University-National Parks Energy Partnership Project

Design for Renewable Energy Systems at Gold Bluffs Beach and Espa Lagoon

Summer 2000

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Executive Summary

This summer's work included two projects. The first project was the design of a solar shower and solar-powered lighting system for the planned new restroom at Gold Bluffs Beach campground. The second project was the design of a renewable energy power system to replace the diesel-powered generators currently in use at the Espa Lagoon ranger residence. In addition to this report, the final design work is being presented to the Park in the form of a draft grant proposal that the Park may use to seek funding for the two energy projects.

This document describes the activities we have performed. It also details our designs for the solar thermal and solar electric systems at Gold Bluffs Beach campground and the solar electric system at the Espa Lagoon ranger residence. Each system is discussed separately, and the activities associated with each design are categorized as follows: existing equipment documentation, data acquisition, conservation measures, and new system specifications. The final designs are described below.

Gold Bluffs Beach Solar Shower

The proposed solar shower is a packaged, indirect system from Heliodyne, Inc. The storage tank, plumbing, and pipe insulation will be purchased locally. The packaged system will cost approximately $6500 and will include

- 4 GOBI 410 collectors
- Mounting hardware
- Helio-Pak 32 heat exchanger
- Heat transfer fluid
- Expansion tank
- Air vent
- Relief valves
- Mixing valve
- 2 DC-powered pumps
- PV module to power pumps

Gold Bluffs Beach Solar Electric System

The proposed solar electric system includes eight 50-watt PV modules, a 30-amp charge controller, and four 6-volt, 170-amp-hour batteries, all existing equipmen. The light fixtures will be DC-powered Thin-Lites with 8-watt fluorescent tube lamps. A photocell will provide primary control to ensure that the lighting does not operate during daylight hours. Motion sensors will provide secondary controls for the restroom lights. The cost for the required new components will be approximately $700.

Espa Lagoon Ranger Residence Hybrid Solar Electric System

The proposed hybrid solar electric system includes twenty 100-watt PV modules from Siemens Solar, a 60-amp PV charge controller and a 24-volt, 4 kW true sinewave inverter from Trace Engineering Inc., and forty-eight 6-volt, 225 amp-hour Trojan batteries. The ideal backup power source for the solar electric system is a 150-watt fuel cell. A 3.5 to 5-kW propane-powered generator could also be included if desired as an additional backup for periods of fuel cell maintenance. The cost for this system, not including the fuel cell backup, will be slightly less than $20,000.

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Background

This document is a report on the activities performed by the engineering students, Angelique Sorensen and Lonny Grafman, during their Humboldt State University Foundation/Redwood National Park Energy Partnership Project internship. The work included the following two projects:

- Design of a solar hot water system and solar-powered lighting system for the planned new restroom at Gold Bluffs Beach campground.
- Design of a renewable energy power system to replace the diesel-powered generators currently in use at the Espa Lagoon ranger residence.

The Gold Bluffs Beach campground and the Espa Lagoon ranger station are both located within Prairie Creek State Park, as shown in the map on the following page. Prairie Creek State Park, located approximately 50 miles north of Eureka, California, is part of the Redwood National and State Parks and home to a 14,000-acre sanctuary of old growth redwoods. Gold Bluffs Beach runs along the coastal side of Prairie Creek State Park and offers year round camp sites on the beach that are visited by over 13,000 people each year.

Redwood National Park, which also contains two other state parks, is operated through a cooperative management effort of the National Park Service and the California Department of Parks and Recreation. This group of state and federal parks is home to some of the tallest and oldest trees in the world. To quote from the "Redwood National and State Parks Electronic Visitor Center" website: "Redwood National and State Parks have been deemed a globally significant biological preserve. As such, they were designated a World Heritage Site by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in 1980. They are also part of the California Coast Ranges Biosphere Reserve, an element of the United Nations International Biosphere Programme. This recognition indicates the world-class status and importance of this protected remnant of old growth coast redwood forest."

Protecting the natural resources of this unique area is of great importance. The use of non-polluting renewable energy systems on Park land is encouraged to help in this protection effort. The "Green Energy Parks: Making the National Parks a Showcase for a Sustainable Energy Future" program aims to promote the use of energy efficient and renewable energy technologies and practices in our National Parks and to educate the visiting public about these efforts. This program is a joint effort between the Departments of Energy and the Interior to advance the use of energy efficient and renewable energy technologies and practices in our National Parks. The two projects described in this report are examples of how renewable energy systems can be used in state and national parks as alternatives to conventional, pollution-producing fossil fuel-based energy sources.


N
SCALE
PACIFIC OCEAN
JEDEDIAH SMITH REDWOODS STATE PARK
DEL NORTE COAST REDWOODS STATE PARK
PRAIRIE CREEK REDWOODS STATE PARK
REDWOOD NATIONAL PARK
SISKIYOU MOUNTAINS
COAST RANGE
SMITH RIVER NATIONAL RECREATION AREA
Six Rivers National Forest
CRESCENT CITY
KLAMATH
ORICK
Butler Creek
Fern Canyon
Gold Bluffs Beach
Prairie Creek Visitor Center
Elk Prairie
Big Tree Wayside
Cal-Barrel Road
Trailers prohibited
Newton B. Drury Scenic Pkwy
Coastal Trail
Klamath River
McGarvey
Prairie Creek
May Creek
Park Boundary
GOLD BLUFFS
North
Redwood National Park boundary
National parkland
State parkland
Trail
Unpaved road
Picnic area
Interpretive trail
Fishing
Wheelchair accessible
Boat access
Campground
Primitive campsite
Steep Cliffs
Cliffs are likely to crumble and slide. Climbing on them or walking near the edge invites catastrophe. Because of falling rocks, walking below cliffs is dangerous. Keep away!
Falling Limbs
Tree limbs can fall during high winds, especially in old growth forests.
5 Kilometers
5 Miles

Gold Bluffs Beach Solar Shower

Existing Equipment

The existing solar hot water system at Gold Bluffs Beach campground is a simple batch heater that supplies heated water for showers. The structures are shown in Figure 1. The batch heater is an integrated collector and storage system in which the storage tanks are the thermal collectors. The tanks are heated during the day, and hot water is available in the late afternoon. A spring-loaded handle is used to operate the shower. The main advantage of this type of system is that it is simple and relatively maintenance-free. The low level of performance is the main disadvantage of a batch heater.

