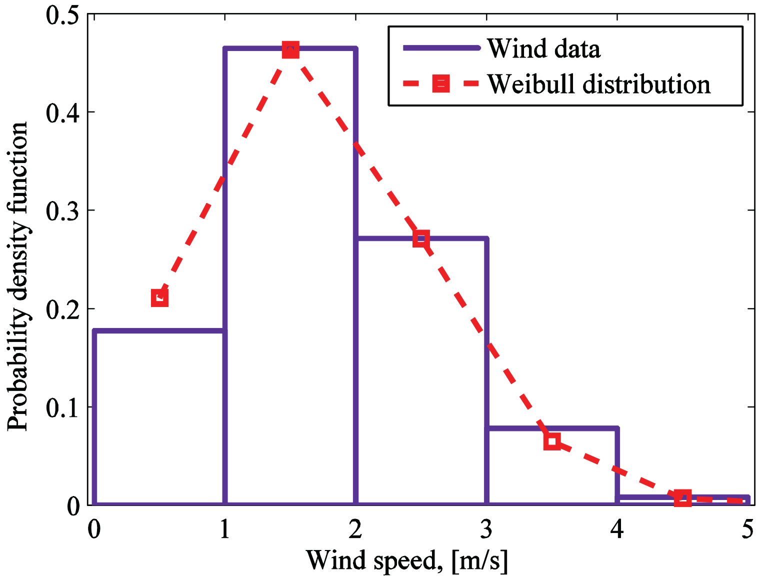

Figure 54: Adjusted probability distribution of Hindmarsh Island wind speed data, May 2009

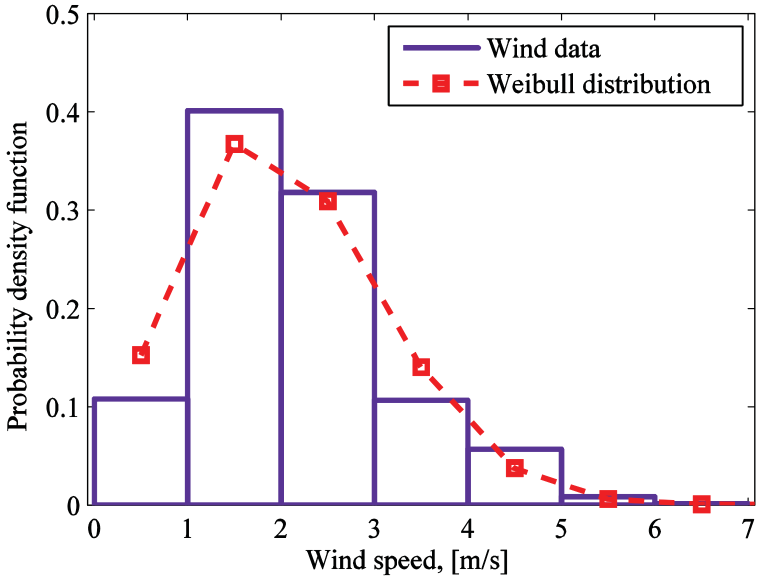

Figure 55: Adjusted probability distribution of Hindmarsh Island wind speed data, June 2009

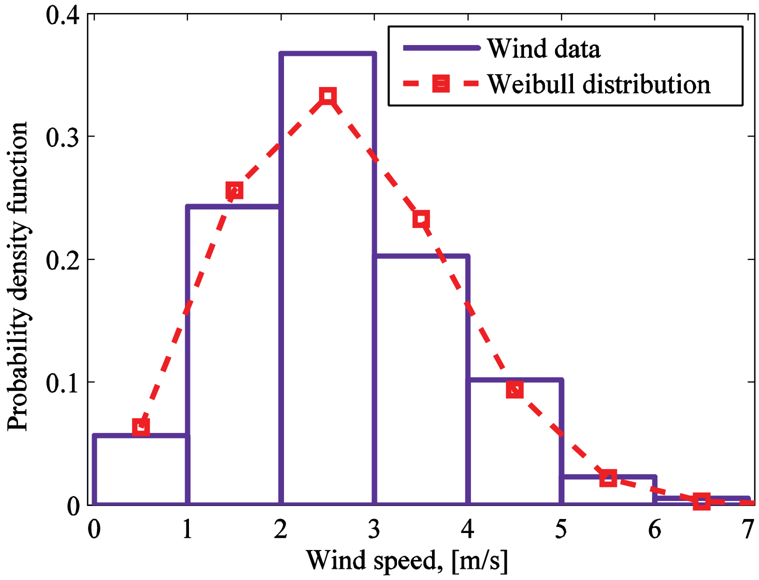

Figure 56: Adjusted probability distribution of Hindmarsh Island wind speed data, July 2009

