FLORIDA SOLAR ENERGY CENTER®

Evaluation of Resources and Energy Systems at Fort Jefferson
Garden Key, Dry Tortugas National Park

Author

Dunlop, James

Publication Number

FSEC-CR-1701-97

Copyright

Copyright © Florida Solar Energy Center/University of Central Florida
1679 Clearlake Road, Cocoa, Florida 32922, USA
(321) 638-1000
All rights reserved.

Disclaimer

The Florida Solar Energy Center/University of Central Florida nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the Florida Solar Energy Center/University of Central Florida or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the Florida Solar Energy Center/University of Central Florida or any agency thereof.

A Research Institute of the University of Central Florida
1679 Clearlake Road, Cocoa, FL 32922-5703 • Phone: 321-638-1000 • Fax: 321-638-1010
www.fsec.ucf.edu

Evaluation of Resources and Energy Systems at Fort Jefferson

Garden Key, Dry Tortugas National Park

Prepared for:

National Park Service
Dry Tortugas National Park
P.O. Box 6208
Key West, Florida 33040

and

Sandia National Laboratories
Photovoltaic Systems Applications Division
Albuquerque, NM 87112

Prepared by:

James P. Dunlop, P.E.
Donard Metzger

Florida Solar Energy Center
1679 Clearlake Road
Cocoa, Florida 32922-5703

EXECUTIVE SUMMARY

This report presents an evaluation of the resources and energy systems at Fort Jefferson, located on Garden Key in Dry Tortugas National Park, Florida. Conducted by Florida Solar Energy Center staff on June 11-12, 1997, this evaluation builds on a prior evaluation conducted in May 1989. The purpose of this evaluation was to document the energy and resource needs at the site, and to identify possibilities for reduced costs through conservation measures and renewable energy options.

Approximately 700 kWh of electrical energy is used at Fort Jefferson on a daily average, supplied exclusively by diesel-fueled generators. Average diesel fuel consumption is on the order of 2400 gallons per month. The predominant electrical loads include air-conditioners (65%), refrigeration (11%) and hot water heating (8%). Peak loads are estimated to vary between 50 and 70 kW, with an estimated minimum load of about 20-25 kW during late evening and early morning hours. The estimated cost of energy is $0.33 per kWh, and includes estimates of fuel delivery and maintenance costs.

Propane is used for cooking and clothes drying only, consuming approximately seventy-five 100-lb cylinders per year. Fresh water is supplied by a combination of rainwater collection systems and seawater desalination from a reverse osmosis plant. A seawater distribution system is provided for all toilet facilities.

A number of conservation measures and renewable energy options are presented in this report. These include considerations for space conditioning and refrigeration equipment and other load management devices. For the purposes of evaluating renewable energy options, solar radiation and wind energy resource data for the Dry Tortugas is provided. The use of retrofit solar water heaters is evaluated, suggesting a simple payback period of three to five years.

Wind energy appears to be a viable resource for the site, with the annual performance of a nominal 10-kW turbine estimated to average 47 kWh/day. Although this represents only 6 percent of the average daily energy use, the simple payback period is estimated to be about four years. The use of a photovoltaic power system was investigated for supplying part of the facility loads at Fort Jefferson, however the economics suggest that this option is marginally cost-effective, with an estimated payback period of over fifteen years at $10 per kWp installed costs. The cost-effectiveness and payback periods for each of these options depends highly on the assumptions made and accuracy of existing and projected energy costs.

Based on the data in this report, conservation measures and some renewable energy options should be strongly considered by NPS personnel responsible for Fort Jefferson. One option to consider would be the U.S. Department of Energy's FEMP program for renewable energy and conservation measures. Some of the options presented in this report may be acceptable for a shared-saving plan, whereas a contractor would install systems and equipment and be paid from savings from NPS operating funds. This arrangement has proved successful for many applications, and should be considered. Even without co-funding or other external financial support, the high energy and operating costs at Fort Jefferson suggest consideration of any viable measures to reduce costs.

Presently, the U.S. Coast Guard delivers fuel to the island, and uses as much fuel to deliver it as NPS uses at the site. The Coast Guard vessel presently used to deliver the fuel to the island will be decommissioned in 1998, and replaced with a vessel to large to dock at Loggerhead Key. Consequently, an alternative plan for fuel deliveries must be arranged for by that time. Currently, there are no known transfer of funds from NPS to the USCG to pay for these fuel deliveries, and it is uncertain as to what the future arrangements will be, or even if the Coast Guard will continue to deliver fuel to the Tortugas. This may have significant cost ramifications, possibly doubling the actual energy costs for the Park Service to maintain Dry Tortugas National Park.

Acknowledgements

Appreciation is given to several NPS staff members at Fort Jefferson who provided input to this evaluation, including Paul Taylor, Mike Amiotte and Cliff Green and Louise Pratt. Special thanks are extended to Al Walsh for his knowledge and assistance in assessing the resource usage and energy systems at Fort Jefferson. Mike Savage of Everglades National Park is acknowledged for coordinating this evaluation and providing follow-up information contained in this report.

Table of Contents

1. INTRODUCTION

On June 11-12, 1997, Florida Solar Energy Center (FSEC) staff conducted an evaluation of the energy use and resources at Fort Jefferson, located on Garden Key in the Dry Tortugas National Park (Figures 1 and 2). This evaluation was requested by Sandia National Laboratories, and follows a prior evaluation conducted by FSEC staff in May 1989. The purpose of this evaluation was to assess the energy systems at the site and to identify possibilities for cost-effective energy conservation measures and renewable energy system options.

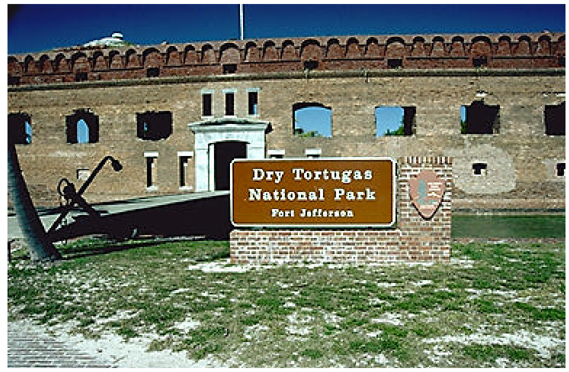

Figure 1. Entrance to Fort Jefferson.

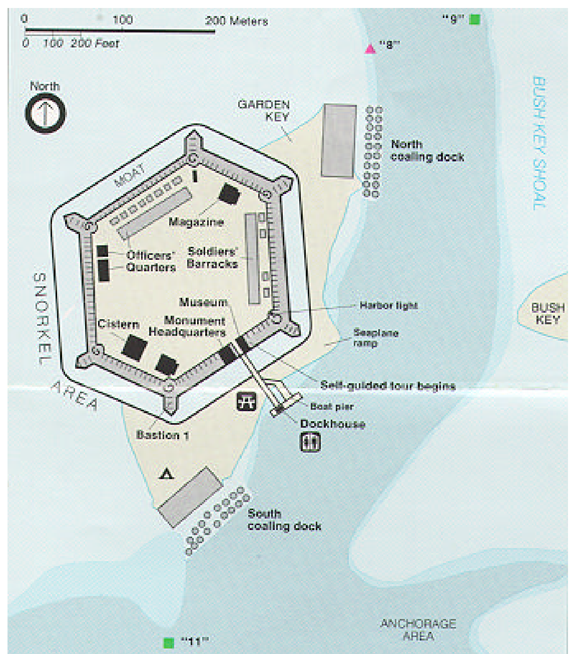

Figure 2. Plan diagram of Garden Key.

The most remote and inaccessible National Park in the U.S., Fort Jefferson is located 68 miles due west of Key West, Florida. Approximately one dozen staff and family members reside at the fort to preserve the historic value of the site for the public. Reportedly, as many as 50,000 persons a year visit the civil war era fortress via seaplane or boat.

Due to the remoteness and lack of energy and water resources on the island, providing basic subsistence for National Park Service staff at Fort Jefferson is a difficult and expensive proposition. All electrical power is generated by diesel engines, requiring frequent fuel deliveries from the mainland. To supplement the limited fresh water supply collected from roof drainage systems, a reverse osmosis unit is operated to supply the balance required. Fresh water, electric power, fuel and other amenities are not available to the general public when visiting Fort Jefferson.

