An Alternate Energy Proposal For Cape Bird Antarctic research station.

David Hume and Pat Bodger

Abstract— **Cape Bird is a narrow strip of stony coastline at the foot of Mt Bird in the north–west corner of Ross Island, Antarctica. Situated at latitude 77.22^oS and longitude 166.43^oE Antarctica New Zealand have built a comfortable eight person research hut used by scientists over the summer months. The hut, measuring approximately 85 square meters, consists of 2 bunk rooms, a kitchen/dining room, pantry, store room and laboratory. The hut is continuously occupied during the summer months from mid October till the end of January. During this time the hut is entirely dependent on the use of fossil fuel for both its thermal and electrical energy requirements. This paper, in conjunction with Antarctica New Zealand and the Electric Power Engineering Centre at the University of Canterbury, investigates the renewable energy potential for Cape Bird hut before describing the current renewable energy design that is to be installed during the 2004/05 summer.**

Keywords— **Energy efficiency, renewable energy, solar energy, photovoltaic (PV), wind energy**

I. Introduction

Antarctica New Zealand, through the Antarctica (Environmental Protection) Act 1994, is dedicated to identifying and managing acceptable human interaction with the Antarctic and Southern Ocean environment. Antarctica New Zealand's goal is to: *"Contribute to the conservation of the intrinsic values of Antarctica through environmental stewardship"*. One major area of concern is the associated

Fig. 1. Cape Bird Hut

effects on the local environment from the burning of fossil fuels. All New Zealand research stations currently rely, almost entirely, on the burning of fossil fuels for their energy requirements. For example, Scott Base burns on average,

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1000 litres of AN8 Aviation fuel per day for its electrical and thermal energy requirement. In contrast, the small Cape Bird hut burns only 700 litres per season as well as a further 72kg of LPG for cooking and freezing food[1].

This paper looks at the available options with regard to renewable energy for supplying the energy requirements for Cape Bird hut (figure 1). The paper is split into four main sections; section II identifies the current energy requirements and any means of reducing current energy demand. Section III, using available data, investigates the renewable energy potential at Cape Bird and looks at various options with regard to conventional solar PV energy including cold temperature issues and Maximum Power Point Tracking (MPPT). Section IV looks at issues relating to batteries and especially cold climate issues while section V provides details on system sizing using estimated losses in the proposed system.

II. Electrical and Thermal load

A. Thermal load requirements

Assuming a Lower Heat Value (LHV) of approximated 10kWh/litre for the heating fuel and also 10kWh/kg for LPG used for cooking and freezing the following section estimates the current thermal energy used by the hut.

The LHV of most petroleum fuels is close to 10kWh/litre for liquids or for gaseous petroleum products such as natural gas or LPG the value is closer to 10kWh/kg. The following list gives an estimate of the average amount of fuel used for heating and cooking at Cape Bird per season.
- Kerosene for space heating–700 litres/season
- LPG for the freezer–45 kg/season
- LPG for cooking–27 kg/season

Hence, using the LHVs described above the average energy per season is approximately 7720kWh. Each season is close to 3.5 months, approximately 108 days or 2592 hours. An average thermal load of approximately 3kW is therefore calculated from the burning of fossil fuels.

B. Electrical load requirements

The electrical load of appliances used in the hut is estimated in table I.

An average power of approximately 75 Watts can be assumed. This is much lower that the estimated thermal load for the hut. In light of the low renewable energy potential at Cape Bird (described in section III) an initial system based on providing only this electrical load is the first step toward a fully renewable system for Cape Bird. The system has been designed with this in mind, allowing

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[1]And an unspecified amount for electricity production.

Item	Energy Wh
Laptops×4×40 W×4 hr/day	640Wh
Freezer×70 W×9 hr/day	630Wh
VHF Radio×25/5 W 0.15 duty	8Wh
Vacuum×1200 W×0.5 hrs/week	86Wh
Task lighting×25 W×2 hr/day	50Wh
Misc. 20 W×16 hr/day	320Wh
Small stereo×10 W×8 hr/day	80Wh
TOTAL ENERGY (ave. power) (75.5W)	1814Wh

for future upgrades. The remainder of this paper provides design details, with respect to the Antarctic environment, for providing a renewable based energy system for the electrical load of the hut.