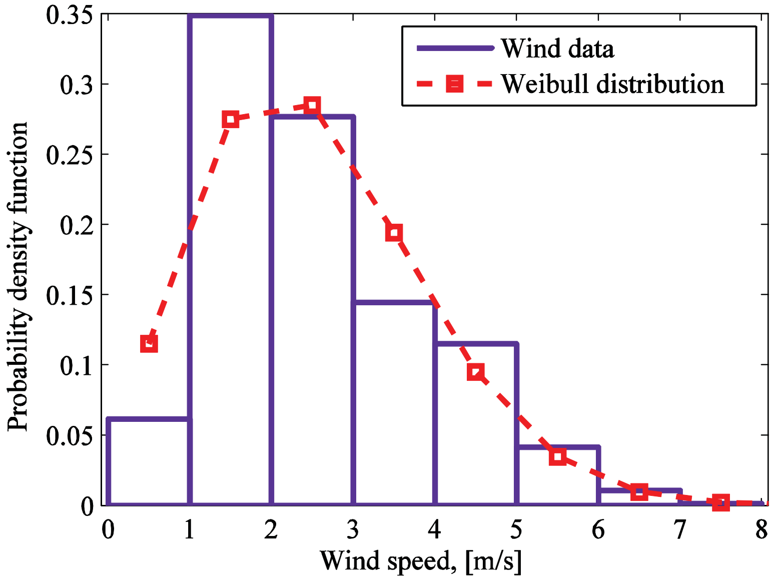

Figure 57: Adjusted probability distribution of Hindmarsh Island wind speed data, August 2009

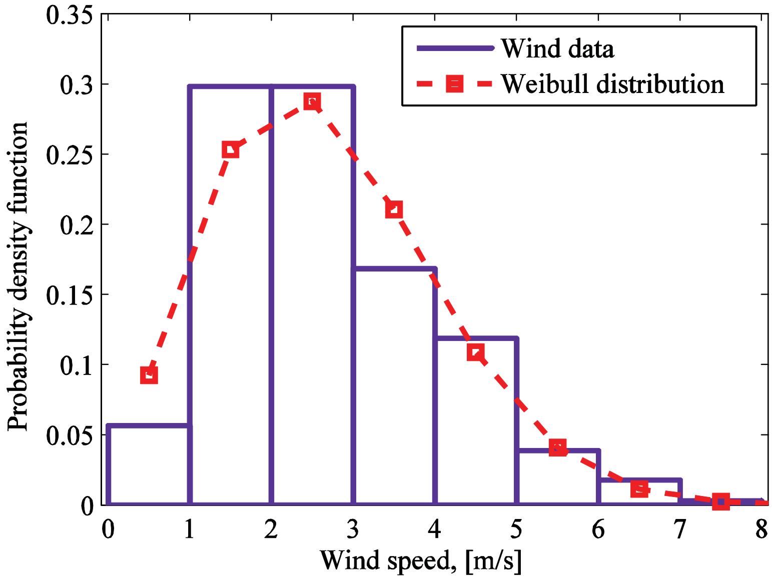

Figure 58: Adjusted probability distribution of Hindmarsh Island wind speed data, September 2009

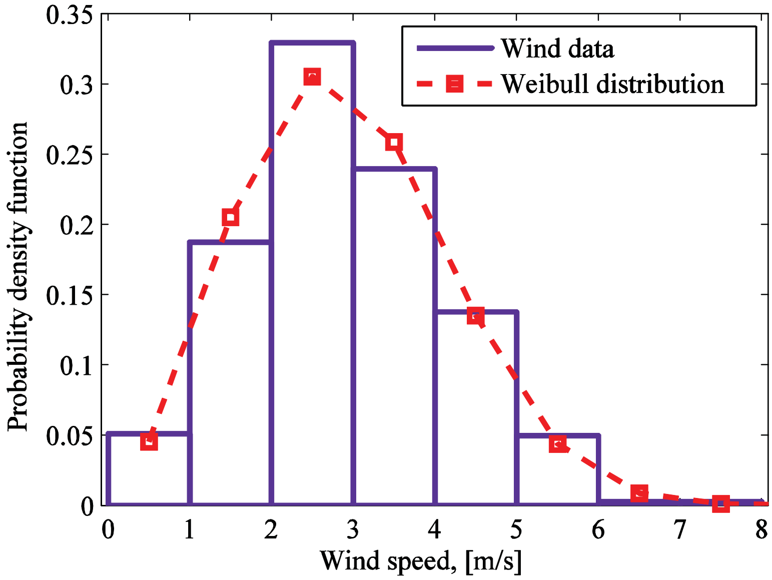

Figure 59: Adjusted probability distribution of Hindmarsh Island wind speed data, October 2009