Data Acquisition

The data required for the design of the solar hot water system include the availability of solar energy, the necessary amount of hot water, and the hardness and pH of the supply water. To measure the availability of solar energy, we purchased and installed equipment at Gold Bluffs Beach campground. Solar radiation was measured with a LI-COR Model LI-200SZ pyranometer and recorded by a HOBO H08-007-02 data logger from Onset Computer Corp. The data were recorded at a programmed sampling interval of 2 minutes. These devices were installed at the campground on the afternoon of June 12, 2000. To improve the accuracy of the data, this pyranometer was calibrated relative to an Eppley Precision Spectral Pyranometer in use at the Schatz Solar Hydrogen Project in Trinidad, CA.

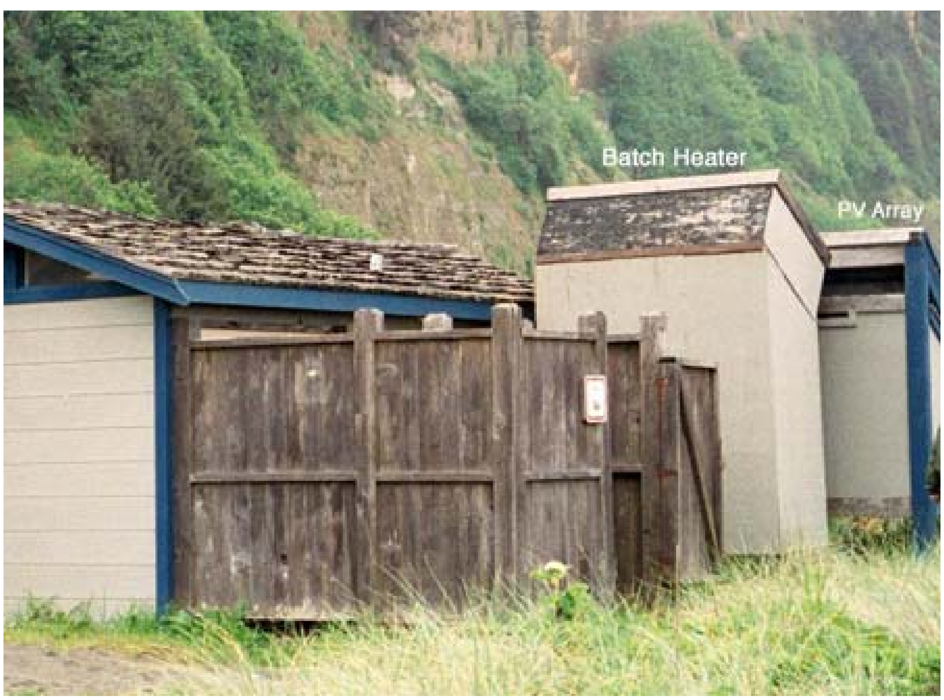


Figure 1. *Existing shower structure and batch heater at Gold Bluffs Beach campground.*

No historical record of solar radiation data is available for Prairie Creek State Park. Although we collected solar data at the Park this summer, the data do not provide a complete picture of year-round solar conditions. Therefore, the actual designs were based on average values calculated from historical records for the two closest locations, Trinidad and Arcata, CA. The Trinidad data were collected over the past ten years at the Telonicher Marine Laboratory by the Schatz Energy Research Center. The Arcata data sets were developed by the National Renewable Energy Laboratory (NREL) [4] and the University of Wisconsin (UW) [3]. Solar radiation data from Trinidad show strong correlations with the Arcata data sets, as shown in Figure 2. Since the data collected at Gold Bluffs Beach indicate a 98% agreement with conditions in Trinidad (as shown in Figure 3), the average values from Trinidad, NREL, and UW were used in the designs.

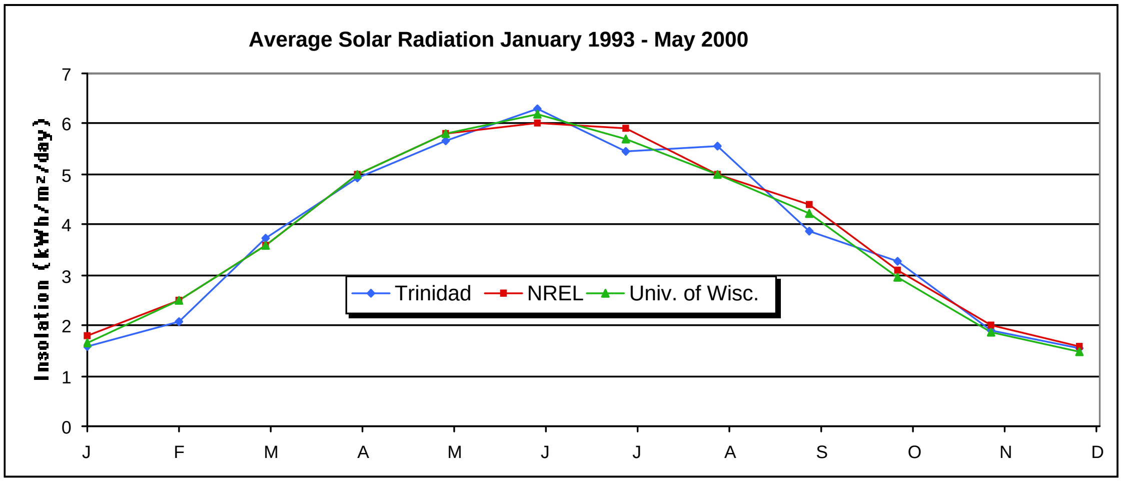


Figure 2. *Relationship between Trinidad, National Renewable Energy Laboratory, and University of Wisconsin solar radiation data sets.*

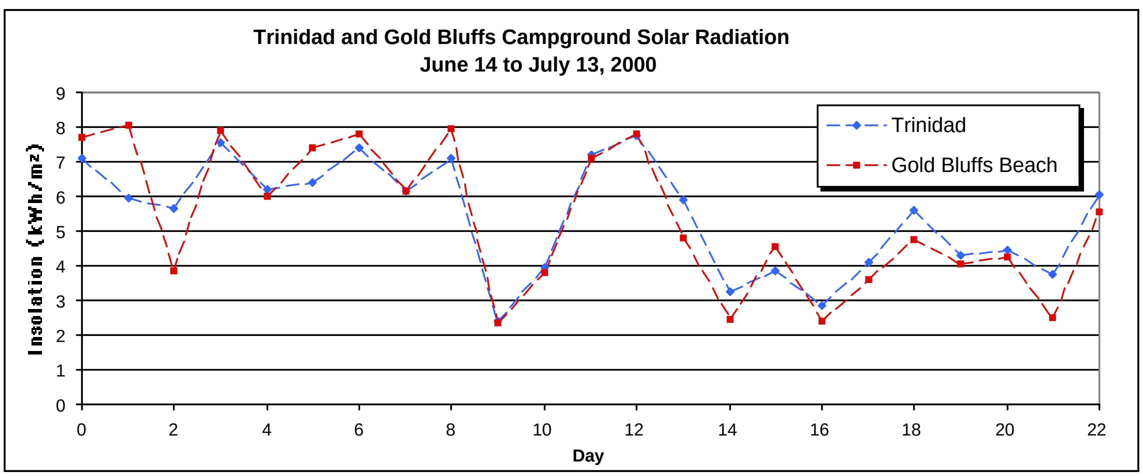


Figure 3. *Relationship between solar radiation data collected at Gold Bluffs Beach and Trinidad.*