Including Fort Jefferson, Dry Tortugas National Park comprises of seven small islands, coral reefs and nesting areas for a variety of wild birds and sea turtles. The park encompasses 64,657 acres, which includes only a small amount of land above sea level.

1.1 Historical Background

Ponce de Leon was the first European to visit these islands in 1513 and called them the "Las Tortugas" for the abundance of sea turtles he found there. Throughout the 1600's and 1700's, the islands were used as a base for pirates attacking merchant shipping in the Gulf. After the United States acquired Florida in 1821, pirating was largely eliminated and a lighthouse was constructed on Garden Key in 1825 to warn mariners of the dangerous coral reefs in the area.

As part of the America's 19th Century coastal defense network, construction of Fort Jefferson began in 1846 and continued for nearly 30 years. The fort was designed to accommodate 450 guns - an impressive array of firepower - located along three tiers of the hexagon-shaped structure. However, due to foundational problems and obsolescence brought on by weapons technology improvements, construction of the fort was never fully completed. Approximately 16 million bricks were used to construct Fort Jefferson, making it the largest masonry structure in North America.

During the Civil War, the fort was occupied by Federal troops and used as a prison for Union deserters. Among the prisoners who served sentences at Fort Jefferson were four convicted of conspiring to assassinate Abraham Lincoln, most notably Dr. Samuel Mudd, who set the broken leg of assassin John Wilkes Booth during his escape. Mudd served heroically as a physician during a yellow fever epidemic at the fort in 1867, during which 270 of the 400 inhabitants acquired the disease and 38 died. Mudd's work was recognized and he was finally paroled 1869 and left the fort.

After a damaging hurricane and another yellow fever outbreak, the army abandoned the fort in 1874 and the facilities were used as a quarantine station from 1888 until the end of the century. In 1898, the military returned to the Fort Jefferson and used it as a coaling depot during the Spanish American War. In 1908 the area was designated as a bird reserve and transferred to the Department of Agriculture. The fort was again briefly garrisoned during World War I and was used as a seaplane base.

On January 4, 1935 the site was designated as Fort Jefferson National Monument by President Franklin Roosevelt, the first marine area to be so protected. On October 26, 1992 the monument and surrounding marine areas were upgraded to National Park status in a bill signed by President George Bush.

2. ENERGY SYSTEMS OVERVIEW

2.1 Electrical Service

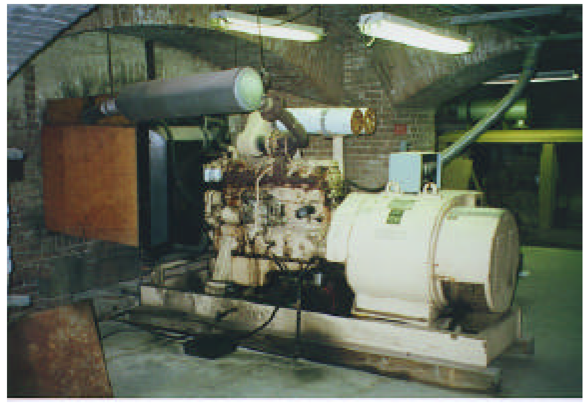

Figure 3. One of four 100 kVA generators.

Diesel generators supply all of the electrical power required at Fort Jefferson. The electrical service is distributed to the residences and other facilities via four main service panels and fourteen subsystem service panels. The generators are configured to provide single-phase AC output at 240/120 volts 60 Hz.

In 1989, three 60-kVA generators and one 45-kVA unit were operated on an alternating basis between maintenance schedules. At that time, one 60-kVA unit had enough capacity to meet the electrical load part of the year, while two of the generators were operated to meet the higher air conditioning load during summer months and to supply adequate voltages.

Between 1990 and 1995, four new 100-kVA generators were installed to replace the preexisting ones (Figure 3). These units were purchased on GSA contract by NPS for approximately $18,000 each and installed by NPS staff.

2.2 Fuel Consumption and Energy Production

Diesel fuel is used primarily for the generators at the fort, although a minor amount is used for boats and other service vehicles. Over the last 20 years, diesel fuel has been delivered to Fort Jefferson at Garden Key and to nearby Loggerhead Key by a U.S. Coast Guard buoy tender ship at no delivery cost to the Park Service. Approximately six fuel deliveries are made annually to Garden Key, with the typical amount being 7,500 gallons per delivery. In 1996, the estimated costs for fuel only (not including delivery) amounted to about $32,000 for both Garden Key and Loggerhead Key.

In the last couple of years, the U.S. Coast Guard has transferred ownership and operation of nearby Loggerhead Key to the Park Service. This presents new problems and issues for fuel deliveries. Presently, the Coast Guard delivers fuel to both Garden Key and nearby Loggerhead Key, and uses as much fuel to deliver it as NPS uses. The Coast Guard vessel presently used to deliver fuel to the island will be decommissioned in 1998, and replaced with a vessel to large to dock at Loggerhead Key, and marginally at Garden Key. Consequently, an alternative plan for fuel deliveries must be arranged for by that time. This may have significant cost ramifications, possibly doubling the actual energy costs for the Park Service to maintain Dry Tortugas National Park. At this time, it is unclear what the future arrangements and costs will be for fuel deliveries to Fort Jefferson.

Currently, three 6000-gallon fiberglass tanks located underground near the south coaling docks are used to store fuel between deliveries. These tanks were upgraded from three 4000-gallon tanks used in 1989. Two 700-gallon tanks in the generator room are used as intermediate storage for the fuel (Figure 4). A 2-Hp pump and fuel flow meter, located between the primary storage tanks and intermediate storage tanks, are used to transfer and monitor the fuel consumption.

Figure 4. Intermediate diesel tanks.

Two rotating disk kilowatt-hour meters are installed on the generator output circuits to monitor energy production, however no record of meter readings existed prior to 1989. Based on readings taken immediately after FSEC's first site visit, the average daily production was 672 kilowatt-hours over a one-week period in May 1989.

To estimate energy production for the generators based on fuel consumption, a diesel fuel heating value of 127,000 Btu per gallon and an average fuel to electrical energy efficiency of 25 percent were assumed. This estimate is intended to take into consideration the variable load on the generator and the effect on the fuel to electric power efficiency. The estimated generator daily energy production for April 1987 through April 1989 is shown in Figure 5, and compares favorably with the readings taken in May 1989 after FSEC's first evaluation.

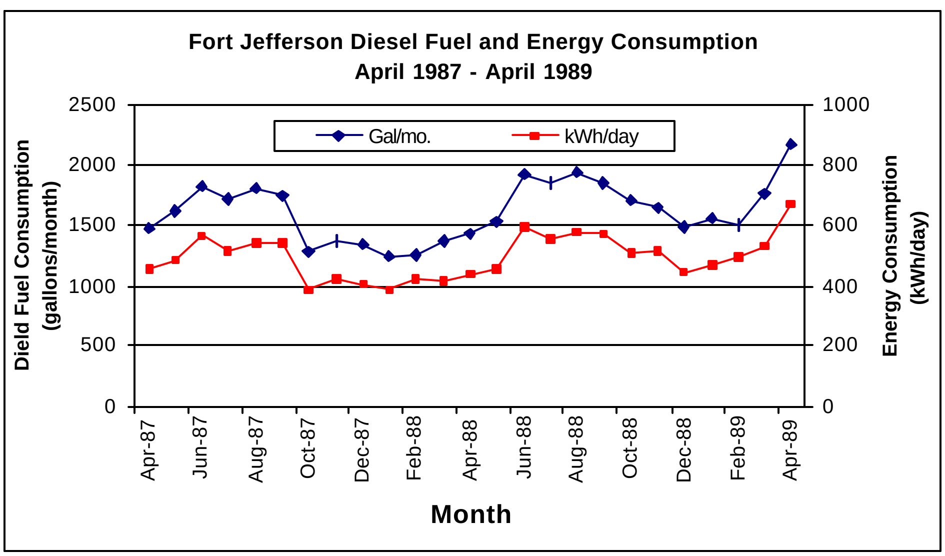

Figure 5. Fuel consumption and estimated energy production, 1987-89.