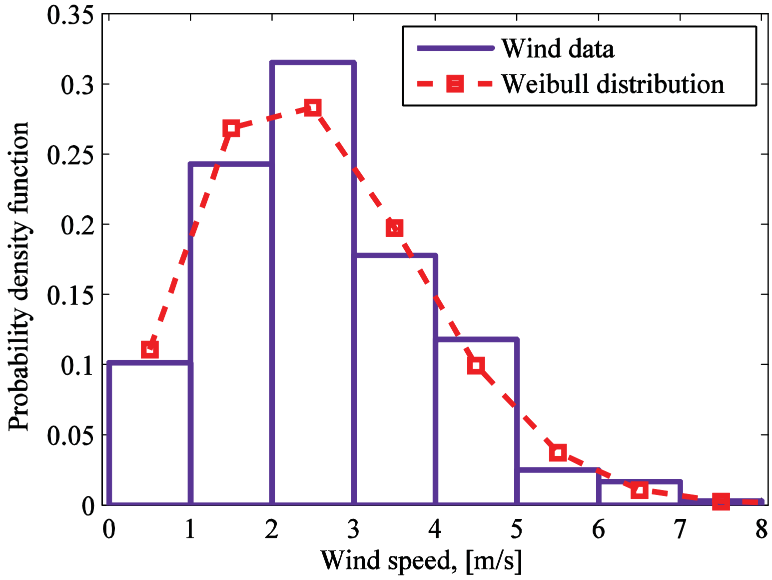

Figure 60: Adjusted probability distribution of Hindmarsh Island wind speed data, November 2009

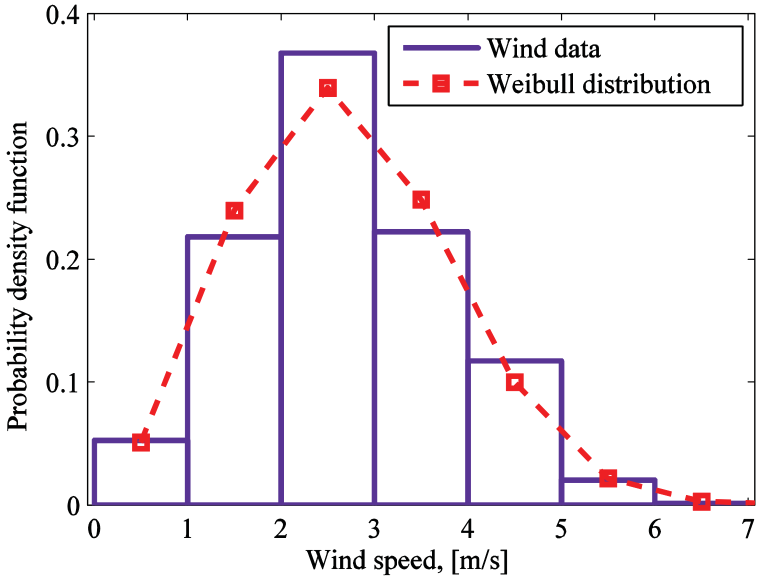

Figure 61: Adjusted probability distribution of Hindmarsh Island wind speed data, December 2009

The original wind speed data measured at the site are presented in Figures Figure **62** to Figure **65**.

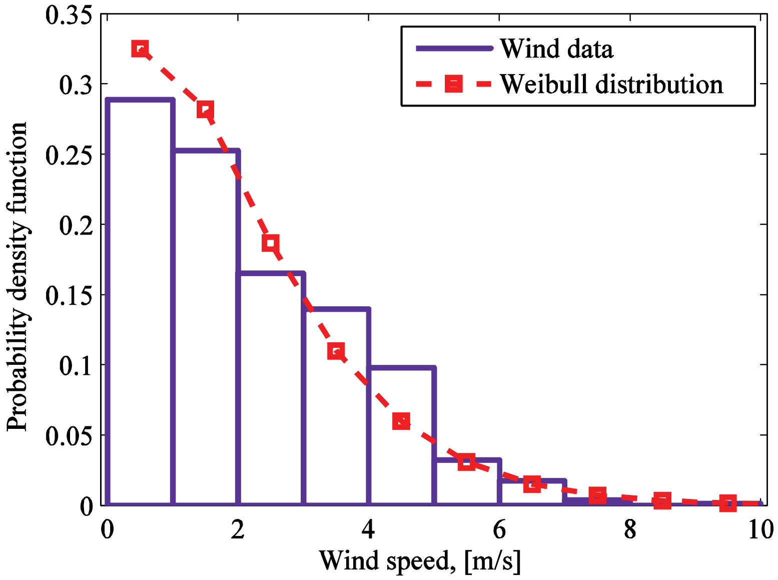

Figure 62: Probability density function for the data measured at the Victor Harbour site, January 2010

