# ANALYSIS OF THE POTENTIAL FOR WIND AND SOLAR ENERGY SYSTEMS IN ANTARCTICA

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## ABSTRACT

As renewable energy generation devices become more efficient and less expensive, the market for providing power to remote communities is expanding. Power for these sites is usually provided by diesel generator sets although, with high winds or solar radiation levels, wind-turbines and solar arrays could prove an ideal alternative. This is especially true for Antarctica.

The Australian Antarctic Division currently ships approximately 750,000 litres of diesel fuel annually to each of three continental stations located on the coastline of East Antarctica. These operations are expensive and savings could be expected from the introduction of a renewable energy generation capability. These stations experience strong winds with gusts recorded at up to 81 m/s, together with temperatures often plunging below -30ºC in winter. This, while providing adequate meteorological conditions for power generation by wind-turbines, also imposes harsh design criteria. Solar also remains an extremely promising alternative during the summer, but is not viable for the winter.

As part of a project investigating 'Alternative Energy for Antarctic Stations', analysis of meteorological data has given wind energy capacity factors estimates of up to 0.7, and summer solar energy capacity factors estimates of up to 0.3. These, combined with station load measurements, have been used to determine the optimal sizing of the number and ratio of wind/solar to storage devices. Results indicate that installation of a 110 kW wind turbine capacity at Mawson would result in a 25% fuel saving, while a 55 kW wind turbine capacity at Macquarie Island would reduce fuel consumption by 30%.

## 1. INTRODUCTION

A market niche that is particularly well suited to wind (and solar) energy generation systems is the provision of electrical power to isolated communities. Remote Area Power Supply (RAPS) systems have been installed extensively throughout remote areas of rural Australia, providing power to communities ranging from 50 kW to 1 MW. Examples of this include the Northern Territory Power and Water Authority (PAWA) which currently services some sixty remote sites scattered across the top end of central Australia. These sites (consisting of isolated ranger stations, homesteads and Aboriginal out-stations) currently operate using diesel generator sets, or natural gas turbines, depending on fuel availability. An increasing number of these sites are now turning to wind and solar energy generation, often combined with battery storage, to reduce the amount of fuel used. Preliminary indications suggest that these hybrid systems are cost effective, a result that will encourage further expansion (1).

Supplemental use of Solar and Wind energy at grid extremities is also gaining attention in parts of Australia. At Kalbarri, located 600 km to the north of Perth on the coast of Western Australia, a 20 kW photovoltaic system has been installed, providing not only local power generation, but also voltage regulation (2). Wind generation has also had success at Esperance in Western Australia where a number of units have been installed to supplement the local grid. The scope for similar grid connected renewable power systems is expected to increase dramatically in the next few decades as costs continue to fall (3).

The Australian Antarctic stations currently rely on diesel generator sets and boiler systems to provide electrical and thermal energy. The introduction of renewable energy generation and storage systems at these sites has been suggested as a method to reduce costs and lower environmental emissions. Wind energy (and solar energy to a lesser degree), were suggested as offering the best opportunities to achieve these goals (4).

To determine the practicality of introducing wind and solar power generation systems to the stations, investigations into the following areas have been initiated (results from numbers 1 and 2 are presented in this paper):

1. Assessment
   - wind resources
   - solar resources
   - station energy needs
2. System identification and sizing
   - wind / solar / diesel systems
   - storage options
3. Testing
   - survival criteria
   - reliability and maintainability
4. Costing

## 2. AUSTRALIAN ANTARCTIC STATIONS

The Antarctic stations operated by Australia are situated in some of the most isolated and inhospitable locations on earth. Three permanent winter stations - Casey, Davis and Mawson - are maintained on the Antarctic continent through ANARE (Australian National Antarctic Research Expeditions). A fourth permanent winter station is also operated in the sub-Antarctic on Macquarie Island, mid-way between the southern tip of Tasmania and the Antarctic continent. The location of the four Australian stations together with their shipping distances from Hobart ia given in Table 1.

Supply to the stations is restricted to the brief Antarctic summer when sea ice conditions allow access to the stations by ship for dry cargo transfer and refuelling. Currently, the research/ressupply vessel *Aurora Australis* is chartered for this purpose, supplemented every three year by a dedicated cargo ship. Typically 6 to 7 voyages are made every season resulting in 2 to 3 calls at each station. One visit to each of the stations is used for re-supply and refuelling, with the other visits used for personnel change-overs. Time and space aboard the ships is at a premium. Marine Science programs also require extensive use of the *Aurora Australis*, one of only a handful of vessels currently devoted to research on a regular basis in the waters surrounding Antarctica, an area immense in size and resources. The introduction of on-site power generation would have considerable advantages over the current system, lowering time and costs associated with refuelling the stations.

The stations themselves are large, modern, extremely well-equipped facilities, extensively rebuilt and upgraded during the 1980s and 1990s, and represent an enormous investment by Australia in the region. Each continental station consists of a collection of approximately 10 to 15 buildings, designed especially for the expected conditions. The largest building at each station is the Domestic building, comprising recreation/sleeping/eating and medical areas - and as such - is the focus of station life after working hours. Other main buildings on station occupied regularly include the Operations building (housing all radio communication equipment and workshops, meteorology and administration offices), the Science building (housing equipment for active research projects into fields such as radio astronomy, upper atmosphere physics and biology) and the Workshop (providing an indoor heated area for mechanical repair and maintenance, and work areas for electricians, plumbers, and carpenters).

The energy systems of the stations are designed to provide a safe, efficient and above all, reliable supply of electrical and thermal energy. Energy is needed in order to maintain the array of scientific programs operated at each station and provide suitable comfort conditions for expeditioners over the long, cold, dark, winter months. The current energy system of the Australian Antarctic stations meets the power needs through the use of co-generation systems comprising diesel generator sets and oil-fired boilers.

The main power houses of the continental stations consist of four 125 kVA Caterpillar 3306 diesel engines coupled with matching alternator sets. Two to three engines are typically engaged at any one time to meet station load demands. Heat recovered from the engines and supplemented by oil-fired boilers is pumped throughout the station to most buildings to meet thermal energy needs, although some buildings use their own independent heating systems. At Macquarie Island a much milder climate, combined with more traditional building methods and lower population levels, has resulted in much lower power demands. Two generator units are maintained in the main powerhouse at the station, with a single unit operated to satisfy power demands at any one time. Efficiencies of 35% (electrical) and 32% (thermal) have been reported for the generators, and 80% (thermal) for the boilers (5).

Assessment of the potential for wind and solar energy generation at the stations will consists of three components: identification of wind reserves, identification of solar reserves, and finally estimation of stations energy needs. Although thermal energy production levels at the stations are of the same order as electrical production levels, this paper will concentrate on electrical energy production, as exact quantification of the thermal needs (as apposed to production), has yet to be determined.

| Station | Latitude | Longitude | Distance to Hobart |
|---|---|---|---|
| Casey | 66$^o$17' S | 110$^o$32' E | 3,427 km |
| Davis | 68$^o$35' S | 77$^o$58' E | 4,816 km |
| Mawson | 67$^o$36' S | 62$^o$52' E | 5,447 km |
| Macquarie Island | 54$^o$30' S | 158$^o$56' E | 1,495 km |

Table 1: Australian Antarctic station locations and shipping distances from Hobart

## 2.1 Wind energy resources

Antarctica has the distinction of being the highest, coldest, driest and windiest continent on earth. Climatic conditions at the stations are harsh. Blizzards periodically blast the continental stations, often resulting in very high wind gusts. Continuous low temperatures also occur at the continental stations, with summer temperature rarely above 0$^{o}$C and never above 10$^{o}$C. Macquarie Island, situated north of the Antarctic convergence zone, has warmer weather with temperatures often above zero and never falling below -10$^{o}$C. This however results in an extra phenomenon rare at the other stations - rain! Fierce winds also lash the island, situated in the middle of the Southern Ocean in the infamous 'furious fifties', creating extremely windy and wet gales that saturate the island. A summary of the climatic extremes in temperature and wind speed recorded at the stations is given in Table 2.