In addition to the availability of solar energy, the amount of hot water used at the campground was also required in the design of the solar shower. The necessary amount of hot water was estimated based on Form DPR 449 campground visitation data obtained from Phil Rovai, State Park Ranger. Park aides record the number of occupied campsites each day, and the total number of visitors is based on Park-specified conversion factors for the number of visitors per campsite. The average number of visitors per day was estimated for each month from January 1997 through May 2000 data, and the values are listed in Table 1. We assumed that the daily number of showers for each month is 70% of the average daily number of visitors. We chose this percentage based on the assumption that at least half of the campground visitors use the shower and 70% of the average accounts for periods of increased visitation. We also assumed that the flowrate at the showerhead is 2.5 gallons per minute and that showers average five minutes in length. Although the measured showerhead flowrate was approximately one gallon per minute, campers often shower for longer than five minutes.

Table 1. *Analysis of Gold Bluffs Beach campground visitation data.*

	Number of Visitors		
Month	**Average**	**Minimum**	**Maximum**
Jan.	5.5	0.0	17.6
Feb.	3.0	0.0	13.2
Mar.	18.0	0.0	41.3
Apr.	28.9	20.0	39.4
May	44.3	15.3	72.5
Jun.	70.3	47.5	84.7
Jul.	81.9	76.5	88.9
Aug.	80.8	62.0	85.8
Sep.	65.7	36.2	84.7
Oct.	31.2	8.3	52.7
Nov.	13.3	1.1	39.6
Dec.	6.8	0.0	34.1

Water quality data were also necessary in the design of the solar shower for the Gold Bluffs Beach campground because the water hardness and pH affect the level of maintenance associated with the system. Water hardness must be considered due to scaling issues, and pH must be considered due to corrosion issues. The water quality analysis of the campground supply water was obtained from John Orozco, State Park Maintenance Mechanic–Water Systems. The data indicate that the supply water is only slightly hard and the pH is neutral. The high quality of the supply water presented no design constraints for the solar shower.

Conservation Measures

In the design of any renewable energy system, energy conservation measures should be included in order to reduce the cost and complexity of the energy supply equipment. Conservation measures associated with the solar shower involve improving the efficiency of the system and limiting hot water use. The proposed system is more efficient than the existing system by design. The storage tank will be well insulated and located inside the building, reducing heat loss. Although it is possible to limit hot water use by arbitrarily controlling the length of each shower, we suggest the following indirect approaches:

1. Maintain spring-loaded faucet control.
2. Post signs asking campers to limit the length of their showers to five minutes.
3. Install a mixing valve to limit maximum water temperature at the showerhead.
4. Install a separate beach shower—using cold water—for rinsing sand and salt water.

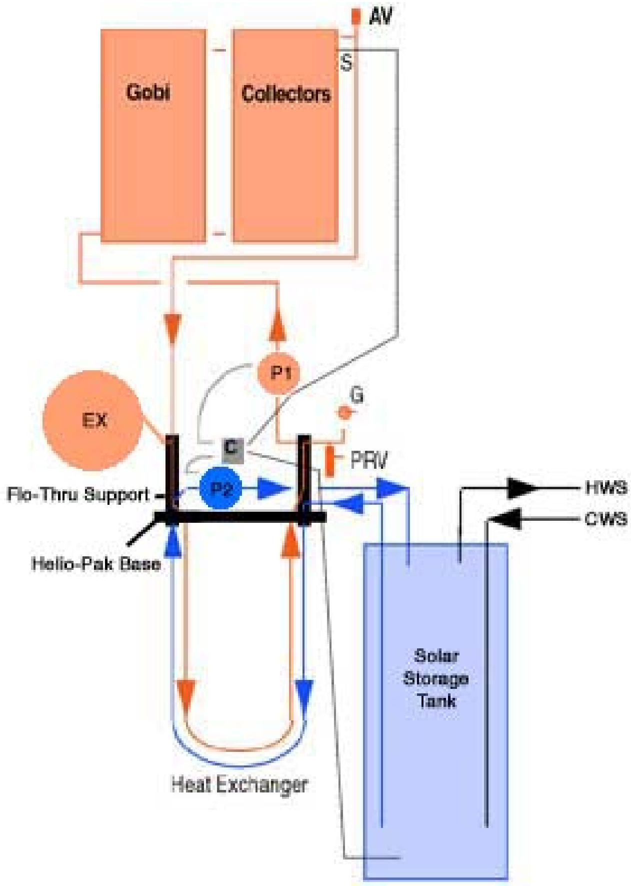
New System Specifications

The proposed solar hot water system is a packaged, indirect system from Heliodyne, Inc. In a direct system, the fluid that flows through the collector is the same fluid that is to be heated. In an indirect system, the fluid that flows through the collectors is separate from the fluid that is to be heated. The fluid from the collectors, usually an antifreeze and water mix, flows through a heat exchanger, in which the heat is transferred to the water for showers. We chose this type of system because it provides a higher level of freeze protection without significantly increasing the maintenance associated with the system.

We chose the packaged system from Heliodyne for several reasons. Heliodyne is a well-known manufacturer of certified solar thermal equipment, and the company provides excellent customer service and technical support. The f-chart method is a standard design procedure for solar thermal systems, and our f-chart analysis indicated that the Heliodyne collectors perform better than other manufacturers' flat plate collectors. The Heliodyne system is widely used in government installations, including State and National Parks. Lists of commercial, institutional, and government projects that utilize the Heliodyne solar thermal system are included in Appendix A.

The proposed solar thermal system includes four Heliodyne GOBI 410 collectors, mounting hardware, the Helio-Pak 32 heat exchanger appliance, non-toxic high-temperature antifreeze, expansion tank, air vent, mixing valve, and other minor system components. The mixing valve is a thermo-mechanical device that mixes hot and cold supply water to limit the maximum temperature of the water delivered at the outlet. Although the storage tank can be included, purchasing the tank locally is often more cost effective and allows for greater flexibility in sizing the tank. The piping and pipe insulation must also be purchased locally. A schematic of the proposed solar thermal system is shown in Figure 4.