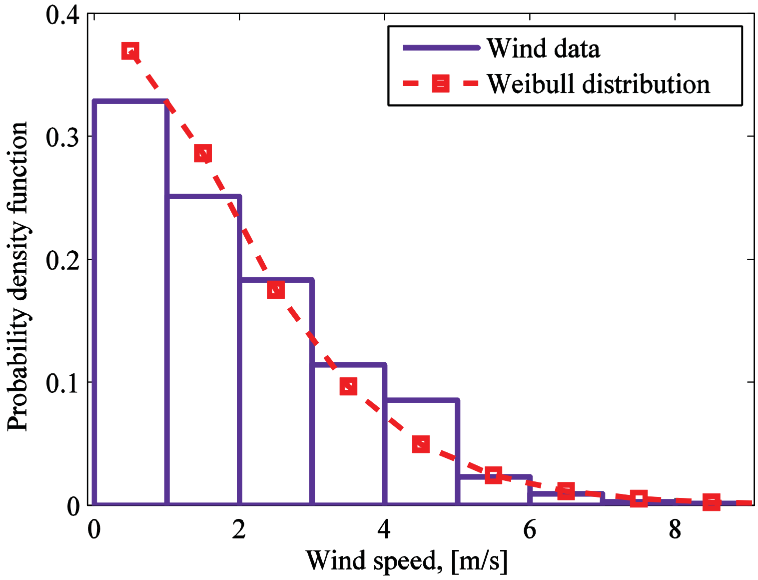

Figure 63: Probability density function for the data measured at the Victor Harbour site, February 2010

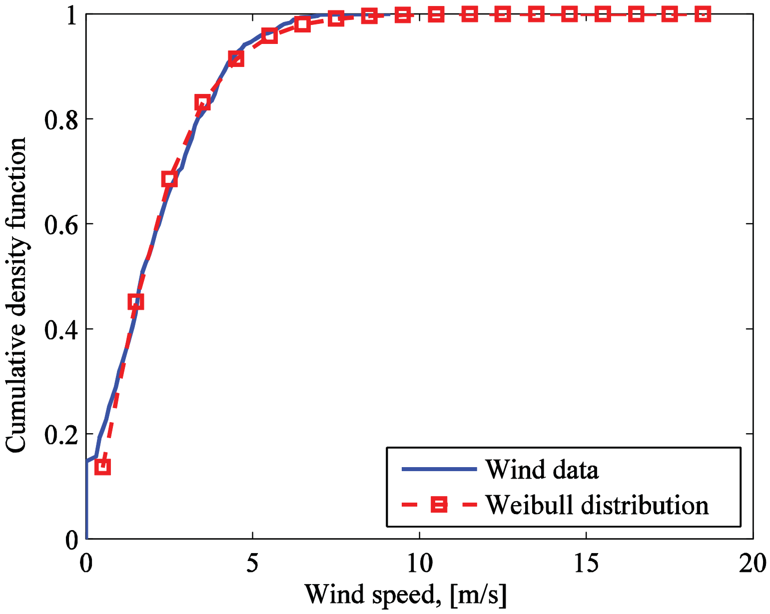

Figure 64: Cumulative density function for the data measured at the Victor Harbour site, January 2010

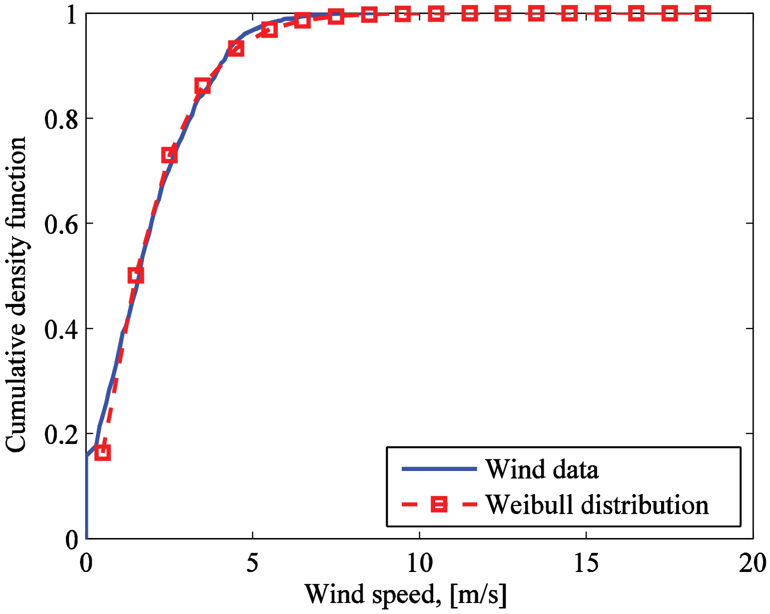

Figure 65: Cumulative density function for the data measured at the Victor Harbour site, February 2010