While the maximum winds encountered at the stations are very high, the average winds are much lower. High winds, averaging above 30 m/s over a ten minute interval, were found to account for at most 5% of all observation made over the last five year at Mawson and Casey, and even less at Davis and Macquarie Island. Resolution of the wind into bins, each 2.5 m/s wide, has been presented in Figure 1, indicating the relative frequency distribution of winds at each of the stations. Weibull functions have been set to these distributions using weighted least-squares techniques with the scale parameter *c* and shape parameter *k*, calculated using the method described by Justus (6).

| Site | Maximum recorded wind gust (m/s) | Minimum recorded temperature ($^{o}$C) |
|---|---|---|
| Casey | 80.8 | -41.0 |
| Davis | 57.1 | -40.0 |
| Mawson | 68.9 | -36.0 |
| Macquarie Island | 51.4 | -8.9 |

Table 2: Extreme climatic conditions recorded at the stations (7)

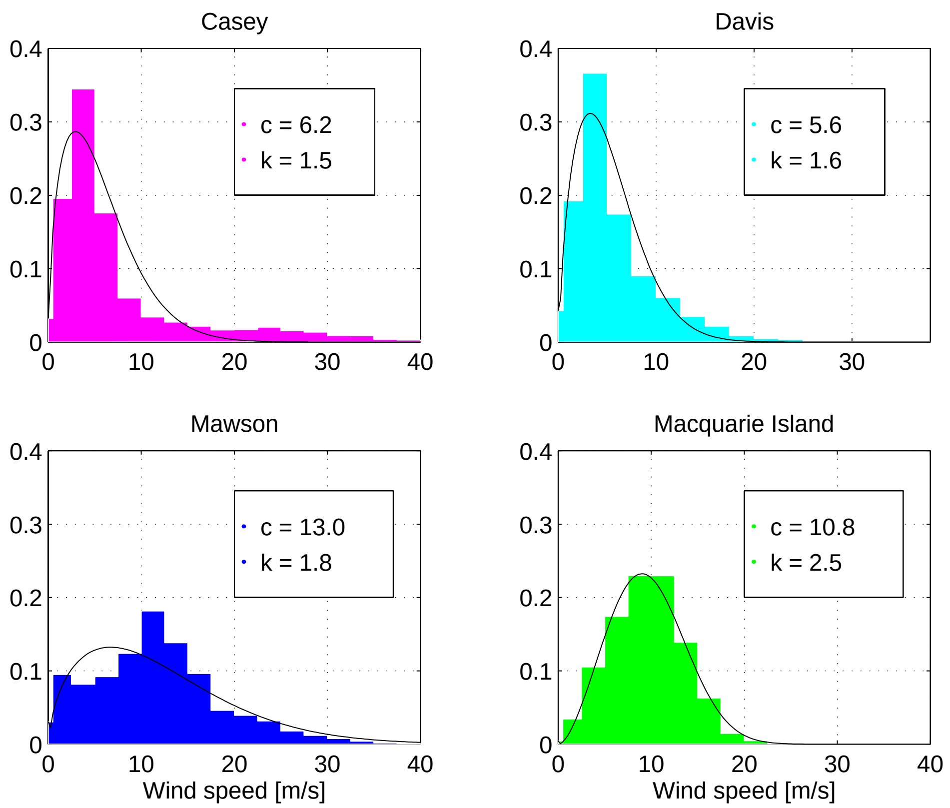


Figure 1: Frequency−of−occurence of wind speeds 1990−94

The mean wind speed, giving an indication of the potential for power generation, was calculated for the stations and is presented in Table 3. To construct these figures, observations recorded by the Australian Bureau of Meteorology (BoM) over last five years were used. These observations consist of 10 minute averages taken immediately before the hour, every three hours, starting at midnight UTC.

There are however differences in the mean wind speed over the year and over the day. The best method to indicate these changes is in the diurnal mean wind speed calendar of Figure 2, intended as a guide to the expected wind resources at the stations for a particular month at a particular time.

Mawson, which experiences strong katabatic air flow off the polar ice cap, is continuously blasted by winds averaging between 12-14 m/s, except for a period of relative calm during the afternoon in summer when winds drop to an average of 6 m/s.

Macquarie Island experiences the second highest average winds, consistently averaging approximately 9 m/s throughout the day, increasing to just over 10 m/s during periods of the equinoctial gales. These occur in March and September whipping up winds into gales, encircling the southern hemisphere in a broad latitude band encompassing the Island.

The average winds reported at Casey and Davis are much lower. At Casey winds average up to 8-9 m/s during the winter months, dropping to 6 m/s over the summer. For Davis, wind speeds average around 5 m/s for most of the year, except for early morning summer when the wind speed average increases to 7-9 m/s.

| Station | maximum wind speed (m/s) | mean wind speed (m/s) | standard deviation (m/s) |
|---|---|---|---|
| Casey | 49.4 | 7.15 | 7.88 |
| Davis | 28.8 | 5.07 | 4.15 |
| Mawson | 39.1 | 11.15 | 6.95 |
| Macquarie Island | 28.8 | 9.45 | 4.13 |

Table 3: Wind-speed statistics using 10 minute BoM 3-hourly observations 1990-94 (8)

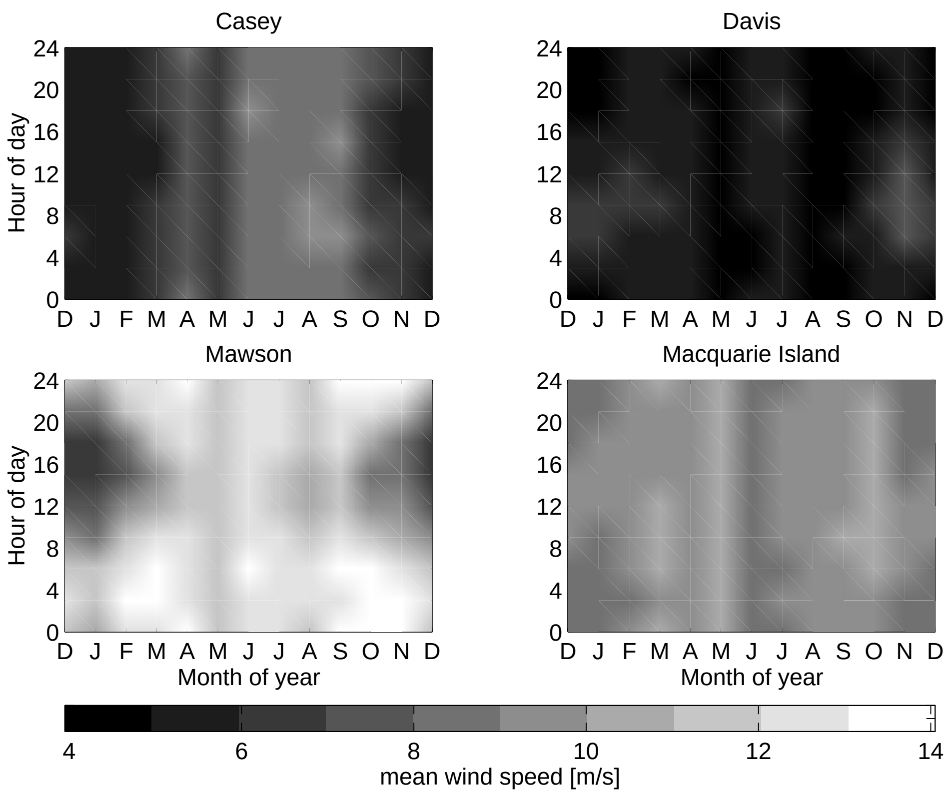

Figure 2: Wind speed annual and diurnal mean 1990−94

Monthly wind capacity factor estimates, based on the reported performance curve of the UM-70X using wind frequency-of-occurrence measurements (see Figure 1), are presented in Figure 3. These capacity factors represent the ratio of the expected output of the machine against its rated output. At Mawson, high wind capacity factors between 0.6 and 0.7 are indicated for most of the year, except for a small decrease during the summer months. Macquarie Island capacity factors are also high over most of the year, especially during the equinoctial periods. Casey and Davis indicate capacity factors at only 0.2 to 0.3, half that at Mawson and Macquarie.

