UNPEPP: Bringing Renewable Energy to Redwood National Park

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Abstract

In the summer of 2000 and the following two summers of 2001 and 2002, Schatz Energy Research Center (SERC) used University-National Park Energy Partnership Program (UNPEPP) funding to hire two student interns from Humboldt State University's Environmental Resources Engineering (ERE) program to identify opportunities to improve energy efficiency or use renewable energy in the Redwood National and State Parks in Northern California. In this paper we will describe each of the three projects and discuss the benefits of involving undergraduate students in engineering design projects.

In summer 2000, the interns, Lonny Grafman and Angi Sorensen, spent twelve weeks monitoring on-site energy use, tracking solar energy availability, and creating preliminary designs for the two systems: a solar thermal water heater and a DC-powered lighting system for the campground restroom at Gold Bluffs Beach and a 2-kilowatt solar electric system for the ranger residence at Espa Lagoon.

In 2001, the second year, interns Matthew Rhode and Steven Koldis designed solar thermal hot water and ventilation systems for the restroom facility at WCOS at Wolf Creek Outdoor School, a new lighting system to illuminate walking paths and the amphitheater, and a 2-kilowatt grid-connected solar electric system to offset the increased electrical load. The Park installed the systems designed by Matt and Steve in 2002-2003 with assistance from Bonneville Power Administration, California Conservation Corps, and HSU ERE students.

For the third year in 2002, interns Kelly Miess and Andrew Sorter designed and installed a solar thermal hot water system for the Redwood Information Center in Orick, California. In the twelve-week project period, they monitored energy use, designed the system, procured materials, and performed the installation.

For each of the three projects, we will discuss the experience of the interns in collecting relevant data, refining the project objectives, developing design alternatives, selecting the alternative of choice, and reporting the results. We will also describe the experience of the third team of interns who were able to procure the materials and equipment and install and test the completed system. We will evaluate the benefits of involving undergraduate students in engineering design projects.

Introduction

The University-National Park Energy Partnership Program (UNPEPP) creates opportunities for students to solve real-world energy problems in national parks. Often the time and resources of park energy managers are entirely consumed with day-to-day tasks, preventing them from addressing larger projects. They welcome the assistance of students, and students are eager to work on projects that lead to real energy savings. Established in 1997, UNPEPP supports university students in performing energy efficiency and renewable energy-related projects in national parks. The program is sponsored by the Green Energy Parks Program, a joint venture of the U.S. Department of Energy and U.S. Department of the Interior, and the Rochester Institute of Technology.

In each summer from 2000 through 2002, the Schatz Energy Research Center (SERC) (http://www.humboldt.edu/~serc/) used UNPEPP funding to hire two student interns from Humboldt State University's (HSU) Environmental Resources Engineering (ERE) program to design renewable energy systems and improve energy efficiency in Redwood National and State Parks (RNSP). As shown in Figure 1, the park is located on the northern California coast, approximately 50 miles from the HSU campus in Arcata. Under the supervision of SERC engineers, the students designed systems that combined load reduction and energy production to reduce the park’s reliance on fossil fuels. In this paper we describe the students’ experiences in collecting relevant data, refining project objectives, selecting the alternative of choice, and reporting the results. We also evaluate the benefits of involving undergraduate students in engineering design projects.

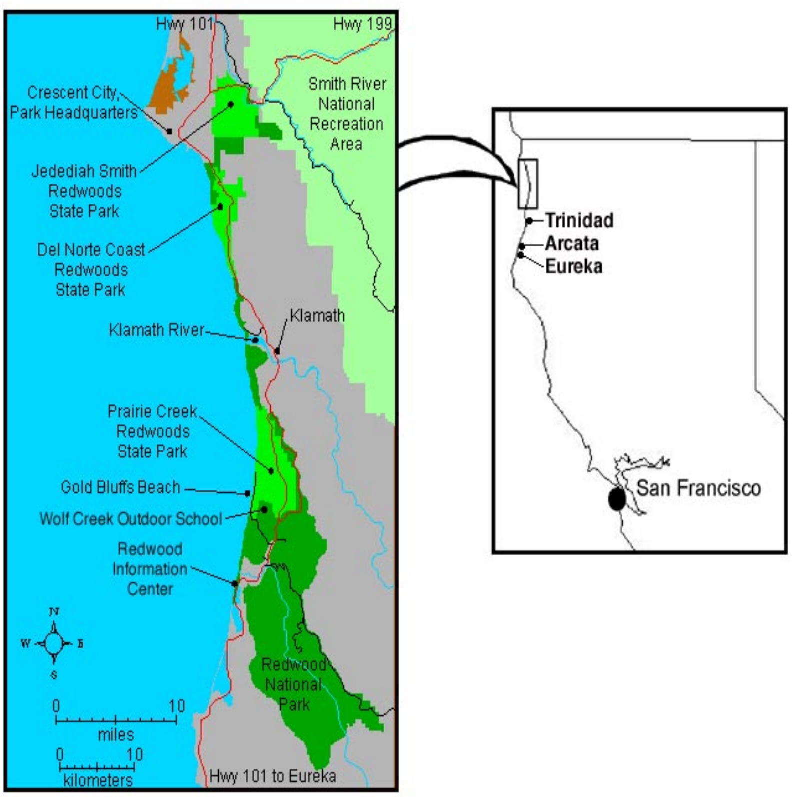

Figure 1. Redwood National and State Parks location map[5].