Appendix D – Turbines of Market Evaluation

This appendix contains the list of turbines used in the turbine market evaluation. Table 11 contains the details of each turbine, the respective manufacturer and type, as well as an approximate cost. The costs have been calculated using price conversion factors presented in Table 12. To approximate the tower costs for HAWTs turbine, the prices for these units have had an extra 22% added as suggested by Manwell *et al.* (2002)[4]. Since VAWTs generally have some form of tower supplied, this cost has not been added to these turbines.

The costs listed in Table 11 cover the equipment supplied with the turbine from the manufacturer. The values do not include the cost of other required equipment such as wiring and electrical conditioning equipment. Therefore they should be used as a guide only.

Table 11: Turbines used in turbine market evaluation

Manufacturer	Model	Turbine Type	Approx. Cost [$AUD]
Jetstream	SP1000	HAWT	$29691.00[21]
Aerostar Inc	Aerostar 6m	HAWT	$24915.00[21]
ARE	110	HAWT	$15798.00[21]
ARE	442	HAWT	$49456.00[21]
Braun Windturbinen GmbH	Antaris 3.5kW	HAWT	$11783.00[21]
A&C Green Energy	Powermax 2000	HAWT	$7306.00[21]
Raum Energy	1.3kW	HAWT	$9179.00[21]
Fortis	Montana	HAWT	$48548.00[22]
Fortis	Passaat	HAWT	$14339.00[21]

Manufacturer	Model	Turbine Type	Approx. Cost [$AUD]
Windside	WS-0,30B	Savonius	$7681.00[21]
Windside	WS-2	Savonius	$21506.00[21]
Windside	WS-4	Savonius	$39760.00[21]
Helix	S322	Savonius	$9150.00[23]
Helix	S594	Savonius	$16960.00[23]
Aerotecture International, Inc.	510V	Savonius	$16737.00[24]
Enviro Energies	2.5kW	Savonius	$12826.00[25]
Enviro Energies	5kW	Savonius	$25658.00[25]
Enviro Energies	10kW	Savonius	$46858.00[25]

Manufacturer	Model	Turbine Type	Approx. Cost [$AUD]
Four Seasons Windpower, LLC	Four Seasons Gyro 1kW	Darrieus	$4162.00[26]
Four Seasons Windpower, LLC	Four Seasons Gyro 3kW	Darrieus	$12003.00[26]
Four Seasons Windpower, LLC	Four Seasons Gyro 10kW	Darrieus	$31987.00[26]
Dragotherm	Windgen 1000	Darrieus	$7181.00[21]
Quiet Revolution	qr5	Darrieus	$60579.00[11]
Windpower	Windbuster	Darrieus	$46084.00[21]

Table 12: Foreign currency conversions as used in market evaluation

Foreign Currency	Conversion to $AUD
$USD	1.12
GBP	1.73
Euro	1.54

Appendix E – Solar Path Diagrams

This appendix contains the solar path diagrams obtained using the Solar Pathfinder tool at the Civic Centre test site (Figure 66). Thirteen sites were originally selected but 1 & 8 had to be dismissed due to existing power line infrastructure. In addition sites 2, 3 & 12 were deemed unfeasible due to an apparent inability to place a hybrid system on top of the Civic Centre.

Figure 66: System siting selection. Possible locations at the Civic Centre test site.

The solar path diagrams for the remaining sites are presented in Figures Figure 67 through Figure 74.