The solar thermal and solar electric (described in the following section) systems are to be incorporated into the roof of the planned new restroom. The packaged solar thermal system also includes two pumps for the water and antifreeze loops and a photovoltaic (PV) module to power these pumps. If the top of the collectors and the bottom of the tank are separated by a vertical distance of 24 inches, then the collector fluid will circulate by natural convection. This configuration eliminates the need for pumps Alternatively, including the pumps in the solar thermal system provides the architect with greater flexibility in the roof design and decreases the overall height of the structure. Our proposed restroom floorplan and possible roof designs are included in Appendix B, and detailed system specifications are included in Appendix C.



Control (C) and Sensors (S): When collector sensor reads 18° F above tank sensor, the control starts both P1 and P2 pumps. Automatic shutoff occurs when the difference drops to 3° F.
Heat Exchanger: U-Shaped copper tube-in-tube construction with augmented surfaces and double wall separation between collector fluid and domestic water. The heat generated by the collectors is transferred to the water inside in this counterflow heat exchanger. The glycol collector fluid circulates in the inside tube and the water in the opposite direction around it.
Collector Fluid: A non-toxic propylene glycol, Dyn-0-Flo HD, inhibited for long life and formulated for high temperatures, mixed with water.
Orange: Collector Loop
P1 pump circulates the collector loop fluid out of the heat exchanger to the collectors, then back down into the heat exchanger loop in a closed loop cycle. EX is an expansion tank to take up fluid expansion as it heats up. G is a pressure gauge for filling and diagnosis. PRV is a pressure gauge for safety. The AV air vent at the top of the collectors is open only during filling and closed during operation.
Blue: Domestic Water Loop
P2 pump circulates the domestic water into and out of the solar storage tank or water heater and through the heat exchanger in counterflow to the collector fluid. P2 pump connects to a short dip tube and returns to the heat exchanger from a long dip tube.

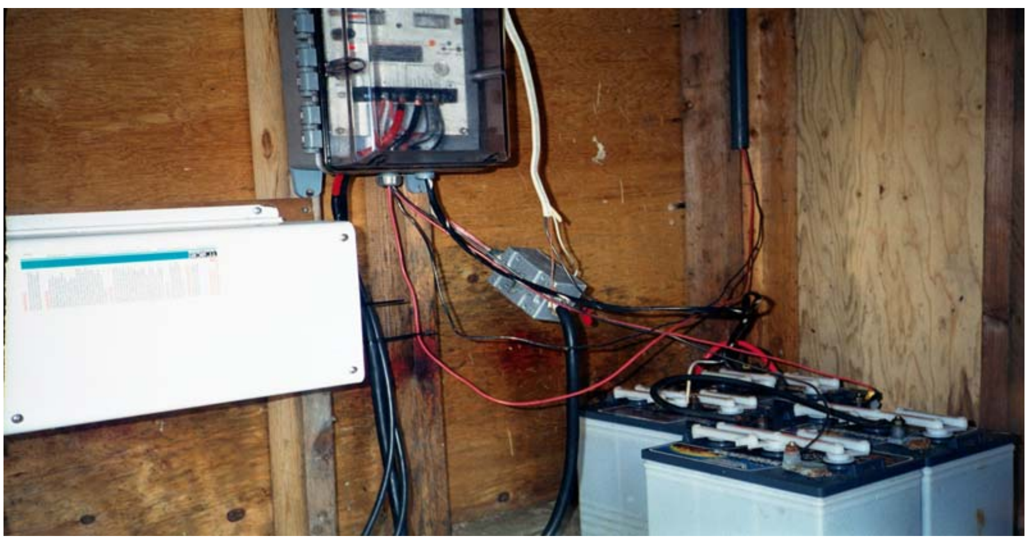
Figure 4. *Schematic of the solar thermal system for Gold Bluffs Beach campground (Source: Heliodyne, Inc).*

Gold Bluffs Beach Solar Electric System

Existing Equipment

The existing solar electric system at Gold Bluffs Beach campground consists of an 8-module PV array powering four incandescent lamps. Other system components include an inverter, a charge controller, and four batteries. These components are shown in Figure 5. Thirty-minute switch timers control the interior and exterior restroom lights. The signpost light is controlled by a photocell, but this device is currently not functioning. The signpost has been without lighting since before May 2000.

(a)



(b)

Figure 5. *Gold Bluffs Beach campground solar electric system components. (a) PV array and (b) (left to right) inverter, charge controller, and batteries.*

PV Modules – *50-watt ARCO M75 modules* – We recommend retaining the ARCO M75 modules for the new system. We cleaned and rewired (using anti-corrosive gel to protect the connections) the PV modules, then generated current versus voltage (I-V) curves for each module and the array as a whole. An I-V curve is the set of operating points for a circuit under various loads in a particular environment, and it is used to characterize the performance of a PV module. The current and voltage measurements are adjusted from the conditions under which the data were recorded to standard conditions (25ºC, 1000 watts per square meter) to allow for comparison with curves published by the manufacturer. The I-V curves for the Gold Bluffs Beach PV modules are shown in Figure 6. The test indicated a total system degradation in the range of 20.5 to 35.0%, as compared to the manufacturer's specifications for new modules. The wide range is a result of the fact that module ratings are often overstated by approximately 10%. The maximum power measured from each module and the entire array are listed in Table 2. Our measurements indicate that the ARCO modules will continue to function well in the new system.

Table 2. *Results of the Gold Bluffs Beach PV module performance analysis. The values listed are the maximum power (in watts) measured from each module and the array as a whole.*

Module	1	2	3	4	5	6	7	8	Ave.	Total
Run 1	34.0	34.5	32.3	28.7	35.0	36.4	33.9	34.0	**33.6**	**268.8**
Run 2	34.1	34.5	32.9	28.7	35.0	36.2	33.9	34.3	**33.7**	**269.5**
Average	**34.0**	**34.5**	**32.6**	**28.7**	**35.0**	**36.3**	**33.9**	**34.2**	**33.6**	**269.1**

	Array
Run 1	274.0
Run 2	266.8
Run 3	266.5
Average	**269.1**

ARCO M75 Specifications: 47 watt (± 10%) @ 25ºC, 1000 W/m^2:
Manufacturer Specified Range: 42.3 – 51.7 watts
Average Measured Performance: 33.6 watts
Percent System Degradation: 20.5 – 35.0%

Inverter – *12-volt, 600-watt Trace Engineering UX612 inverter* – We recommend eliminating the inverter from the new system. The batteries provide direct current (DC) to the loads, and using an inverter to convert DC to alternating current (AC) decreases the efficiency of the system. A system with AC-powered loads requires a larger PV array than one with DC-powered loads, as indicated by the values in Table 3. Although the Trace inverter in the existing system is efficient and in good condition, the new system will contain only DC-powered loads. Therefore, the inverter is unnecessary and may be used in another application.