Prairie Creek State Park

In summer 2000, interns Lonny Grafman and Angi Sorensen designed renewable energy systems for two locations in Prairie Creek State Park, a unit of RNSP. Both locations, the campground comfort station at Gold Bluffs Beach and the ranger residence at Espa Lagoon, are outside the electric power grid and natural gas distribution system. In the twelve-week project period, the interns examined the existing equipment and design constraints, gathered appropriate data, developed and presented preliminary designs to park staff, and completed a final project report.

Early in the project period, the interns and their mentors from SERC met with park staff to tour the two sites and examine the existing equipment. Park staff planned to build a new building to replace the outmoded campground restroom and asked the UNPEPP interns to specify solar electric and solar water heating systems for the new facility that would perform better than the existing systems. Equipment at the site included a simple batch solar water heater and a 400-Watt (W) solar electric system, consisting of eight 50-W photovoltaic (PV) modules, an inverter, charge controller, and four batteries. The PV system provided power for a lamp at the information kiosk and for three incandescent lamps (each restroom and an exterior light) controlled by 30-minute switch timers. The kiosk light had not functioned for years before the project period. Park personnel also requested a design for a solar electric system for the ranger residence at Espa Lagoon. The existing electrical system consisted of two diesel-powered generators (one primary and one backup), a battery charger, two inverters, twenty batteries, and an energy monitor. The generators were grossly oversized for the residential load, created excessive air and noise pollution, and were located dangerously close to the edge of the pristine lagoon.

Working in the park setting involves design constraints such as security, availability of replacement parts, and aesthetics, which are beyond those typically presented in classroom exercises. Theft and vandalism are persistent problems, so security is a top priority in all park installations. To prevent theft, the campground batteries, inverter, and charge controller were locked in the shed shown in Figure 2; the light fixtures were enclosed in metal cages; and the PV array was securely fastened to an elevated structure. The PV array was also covered with a sheet of rigid clear plastic to protect it from projectiles.

Figure 2. Gold Bluffs Beach campground solar electric system.

In addition to durability and security requirements, replacement parts must be readily available and aesthetic impacts must by considered. Originally, the restroom light fixtures were powered by direct current (DC) electricity, but replacement lamps were difficult to find. Therefore, park staff installed an inverter, charge controller, and new fixtures that accept standard incandescent light bulbs. The new lights required more power than the system was designed to support, resulting in frequent power outages at the campground. Aesthetic impacts are also critical design factors in the national parks. All installations must complement or enhance the aesthetic quality of a site, especially in RNSP, a World Heritage Site and part of the California Coastal Ranges Biosphere Preserve[5]. The opportunity to examine the effects of real-world design constraints on system cost and efficiency is one of the many benefits of the UNPEPP internships.

Data management is a major component of the UNPEPP experience. Under the guidance of their SERC mentors, the interns decide what data are necessary and how to collect them in the twelve-week project period. They used the *f*-chart method[3] to design the solar thermal system for the campground comfort station. Variables for *f*-chart performance simulations include the collector area and thermal transfer characteristics, the availability of solar energy, and the hot water load. The interns also investigated water quality parameters to determine maintenance requirements. Solar electric system design is based on solar availability and the power and operating schedule of each appliance. The following describes the interns' techniques for acquiring these data:

- *Availability of Solar Energy*—Solar energy availability depends on both the amount of incoming solar radiation and access to that insolation. Historical insolation records were available for nearby locations, Arcata and Trinidad (Figure 1), but not the project site. The interns purchased and installed a low-cost pyranometer and data acquisition system at the campground and compared the site-specific data with those measured in Trinidad during the same time period. The total daily insolation [kilowatt-hours per square meter per day (kWh/m^2/day)] data sets are strongly correlated, as are historical records for Trinidad and Arcata. Therefore, the interns based their designs on the monthly average daily insolation values published for Arcata in the National Solar Radiation Database[6]. Unobstructed access to incident solar radiation is the other component of availability. The interns evaluated solar access at two potential sites for the Espa Lagoon PV array using the Solar Pathfinder™ shown in Figure 3. This device displays all obstructions to the solar window throughout the entire year and indicates the degree to which these obstructions will decrease energy availability. Labels on the latitude-specific sunpath diagram determine the percentage by which shading in each half-hour segment will decrease the total daily insolation.

Figure 3. Solar Pathfinder™ showing shading at Wolf Creek Outdoor School.