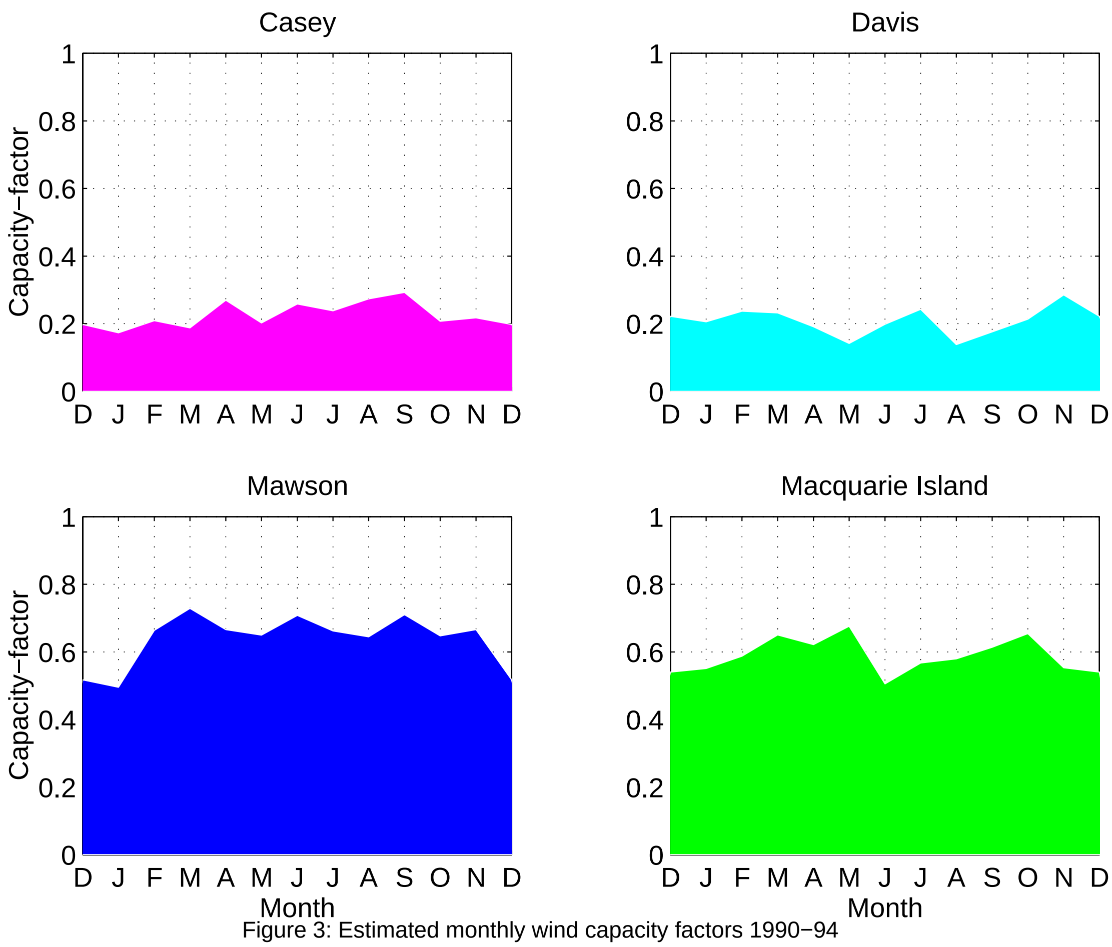

Figure 3: Estimated monthly wind capacity factors 1990−94

## 2.2 Solar energy resources

Clear skies, frequent in Antarctica, offer the potential to supplement power from wind turbines with solar power using photovoltaics. Cloud cover in the latitude 60°S band in Antarctica is characteristically U-distributed, with either complete cloud cover or no cover at all (9). This, combined with high albedo values due to snow cover, lack of moisture in the dry, dust free pristine air over the continent and long daylight hours during the summer months, provides for extremely high insolation rates at the continental stations. These conditions unfortunately only occur during the summer months, precluding the use of photovoltaics in winter. Conditions at Macquarie Island are not as constructive, with high cloud cover occurring for most of the year reducing incident solar insolation levels.

Monthly averages of the daily global and diffuse radiation levels recorded at Casey, Mawson and Macquarie Island are presented in Figure 4. These averages are based on the information available. Data was provided by the BoM from 1973 to 1977 for Casey, from 1968 to 1993 for Macquarie Island; while for Mawson, totals are based on recordings conducted over an 18 month period from 1961 to 1963 by Weller (10). Unfortunately no data was available for Davis.

This data is only available on a monthly basis. To obtain daily and hourly solar radiation levels an empirical model has been used. This model incorporates an empirical relationship between solar altitude and incident radiation level, modified by an extinction factor calculated from cloud measurements (11). Comparison with the recorded monthly reading indicated agreements to with 10% for global radiation estimates and 20% for diffuse radiation estimates; values deemed sufficient for our purpose. The estimated diurnal and seasonal average solar radiations incident at the stations are presented in Figure 5.

(Note: the inclination angle of the photovoltaic panel was set to 60° on the continent, and 40° at Macquarie Island - calculated to maximise exposure rates from model simulation runs).