During the recent evaluation, records were obtained documenting the diesel fuel used and the daily kWh meter readings for the generator output circuits. During the period January 1994 through May 1997, the average monthly fuel consumption was about 2400 gallons and the energy production averaged about 700 kWh/day, exceeding 900 kWh/day during the peak air-conditioning months. This data is shown in Figure 6 along with the ambient temperature data for the same period.

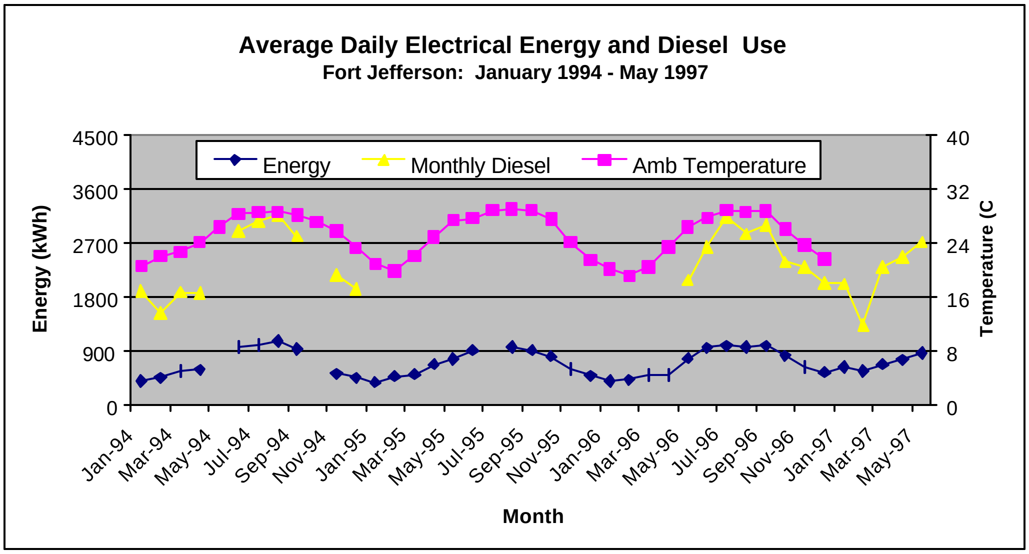

Figure 6. Average daily energy and fuel usage, 1994-97.

Note the strong correlation in Figure 6 between the average ambient temperature and energy use, showing the significant effect of the air-conditioning load. By simple estimates, it appears that the base load is on the order of 500 kWh/day for the minimum load period of the year (winter), indicating approximately 400 kWh per day used for air-conditioning during the peak summer months. The milder winter during 1996-97 had a noticeable effect on energy use compared with prior years, suggesting some use of air-conditioning year-round. Detailed breakdown and estimates of end-use energy consumption are presented later in this report.

2.3 Operations and Maintenance

Operation and maintenance requirements for the energy systems at Fort Jefferson are a continual, time-consuming and expensive process. In addition to the efforts required for fuel delivery and periodic replacement of storage tanks, regular maintenance is required for the generators. This maintenance includes oil and filter changes, replacement parts, and other needs. With an experienced diesel mechanic now on site, the need for professional service visits from the mainland has essentially been eliminated from prior years.

Currently, each of the four 100-kVA generators operates for a week at a time, then is removed from service for maintenance approximately twelve times per year. The four generators are used for redundancy, as replacement parts may take several weeks to arrive from the mainland and would result in prolonged downtime.

The monthly scheduled maintenance for each generator includes about six gallons of oil at $8 per gallon, filter and oil filter replacement and about two hours labor. Serviced twelve times each per year, 48 times for the four generator units, the annual costs are estimated to be about $6,000. This number is significantly lower than the estimate derived in 1989, primarily due to the on-site expertise and the lower maintenance needs for the higher quality marine-grade generator units now in use.

2.4 Economics

The economic considerations for the energy systems at Fort Jefferson include the capital costs for equipment, fuel costs and delivery, and maintenance requirements. Assuming that a generator is replaced once every 1.5 years (as the case was during 1990-95), a life of six years per unit at 25 percent duty cycle gives 13,000 hours before major overhaul or replacement. While it is recognized that this estimate may be less than expected, the aggressive marine environment takes a toll on equipment. The annual replacement costs are estimated to be $20,000 to include replacement, installation and labor. Although the USCG cost of fuel deliveries are not incurred by the Park Service, they are estimated to be on the order of the cost of the fuel delivered. These costs are assumed to include fuel for the delivery ship, manpower and vessel maintenance. The total annual costs are estimated to be $86,000 as shown in Table 1.

Table 1. Estimated Annual Generator Costs

Item	Cost ($)
Fuel	$ 30,000
Fuel Transport	$ 30,000
Maintenance	$ 6,000
Replacement (approx.)	$ 20,000
Total	**$ 86,000**

Using the measured annual energy production of 260,000 kWh and the estimated costs for fuel, operations and maintenance, the estimated cost of energy production is about $0.33 per kWh. Future discussions with Coast Guard and Park Service personnel will attempt to define this number more accurately and assess how the logistical changes will impact costs.

3. WATER RESOURCES AND USAGE

Fresh water resources are in limited supply at Fort Jefferson. A complete absence of fresh water earned the group of islands the prefix ‘dry’, thus the Dry Tortugas. In the original design of the fort, 109 cisterns were located below the foundation with a total capacity of 1.5 million gallons. Rainwater was collected on the roof of the fort and channeled into the cisterns. During the Civil War, the rainwater collection system was supplemented with coal-fired steam condensers were installed capable of producing 7,000 gallons of fresh water per day. Later, during the Spanish-American War, a steam condenser capable of producing 60,000 gallons of freshwater daily was installed by the Navy.

As the fort settled due to the tremendous weight on the foundation, many of the cisterns cracked and became infiltrated with seawater. In the 1960’s, vinyl linings were installed underneath the sand and limestone base of the fort’s roof collection system in attempts to utilize some of the original cisterns and to reduce the constant seepage of water into the living quarters and other facilities at the fort. However this proved unsuccessful and water seepage through the masonry continues to be a problem in most areas of the fort. A few of the original cisterns are thought to be intact today, and this water is used for ongoing masonry repairs at the fort.

3.1 Current Water Usage

Today, freshwater is provided by a combination of rainwater collection systems and a 2000-gallon per day reverse osmosis unit (Figure 7). Water is available only for Park Service staff and operations; no water is available to the general public. Water conservation is imperative at the fort in managing the limited resources. Low-flow showerheads are used and signs are posted at all sinks and baths to emphasize conservation. Even condensate from the numerous air conditioning units is collected for rinsing equipment and watering small gardens. A seawater supply system is used for all toilet facilities.

Figure 7. Reverse osmosis system, freshwater and seawater pumps.

Based on available data and conversations with personnel on site, the freshwater usage varies between 400 and 500 gallons per day, and increases to as much as 1000 gallons per day with additional visitors and work crews on site. Records from water meter readings for the period April 1994 through May 1997 were obtained during the evaluation and are plotted in Figure 8. From this data, the average daily freshwater use is shown to increase during the summer months to above 600 gallons per day, while the usage decreases to around 400 gallons per day during winter months.

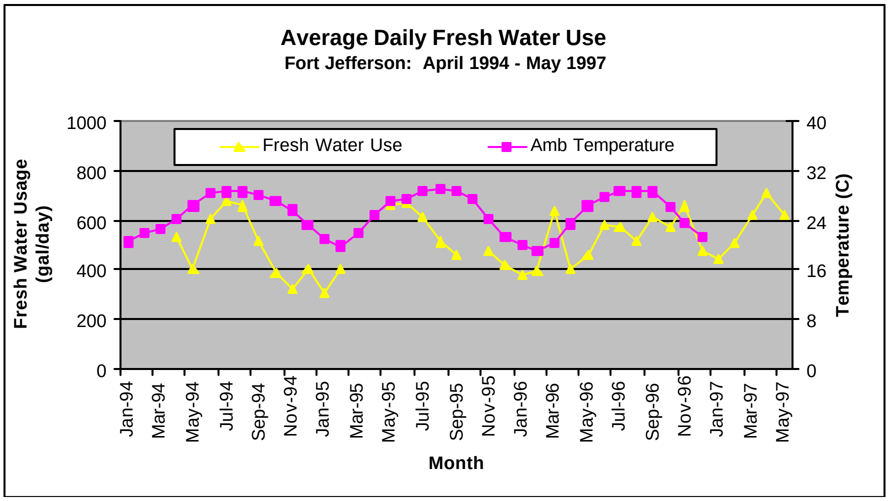

Figure 8. Freshwater usage, 1994-97.