- *Hot Water Load*—Although park officials did not intend to provide a hot shower for every campground visitor, they did request that the new solar water heating system supply more hot water than the existing batch heater; therefore, visitation records were used to estimate the design load. The interns calculated the average daily number of visitors for each month from 3.5 years of visitation data supplied by the park ranger and assumed the daily number of showers to be 70% of the average number of visitors. They assumed that at least half of the visitors use the shower and chose 70% to account for periods of higher than average visitation. They measured a supply temperature of 19ºC with a handheld thermometer on various visits and assumed a delivery temperature of 45ºC. They also assumed a shower volume of 18 liters based on their literature review.
- *Water Quality*—Data supplied by the park maintenance mechanic in charge of water systems indicated that the quality of the supply water, hardness and pH in particular, presented no additional maintenance requirements for the solar thermal system.
- *Gold Bluffs Beach Electric Energy Use*—To minimize the power requirements at the campground, the interns specified energy efficient DC-powered lighting devices controlled by a photocell and occupancy sensors to ensure that the lights would operate only when necessary. After examining the interns' cost estimates for a PV system powering alternating current (AC) devices, park officials agreed that adding DC-powered lamps to their inventory was an acceptable trade-off for the cost savings. The interns calculated the number of nighttime hours on the average day of each month[3] to estimate duration of operation for the kiosk light. Duty cycle estimates for the restroom lights were based on the average daily visitation for each month, assuming that each visitor would spend four minutes in the restroom during evening hours.
- *Espa Lagoon Electric Energy Use*—The interns estimated electric energy use at the residence with both an energy audit and direct measurement. They measured, or used the manufacturer's specifications to estimate, power requirements of specific appliances in the home and estimated the duty cycle of each load from a 2-week survey completed by the ranger. They also measured AC current flowing into the house and integrated over time to estimate total energy consumption in the home.

The interns also needed data on the generators' duty cycles and diesel fuel consumption at Espa Lagoon to compare life cycle costs of the existing and proposed systems. The park ranger supplied fifteen months of generator data, and the interns calculated an average duty cycle of 4.7 hours per day. The ranger also supplied three years of diesel fuel purchase data, and the interns calculated an average fuel consumption rate of 2.1 gallons per day. They assumed a value of 40 kWh/gallon[2] for the energy content of the fuel and calculated the efficiency of the existing system to be 7.1%.

In addition to performing the engineering calculations required to design the solar thermal and solar electric systems, the students researched a variety of topics, including renewable energy and energy efficiency technologies and architectural design guidelines for public restrooms. Determining the amount of available energy is a critical step in solar design. Insolation data is measured on a horizontal plane, so the interns estimated the amount of energy available at other angles by calculating the beam and diffuse components of solar radiation[3]. They determined that an array sloped at 35º from the horizontal and oriented directly south would maximize year-round energy production and used the resulting insolation data in their design calculations. They programmed a spreadsheet based on the worksheets published by Sandia National Laboratories[8] to design the solar electric systems, and they used the *f*-chart method[3] to design the solar thermal system. The spreadsheets allowed them to compare twelve hypothetical PV systems and thirteen solar thermal collectors. They investigated the various solar thermal technologies to determine which type was most appropriate for the campground. Although the heat exchanger in an indirect system increases the complexity and decreases thermal efficiency, the interns selected this type of system to ensure adequate freeze protection. They also researched energy efficient lighting equipment for the campground and refrigerators for the residence and studied Americans with Disabilities Act guidelines for lighting levels and spatial requirements in public restrooms. Periodic consultations with park staff ensured that the interns' research focused on technologies appropriate for the park.

Lonny and Angi delivered their final report and presented energy conservation recommendations and renewable energy system designs at a meeting with representatives from RNSP and Prairie Creek State Park. For the Gold Bluffs Beach campground shower they proposed a packaged, indirect solar hot water system from Heliodyne, Inc. They provided alternative configurations with and without circulation pumps because the solar collectors would be incorporated into the roof of the planned new building. Including pumps provided the architect with greater flexibility in the roof design and decreased the overall height of the structure. The pumps are powered by a dedicated PV module and therefore do not affect overall electric energy consumption at the site. However, the water will circulate by natural convection if the top of the collectors is at least two feet below the bottom of the hot water storage tank.

The interns proposed the following indirect approaches to limit hot water use at the campground:

- Install spring-loaded faucet control.
- Post signs asking campers to limit the length of their showers to five minutes.
- Install a mixing valve to limit maximum water temperature at the showerhead.
- Install a separate beach shower with cold water only for rinsing sand and saltwater.

The proposed solar electric system for the Gold Bluffs Beach campground included the existing PV modules, charge controller, and batteries. After measuring the performance characteristics of the PV modules, the interns determined that the array would provide sufficient power for the proposed lighting circuit. Although retaining the existing equipment was preferred, they provided specifications for appropriate alternative PV modules as well. For the lighting circuit, they specified energy efficient DC-powered Thin-Lite fixtures with 8-W fluorescent tube lamps. These fixtures are cost-effective, vandal-proof, and rated for outdoor use. The interns measured the specific gravity of the electrolyte in the existing batteries at full charge and recommended retaining them. Their measurements indicated that the batteries had maintained nearly 100% of their charge capacity and would provide approximately four days of storage in the new system.

The interns proposed replacing the generator system at Espa Lagoon with a 2-kW PV system consisting of an array of twenty 100-W PV modules, a 60-Amp charge controller, and twenty 6-Volt, 225-Amp-hour batteries. The battery bank was sized to provide 3.5 days of storage, and a 3.5- to 5-kW propane-powered generator would provide backup power when necessary. The residential energy audit revealed that the ranger was already very conservative in his energy use. His consumption rate of 6 kWh/day is a small fraction of the California state and Humboldt county averages of 19 and 18 kWh/day[1], respectively. Therefore, the only recommended conservation measure was replacing the existing refrigerator with an energy efficient model.