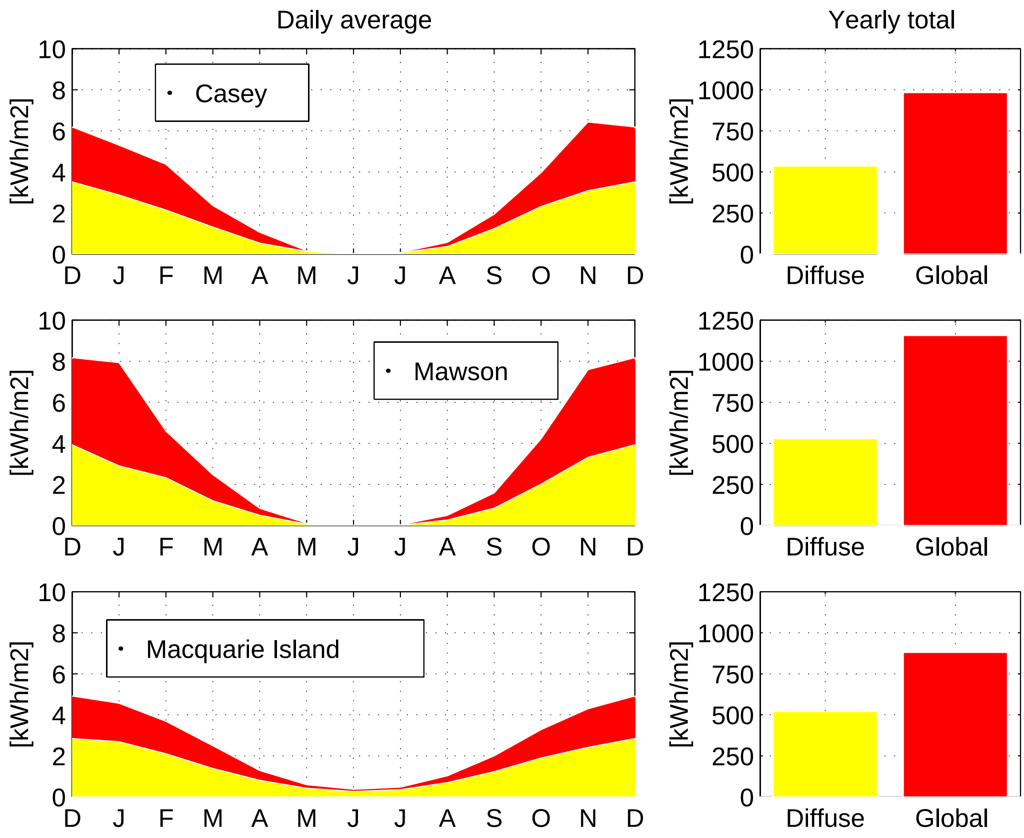


Figure 4: Monthly recorded solar rdiation levels

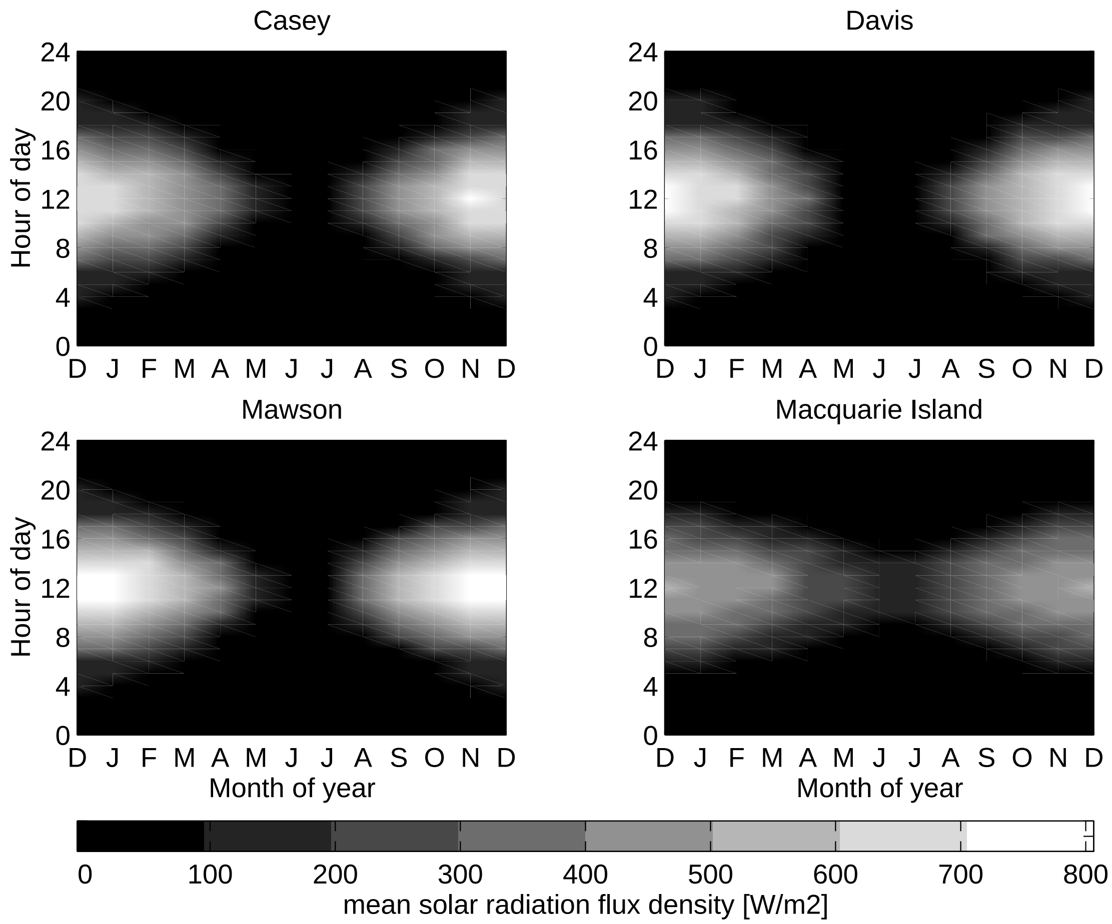


Figure 5: Solar Radiation annual and diurnal mean 1990−94

Average solar insolation levels are extremely high during the summer period centred about mid-day. The general difference between the best solar power and wind power production times, offers promising potential for mixed systems. This is clearly evident for Mawson, where times of high solar insolation almost perfectly coincide with the reduced summer mean wind speed.

Expected solar energy conversion efficiencies for photovoltaics typically range from 10% in production line cells to up to 23% in new-generation experimental cells. To gain an indication of the performance of these cells at the stations, a term analogous to the capacity factor of wind turbines will be used. The solar capacity factor, defined as the ratio of the expected output of the cell to the rated output of the cell under cloud free solar insolation levels of 1 $kW/m^2$(for which panels are rated), was calculated for the stations and is presented in Figure 6.

High returns (useable power production for a given installed solar power capacity) are evident over the summer at each of the continental stations over a seven month period, beginning of September and ending March. Macquarie Island returns are approximately 30-40% lower than on the stations, although winter insolation levels are higher.