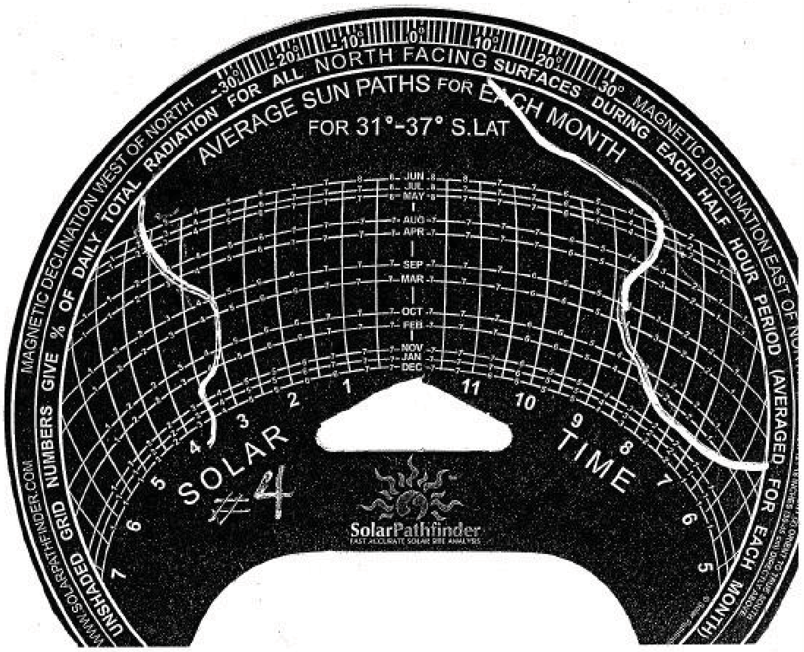

Figure 67: Solar diagram for site 4.

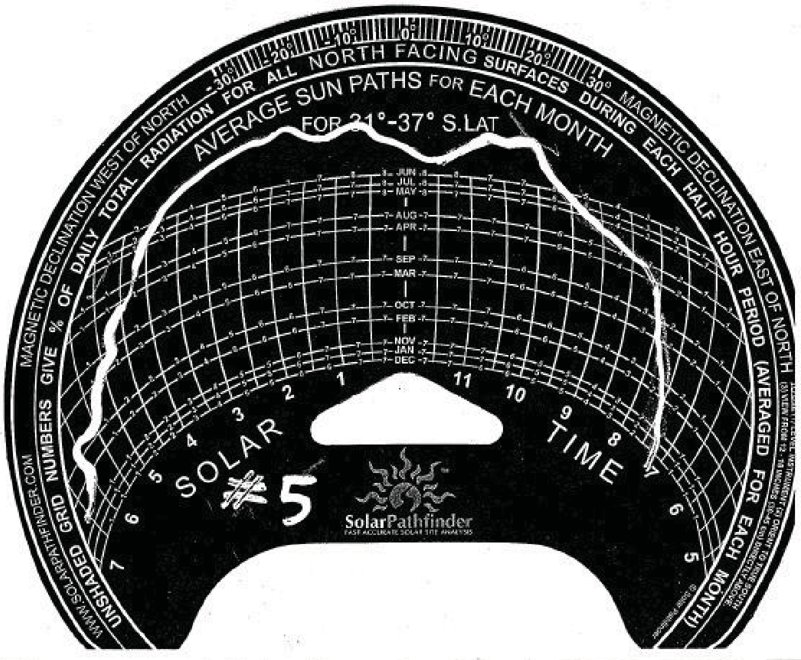

Figure 68: Solar diagram for site 5.

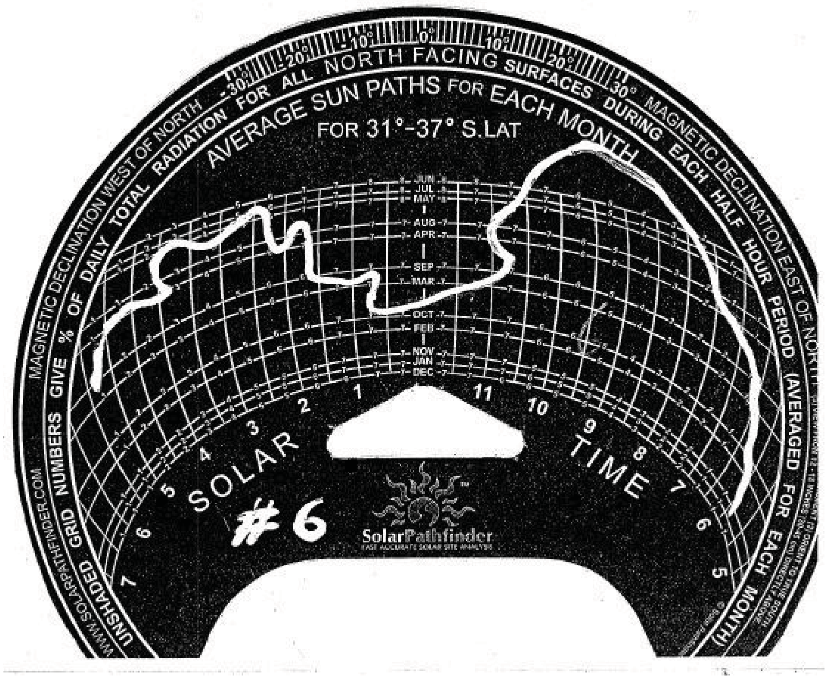

Figure 69: Solar diagram for site 6.