Wolf Creek Outdoor School

In 2001, the second year, interns Matthew Rhode and Steven Koldis were charged with reducing electricity consumption while increasing comfort and functionality at Wolf Creek Outdoor School (WCOS) in RNSP. The school hosts elementary school students on field trips and serves as a conference site for business groups. As shown in Figure 4, the site includes six 16-person cabins, a restroom with six showers, an outdoor amphitheater, and a lodge with kitchen, office, and presentation space. Although utility power is available, only the lodge and restroom are connected to the grid. The facility director requested energy efficiency recommendations to reduce the excessive amounts of electric energy used at the site, as well as specifications for laundry equipment and lighting for the cabins, walking paths, and amphitheater. An additional project objective was to design a solar electric system to both offset fossil fuel energy use and educate park staff and visitors.

The existing space and water heating equipment in the restroom was inefficient and inappropriate, resulting in wasted electric energy and exorbitant utility bills. The women's and men's restrooms were each equipped with a 400-W ventilation fan and three 1500-W ceiling-mounted electric space heaters. One 120-gallon electric water heater provided hot water for both restrooms. The restroom interiors and exterior were illuminated by 4-ft fluorescent tube lights and a 50-W high-pressure sodium bulb, respectively.

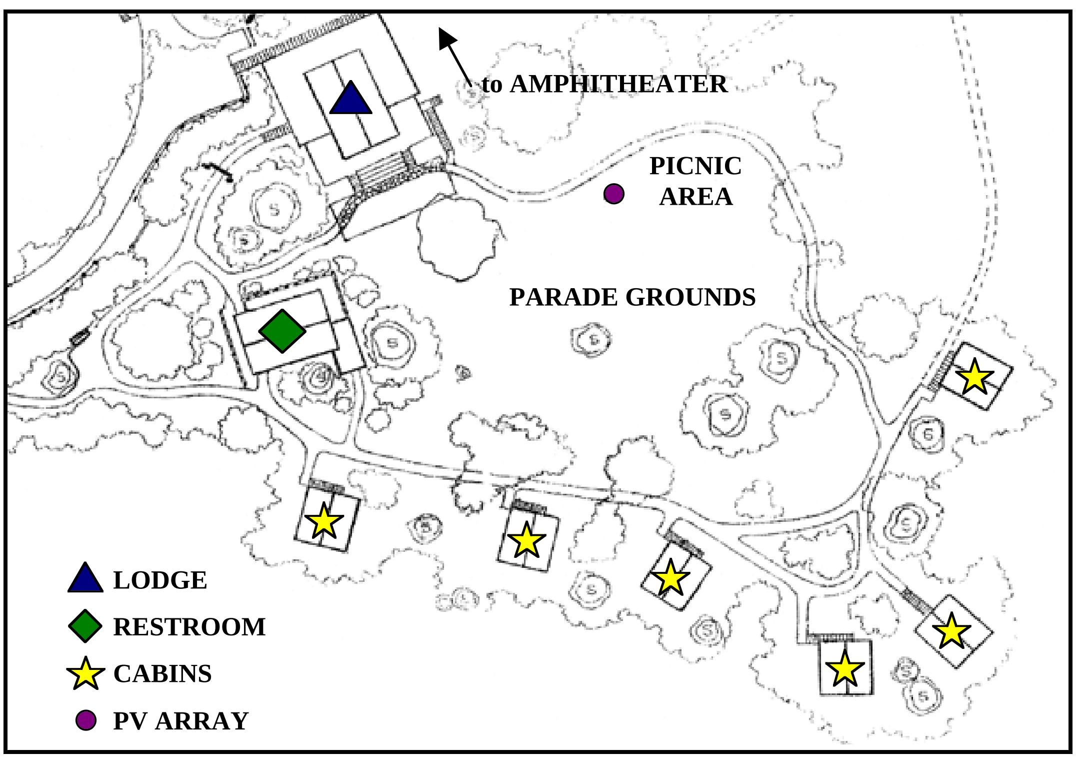

Figure 4. Wolf Creek Outdoor School site map. Map courtesy of Redwood National and State Parks.

Preserving the rustic nature of the outdoor school was a critical factor in selecting lighting devices for the walking paths and a site for the PV array. The interns identified highly efficient 2.2-W fixtures that use light emitting diodes (LED) with lifetimes over 100,000 hours. Each fixture is composed of three LEDs with a durable plastic diffuser that can be mounted on the wooden posts commonly used in parks. Field tests verified that the fixtures would indeed provide adequate illumination without excessive light pollution, meeting the park's need for safety without compromising the aesthetic quality of the site.

Siting the PV array required creativity and flexibility because a solar electric system is not a natural complement to the shady forest setting. To minimize visual impacts and protect it from the students' play area, park staff and the interns initially considered the lodge roof, but the roof's east-west orientation and the surrounding trees severely limited the solar window. The interns analyzed solar access at several other sites and found the fewest obstructions on the northern edge of the parade ground. This site was less desirable due to its proximity to the students' play area and the aesthetic impact of energy supply equipment in the middle of the camp. In consultation with park staff, the interns designed a south-facing structure to provide shelter for the picnic area, a place for interpretive displays, and a mounting structure for the PV array. The open-air wooden structure blends in with the existing buildings, and the prominent location incorporates the PV array into the educational experience.