Table 3. *Comparison of the number of PV modules required for the Gold Bluffs Beach solar electric system with AC- and DC-powered loads.*

	PV Module	ARCO M75	SR100	SM55	MSX-38MM	PV Shingle
AC	**# Modules**	5	3	5	7	8
	Area (ft^2)	21.7	28.8	23.0	38.1	115.2
	Cost	-	$ 1260	$ 1425	$ 4949	$ 2240
DC	**# Modules**	3	2	3	4	6
	Area (ft^2)	13.0	19.2	86.4	13.8	21.8
	Cost	-	$ 840	$ 855	$ 2828	$ 1680

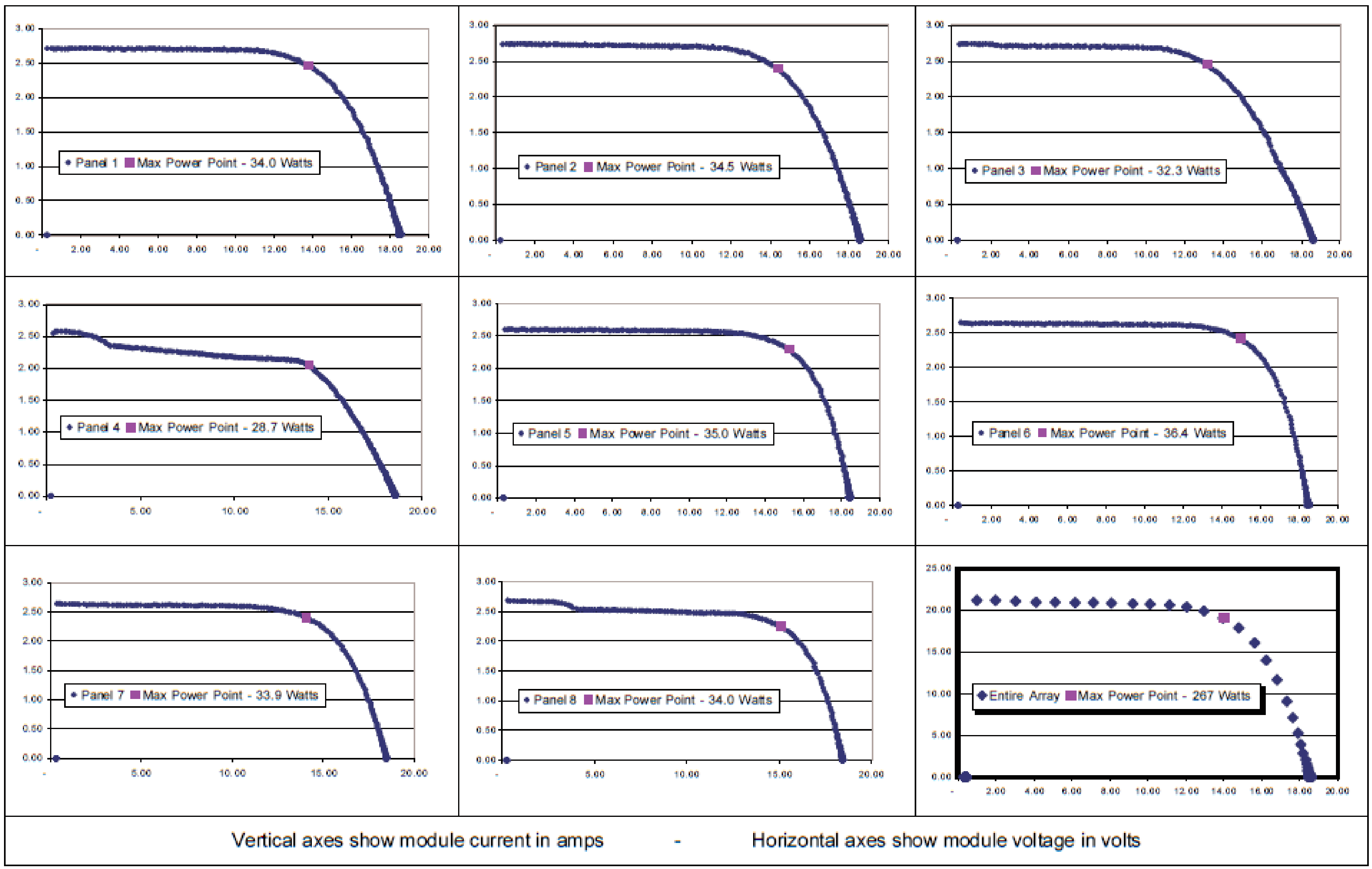


Figure 6: *Gold Bluffs Beach PV module I-V Curves.*

Charge Controller – *30-amp Specialty Concepts, Inc. (SCI) PPC-12-M charge controller* **–** We recommend retaining the SCI charge controller for the new system.

Batteries – *6-volt, 170-amp-hour batteries* **–** We recommend retaining the batteries for the new system. We removed the batteries from the Gold Bluffs Beach system, charged them overnight at the Schatz Laboratory in Arcata, and measured the specific gravity of the electrolyte in each cell at full charge. The condition of a battery is determined from measurements of the specific gravity of the electrolyte in each cell at full charge. The electrolyte specific gravity is an indication of the battery's state-of-charge, and as the condition of a battery deteriorates, the charge capacity decreases. Therefore, the specific gravity of the fully charged battery is an indication of its condition. Our measurements indicated that the batteries have maintained nearly 100% of their charge capacity, and they will continue to function well in the new solar electric system.

Data Acquisition

The data required for the design of the solar electric system for the campground include the availability of solar energy, the wattage of each lamp in the system, and the amount of time each lamp is used. Acquisition of solar data was described in the previous section, and the wattages of the lamps were design variables. Estimates of the duty cycles associated with the restroom lights were based on the estimates of average campground visitation values (Table 1). We assumed that each campground visitor spends ten minutes in the restroom during the evening hours. The number of hours that the exterior restroom light will operate is given by the product of the daily average number of visitors and the assumed 10-minute value. The number of hours that the interior restroom lights will operate is half the number of hours associated with the exterior light, which assumes that half the visitors are women and half are men. We used solar geometry [2] to calculate the daily average number of daylight hours for each month as an estimate for the number of hours that the signpost light will operate.