C. Reducing energy demand

From section II-A it is obvious that the thermal load from heating and cooking is high with regard to the electrical load. The thermal insulation of the hut is 100mm polyurethane with several double glazed windows. Heat transfer from these to the outside of the hut is the main associated loss of energy. Hence, increased thermal cladding is desirable before the hut becomes fully renewable. The heat transfer Q, measured in Watts, through the hut can be estimated using the folowing equation;

$$Q = \frac{A\delta T}{R} \qquad (1)$$

where, R is the thermal resistance, δT the difference in temperature and A the surface area of the hut. Hence, for example, doubling the insulation should approximately half the thermal heat loss.

III. Renewable energy potential at Cape Bird

A. Wind Energy

Cape Bird, despite being situated in Antarctica is, on average, quite a sheltered area. An average wind speed of only 4m/s has been recorded by an automatic weather station (AWS) since 1999/2000. To make matters worst, during the summer occupancy months this average drops to under 4m/s. Figure 2 shows the recorded wind speed at Cape Bird during the occupancy months in 2003. The raw 10 minute data is top left while the remanding figures show the wind data as it passes through a rolling average filter for daily, weekly and four weekly periods. The horizontal line in the four weekly rolling average shows the average wind speed during the occupancy months of 2003–2004 at Cape Bird – in this case, slightly under 4m/s. Using this historical wind data the power generated from a small wind turbine can be predicted. The power recovered from the wind using a turbine can be estimated knowing that wind power is proportional to the cube of the wind speed [2], or;
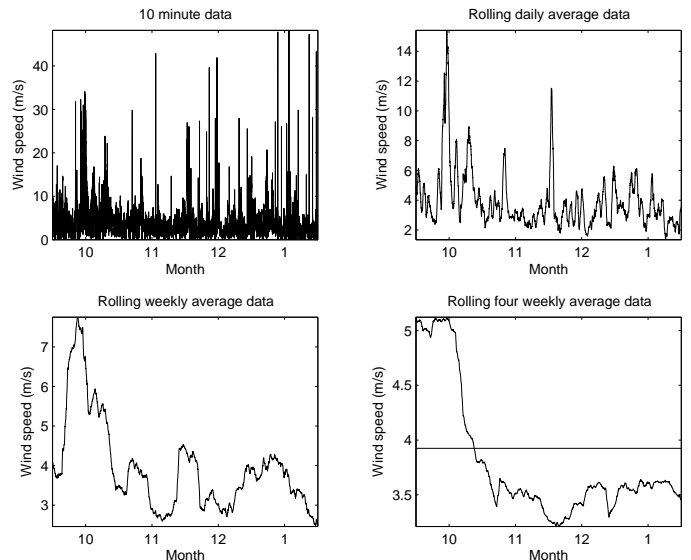
$$P_{wind} = kv^3 \qquad (2)$$

Fig. 2. Cape Bird Hut wind speed during 2003–04 summer

Typically wind turbines are rated at some power output at a given (usually maximum) rated wind speed. The constant k in equation 2 is dependent on several factors, but most notably the size of the turbine, the density of air (dependent on the temperature) and the physical wind turbine properties.

For example, an "off the shelve" wind turbine such as the Air–X Industrial is rated at 300 Watts output when running at its rated maximum speed of 12.5m/s. Hence, k can be estimated as, $k = 300/12.5^3 = 0.15$. Using wind data such as that in figure 2, generated wind power can be estimated. Figure 3 shows the estimated output of an Air–X industrial wind turbine if placed at Cape Bird during the 2003–04 season. As with figure 2 the 10–minute data is shown at top left with the smoothed effects of the daily, weekly and four weekly filters. As shown, an average output power of only 16.5 Watts is produced. This equates to a capacity factor of only 5% indicating a high cost for wind energy at Cape bird. The Air–X Industrial will cost in the vicinity of US$80–90 per generated Watt.