After examining the existing equipment and design constraints, the interns worked with the project supervisors at SERC to prepare a data monitoring plan. To design a solar hot water system that would reduce the fossil fuel energy use in the restroom, they needed to know the availability of solar energy, the hot water load, and the cold and hot water supply temperatures. To design the space heating and ventilation system they investigated the heat transfer characteristics of the restroom building, including interior and exterior temperatures, insulation type and thickness, and room volume. They also performed an energy audit to discover how and where electricity was being used and to recommend ways to reduce or eliminate waste. The following describes how the interns collected these data:

- *Availability of Solar Energy*—As was the case in the first year, no historical insolation record existed for WCOS, so the interns installed a pyranometer on the northern edge of the parade ground. They mounted the instrument on a pole at a height of 8 feet to minimize shading and secured the data logger in a standard electrical enclosure to minimize the potential for damage by students. They compared the site-specific data with those measured in Trinidad during the same time period. The total daily insolation (kWh/m^2/day) data sets are strongly correlated, so the interns based their designs on the historical record from Trinidad. They also evaluated solar access at various locations around the school with the Solar Pathfinder™.
- *Hot Water Load*—The existing electric water heater provided only enough hot water to run the six showers for ten minutes, which did not meet the current or projected load. The school operates from April through October, and occupancy varies monthly, ranging from 30-45 students on 5-day field trips during the academic months to 85 students on 3-day field trips during the summer months. The interns measured the shower flowrate at 2.1 gallons per minute with a graduated cylinder and stopwatch and assumed a maximum of 45 showers per day. They also investigated the sensitivity of the hot water storage tank size to the number of consecutive showers and shower length, as shown in Table 1.

Table 1. Effect of varying shower duration and number of shower cycles on volume of water and tank size.

Shower Cycles per Day	# of Consecutive Showers	Shower Duration (min)	Hot Water Volume per Cycle (gal.)	120-gal. Storage Tanks Required
1	45	5	472.5	3
1	45	3	283.5	2
2	22.5	5	236.3	2
2	22.5	3	141.8	1

- *Water Supply Temperatures*—The interns attached temperature sensors with a data logger to the inlet and outlet pipes of the water heater for 8 weeks to measure the temperatures of the water supplied to the heater (17.2ºC) and delivered to the shower (43.3-47.8ºC).
- *Heat Transfer Characteristics*—The heat transfer characteristics of a room depend on interior and exterior temperatures, volume, and insulation type. The interns installed a temperature sensor with a data logger 3 feet below one of the ceiling-mounted heaters in the men's restroom for 7 weeks to measure the interior temperature. From this data set, they determined the maximum and minimum room temperatures, as well as the duty cycle associated with the heaters. They measured a maximum room temperature of 24ºC and informed the park electrician of the excessive heating. She immediately lowered the thermostat setting to 18ºC, and the resulting decrease in electricity use is shown in Figure 5. The interns installed another temperature sensor and data logger outside the restroom to make correlations between heater operating time, time of day, and outside temperature. Park staff supplied the insulation type (R-11), and the interns measured the dimensions of each restroom and the utility room directly.
- *Electricity Use*—The interns read the utility meters for the facility as a whole and the restroom alone twice weekly for 8 weeks to measure electricity use at WCOS. They also installed a current transducer with a data logger on the water heater (3 weeks), exterior light (2 weeks), and the interior lighting and ventilation circuit (2 weeks) to determine the total energy used by, and the duty cycle of, each load.

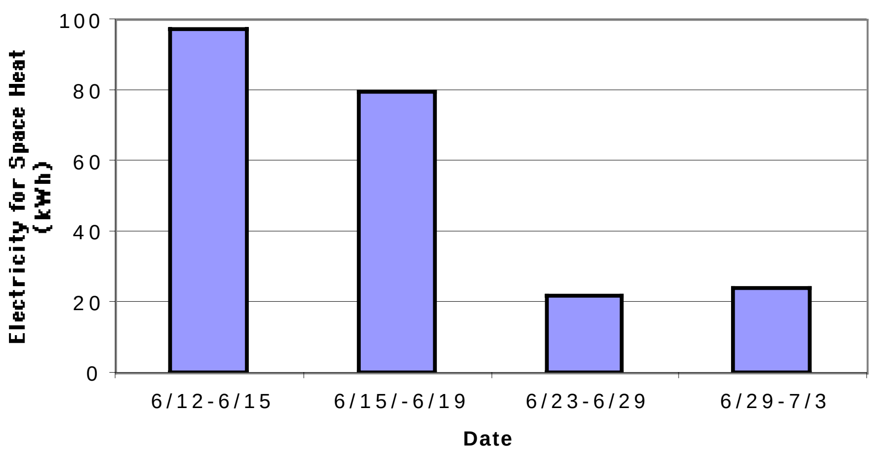

Figure 5. Electricity for space heat in the Wolf Creek Outdoor School restroom before and after the thermostat was reset on June 19, 2001.