3.1.1 Rainwater Collection and Storage

The existing rainwater collection system uses several of the ducts from the original roof drainage system, as well as collection from the roofs of residences in the parade grounds. All water collection is channeled through PVC pipe to a sump pump and into a 72,000-gallon cistern located in the parade grounds (Figure 9). Specific information on the amount of rainwater collected was not available.

Figure 9. 72,000-gallon cistern in parade grounds.

Figure 10 shows one of the many ducts located between the casements that are used to channel water from the roof of the fort into the cistern. In addition, water produced from the reverse osmosis plant is stored in the cistern.

Chlorination and other water treatment methods are applied to the water in the cistern before distribution to end-uses. For emergency purposes, the water level in the cistern is kept as high as possible, supplemented by the reverse osmosis plant. However, cracks are developing in one of the three cistern reservoirs, limiting the total useable capacity to less than 68,000 gallons.

Figure 10. One of original ducts used for rainwater collection.

3.1.2 Reverse Osmosis Plant

The reverse osmosis (RO) system is a 2000-gallon per day seawater purification system manufactured by Village Marine, purchased by the Park Service for approximately $15,000 (Figure 7). It was stated by NPS staff that the RO unit was operated for about 8 hours per day, resulting in an estimated production of approximately 600 gallons per day. However, no specific information on RO water production was available, only the total freshwater use from the cistern.

Figure 11. Freshwater and seawater bladder tanks.

The RO system first feeds a 500-gallon emergency storage tank located on the roof of the fort, with the excess water diverted to the cistern in the parade grounds. In the event the emergency storage and cistern are full, the RO system is shut down. One of two parallel ¾-Hp pumps feed low turbidity seawater to a series of four bladder tanks as shown in Figure 11. Low and high-pressure positive displacement pumps provide the osmotic pressure for the RO system.

Due to the variability in rainfall and the threshold amounts needed to saturate the sand fill on the roof of the fort, it is expected that the RO plant provides the bulk of the average daily water requirement. Rainwater collection supplies the balance and excess required for additional visitors and work crews.

3.1.3 Seawater Use

In addition to supplying water for the RO system, seawater is used exclusively in all toilet facilities at Fort Jefferson. Data recorded from elapsed time meters indicate that the seawater pumps operate between one-half and one hour per day to serve the RO system and seawater distribution system for the toilets.

3.2 Water Distribution

From the cistern, chlorinated freshwater is pumped into the series of four bladder tanks by either of two parallel ¾-Hp pumps (Figure 11). Only one pump operates at a time, the parallel configuration being used for redundancy in the event of pump failures and required maintenance. The pressure differential for the system is between 20 and 50-psi and the flow is about 120 gallons per cycle. Estimates indicate the pumps operate about one-half hour per day.

3.3 Sewage Treatment

A total of three lift stations transfer sewage to septic tanks located in the parade grounds and in the camping area. Two of the lift stations are located in the parade grounds, each operated by a ¾-Hp pump. These pumps are sequenced so that not all operate at the same time. The other sewage pumps are located at the boat dock for the public facilities located there.

Figure 12. Sewage lift station located in parade grounds.

4. ELECTRICAL LOADS AND OTHER ENERGY USES

The primary form of energy use at the site is electrical power supplied by the diesel-fueled generators. Approximately 700 kWh of electrical energy is used at Fort Jefferson on a daily average, peaking at over 900 kWh per day during the summer months due to the significant air-conditioning load.

During the recent evaluation a facility-wide inspection was made to document the electrical energy consumption at the fort. A summary of these estimates, categorized by load type and location are given in a spreadsheet in the Appendix of this report.

Based on these estimates, the predominant electrical loads include air-conditioners (65%), refrigeration (11%) and hot water heating (8%). The percentages indicate the approximate contribution to the total daily energy (kWh) consumption. Figure 13 summarizes this information in a pie chart format.

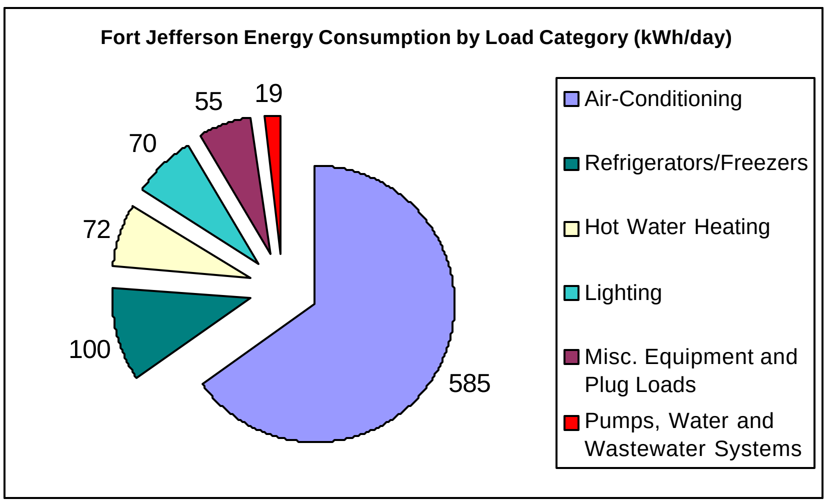

Figure 13. Daily energy consumption as a function of load category.

In estimating the peak load conditions, limited information was available. Based on the total of all loads identified, the peak load could be as high as 107 kW, but more likely limited to between 50 and 70 kW, depending on the time of use profiles for the various loads. The minimum load is estimated to be between 20 and 25 kW during late evening and early morning hours, primarily due to the air-conditioning and refrigeration loads. Figure 14 shows a pie chart for the estimated contributions to the peak load as a function of load category.

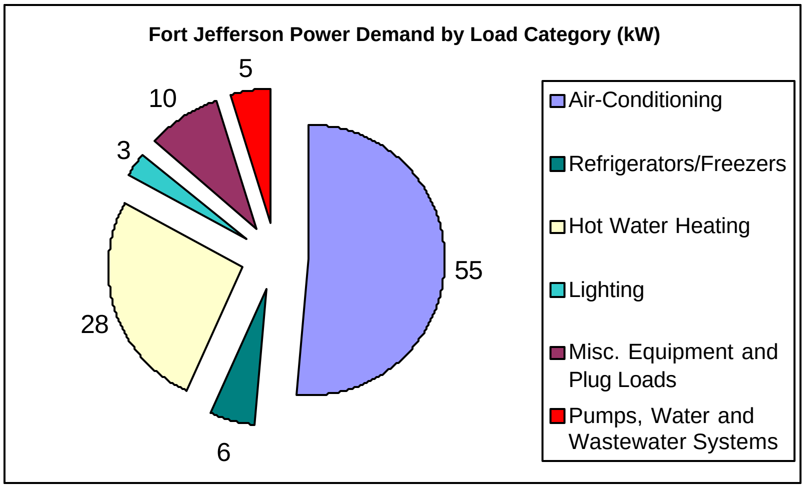

Figure 14. Power demand as a function of load category.

4.1 Air Conditioning

Due to the humid and corrosive marine environment, air-conditioning plays a critical role in preserving equipment, personal belongings, furnishings and providing basic comfort for the Park Service personnel working on the island. Air-conditioning is by far the most significant electrical load at Fort Jefferson, estimated to account for 65 percent of the average daily energy use, and 50 percent or more of the peak power demand.

Figure 15. Crews #4 quarters with typical window A/C units.