B. Solar Energy

Despite there being plenty of wind energy data available for Cape Bird, there is no available recorded solar radiation/insolation data for Cape Bird. It was decided to use Scott Base radiation data as a substitute. The likely effects of this estimate are unknown, although it is thought that it may be, on average, cloudier at Cape Bird than at Scott Base. The author is unsure weather this statement is true and it is only from discussions with staff that frequent Cape Bird that this statement has been made. Hence, Scott Base data, multiplied by a factor of 0.75 has been used as a substitute. This assumption of 25% lower radiation is a worst case estimate used for additional security that should result, at worst, with an oversized system.

Solar power has an advantage during summer months in Antarctica as the sun shines for 24 hours. Hence, solar
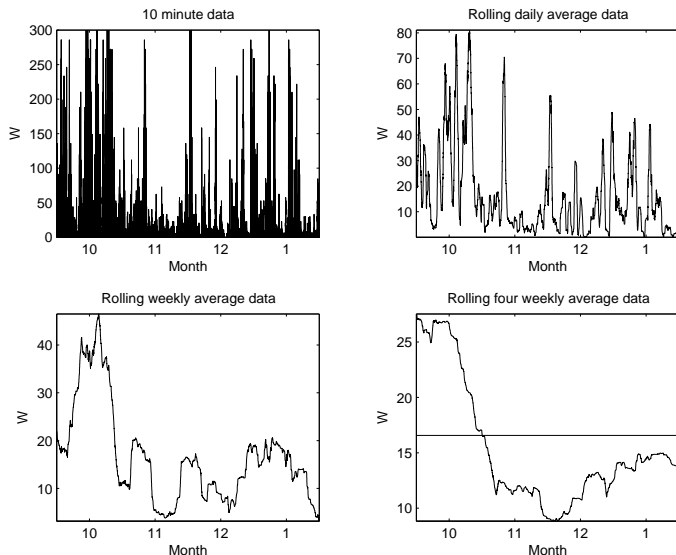
Fig. 3. Predicted output power from Air–X Industrial 300W@12.5m/s rated wind turbine

becomes favourable in such a situation, despite its high cost. As the sun rotates around the hut from all directions, and the hut roof is relatively flat, is it thought that the best position for attaching the panels is flat on top of the roof.

Table II shows estimated global radiation figures for the occupancy period at Cape Bird. Global radiation is measured in W/m^2 and has two components, Direct radiation and Diffuse radiation. These are described more fully in the Appendix. October sees significantly less Global radiation than the months, November, December and January. However, the hut is usually occupied from mid-October when the global radiation will be higher than correspondingly earlier in the month.

TABLE II

Cape Bird estimated Global Radiation and output from Poly and Monocrystalline Photovoltaic panels (CB → Cape Bird, SB → Scott Base)

Month	G. Rad (SB)	G. Rad (CB)	PV (poly)	PV (mono)
Oct	$132W/m^2$	$99W/m^2$	$12.9W/m^2$	$15.3W/m^2$
Nov	$259W/m^2$	$194W/m^2$	$25.2W/m^2$	$30.1W/m^2$
Dec	$345W/m^2$	$259W/m^2$	$33.7W/m^2$	$40.1W/m^2$
Jan	$283W/m^2$	$212W/m^2$	$27.6W/m^2$	$32.9W/m^2$
Ave	$255W/m^2$	$191W/m^2$	$24.8W/m^2$	$29.6W/m^2$

Using the current price of MSK125–180 Monocrystalline panels, solar PV power generation will cost in the vicinity of US$25 per generated Watt, not including the associated power electronics of the system. This is almost three times more economic than wind power generation.

B.1 Solar Panel types

There are two main types of panels used today; mono and polycrystalline. Monocrystalline panels are made up of silicon atoms aligned in a highly organized crystal. They require highly pure silicon that necessitates an expensive manufacturing process. However, cell efficiencies can reach up to 14-17% (15.5% ave.). Polycrystalline panels on the other hand are made up of multiple crystals each with atoms aligned in a different direction, bound together. This cell type can be produced by a number of techniques that lend themselves to easier and faster production using less pure silicon. At 12-14% (13% ave.) commercial polycrystalline cells are only slightly less efficient and due to their cost savings are widely used.