Although calculating the optimal tilt angle for the PV array and performing *f*-chart simulations of the solar thermal system were important aspects of the design process, the interns were also very busy with product research on lighting technologies, space heating equipment, and renewable energy systems. They examined LEDs for lighting the pathways because standard lighting technologies were inappropriate due to excessive power requirements and lighting levels. The pathway lighting needed to provide sufficient illumination for safety without disrupting the outdoor experience. Durability, reliability, and cost were also important factors. The interns field-tested sample LED saucer lights on a dark night in a local park to verify that these lights would meet the park's needs. They were pleased with the results, and park staff shared their enthusiasm for the product.

The interns investigated various propane-based space heating equipment for the restroom to replace the existing ceiling-mounted electric heaters. At a preliminary meeting, they presented three options for space heating: a ceiling-mounted convection furnace in each restroom, hydronic baseboard panels, and a hydronic heat exchange heater/ventilator. Due to concerns about the potential for vandalism, park officials chose the hydronic heat exchange heater/ventilator for which all equipment would be housed in the utility room.

The interns also researched the requirements for interconnecting a solar electric system with the utility grid and the various types of PV modules. They informed park officials about the interconnection agreement required between the park service and the utility company, as well as the California Energy Commission's rebate program for grid-connected renewable energy systems. In addition to policy research, the interns studied PV technology to determine which type of module was most appropriate for the site. Although they require more area, the interns recommended amorphous silicon modules because they perform better in partial shade than crystalline modules and can withstand direct hits from golf balls without breaking. Through their extensive research the interns identified products that met the park's unique needs without compromising the environment of the school.

At the end of the project period Matt and Steve presented their final design recommendations to park officials and provided a written description in the form of a grant proposal the park could use to seek funding for implementation. Final designs for WCOS included energy efficient equipment for the laundry, ventilation, and space and water heating in the restroom. The interns specified two stackable clothes washer/dryer units for the laundry facility. They selected the Maytag Neptune model for its high ranking on the Energy Star[4] list, compact dimensions, and large capacity. For central heating in the restrooms they specified a hydronic heat exchange ventilator/heater with parallel thermostat, occupancy sensor, and electric timer controls. The ventilator size was based on the minimum airflow recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). The combination of control devices provided heating and ventilation only when necessary for comfort and preventing mildew growth, which had been an issue in the restroom. The interns also proposed a new water heating system that combined solar thermal technology with a propane-fired water heater, improving performance and efficiency and incorporating renewable energy technology for both domestic hot water and space heat. To minimize the size of the storage tank, they recommended a two-cycle shower schedule (Table 1), allowing half of the students to shower in the morning and the other half to shower in the afternoon. They also recommended installing a 1.5-gallons per minute showerhead and posting signs that encourage shorter showers and using the temporary shut-off valve to save water and energy. The solar thermal and space heating systems were installed in early 2003, and have maintained sanitary conditions and increased hot water availability and thermal comfort, as well as energy efficiency.

The interns also specified energy efficient lighting devices for the cabins, trails, and amphitheater and designed a 2-kW grid-connected PV system to both offset the increase in energy demand from the new loads and educate park staff and visitors about renewable energy. They recommended extending a standard 110-Volt AC power line to supply power for a single ground fault interrupter-protected outlet and a 20-W tube-type fluorescent light in each cabin. The aforementioned LED lighting was recommended for the walking paths and amphitheater seating, and post-mounted 20-W compact fluorescent bulbs housed in floodlight fixtures were recommended for stage lighting. An additional AC line was recommended to provide power for the pathway and amphitheater lighting and an outlet for a film or slide projector. The Bonneville Power Administration installed the lighting and solar electric systems the following year with assistance from senior level ERE students in the Renewable Energy Power Systems class and California Conservation Corps volunteers. The completed array and some of the students who took part in the installation are shown in Figure 6.

Redwood Information Center

In an effort to enhance the learning experience for the students and value to the park, SERC and RNSP expanded the project scope in 2002 to include system installation as well as design. The project site, Redwood Information Center (RIC) in Orick, California, serves as the main visitor center within the park. The facility's public and staff restrooms were served with hot water from an electric water heater that functioned poorly and was expensive to operate. Park staff requested a solar water heating system to supplement or replace the existing water heater. SERC agreed to provide two student interns to design and install the system, and RNSP agreed to expedite the approval and procurement processes and to provide support personnel for the installation and $5000 for materials. Kelly Miess and Andrew Sorter were selected from a strong pool of applicants and accomplished all project objectives on time and under budget.

Figure 6. Humboldt State University engineering students with the newly installed PV array at Wolf Creek Outdoor School.

After meeting with the client and touring the project site, the interns identified the necessary data and appropriate collection methods. They measured solar energy availability and electricity used by the existing electric water heater and performed a thorough energy audit of the facility.

- *Availability of Solar Energy*—The interns' decision to base their design on the Arcata insolation data set was validated by a comparison between 2 weeks of site-specific data and the published values. The Solar Pathfinder™ confirmed that RIC enjoys unobstructed solar access throughout the year.
- *Water Heater Electric Energy Consumption*—The interns installed a current transducer with a data logger on one leg of the existing water heater circuit and measured energy use over a 2-week period that corresponded to peak visitation. Neglecting stand-by losses, they estimated the hot water demand to be 30-40 gallons per day.
- *Facility Electric Energy Consumption*—The interns conducted a facility-wide energy audit to verify the accuracy of their measurement of energy used by the water heater and to identify conservation opportunities. They estimated power requirements for individual appliances from a combination of nameplate ratings, direct measurements, and generic ratings for common loads[7]. Duty cycle estimates were based on interviews with staff and data from hard-wired electric timers. The energy audit indicated a total monthly energy use of 3059 kWh, which agreed with the average monthly use reported in the park's utility bills. The water heater represented only 4% of the total load, and indoor (32%) and outdoor (26%) lighting were the largest energy consumers in the facility.