Twenty-four window units (mostly ½-ton and 1-ton systems) and two central systems with split condenser and evaporator units are used for the residences, offices, radio room, storage rooms and visitor's center at Fort Jefferson. Typically, these units are purchased on GSA contract, and are replaced every four years due to corrosion of the coils and other components. Figure 15 shows the installation of two of the window units in living quarters built into the casements of the fort.

Humidity control is a major objective of air-conditioning at the fort. Because the masonry arches are the interior roofs in many of the living quarters, moisture penetration through the deteriorating brick is continual, both naturally and as a result of the leaking rainwater collection system on the roof. Even at indoor temperatures of 75 degrees F, one still can sense the damp air. Mortar from the bricks routinely falls from the ceiling in all areas of the fort in both conditioned and unconditioned spaces. A shingled roof has been installed over some of the residences to reduce the moisture problem. However this has been somewhat ineffective, as water is leaking in around the edges.

In general, the energy efficiency of conditioned spaces dictates the limits on reducing cooling loads. However, human practice and operational strategies play an important role. Due to the high cost of energy at Fort Jefferson, special attention should be directed towards the air-conditioning load. Following are some suggestions on how the air-conditioning loads may be minimized.

- Weather-strip doors, windows and seal other openings to the conditioned spaces. Most doors were found to have significant infiltration (no weather-stripping), and even some areas (around a stove ventilation fan) had several sq. feet of area open to the outside. Sealing of these areas is a low-cost measure, and would have significant returns on lower humidity levels and reduced air-conditioning costs.

- Select the highest SEER rated air-conditioning units as possible when replacing existing units, preferably with a variable fan speed option. High efficiency air-conditioners are rated for their sensible performance and not on their ability to remove moisture. The units use high fan speeds which improve the overall cooling efficiency of the system, however lower fans speeds will result in better moisture removal performance.

- If practical, lower efficiency window units should be replaced by more efficient split systems. These special requirements and the higher than normal energy costs at the site may dictate other than GSA contracted purchases for standard efficiency equipment.

- Make special attempts to turn off or raise the thermostat settings on air-conditioners used in unoccupied areas overnight. Low-cost time clocks may be used for this purpose.

- Consider consolidating existing air-conditioning systems into a fewer number of split systems serving more than one residence. If possible, install ducts internal to conditioned spaces to minimize losses.

4.2 Refrigeration

Figure 16. Interior of Crew #4 quarters, showing refrigerators and masonry ceiling.

Refrigerators, freezers, ice machines and a water cooler are the second largest load next to air-conditioning, accounting for an estimated 11% of the average daily energy use, and 6% of the peak demand. Fifteen refrigerators, ten freezers and two ice machines are used at Fort Jefferson. The large number of refrigerators and freezers are necessary to provide storage for the NPS staff between monthly grocery trips to Key West.

While nothing significant can be done to reduce the existing refrigeration loads, a couple of suggestions can be made. A simple load reduction measure would be to install a timer on the water chiller in the visitor center to operate only when the facility was open. The other suggestion would be to procure the highest efficiency units available, which may have less than half the energy consumption of the older existing models. Again, these higher efficiency units may not be available on GSA contract. An example is the Whirlpool model ED25PS*D*O side-by-side refrigerator/freezer unit, which won the manufacturers' competition for the U.S. Department of Energy's Super Efficient Refrigerator Program (SERP). In FSEC evaluations, this 25 cu. ft. unit consumed 73 percent less energy than typical refrigerators used in Florida residences.

4.3 Water Heating

Electric water heating represent another significant energy load at Fort Jefferson, accounting for an estimated 8 percent of the average daily energy use, and potentially 26 percent of the peak demand. A total of thirteen electric water heaters are used on site, including eleven 30-gallon units using 2-kW elements and one 55-gallon unit with 3.8 kW elements.

In the early 1980's under a U.S. Department of Energy conservation grant, R-4 insulation jackets and 7-day clock timers were installed on the water heaters. During the 1989 evaluation by FSEC staff, timers were found installed on the water heaters to limit and sequence their time of operation. During the recent evaluation, it was stated that the timers were no longer used and considered to be ineffective. Considering the potential impact on peak demand, timers can serve a critical purpose for peak shaving if the electrical water heaters remain and energy use continues to grow at Fort Jefferson.

4.4 Lighting

Lighting is estimated to account for 8 percent of the average daily energy use and 3 percent of the peak load at Fort Jefferson. The majority of lighting fixtures use four-foot 34-watt T-12 fluorescent lamps, however there are a significant number of incandescent lamps used as well.

Although lighting does not comprise a significant portion of the energy use at the site, some load reductions may be possible by the use of highly efficient lamps and ballasts and control systems available on the market today. All incandescent lamps should be replaced with compact fluorescent units, which provide comparable light output at one-fourth the power requirement and ten times the life as incandescent lamps. As ballasts fail in the existing 4-foot fluorescent fixtures, they should be replaced with high-efficiency electronic types with high power factor. Another viable option would be to install low-cost motion sensors on applicable lighting circuits to reduce unnecessary and unattended use.

4.5 Other Facilities and Loads

4.5.1 Laundry and Recreation Facilities

The laundry room contains two washers and two dryers for use by NPS staff, used for approximately 20 loads per week (Figure 17). Towels, sheets, and other linens are sent to Key West on the supply ship Activa once a week for laundering. The two washers have a 20-gallon capacity, with hot water supplied from a 30-gallon, 2-kW electric water heater in the laundry room. The two dryers utilize LP gas and consume about four 100-lb LP gas cylinders per month. Some clothes are dried on clotheslines, but not often due to the humid conditions.

Figure 17. Conventional washers and LP gas dryers.

A recreation room is provided for the residents, and includes a pool table, a weight machine, a TV, VCR and stereo. More prominent energy loads in the recreation room include one of the two ice machines on site, a window air-conditioning unit, a ceiling fan and a 6-kW sauna. It was stated that the sauna is used on an infrequent basis, if at all.

4.5.2 Boat Dock

The boat dock is used for the Park Service patrol boats and complimentary 2-hour docking for visiting boats (Figure 18). No overnight docking is allowed, however an anchorage is provided in the harbor next to the island.

Figure 18. Boat dock at Garden key with supply ship Activa.

Lighting and shore power are provided on the dock for the benefit of campers and supply ships. Restroom facilities are available with seawater toilets and no sinks. Two sewage pumps are located on the dock as mentioned previously. Boat hoists for the patrol boats are also present, but used infrequently. An air-compressor for dive tanks is located in a sore room on the dock for Park Service use only.

4.5.3 Park Offices and Visitor's Center

The park office energy use consists of a window air-conditioning unit, lighting, computer, copy machine and fax machine. An adjacent room, partly used for storage and as a mini-library has a ½-ton A/C unit and another computer. The visitor's center includes a museum and gift-shop and has two window air-conditioning units, assorted lighting, and a TV/VCR setup. A chilled water fountain is also located in the visitor's center.

4.5.4 Employee and Visitor Residences

Over one dozen living quarters are used at Fort Jefferson for NPS staff and invited guests. These quarters include a variety of one and two bedroom units built into the casements of the fort, as well as an historic building (formerly officers quarters) on the parade grounds divided into two units (Figure 19).

Figure 19. Saff residences.

Each living quarters contains one or more air-conditioners, an electric water heater, a separate refrigerator and freezer, lighting and miscellaneous plug loads. It is estimated that the living quarters account for approximately two-thirds of the energy use at Fort Jefferson.

Each residence is supplied with an LP gas stove for cooking. Two 100-lb LP gas cylinders are used at each residence and require replacement on the average of every four months. Approximately seventy-five 100-lb propane cycling refills were purchased last year for cooking and the clothes dryer use.

At this time, NPS Everglades has preliminary designs for new living quarters at Fort Jefferson. In addition to solving the problems associated with moisture in conditioned spaces, these units could benefit greatly from conservation measures and use of efficient equipment. NPS staff should seize this opportunity to help manage the electrical load at Fort Jefferson as these new modular units are installed and existing quarters are phased out of service.

4.5.5 Storage Rooms

A number of conditioned storerooms are used at Fort Jefferson, each using a window air-conditioning unit. These storage rooms include a hurricane supply room, radio room and dry storage for the Activa supply ship.