Antarctica New Zealand has operational experience with BP Solarex solar panels. These panels are a polycrystalline type. As shown in Table II the use of a monocrystalline panel gives an average energy density at Cape Bird of $29.6W/m^2$ whereas a polycrystalline panel would give $24.8W/m^2$ during the occupancy period. Although the panel efficiency varies by only 2.5% the monocrystalline panels give 20% more output energy per square meter. As Cape Bird hut has a roof area of approximately $85m^2$ the use of monocrystalline panels gives more available power without having to build apparatus for extra solar panels. Ignoring losses, an average load of 75 Watts would requires approximately 3 square meters of panels if polycrystalline, or 2.5 square meters if monocrystalline.

If the total roof area of the hut were to be covered, a possible solar load average power of 1180W (using monocrystalline panels) or 990W (using polycrystalline panels) could be achieved. Future upgrades to convert the huts heating and cooking apparatus to renewable energy (and hence electrical energy) may need to take this into account.

B.2 Photovoltaic modules in cold climates

PV modules perform slightly differently in cold climates. Cold cell temperatures, low light levels, altered light spectrum, high incidence angles of the suns rays and snow and ice accumulation all affect the modules operational characteristics. In general, efficiency falls with low light levels, however, cold cell temperatures are probably the more important consideration and fortunately, cell efficiency improves at lower temperatures. To take advantage of this the solar panels must be operated at their maximum power point[2]. The current produced by the cells typically stays constant with temperature; however, the cells produce more voltage at lower temperatures and to take advantage of this a Maximum Power Point Tracking (MPPT) type controller must be used.

B.3 MPPT Charge Controller

Several MPPT charge controllers are available on the market. The Outback MX60 PV MPPT Charge controller is one that allows maximum efficiency to be gained from the solar panel output in the harsh conditions faced in Antarctica. This device operates the panels at their peak power point, or the knee–point of the V–I curve. It incorporates a DC–DC converter so the panel voltage and battery voltage can be different, meaning higher panel voltages can be used.

[2]This point is a knee point on a cells V–I characteristic curve where maximum voltage and hence power is produced [1].

The proposed system is to either use a 48VDC panel array charging a 24VDC battery bank, or a 24VDC panel array charging a 24VDC battery bank. The MX60 can handle either of these situations. It is also capable of monitoring battery temperature which is important for cold climates applications so as to not over/under charge the batteries.

IV. Battery Storage

Batteries provide three important functions in a photovoltaic system; Autonomy, by meeting the load requirements at all times at night or during overcast periods; Surge–current capability, by supplying, when necessary, currents higher than the PV array can deliver; voltage control, thus preventing large voltage fluctuations that may damage the load.

For Cape Bird the sizing of the battery system is determined by the number of cloudy days likely to be encountered, the battery temperature, which directly affects the battery capacity and the Depth of Discharge (DOD) and hence, lifetime. Sealed Lead Acid batteries are to be used as these are readily available, contained, and are cost effective compared with other battery technology. Due to their better cold weather tolerance, Absorbed Glass Matt (AGM) type batteries are perhaps the preferred option over gel type batteries if the batteries are to be housed year round at Cape Bird Hut. This is discussed in more detail in the following sections.

A. Battery Life

One main question that must be considered is *"what is an acceptable life time for the battery before it needs replacement?"*. At remote locations such as Cape Bird maximising the life of the battery is important. Generally speaking a 25–30% DOD or less (Depending on ambient temperature) will ensure the maximum life and will be the most economical. At Cape Bird the batteries are to be housed inside the hut and will hence be near the average room temperature, or thereabouts while being used during the summer and at or close to the minimum winter temperature during the winter.

B. Temperature issues for sealed lead acid batteries [1]

Low temperature affects many different aspects of lead acid batteries, including lifetime, capacity, end–of–charge and the possible freezing of the electrolyte.

The internal corrosion processes in lead acid batteries approximately double in rate for every 10^oC rise in temperature. Conversely, the service life may double for every 10^oC decrease. Below 10^oC, other factors ultimately reduce the lifetime of the battery and the service life will not increase much.