Based on their research on solar thermal technologies, analysis of site-specific data, and consultations with park staff, the interns recommended an active, indirect solar water heating system with a propane-fired on-demand water heater as backup. Three weeks into the project period, they met with park officials to present four alternatives:

A. *Solar Water Heater with Flush-Mounted Panels and Flash Heater*—A solar water heater with flush-mounted panels on the 18° slope, east-facing roof (Figure 7a) required a collector area of 65 ft^2, or two standard 4 ft by 10 ft panels. This alternative involved the greatest capital investment and resulted in the highest 25-year life cycle cost (LCC) at $8,450.
B. *Solar Water Heater with South-Facing Panels and Flash Heater*—A solar water heater with panels oriented to the south and tilted at a angle equal to latitude (Figure 7b) required a collector area of 37 ft^2. This alternative involved less capital than Alternative A and resulted in a 25-year LCC of $7,820.
C. *Electric Water Heater*—Replacing the existing electric water heater with a similar model involved the least amount of capital investment and the greatest operating costs. The 25-year LCC for this alternative was $8,180.
D. *Flash Water Heater*—Replacing the existing water heater with a propane-fired flash heater involved more capital investment than Alternative C, with a slightly lower operating cost, resulting in a 25-year LCC of $7,390.

The interns' relationships with park personnel helped them overcome the challenges of the state approval and procurement processes. Their timeline for the remaining nine weeks of the project period allotted one week for approval and two weeks for ordering and receiving the equipment.

7a 7b

Figure 7. Digital renderings of solar thermal collector configurations on the roof of Redwood Information Center. (a) Rendering of two flush-mounted collectors, as decribed in Alternative A. (b) Rendering of one south-facing collector tilted at a 40º angle from the horizontal, as described in Alternative B.

Within one week, park officials selected the preferred system, Alternative A, a solar thermal system with two flush-mounted collectors, and received formal approval from all necessary individuals. Immediately following approval, the interns provided price quotes from two manufacturers and several suppliers, and the park purchasing officer began procurement. The quality of the information the interns provided was critical to expediting the process.

Although the equipment did not arrive within the allotted two weeks, the interns made excellent use of their time in the interim. They submitted to the park plumber a list of tools and materials they would need for the installation and developed preliminary designs for interpretive materials to explain the solar thermal system to visitors. On July 11, they began extending galvanized propane piping from the north end of the property to the utility room between the restrooms, as shown in Figure 8. By the end of the following week they had finished installing the propane piping for the flash heater, removed the electric water heater, and begun installing the solar storage tank and heat exchanger. On July 24, the park's boom truck lifted the collectors onto the roof as shown in Figure 9, and the interns secured them to the roof and made the plumbing connections the following week (Figure 10). With nearly two weeks remaining in the project period, they finished all plumbing and pressure tests (Figure 11) and scheduled final inspections (Figure 12). The actual installed cost was $4,813.48. The solar thermal system has provided nearly all of the facility's hot water since operation began on August 7, 2002.

Figure 8. Andy and Kelly install galvanized propane piping in the Redwood Information Center crawlspace.

Figure 9. The park's boom truck hoists the solar thermal collectors onto the Redwood Information Center roof.

Figure 10. Kelly and Andy secure the solar thermal collectors to the roof and measure for plumbing penetrations.

Figure 11. Andy and Kelly complete final tests and pose with the solar hot water storage tank and heat exchanger.

Figure 12. After final inspections, Richard Engel (Schatz Energy Research Center), Jeff Denny (Redwood National and State Parks), Andy, and Kelly pose with the solar thermal collectors.

After completing the installation, Kelly and Andy conducted tours, installed environmental monitoring equipment, and finished the project documentation. The park carpenter and plumber, as well as the buildings and maintenance supervisor, inspected and approved all roof penetrations and plumbing work, and the interns began training RIC and maintenance personnel on the operation and maintenance of the system. Several officials from park headquarters were also eager to learn about its features and capabilities. The interns installed temperature sensors and a pyranometer to monitor system performance, and maintaining the data acquisition system remains one of Andy's responsibilities as a student assistant at SERC. Final documentation for the project included both a report detailing the design process and an operation and maintenance manual for the water heating system. A modified version of the final report was published in the *American Journal of Undergraduate Research*[9] in March 2003.

Benefits to Students

All parties involved in UNPEPP partnerships benefit from the program, as evidenced by the continuing SERC-RNSP partnership. The park's new renewable energy systems have saved energy and money while improving functionality and educating staff and visitors. SERC has benefited from the opportunity to employ and train students, and the students' work illustrates the breadth and quality of the education offered by the ERE program. The greatest benefit of the UNPEPP internships is the real-world engineering experience for the students. Although each of the SERC-RNSP projects involved unique experiences, all three provided excellent opportunities for the students to apply classroom training in a professional setting and demonstrate their project management skills.