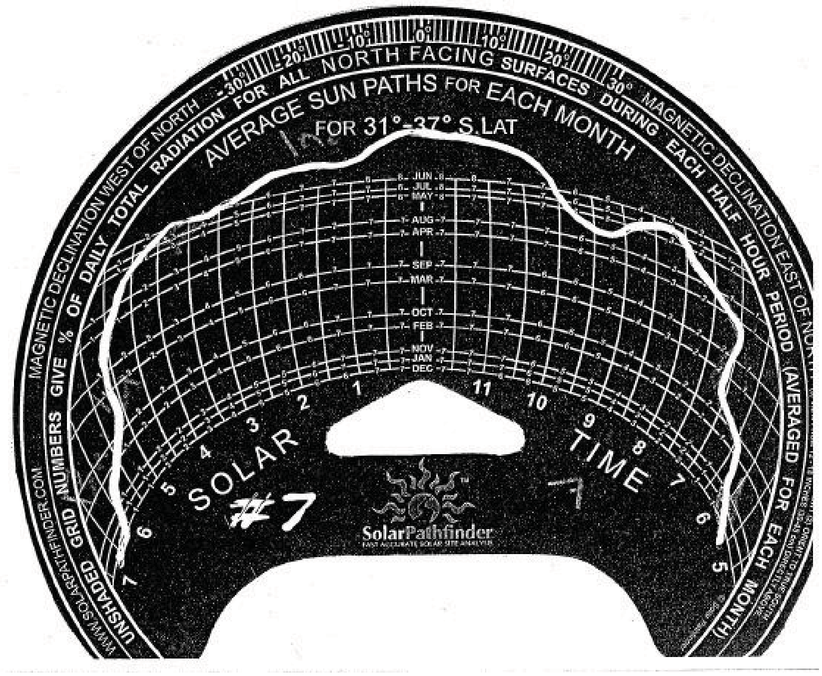

Figure 70: Solar diagram for site 7.

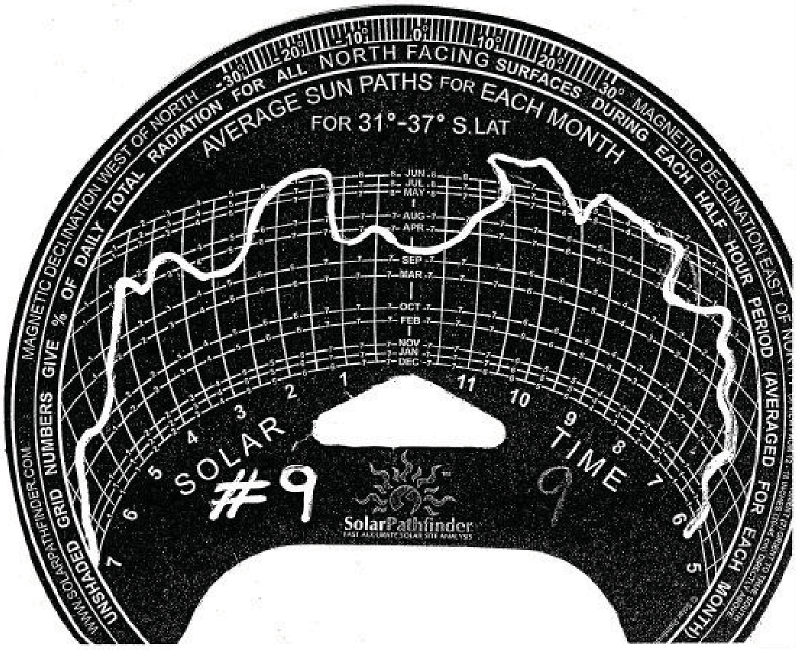

Figure 71: Solar diagram for site 9.