Cape Bird presents an unusual situation in that the batteries will be used during the relatively warm summer months and then left at the hut, unused over the winter period. This presents difficulties in that the batteries may freeze if not managed accordingly. The freeze point of the electrolyte in lead acid batteries is dependent on the acidity of the cells. This, in turn, is dependent on the charge. The higher the charge, the higher the acidity and the lower the freeze point. Hence, as the the cells are to be "wintered" over they must be left in a state of full charge. In a state of full charge sealed lead acid batteries should be able to survive very cold temperatures, up to, and less than -50^oC depending on the type of sealed lead acid battery used.

Figure 4 shows the temperature throughout the year at Cape Bird for four years, 2000 through to 2003. As shown, the temperature can often reach in excess of -35^oC during the winter periods.
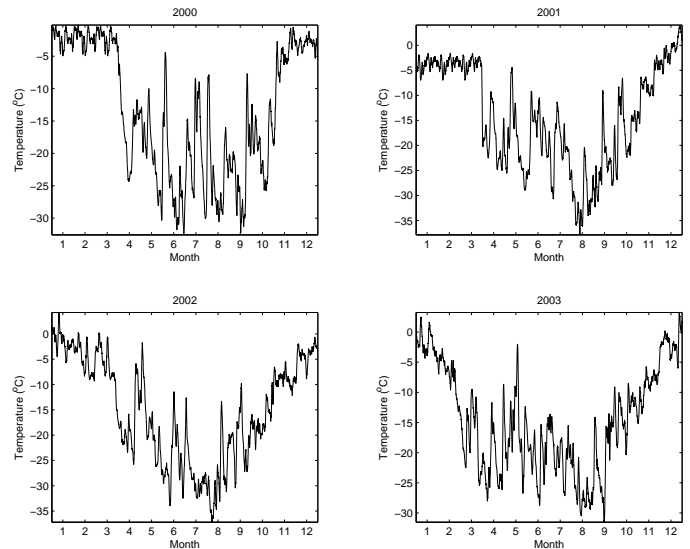

Fig. 4. Temperature at Cape Bird, 2000–2003

Absorbed Glass Matt (AGM) sealed lead acid batteries perform well in colder climates. These batteries use highly porous micro fibre glass separators that completely wrap around the positive plate to absorb and immobilise the electrolyte; this allows the oxygen formed at the positive plate to react with hydrogen from the negative plate to recombine as water forthe electrolyte. By design, AGMs low gassing characteristics mean there are no special ventilation requirements in normal use. Position independent, AGMs may be installed and secured pretty much anywhere except upside down. These types of batteries generally have a low self discharge rate of approximately 1% per month at 25^oC, and this will be lower at lower temperatures. They operate at temperatures as low as -40^oC and are often labelled as having up to twice the expected life cycle of Gel–type batteries. They are classified as a "Non–Spillable Battery" for transportation purposes. They are hence recommended for use at Cape Bird.

V. System Sizing

Sizing the system is dependent on several variables. Notably; the average load, solar insolation, system losses and battery autonomy.

The average load of the initial electrical system has been estimated at 75 Watts or 1800Wh per day in section II-B. However this does not take into acount the system losses. This section estimates various system losses and sizes the

battery bank in accordance to the number of days of backup power required.

A. Losses

There are losses in all parts of the system but most notably the main losses will be in the solar panels, especially if dirty (or snowy/icey), power electronics and batteries. An estimate, or provision, of these losses is required, as follows;

TABLE III

SYSTEM LOSSES - ESTIMATED

Battery charge loss	10%
Dirty Panels	5%
MPPT controller	7.5%
Inverter losses	7.5%
Total estimated Losses	30%

These are only estimates and will vary depending on the operating point of the system and how dirty the panels become. Working with this, the average power from the solar panels required to maintain 75 Watts, becomes 75/0.7=110 Watts. Hence, on average 110 Watts is required from the output of the PV panels. From Table II this gives a total area of panels as $3.7m^2$ for monocrystalline and $4.4m^2$ for polycrystalline.

An example of a standard Monocrystalline PV cell would be the MSK125–180 which is rated at 180W and has an area of $1.2m^2$. Four of these panels would give about $4.8m^2$, or using the solar energy density values for Cape Bird in Table II an average electrical output from the PV panels of around 140 Watts. Hence, this system should provide, after system losses, an average output power of about 100 Watts which should be more than enough to supply the estimated 75 Watt load.