5. CONSIDERATIONS FOR ALTERNATIVE ENERGY SYSTEMS

Due to the great expense and difficulties in supplying water, energy and other needs at Fort Jefferson, consideration was given to the potential and cost-effectiveness of several renewable energy system options. These options include solar water heating, and wind turbines and photovoltaic systems for electrical energy production. In the following sections, the solar radiation and wind energy resources in the Dry Tortugas are examined, and each renewable energy system option are investigated with respect to their practicality and economics.

5.1 Solar Radiation and Wind Energy Resources

Although no solar radiation data is available for the Dry Tortugas, historical data has been collected at Key West, Florida. This data is available for the period 1961-1990 from the National Renewable Energy Laboratory (NREL) and includes data for flat-plate, single and dual-axis tacking surfaces. This information is part of the National Solar Radiation Database and can be found on the Internet at URL http://asd.nrel.gov/solar/. Average daily solar radiation for selected surfaces at Key West is shown in Figure 20.

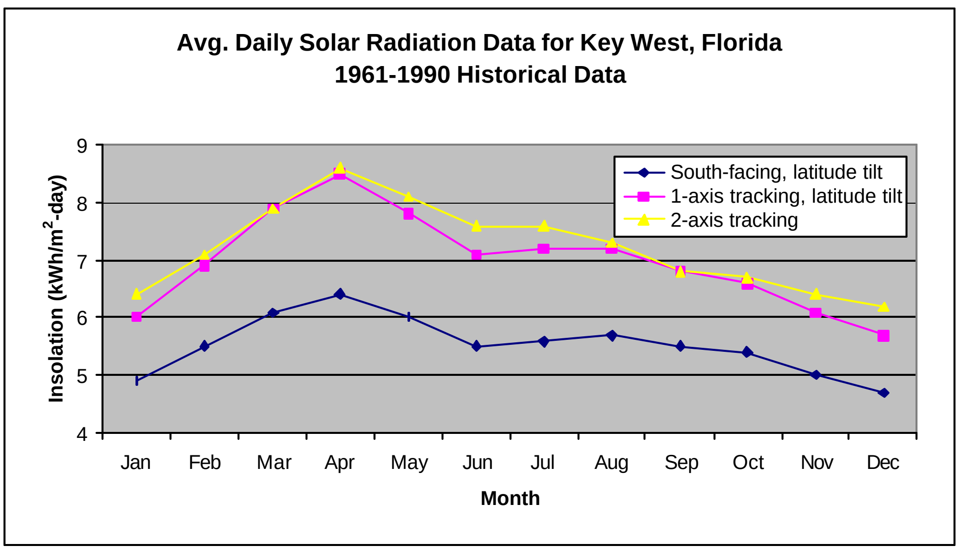

Figure 20. Solar radiation data for Key West, FL.

In summarizing the data in the above chart, the solar radiation for fixed south-facing surfaces at latitude tilt averages 5.5 kWh/m^2-day annually, while a 30 percent enhancement can be achieved by use of a single-axis tracking surfaces. Little gains are achieved from using dual-axis tracking over single-axis tracking. This data will be considered later in the discussion of solar thermal and photovoltaic systems performance.

Figure 21 shows the monthly average and maximum wind speeds for C-MAN station DRYF1 located in the Dry Tortugas for the period 1993-96. This is a fixed marine data platform located near Garden Key, and the instrumentation for wind speed measurements is located six meters above mean sea level. This data is part of the USCG marine data network, for which real time data is available over the Internet at URL http://www.nws.fsu.edu/.

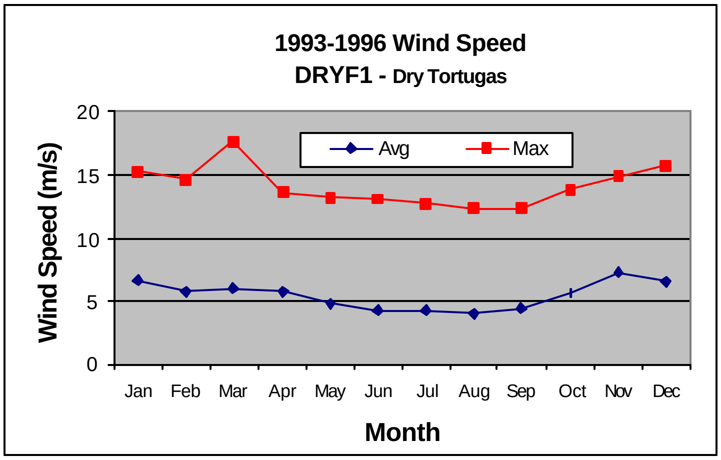

Figure 21. Wind speed at Dry Tortugas, 1993-96.

Figure 22 shows the wind speed frequency distribution for the Dry Tortugas for the period 1993-96. This information was developed from hourly measurements, and gives the percentage time the wind speed is within a given range, useful in predicting the performance of wind energy systems as will be discussed later.

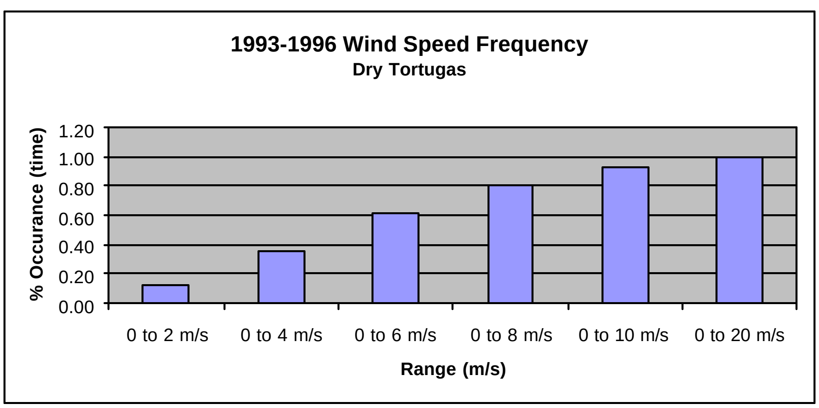

Figure 22. Wind speed frequency distribution, Dry Tortugas 1993-96.

5.2 Temperature and Humidity Data

Also included in the solar radiation database are selected meteorological data for the period 1961-1990. Figure 22 summarizes the average daily maximum and minimum ambient temperatures, and the relative humidity for Key West, Florida. In general the relative humidity averages above 70 percent as expected for a highly condensing marine climate. The average minimum and maximum temperatures range between about 18 and 32 degrees C. This data is considered to be fairly representative of the conditions at Garden Key.

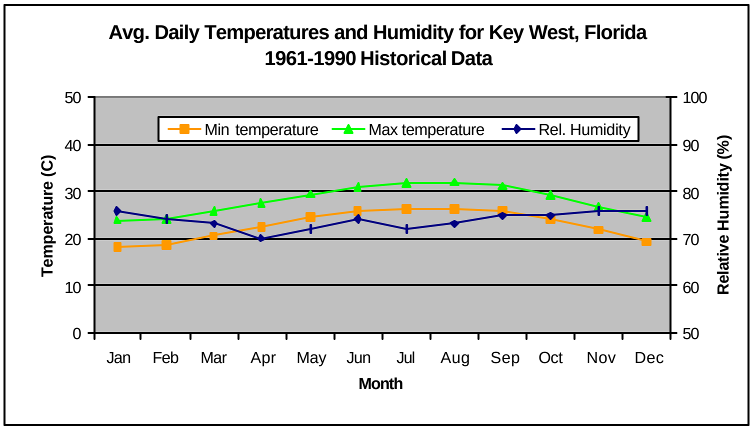

Figure 23. Temperature data for Key West, FL.

For comparison, temperature data is also available from the C-MAN station at Dry Tortugas. This data for the period 1993-96 is presented in Figure 23.