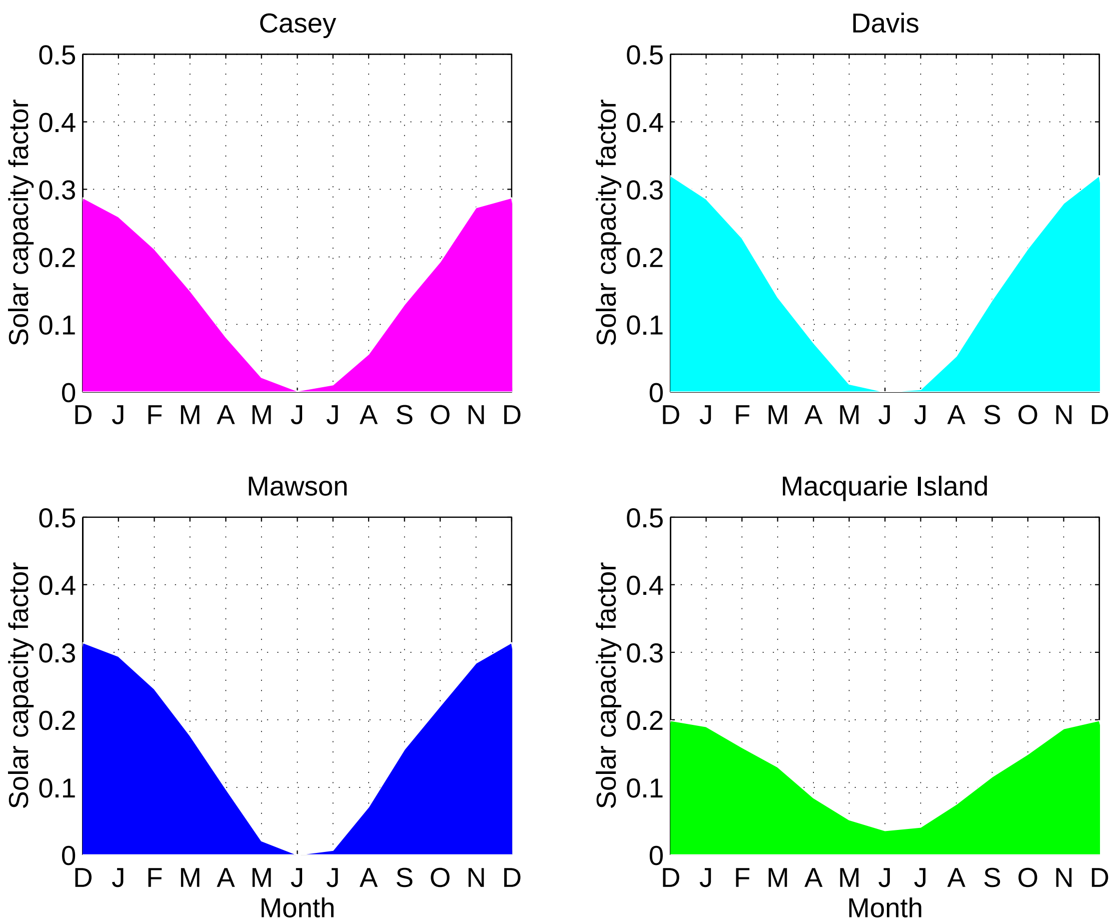


Figure 6: Estimated solar capacity factors

## 2.3 Station energy demands

Electrical and thermal energy demands at the stations are high, requiring the use of large quantities of fuel. Table 4 and Table 5 indicate the quantity of fuel and used in the generator sets and boilers at each station over the last four years.

Costs associated with shipping and handling cargo to Antarctica effectively triples the end price per litre of fuel. Exact costs are hard to assess, but current estimates place the unit price per litre at $1 (AUD) (5). This high cost has further focused attention to the possibility of on-site power generation from renewable sources.

The introduction of renewable systems would also have the added advantage of reducing the overall emission levels of the stations, the most prominent local pollutant source in the near pristine air over the continent - important for scientific and environmental reasons. Reduced fuel handling also will reduce the risk of fuel spillage, another major concern in the fragile Antarctic environment. The electrical energy production levels met by the diesel generator sets are given below in Table 6.

To obtain an indication of the inter-daily and intra-daily variation in electrical power, recordings of 10 minute averages of the power were initiated. A daily cycle of between 20-30 kW was identified at Davis station, superimposed onto a day-to-day varying base load averaging approximately 220 kW over the year.

Using regression analysis based on a method described by (13), this load was resolved into components correlated with station population numbers, air temperature gradients and wind speed. Results indicate the power load is heavily correlated with station population numbers and outside ambient air temperature. Wind induced loads were identified as having a low correlation with power loads. The remaining base load was found to be fairly constant, with only a 20-30 kW seasonal variation.

| Site | Yearly diesel use by generator sets (kl) | | | |
|---|---|---|---|---|
| | 1992 | 1993 | 1994 | 1995 |
| Casey | 584.8 | 538.0 | 483.4 | 447.2 |
| Davis | 526.5 | 535.3 | 646.4 | 561.4 |
| Mawson | 630.4 | 607.5 | 629.8 | 652.8 |
| Macquarie Island | 202.1 | 173.7 | 168.4 | 174.4 |

Table 4: Total diesel usage in generator sets 1992 - 95 (12)

| Site | Yearly diesel use by boilers sets (kl) | | | |
|---|---|---|---|---|
| | 1992 | 1993 | 1994 | 1995 |
| Casey | 139.9 | 89.6 | 131.1 | 121.1 |
| Davis | 324.1 | 151.7 | 165.9 | 125.7 |
| Mawson | 122.2 | 133.9 | 144.8 | 141.6 |
| Macquarie Island | 37.8 | 51.2 | 45.8 | 29.7 |

Table 5: Total diesel usage in boilers 1992 - 95 (12)

| Site | Yearly electrical energy production (MWh) | | | |
|---|---|---|---|---|
| | 1992 | 1993 | 1994 | 1995 |
| Casey | 1,871.6 | 1,786.1 | 1,630.3 | 1,595.1 |
| Davis | 1,756.7 | 1,919.9 | 2,311.1 | 1,996.7 |
| Mawson | 2,255.1 | 2,162.9 | 2,283.6 | 2,368.3 |
| Macquarie Island | 584.4 | 521.1 | 541.8 | 593.6 |

Table 6: Total electrical energy production 1992 - 95 (12)

## 3. SYSTEM IDENTIFICATION AND SIZING

In order to determine system sizing and performance, a computer model of station electrical load and energy outputs of wind turbines and photovoltaics was constructed. The model design follows that suggested by (14) using simple efficiencies to estimate the performance of wind turbines and photovoltaics. A one-hour time step has been employed in the model at which the anticipated station energy demands at the stations are compared to the available wind and solar energy resources. The effect of battery storage was included by assuming a 90% energy conversion efficiency into and out of storage (resulting in an overall efficiency of 81%).

Station electrical load levels were constructed using monthly electrical power levels (reported from the stations), combined with temperature, wind, population , daily and weekly cycles identified from observed recordings. Using the method described by Little (13), these were combined to conduct one-hour time series representative of typical conditions observed at the stations.

Hourly wind energy estimations (linearly interpolated from 3-hourly BoM observations), were used to estimate the available wind power over the hour at each of the stations. The wind-power response curve reported for the Aérowatt UM-70X in turbulent conditions (Figure 7) was used to determine the expected power for a given wind speed. This value was then divided by the rated power of the unit (10 kW) to define a per unit kilowatt capacity factor. For scaling in the case of multiple units, this per unit kilowatt capacity factor has been assumed constant - allowing for power estimations to be calculated against an installed wind-turbine capacity.

Solar energy power outputs have been similarly estimated for an installed photovoltaic capacity. Estimated hourly solar insolation levels for a plane, facing north and tilted at an angle of 60º to the horizon (40º for Macquarie Island), were divided by the standard 1 kW/m$^2$ to order to calculate the per unit kilowatt solar power capacity factor.

Using these time series for station load, wind and solar power, three system configurations have been investigated: envisaged as possible implementation steps of renewable energy generation systems at the stations.

1. Direct use of renewable power generation to supplement station power with penetration restricted to 40% of station load at each given time step, allowing adequate frequency and voltage regulation by the diesel generator sets. Any additional power produced above the 40% of station load is dumped.
2. Inclusion of power regulation equipment, stabilising load over the one-hour time step, thus allowing for full load penetration of renewables for a given time step and intermittent diesel usage (any additional power production above station load is dumped).
3. Inclusion of storage in the form of batteries, with two-way inverters sized to take all excess power produced from renewables above station load and provide full station load during periods of insufficient renewable energy generation (if maximum energy storage has reached, any addition power above station load is dumped).

Model runs were performed on the CRAY J90 computer located at the Antarctic CRC (Co-operative Research Centre) in the University of Tasmania. All programs were written using the MatLAB programming language and run on a UNIX platform.