Conservation Measures

Energy conservation measures at the campground include the use of lower wattage lamps and more precise control devices. A compact fluorescent lamp (CFL) uses only a fraction of the energy consumed by an incandescent lamp to produce an equivalent amount of light. The primary control on the lights will be a photocell to prevent operation during the day, and the secondary controls will be motion sensors. All of the lighting will be on one circuit, as shown in Figure 7. The entire circuit will be controlled by the photocell, and motion sensors in the restrooms and on the exterior of the structure will control those legs of the circuit. Lighting the restroom with CFLs and installing motion sensors for each restroom will reduce the existing load.

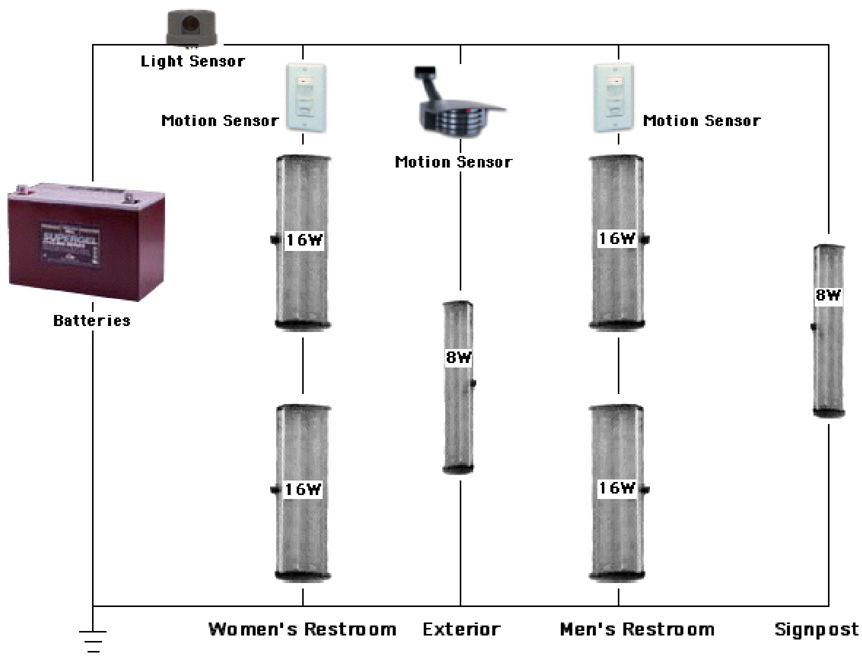


Figure 7. *Diagram of the lighting circuit for the restroom at Gold Bluffs Beach campground.*

New System Specifications

The proposed solar electric system for the Gold Bluffs Beach campground includes the existing PV modules, charge controller, and batteries. The battery bank will provide about four days of storage. We used the following criteria when selecting light fixtures and control devices for the system:

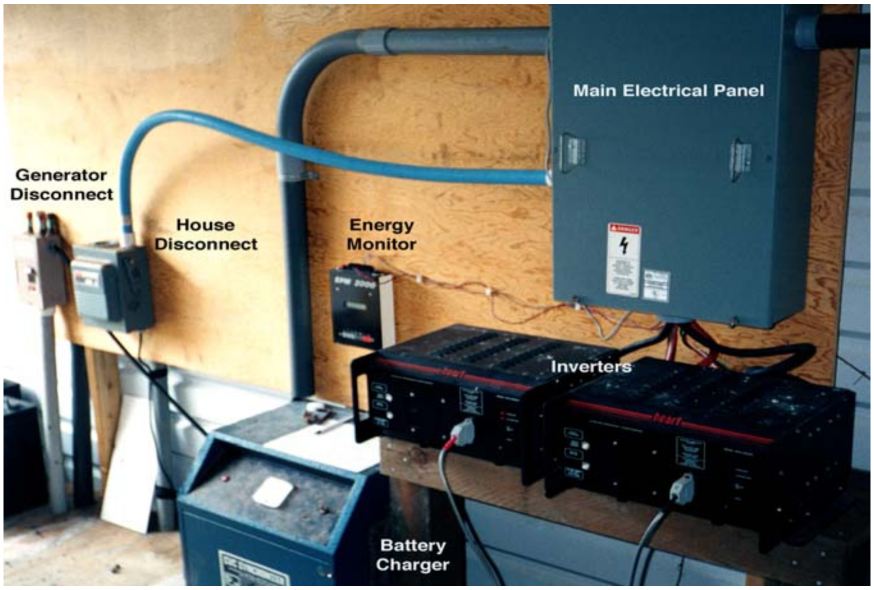
- DC-powered
- Rated for outdoor use
- Vandal-proof
- Cost effective

The light fixtures are DC-powered devices from Thin-Lite that use 8-watt fluorescent tube lamps (F8T5/CW lamps). A PC20 12-volt photocell will provide primary control on all lights to ensure that the lighting does not operate during daylight hours, and motion sensors will provide secondary controls for the restroom lights. Detailed solar electric system specifications are included in Appendix C.

ESPA LAGOON RANGER RESIDENCE HYBRID SOLAR ELECTRIC SYSTEM

Existing Equipment

The existing electrical system at the Espa Lagoon ranger residence consists of two diesel-powered generators (one primary and one backup) that provide power for the residential loads. Other system components include a battery charger, two inverters, twenty batteries, and an energy monitor. The system components are shown in Figure 8, and drawings of the site and system configurations are included in Appendix D.



(a)

(b)

Figure 8. *Espa Lagoon electrical system components. (a) disconnect switches, battery charger, energy monitor, main electrical panel, and inverters and (b) batteries.*

Generators – *15.9-kW diesel-powered Lister-Petter, Ltd. TR3A generators* – We recommend removing the diesel-powered generators from the Espa Lagoon site. These generators are very close to the lagoon, as shown in Figure 9, and the potential for air, water, and soil contamination is significant. Figure 10 shows a pool of diesel fuel on the floor of the generator shed. The bricks in the foreground are part of the containment structures that surround each generator, but the spilled fuel is outside this containment area. Replacement of the diesel generators with a renewable energy power system is an action that is endorsed by the "Green Energy Parks" program.

Figure 9. *Generator housing on the edge of Espa Lagoon.*

Figure 10. *Pool of diesel fuel on the floor of the generator housing at Espa Lagoon.*

Battery Charger – *CVC Synchronizer battery charger* – We recommend replacing the CVC Synchronizer battery charger because removing the generators renders this device obsolete. The new system includes three PV charge controllers and an inverter with an internal charge controller function that will accept AC input from a propane-powered generator.