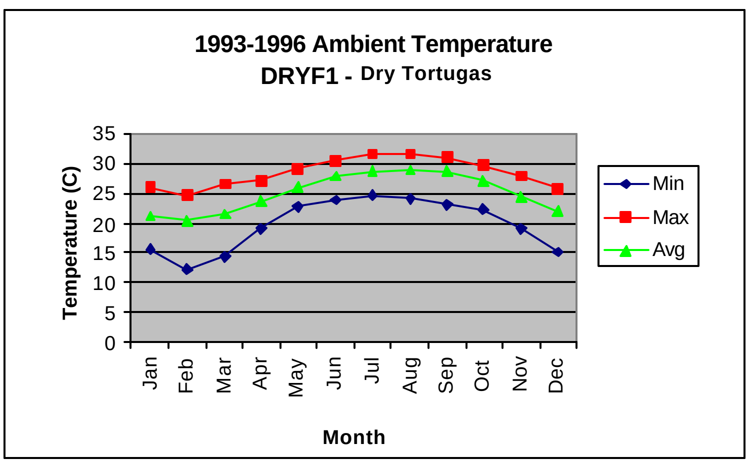

Figure 24. Temperature data for Dry Tortugas.

5.3 Solar Water Heating Options

Considering the percentage and magnitude of the peak load attributed to electric water heating, the potential for other options and load management strategies exist. Of the estimated 107 kW maximum load, 28 kW or approximately 25 percent may be due to the dozen or so electric water heaters on site if operated concurrently.

In light of the expensive energy costs incurred at Fort Jefferson, solar water heating should be considered. Due to the distributed nature of the water heaters and no interconnected hot water plumbing, a centralized solar water heating system may not be practical. However, distributed solar collectors, interfaced with each heater may be a practical and cost-effective option.

Figure 25 shows a low-cost add-on solar water heater manufactured by Solar Development, Inc. of Riviera Beach, FL. The unit is so-called an add-on because it can be retrofitted to existing electric water heaters and tanks with minimal effort and use of special materials. The collector is only 20-sq. ft. and used a small photovoltaic-powered dc pump for circulation.

Figure 25. Low-cost solar water heater.

In FSEC field evaluations of typical Florida residences, this unit has resulted in 70 percent savings, estimated at over 1000 kWh/year. At an estimated energy cost of $0.33 per kWh, this unit could result in up to $300 per year in savings for each residential unit at Fort Jefferson. At an estimated installed cost of $1000 per unit, the simple payback period would be 3 to 5 years. Figure 26 shows a basic installation schematic of this solar water-heating unit. Copies of the manufacturers Web pages are contained in the Appendix of this report and can also be found at http://www.solardev.com/.

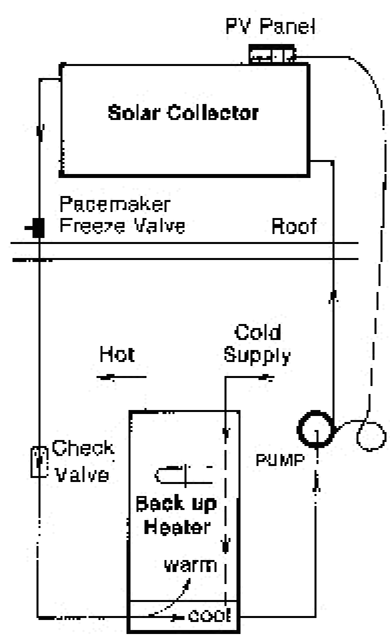

Figure 26. Solar water heating system schematic (SDI).

The practical considerations in using solar water heating at Fort Jefferson are the location of the solar collectors and the associated plumbing configurations. A couple of collector locations are possible, but each would have to be considered with respect to historic preservation concerns at the fort. One potential location would be to mount the collectors above or adjacent to the cistern in the parade grounds. The other option would be on the roof of the fort or on the roofs of the two residences in the parade grounds. In any case, the routing for plumbing would be a key consideration.

5.4 Photovoltaic System Options

Due to the abundant solar resource in the Tortugas, consideration was given to the use of photovoltaic (PV) power systems to meet part of the electrical load at Fort Jefferson. Based on the solar insolation data presented previously in Figure 19, the estimated annual energy production per kW of photovoltaic array would be 2000 kWh, or an average of 5.5 kWh/day. Assuming 10 percent conversion efficiency, the array size per kW of installed PV capacity would be approximately 10 sq. meters.

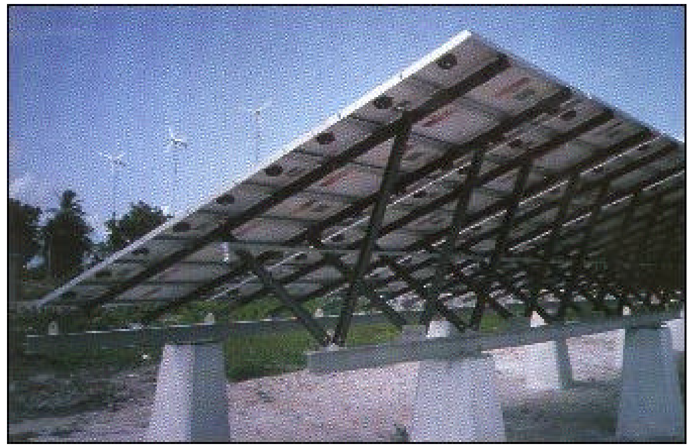

Figure 27. PV - wind hybrid system (SSI).

For example, to supply 25 percent of the estimated 700 kWh/day would require a PV array rated at approximately 40-kW with a collector area of about 400 sq. meters. With the current estimated energy cost of $0.33 per kWh, a 40 kW PV system delivering all of its energy to end use loads (80,000 kWh/yr) would avoid approximately $26,500 per year in energy costs. Installed costs are estimated to be about $10,000 per peak kW, or about $400,000 for a 40-kW peak rated system. The cost would of course depend on the amount of balance-of-system equipment required, included batteries and controls. This considered, the simple payback period would be more than fifteen years, depending on how effectively the PV array energy was utilized.

Photovoltaic power can be interfaced with the existing electrical system in a variety of ways, depending on the desired objectives. Including an inverter, a PV system can be interfaced directly with the generator grid to supply ac power. Coupled to a large battery bank, a PV system can charge batteries which can be used to power an inverter to offset peak loads and/or supply all of the energy requirements to the loads during low peak times (Figures 27 and 28). Case studies of hybrid PV installations from Siemens Solar and Sandia National Laboratories are contained in the Appendix.

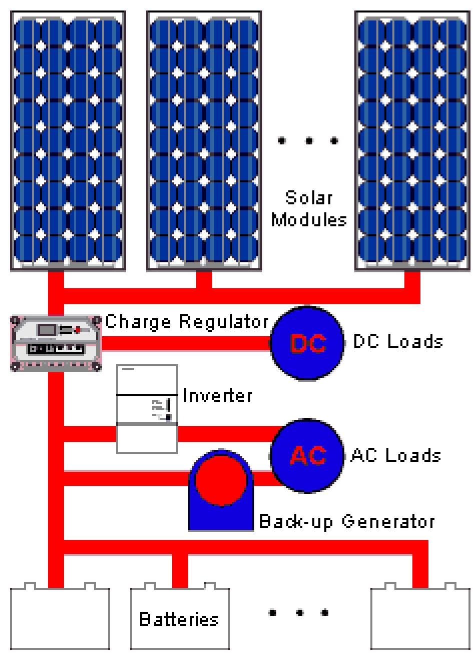

Figure 28. PV-hybrid configuration (SSI).

The benefits of photovoltaic power can be realized by reducing peak demand on the generators and by supplying a portion of the daily energy requirement. Even without a PV array, a battery storage system, coupled with an inverter and battery charger can have value-added benefit if the costs are competitive with the avoided generator operation and maintenance costs. A key objective when analyzing generator performance is to maximize the efficiency of operation and to minimize operation time. Due to the marketed increase in fuel efficiency at full load, it is desirable to operate the generator at as full load as possible.

Dividing the estimated annual kWh production by the number of hours in the year gives an average load of about 30-kW on the generator units at Fort Jefferson. This indicates that the generators are not loaded to capacity, and as a result, suffer some loss in fuel efficiency. If the generators were allowed to operate near capacity by charging batteries, and the battery storage was sufficient to meet the lower nighttime loads, the generator could remain off over half the time. Again, the costs of the backup system would have to be compensated for by reduced fuel and maintenance costs for the generators.