B. Battery Autonomy

Two days of autonomy, i.e., little or no solar radiation, would require 2x1800Wh=3600Wh storage. However, as discussed in sections IV-A and IV-B the life of the batteries is affected by the depth of discharge (DOD) and temperature of lead acid batteries. Assuming a 25% DOD gives 4 times the required or, 14.4kWh of battery storage. Obviously a lower rate of electrical energy use by the hut occupants, when very overcast, etc, will lead to increased autonomy.

C. Sine Wave Inverter

Most loads at Cape Bird will be AC, 230V. OutBack Power systems, as well as the MX60 also produce a very robust sine wave inverter. Rated at 2kVA, this is a little big for the Cape Bird situation, but allowing for further system expansion the FX2024ET, 2kW/24VDC/230VAC/50Hz unit is proposed. This unit is also compatible with the MX60 MPPT charge controller and the MATE control unit. The OutBack MATE is a system controller and pro-grammer for the MX60 MPPT Charge controller as well as the FX2024.

Using this system allows for further system expansion in the future, if, for example Cape Bird were to go fully renewable as well as possible system monitoring through the use of a RS232 serial port.

VI. CONCLUSIONS

The approximate load average for Cape Bird hut is currently around 3 kilo–watts of thermal power and a further 75 Watts of electrical power. The required thermal power can be decreased with increased insulation in the form of extra hut cladding and perhaps a better thermal management plan for the hut. It is very likely that as the energy source for Cape Bird hut moves from conventional fossil fuel to renewable energy sources, an increase in the use of electrical energy will be required. Future renewable sources will be required to power not only the electrical load but also the thermal load of the hut. Although the current system design provides only 75–100 Watts for the electrical load, it has been designed to use modular power electronic components from the OutBack Power range. These can be easily paralleled to give higher power throughput.

An investigation into the renewable energy potential at Cape Bird discovered a relatively low wind energy density and a reasonable solar energy density during the summer months. The current initial system, based around these findings, uses solar PV with battery autonomy for up to two days. The system is designed with cold temperatures and future upgrades in mind. As of writing, the system is currently being procured by Antarctica New Zealand for commissioning at the University of Canterbury before shipment and installation at Cape Bird hut in the 2004–05 summer.

VII. ACKNOWLEDGEMENTS

APPENDIX

I. SOLAR RADIATION DEFINITIONS

A. Solar Irradiance

Solar radiation quantities are generally expressed in terms of either irradiance or radiant exposure. Irradiance is a measure of the rate of energy received per unit area, and has units of Watts per square metre (W/m^2). Radiant exposure, sometime referred to as solar insolation, is the time integral of irradiance.

A.1 Direct solar irradiance

Direct solar irradiance is a measure of the rate of solar energy arriving at the Earth's surface from the Sun's direct beam, on a plane perpendicular to the beam, and is usually measured by a device called a pyrheliometer mounted on a solar tracker. The tracker ensures that the Sun's beam is always directed into the instrument's field of view during

the day. In order to use this measurement for comparison with global and diffuse irradiances, it is necessary to obtain the horizontal component of the direct solar irradiance. This is achieved by multiplying the direct solar irradiance by the cosine of the Sun's zenith angle.

A.2 Diffuse solar irradiance

Diffuse solar irradiance is a measure of the rate of incoming solar energy on a horizontal plane at the Earth's surface resulting from scattering of the Sun's beam due to atmospheric constituents. Diffuse solar irradiance is measured by a pyranometer, with its glass dome shaded from the Sun's beam. As diffuse solar irradiance is a component of global solar irradiance, diffuse solar irradiance should be less than or equal to global irradiance measured at the same time. Global and diffuse irradiance will be equal when the contribution from direct solar irradiance is zero, that is, when the Sun is obscured by thick cloud, or the sun is below the horizon.

A.3 Global solar irradiance

Global solar irradiance is a measure of the rate of total incoming solar energy (both direct and diffuse) on a horizontal plane at the Earth's surface. A pyranometer sensor can be used to measure this quantity with limited accuracy. The most accurate measurements are obtained by summing the diffuse and vertical component of the direct irradiance.

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II. AUTHOR

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