Inverters – *2500-watt Heart Interface modified sinewave inverters* – We recommend replacing the two Heart inverters based on the manufacturer's specifications for these antiquated devices. The inverters are inefficient and technologically obsolete. The actual efficiency of the inverters measured 80%. New inverters are typically more than 90% efficient. In addition to improving the efficiency of the system, new inverters with true sinewave output will improve compatibility with computers, telecommunications equipment, and other modern consumer electronics.

Batteries – *6-volt, 305-amp-hour Exide and Commercial batteries* – We recommend replacing the Espa Lagoon batteries based on their charge history. Specifically, the batteries are often drained to an excessive depth-of-discharge, and rarely are they fully recharged. According to resident ranger Phil Rovai, the batteries are no longer holding their charge, indicating that new batteries are needed for the new solar electric system.

Energy Monitor – *SPM 2000* – We recommend retaining the SPM 2000 energy monitor for the new solar electric system at the Espa Lagoon site. We determined that Channel 2 on the SPM 2000 was inaccurate by comparing its measurements with measurements from a clamp-on amp-meter. The error was due to Channel 2 being grounded to an inappropriate shunt. To improve the accuracy, the meter was wired to the more appropriate shunt, as shown in Figure D-2 (Appendix D). After rewiring, the SPM 2000 measurements agreed with the direct measurements from the clamp-on amp-meter.

Data Acquisition

The data required for the design of the solar electric system for the ranger residence include the availability of solar energy, the wattage of each electrical device in the system, and the amount of time each device is used. Acquisition of solar data was described in a previous section, and data for the individual load analysis were obtained from Phil Rovai, the resident ranger. We measured, or used the manufacturer's specifications to estimate, the power required by specific loads. The time of use associated with each load was estimated from a two-week survey of the ranger's use patterns.

In addition to the individual load analysis, the total energy consumption in the residence was also estimated from AC current measurements, assuming a constant AC voltage of 120 volts. The current drawn by the loads was measured with an AC current transformer (AC current to DC voltage) from Onset and recorded by a HOBO H08-008-04 data logger at a programmed sampling interval of 10 seconds. On the afternoon of June 12, the current sensor was installed between the inverters and the main panel, as indicated by Point A in Figure D-2 (Appendix D). Energy consumption monitoring in the residences was discontinued on the morning of July 10, at which time the current sensor was installed on the water pump. The current drawn by the water pump was measured for two weeks at the same sampling interval of 10 seconds. The current sensor was again installed between the inverters and the main panel on July 27. This device was removed from the field on the afternoon of August 15.

The load analysis was used to estimate the daily amp-hour load that will have to be met by the renewable energy power system. Energy consumption data collected at the Espa Lagoon site show an average consumption of 6.0 kilowatt-hours per day (kWh/day), with a range of 4.1 to 9.6 kWh/day. The refrigerators in the year-round and seasonal residences consume 1.3 and 2.8 kWh/day, respectively. Each refrigerator was monitored with an accumulating energy meter for 15 days. The seasonal refrigerator represents about 47% of the measured load. We assumed that the refrigerator in the seasonal residence would be replaced with one that consumes no more than 1.3 kWh/day, which would reduce the peak consumption to 4.5 kWh/day. The new system is designed to meet a daily load of approximately 200 amp-hours during the summer months (June through September) and approximately 145 amp-hours the remainder of the year, with the difference being the refrigerator in the seasonal residence.

Additional data required for the design process and life cycle cost analysis include:

- **Shading –** The viability of a prospective site for a PV array is based in part on the amount of shading that occurs at the site. We used two solar path-tracing devices (Solar Site Selector and Solar Pathfinder) to evaluate and compare solar access at two sites where PV modules could potentially be installed. These two sites are shown in Figure D-1 (Appendix D) as Site A and Site B, and they were chosen based on their solar access, availability of space for the actual array, and proximity to the residences. The Solar Pathfinder indicated 70 and 78% solar availability at Sites A and B, respectively, and the results are summarized in Table 4. The trees along the eastern edge of the area will shade both sites until approximately solar noon in November, December, and January, but both sites enjoy good solar access May through September, which is when annual energy use peaks. The measured available solar energy was adjusted according to the results of the shading analysis. Although Site B is the better site in terms of shading, Site A was chosen as the location for the PV array due to the proximity of this site to the existing battery shed. Installing the PV array on Site A will also make the array less visible from Espa Lagoon and less intrusive to the rangers' living space.

Table 4. *Summary of results of the Solar Pathfinder PV array site analysis. The values listed are the percentages of available solar radiation for each month.*

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Avg.**
Site A	50	57	61	80	87	86	90	87	80	65	49	48	**70**
Site B	57	65	80	85	94	97	96	89	80	84	55	57	**78**

- **Generator use schedule** – Fifteen months (March 1, 1999 to May 31, 2000) of generator use data were obtained from records kept by Phil Rovai. The generator ran 2139 hours during the 457-day period, averaging 4.7 hours per day.

- **Diesel fuel consumption** – Three years (June 24, 1997 to June 2, 2000) of diesel fuel consumption data were obtained from records kept by Phil Rovai. Diesel fuel use over the past 3 years has averaged 2.1 gallons per day. Based on the estimates of 4.7 hours and 2.1 gallons per day, the generator will run for 2.2 hours per gallon of diesel fuel. Assuming that each gallon of diesel fuel provides 40 kWh [1], the efficiency (η) of the existing system is 7.1%, as given by

$$\eta = \frac{6.0\ kWh/day}{(2.1\ gal/day)(40\ kWh/gal)}\ x\ 100\% = 7.1\%$$

Conservation Measures

Energy conservation at the residence is extremely important because a renewable energy power system requires a large capital investment, and the total load dictates the size of the system. Therefore, a reduction in the total load will reduce the initial investment. The load analysis involves evaluating the energy efficiency, necessity, and duty cycle of the individual loads. Less efficient appliances should be replaced or removed. A general rule of thumb states that every dollar spent on an energy-efficient appliance will result in approximately three dollars saved on the energy system [5]. Unnecessary or obsolete loads, such as an eight-track player, should also be removed.

Another important factor in the load analysis is the duty cycle associated with each load. Reducing the amount of time that a load, such as a vacuum cleaner, is used can decrease the size of the system, and additional reductions can be realized by eliminating phantom loads. Phantom loads occur in devices that consume energy even when they are turned off. A device with a phantom load is only truly off when it is unplugged from the wall or plugged into a power strip that is turned off. Because some phantom loads are inconvenient or impossible to eliminate, we assumed that only half of the 22-watt phantom load in the residence will be reduced before the renewable energy power system is installed.