5.5 Wind Energy Options

As with many exposed islands, the wind energy resource in the Dry Tortugas should be considered for production of electrical energy. To investigate this potential, the wind speed data from the preceding section can be utilized to predict the performance of commercially available wind turbines.

Bergey Windpower Co. of Norman, Oklahoma manufactures small wind turbines used in many remote and island locations around the world. Information on Bergey Windpower and their products can be found on their homepage at URL http://www.bergey.com/. Selected information from Bergey's homepage is contained in the Appendix of this report.

Figure 29 shows the nominal 10 kW EXCEL turbine from Bergey Windpower. This turbine has a 7-meter diameter 3-blade rotor and achieves the 10 kW rating at 29-mph wind speed. Initial cost for this unit is approximately $20,000.

Figure 29. Bergey 10-kWp wind turbine (BWC).

To examine the performance of the Bergey EXCEL turbine as a function of wind speed, the cubic relationship of power was developed as shown in Figure 30.

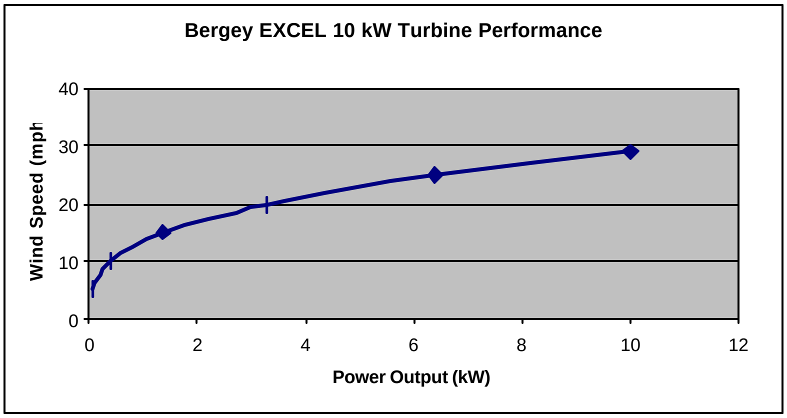

Figure 30. Power output for 10-kWp wind turbine.

Based on the data in Figure 30 and the wind speed frequency distribution data presented in Figure 22, the estimated annual energy production for the Bergey 10 kW turbine at Garden Key is over 17,000 kWh, or an average of about 47 kWh/day. Although this represents only about six percent of the average daily energy use at Fort Jefferson, the simple payback period per unit would be about four years assuming $0.33 per kWh existing energy costs and an avoided cost of over $5600 per year.

These wind turbines can be interfaced with the energy systems at Fort Jefferson in two fundamental ways. The first would be a direct alternating current interface with the generator-supplied mini-grid, and the other would require a battery system for direct current produced directly from the turbines. As with the solar thermal and photovoltaic system options, the location of wind turbines is a concern. However, there are several areas external to the fort that would be suitable locations and would not compromise the historic preservation of the site.

6. LOGGERHEAD KEY

Located only 2 miles from Garden Key is Loggerhead Key, the only other developed island in the Tortugas (Figure 31). Ownership of Loggerhead Key is presently being transfer from the U.S. Coast Guard to the National Park Service. Although an evaluation of this site was not made by FSEC staff, the following information was provided NPS personnel.

Figure 31. View of Loggerhead Key from Garden Key.

Facilities at Loggerhead Key include two separate quarters, one 1-bedroom, the other 2-bedroom. These quarters include two refrigerators, two freezers, nine window air-conditioning units, two electric stoves, one washing machine and one clothes dryer. Also included on the island are a reverse osmosis system and a communications room with three radio transmitters. Some floodlights and general lighting are used on the dock. The lighthouse is powered by a photovoltaic system, but the system is either undersized or not functioning properly to meet the load, and a battery charger is connected to the generator electrical system.

Three 50-kVA diesel-fueled generators are used on Loggerhead Key, each operated for a week at a time then alternated. Diesel fuel consumption averages 175 gallons per week, or 700 gallons per month. Estimated electrical energy consumption is 94 kWh per day, resulting in an average load demand of less than 4 kW. Based on the existing loads, it is expected that the peak load could be as high as 25 kW if all loads are operating and the site is fully staffed. During most of the time however, these generators are oversized for the needs of the island.

Presently, the U.S. Coast Guard delivers fuel to Loggerhead Key, and uses as much fuel to deliver it as NPS uses at the site. The Coast Guard vessel presently used to deliver the fuel to the island will be decommissioned in 1998, and replaced with a vessel to large to dock at Loggerhead Key. Consequently, an alternative plan for fuel deliveries must be arranged for by that time. Currently, there are no known transfer of funds from NPS to the USCG to pay for these fuel deliveries, and it is uncertain as to what the future arrangements will be, or even if the Coast Guard will continue to deliver fuel to the Tortugas. This may have significant cost ramifications, possibly doubling the actual energy costs for the Park Service to maintain Dry Tortugas National Park.

Due to the relatively small and manageable electrical load on Loggerhead Key, and the somewhat inefficient use of the existing generators, the site presents a viable opportunity for photovoltaic and/or wind turbine systems. There is more than adequate space on the island for PV arrays. Based on the load information presented above, the entire island could be powered with a nominally rated 20-kWp PV system, or a single 10-kW rated wind turbine. These options would require battery storage and a dc/ac power inverter capable of handling the peak load. In addition, a smaller generator and battery charger may be incorporated in the design, and used on an intermittent basis to meet peak loads and battery deficit conditions resulting from higher than normal energy use.

As with similar recommendations for Fort Jefferson, load management is critical in keeping costs for Loggerhead Key to a minimum. The most efficient equipment should be considered, and clothes drying and cooking should be converted to LP gas as this will help in reducing the electrical load (assuming LP gas cylinders are easier to deliver than diesel fuel). Load control devices, where appropriate should be implemented along with prudent conservation practices. Due to the manageable and moderate electrical load at this site, Loggerhead Key represents a real opportunity for being entirely powered by renewable energy, with a small generator backup.

7. SUMMARY

This report presents an evaluation of the resources and energy systems at Fort Jefferson, with the objective of identifying possibilities for reduced costs through conservation measures and renewable energy options.

Approximately 700 kWh of electrical energy is used at Fort Jefferson on a daily average, supplied exclusively by diesel-fueled generators, with an average diesel fuel consumption of 2400 gallons per month. The predominant electrical loads include air-conditioners (65%), refrigeration (11%) and hot water heating (8%). Peak loads are estimated to vary between 50 and 70 kW, with an estimated minimum load of about 20-25 kW during late evening and early morning hours. The estimated cost of energy is $0.33 per kWh, and includes estimates of fuel delivery and maintenance costs.

Propane is used for cooking and clothes drying only, consuming approximately seventy-five 100-lb cylinders per year. Fresh water is supplied by a combination of rainwater collection systems and seawater desalination from a reverse osmosis plant. A seawater distribution system is provided for all toilet facilities.

A number of conservation measures and renewable energy options are presented in this report. These include considerations for space conditioning and refrigeration equipment and other load management devices. The use of retrofit solar water heaters is considered, suggesting a simple payback period of three to five years. Wind energy also appears to be a viable resource for the site, with the annual performance of a nominal 10-kW turbine estimated to average 47 kWh/day with a simple payback period of about four years. The use of a photovoltaic power system was investigated for supplying part of the facility loads at Fort Jefferson, however the economics suggest that this option is marginally cost-effective, with an estimated payback period of over fifteen years at $10 per kWp installed costs. The cost-effectiveness and payback periods for each of these options depends highly on the assumptions made and accuracy of existing and projected energy costs.

Based on the high energy costs at Fort Jefferson, conservation measures and some renewable energy options should be strongly considered. Due to the uncertainties about future fuel deliveries by the USCG, this becomes en even more critical issue. This may have significant cost ramifications, possibly doubling the actual energy costs for the Park Service to maintain Dry Tortugas National Park.

8. APPENDIX

- Fort Jefferson Electrical Load Assessment
- Key West Solar Radiation and Climate Data
- Solar Development Low-Cost Solar Water Heater
- Bergey Windpower Wind Tubines
- Siemens Solar Application Bulletin
- Sandia National Laboratories Success Stories