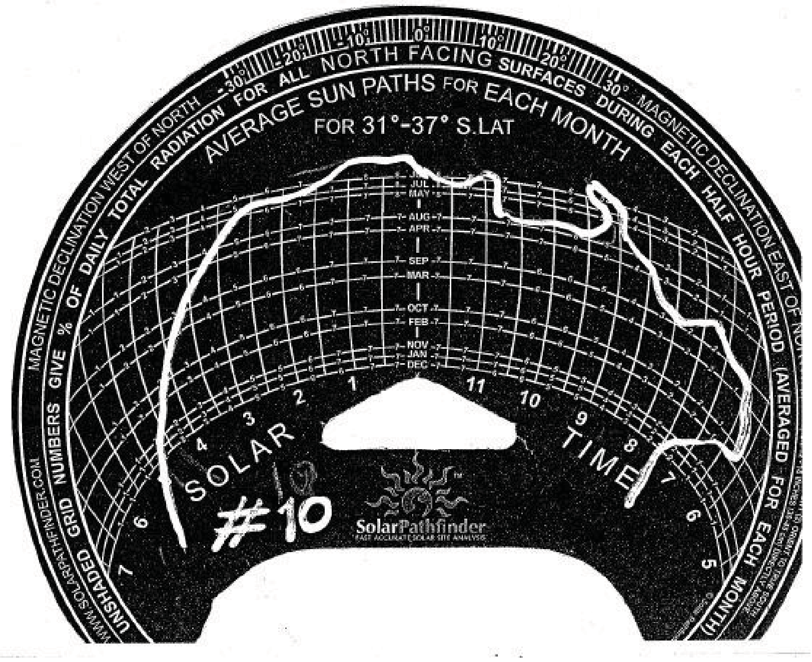

Figure 72: Solar diagram for site 10.

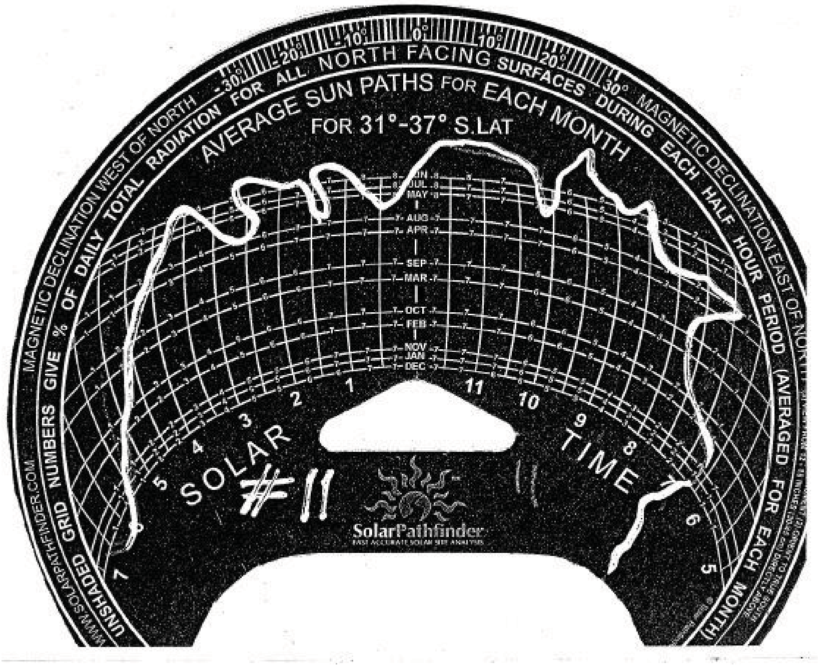

Figure 73: Solar diagram for site 11.

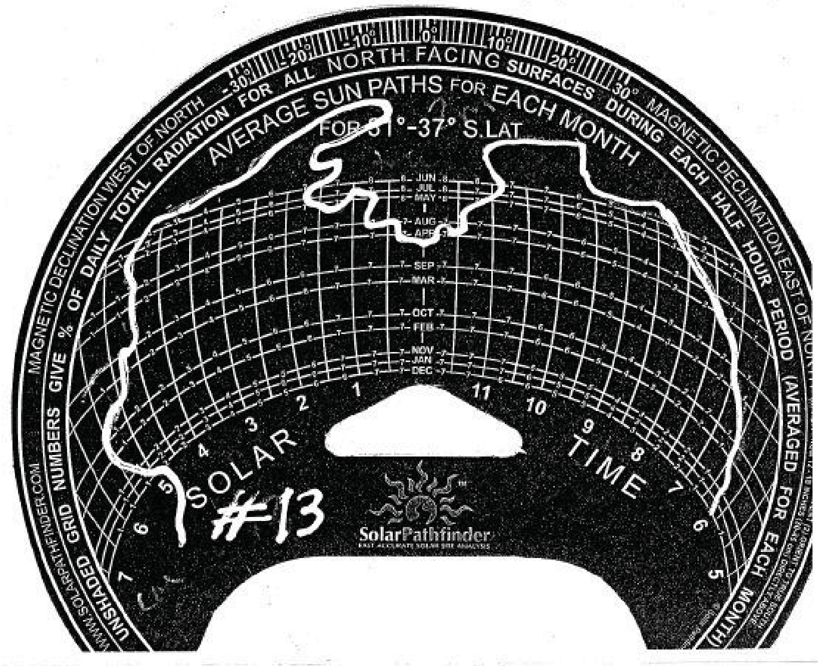

Figure 74: Solar diagram for site 13.