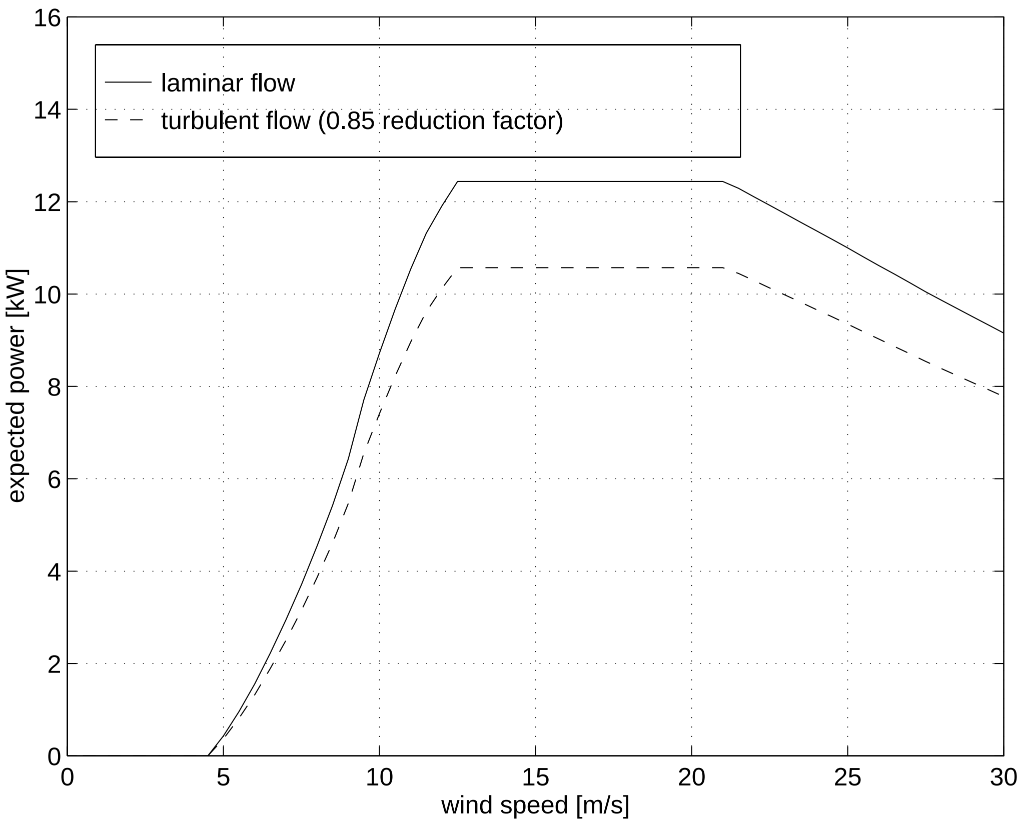


Figure 7: Power curve for UM−70X

### 3.1 <u>Renewable load penetration limited to 40%</u>

Results from the 40% penetration limited renewable power use are presented in Figure 8 for each of the stations, indicating the ratio of total station energy met through the presented installed wind and solar energy capacities. These results have been calculated using a twenty by twenty grid based on data recorded during 1995. Some of the best systems, allowing the greatest yearly energy production ratios for a given installed generation capacity, are presented in Table 7.

The amount of fuel savings has been calculated using the average fuel efficiency as reported at the stations over the period 1992-95 (15). The plant utilisation factor indicates the return expected from the given system, with high dump loads and/or low renewable energy resources resulting in low values. Combined wind/solar options have lower returns per unit kW installed, but meet a higher proportion of the overall station energy demands.

Returns for Mawson are excellent, with wind only systems able to produce 25% of the stations needs for an installed capacity of 110 kW. The plant utilisation factor is three times that for the other continental stations of Casey and Davis. Macquarie Island also has excellent conditions, with a 55 kW installed wind capacity expected to meet 30% of the stations electrical energy needs.

Mixed systems, comprising 100 kW wind and 100 kW solar, offer methods to increase the ratio of the total station energy needs (met by renewables), to 15% at both Casey and Davis. The use of solar is hardly warranted at Mawson under a 40% renewable load limited system, and likewise for Macquarie Island.

A 40% renewable load limited system offers the most simple method to include a renewable power generation component to the stations (requiring no extensive capital investment other than that for wind turbines and photovoltaics). For higher energy production ratios above these, however, power regulation must be included in order to reduce the negative impact of high diesel cycling resulting in lower fuel efficiencies and increased wear.

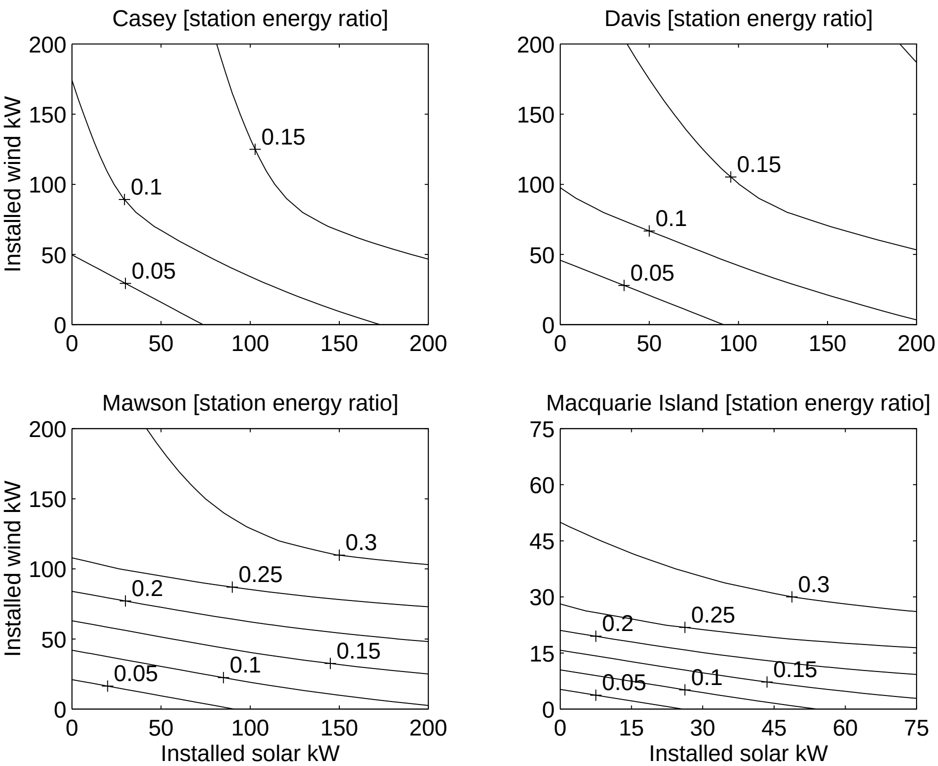


Figure 8: Station energy ratio met by renewables (40% load limit)

| Site | installed wind (kW) | installed solar (kW) | station load met | useable energy (MWh/y) | fuel savings (ltrs/y) | plant utilisation factor |
|---|---|---|---|---|---|---|
| Casey | 75 | - | 8% | 128 | 37,776 | 0.19 |
| | 100 | 100 | 15% | 239 | 70,830 | 0.14 |
| Davis | 100 | - | 10% | 200 | 56,708 | 0.23 |
| | 100 | 100 | 15% | 300 | 85,062 | 0.17 |
| Mawson | 110 | - | 25% | 592 | 164,602 | 0.61 |
| | 150 | 75 | 30% | 710 | 197,523 | 0.36 |
| Macquarie | 55 | - | 30% | 178 | 57,170 | 0.37 |

Table 7: Estimated performance of wind/solar systems limited to 40% of load

### 3.2 Load regulation of renewables with intermittent diesel usage

A substantial renewable energy production ratio at the stations is possible with power regulation; resultant from 100% load penetration of renewable together with intermittent diesel usage. Figure 9 indicates these results, the most impressive of which are presented in Table 8.

Mawson and Macquarie Island continue to offer extremely promising potential. Up to 60% of the stations total energy requirements can be met through the use of wind-turbine capacities of 250 kW and 70 kW respectively; an additional 30% on top of systems limited to 40% penetration. At Casey and Davis, station energy ratio met by renewables of 30% can only be achieved if solar is combined with wind (at a reasonable plant utilisation rate). Even in this case, the resultant savings in fuel are three to four times less than at Mawson and Macquarie.