The residential load analysis indicated that the refrigerator in the permanent residence is fairly efficient, but the refrigerator in the seasonal residence should be replaced with a more energy efficient model. Table 5 lists specifications for refrigerators from smaller manufacturers specializing in energy efficient appliances. Performance comparisons among refrigerator/freezer models from major manufacturers can be found at the Internet sites for the California Energy Commission (www.energy.ca.gov/) and the American Council for an Energy Efficient Economy (www.aceee.org/). At the preliminary meeting on August 10, Park personnel decided to transfer the refrigerator in the permanent residence to the seasonal residence and purchase a highly efficient model for the permanent residence.

Table 5. *Specifications for energy efficient, AC-powered refrigerators.*

Manufacturer	Model	Capacity (ft^3)	Price	kWh/day	KWh/day
Unknown lead time				**at 68 ºF**	**At 77 ºF**
ConServ (Vestfrost)	BSKF 375	10.5	$949	0.7	0.9
5 week lead time				**at 70 ºF**	**At 90 ºF**
SunFrost	RF12A	12	$1,649	0.35	0.56
SunFrost	RF16A	16	$2,299	0.56	0.81
SunFrost	RF19A	19	$2,349	0.77	1.03

New System Specifications

The proposed hybrid solar electric system for the Espa Lagoon ranger residence includes twenty 100-watt PV modules from Siemens Solar, a 60-amp PV charge controller and a 24-volt, 4 kW true sinewave inverter from Trace Engineering, Inc., and forty-eight 6-volt, 225 amp-hour Trojan T105 batteries. The battery bank is sized to provide 3.5 days of storage. The ideal backup power source for the solar electric system is a 150-watt fuel cell. A 3.5 to 5-kW propane-powered generator could also be included if desired as an additional backup for periods of fuel cell maintenance. A schematic of the proposed system is shown in Figure 11, and detailed component and system specifications are included in Appendix E.

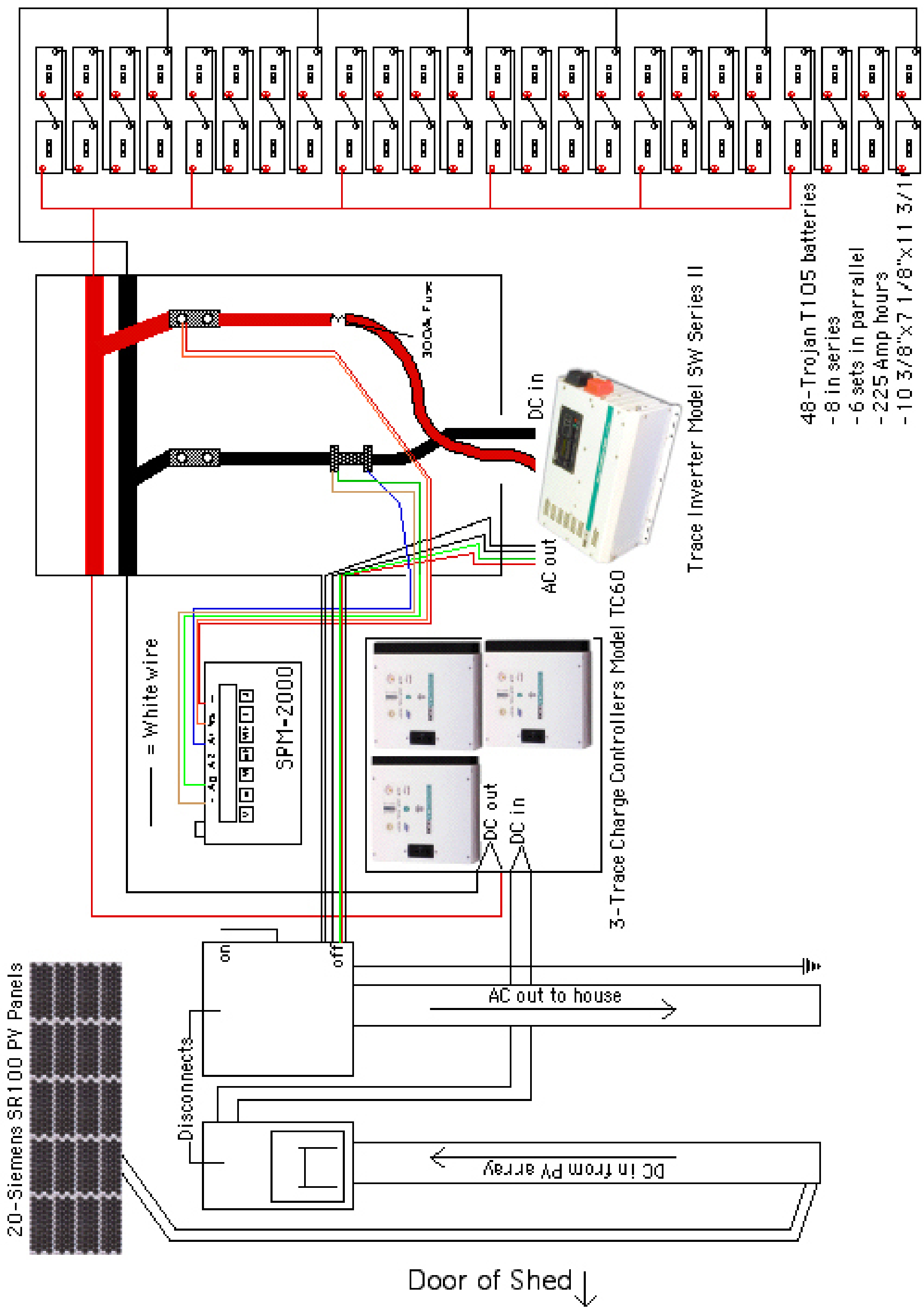


Figure 11. *Schematic of the hybrid solar electric system for the Espa Lagoon ranger residence.*

Summary

This summer's work included the design of renewable energy power systems for the Espa Lagoon ranger residence and Gold Bluffs Beach campground and the design of a solar hot water system for the campground. Implementation of these project designs will reduce environmental impacts within the Park and demonstrate clean, renewable energy technologies to Park visitors. The work was completed by the engineering interns, Angelique Sorensen and Lonny Grafman, under the supervision of Richard Engel and Nate Coleman at the Schatz Energy Research Center.

Please contact the Schatz Laboratory if you have any questions or comments or if you need assistance in locating retailers.

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