For further increases in the energy production ratios above these, a storage medium is required.

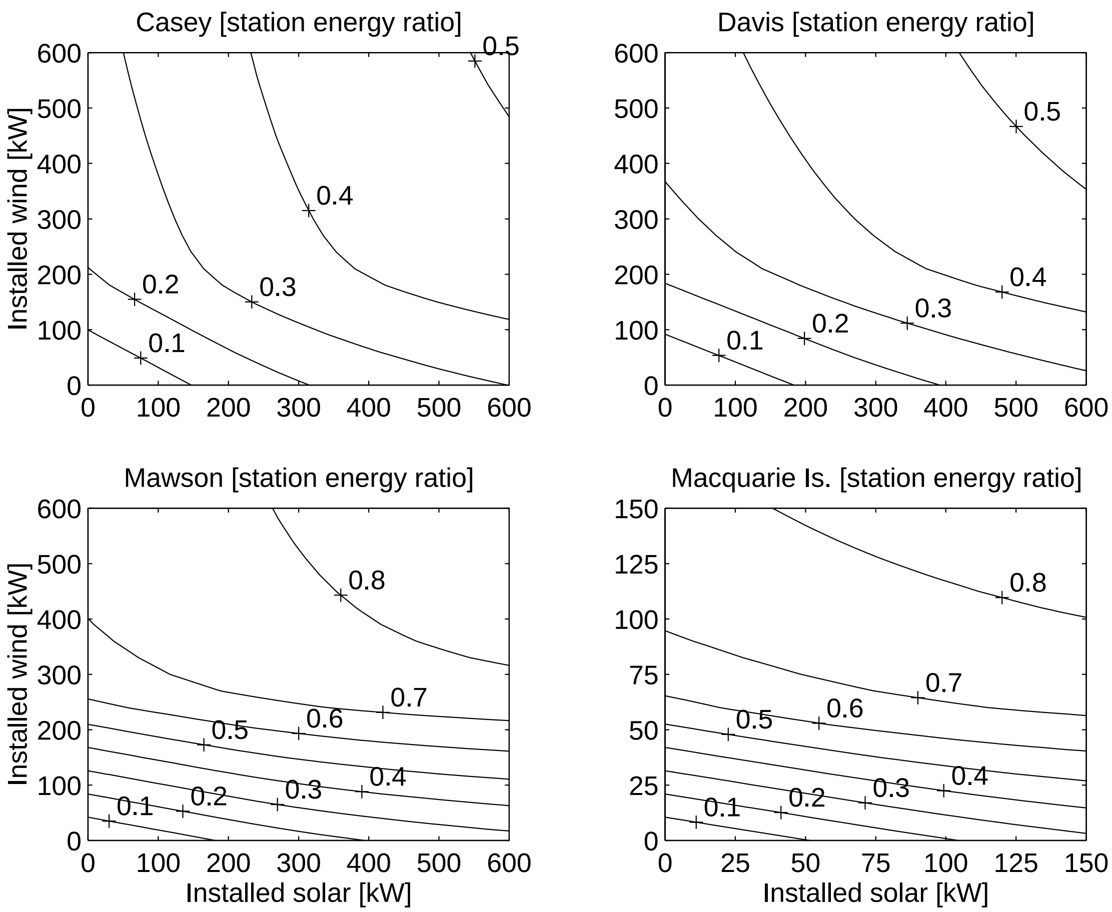


Figure 9: Station energy ratio met by renewables (with power regulation)

| Site | installed wind (kW) | installed solar (kW) | station load met | useable energy (MWh/y) | fuel savings (ltrs/y) | plant utilisation factor |
|---|---|---|---|---|---|---|
| Casey | 200 | - | 20% | 319 | 94,440 | 0.18 |
| | 200 | 200 | 30% | 479 | 141,661 | 0.14 |
| Davis | 200 | - | 20% | 399 | 113,417 | 0.23 |
| | 200 | 200 | 30% | 599 | 170,125 | 0.17 |
| Mawson | 250 | - | 60% | 1,421 | 394,995 | 0.65 |
| | 250 | 200 | 70% | 1,658 | 460,828 | 0.42 |
| Macquarie | 70 | - | 60% | 356 | 114,337 | 0.58 |

Table 8: Estimated performance of wind/solar systems with power conditioning

### 3.3 Addition of Storage

Finding a suitable storage medium is the major difficulty for renewable energy power generation systems. Storage requirements can be minimised through adequate scheduling of loads, removing non-critical loads to periods of adequate power production.

This combined with a general policy to reduce short term power peaks by making consumers more aware of power production limitations, will be necessary for a system able to obtain a high renewable energy production ratio. For this reason, systems able to meet 80-90% of current usage demands will be considered as sufficient. In many cases the sizing and cost of systems required to meet the addition 10%-20% would be unrealistic, requiring huge investments for very little increases in return. Compromises to the accessibility of power in a renewable energy system must be expected.

Investigations into the sizing and effect of battery storage at the stations has quite dramatic effects. Addition of storage, equivalent to quarter and full day energy requirements, result in the increased energy production ratios indicated in Figures 10 & 11 with the best options summarised in Table 9.

The addition of storage is very promising at Mawson and Macquarie Island, with 6 hour storage (2000 kWh and 500 kWh respectively), able to increase the total energy met through renewables to 80%. Further increases to 90% require a four-fold increase in storage or massive investment in solar (for Mawson). For a net 10% gain in useful energy, these increases are not warranted. Casey and Davis do benefit from the introduction of storage, but only up to a total energy production level of 50%. Further increases above this would require mass storage (in the order of weeks), and an increase in power generation capacity, resulting in major cost increases.

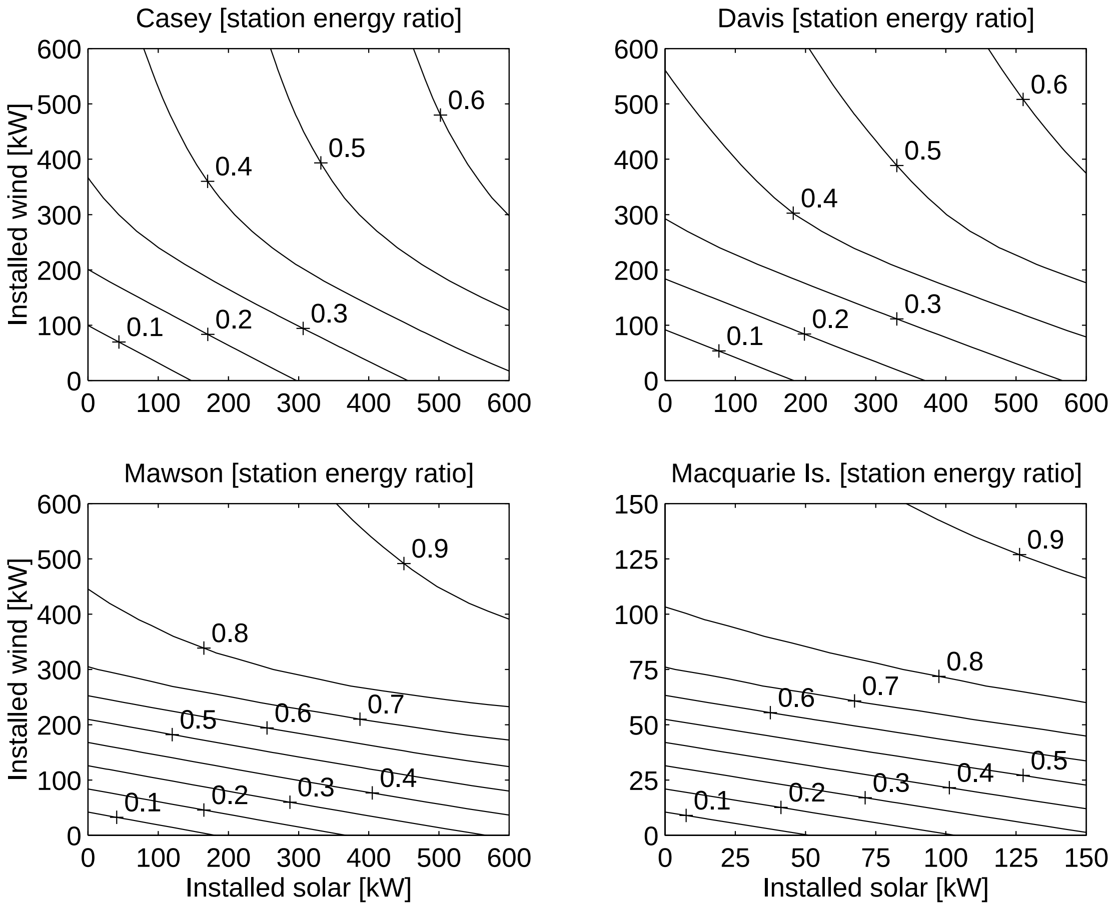


Figure 10: Station energy ratio met by renewables (with 6h storage)

| Site | storage (kWh) | installed wind (kW) | installed solar (kW) | station load met | useable energy (MWh/y) | fuel savings (ltrs/y) | plant utilisation factor |
|---|---|---|---|---|---|---|---|
| Casey | 2000 | 300 | 200 | 40% | 638 | 188,880 | 0.15 |
| | 2000 | 400 | 300 | 50% | 798 | 236,101 | 0.13 |
| | 8000 | 400 | 200 | 50% | 798 | 236,101 | 0.15 |
| | 8000 | 500 | 300 | 60% | 957 | 283,321 | 0.14 |
| Davis | 2000 | 300 | 200 | 40% | 799 | 226,833 | 0.18 |
| | 2000 | 400 | 300 | 50% | 998 | 283,541 | 0.16 |
| | 8000 | 400 | 200 | 50% | 998 | 283,541 | 0.19 |
| | 8000 | 400 | 400 | 60% | 1,198 | 340,250 | 0.17 |
| Mawson | 2000 | 450 | - | 80% | 1,894 | 526,661 | 0.48 |
| | 2000 | 500 | 400 | 90% | 2,131 | 592,494 | 0.27 |
| | 8000 | 400 | 200 | 90% | 2,131 | 592,494 | 0.41 |
| | 8000 | 525 | - | 90% | 2,131 | 592,494 | 0.46 |
| Macquarie | 500 | 100 | - | 80% | 475 | 152,450 | 0.54 |
| | 2000 | 125 | - | 90% | 534 | 171,506 | 0.49 |

Table 9: Estimated performance of wind/solar systems with storage

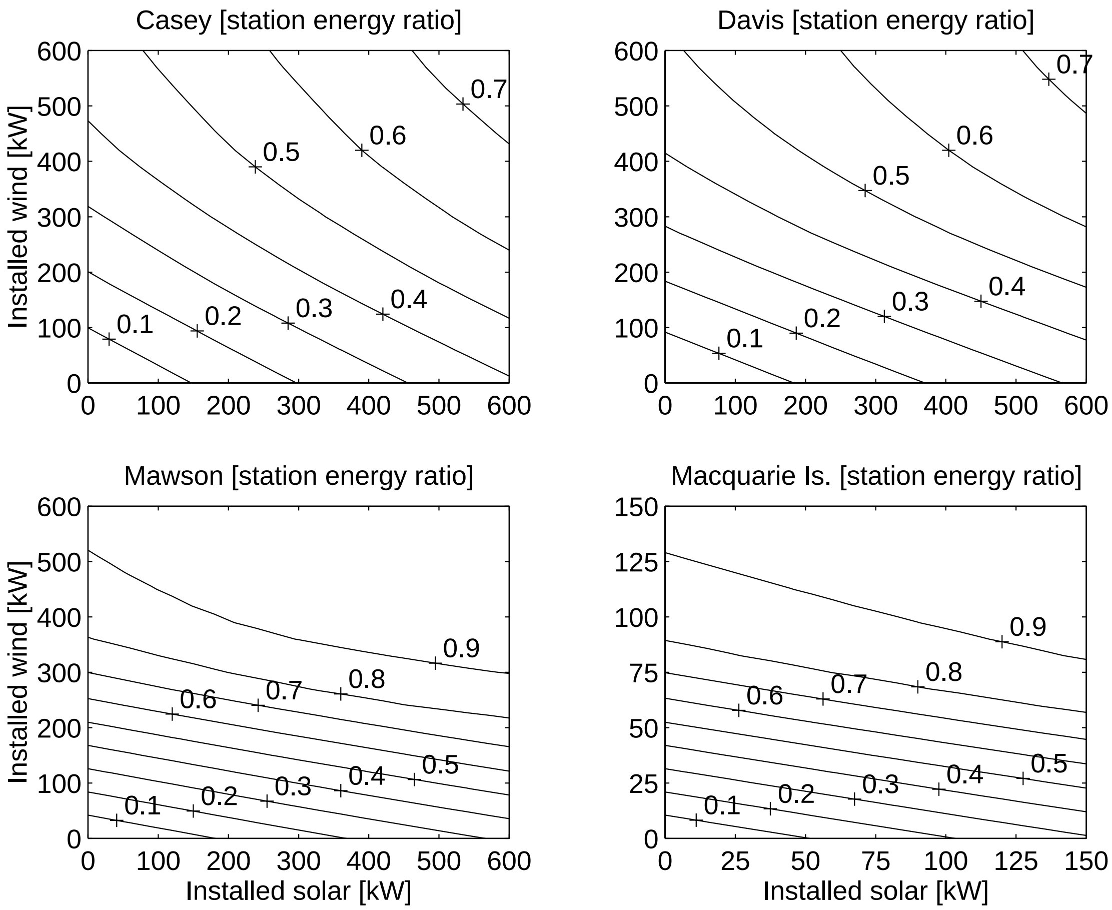


Figure 11: Station energy ratio met by renewables (with 24h storage)

## 4. CONCLUSIONS AND FUTURE POSSIBILITIES FOR THE STATIONS

In order to exploit the available renewable energy resources at the stations reliable, cost effective wind turbine designs must be found, able to survive the expected extreme conditions.

The long term reliability of wind and solar generation units needs to be proved before users are confident to make large scale investment in wind and solar energy systems at the Australian Antarctic stations (and indeed other remote sites requiring power with similar conditions). This now remains as the next challenge.

As an initial step to achieve this goal, a test program has been initiated at Casey, the station which experiences the strongest recorded wind gusts of the four Australian stations. A 10 kW wind turbine, the Aérowatt UM-70X (upgraded recently with a Vergnet GEV 7.10), was installed at Casey in 1995 for trials. Results from the use of this unit are important, enabling potential problems to be identified and methods developed to overcome them.

Once suitable design have been identified, the wind and solar resources at the stations suggest much promise. The inclusion of power regulation and limited (6 hour) storage allows for a very high level of the total electrical energy needs of the stations to be met at Mawson and Macquarie. Investigations into costing and offsets to thermal production levels at the stations are currently being made in order to determine the feasibility of these systems.

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