All aspects of the design process, including environmental monitoring and economic analyses, allow the interns to integrate tools and concepts from a variety of science, mathematics, and engineering courses. Data acquisition is one of the interns' early steps in the design process. They collect the information park staff can provide through interviews, past records, and utility meters, then decide how to measure the data that are not readily available. They learn about energy use in buildings and the effects of behaviors and personal habits by performing energy audits. They learn about various measurement tools, signal types, and recording intervals by assembling automated data collection systems, calibrating instruments, and analyzing the resulting data.

In the first year, Lonny and Angi purchased a LICOR pyranometer to measure insolation, a HOBO data logger, and an operational amplifier designed to increase the pyranometer's millivolt signal to the logger's required input range. In calibrating the pyranometer relative to an Eppley Precision Spectral Pyranometer at the Schatz Solar Hydrogen Project in Trinidad, California, they discovered that the pyranometer's calibration constant was incorrect. Recognizing that the measured values were not accurate, they developed a calibration equation based on the two data sets to analyze the insolation data measured at Gold Bluffs Beach. The following year Matt and Steve purchased an identical set of equipment and discovered that the error was actually inherent in the calibration constant for the operational amplifier due to the manner in which it had been connected to the pyranometer. Working with this data acquisition circuit has taught all of the interns useful lessons about electronics, measurement tools, and data.

In addition to data management, economic analyses are also important aspects of the UNPEPP internships. The students perform all product research, comparing prices and discussing specifications with vendors, and make appropriate assumptions regarding interest rates, lifetimes, and salvage values. These calculations teach the time value of money more effectively than classroom exercises because the students develop all the inputs for themselves and apply them in the real world, where they can observe the results. In the third year, the interns initially assumed that the life cycle cost of the flash water heater by itself would be far less than the solar thermal alternatives, causing the park to forego the renewable energy system, but the economic analysis showed a relatively small cost difference. Although the preferred alternative was the most expensive, minimizing aesthetic impacts and showcasing renewable energy technology were more important to park officials than the capital cost. The life cycle cost analysis did not include these factors, but they were critical to the ultimate decision. Comparing the life cycle costs of energy efficiency and renewable energy equipment to those of fossil fuel-based power systems is an instructive element of the UNPEPP experience.

Although SERC engineers are available for guidance, the UNPEPP interns are responsible for all aspects of their projects, allowing them to practice essential skills they will need in the engineering profession, such as time and project management, vendor and client relationships, and written and verbal communication. After the initial meeting with the client to tour the project site and discuss design objectives and constraints, the interns decide how to collect the necessary data and accomplish all goals within the twelve-week period. They develop project timelines and decide which team member will assume primary responsibility for each task. Product research provides opportunities to communicate with vendors regarding specifications, price quotations, and appropriate applications. The interns also communicate with their clients, the park staff, throughout the project period, providing progress updates and requesting facility access and data when necessary. They schedule and conduct meetings to present alternatives and final design recommendations. The students are also responsible for writing weekly field reports for SERC's records, monthly progress reports for the funding agency, and a final report detailing their accomplishments. Classroom experiences have prepared them well; all six interns have demonstrated both their academic and leadership abilities.

Serving as an UNPEPP intern is valuable experience both personally and professionally. Andy Sorter continues to work at SERC while finishing his degree. As a student assistant, his responsibilities include the operation, monitoring, and maintenance of the Schatz Solar Hydrogen Project; renewable energy technology research and report writing; and educational outreach. Kelly Miess and Lonny Grafman are also continuing to work toward their degrees. Matt Rhode is a technical specialist for the Renewable Energy Development Institute (REDI) in Willits, California, a nonprofit educational and scientific corporation that promotes the use of renewable energy and clean air transportation technologies. Steve Koldis is an engineer at a firm in Sonoma County, California, and Angi Sorensen is a research engineer at SERC. In addition to project documentation and electrical wiring, she focuses on educational activities for the Center, participating in high school career fairs and community events and teaching energy science to students of all ages in classrooms throughout Humboldt County and California.

In addition to the benefits common to all three, each project involved unique experiences. The students in the first year tested the existing equipment to verify that the components could be retained for the new systems. They measured the specific gravity of the electrolyte in the batteries at Espa Lagoon and Gold Bluffs Beach to determine charge capacity and found that the campground batteries were in excellent condition. They also replaced the wiring and measured the performance characteristics of the Gold Bluffs Beach PV modules to determine their condition after nearly twenty years in the marine environment. Following the standard laboratory procedure used in the Renewable Energy Power Systems class, they used SERC's automated data collection system to record current and voltage measurements for each module and the array as a whole under various loads. They measured these parameters both with and without the plastic cover and accumulated sand to determine the magnitude of their effects on performance. For a given module, the maximum power and open circuit voltage were greater with the plastic in place, and the short circuit current increased when it was removed. The interns theorized that although the plastic sheet decreased the amount of insolation on the module and hence the current output, it also decreased the cell temperature, resulting in higher voltages and power output. Testing in-service renewable energy equipment was a rare opportunity for the interns, and they were very pleased to provide this service to the park.

The second project led to real energy savings at WCOS and provided educational opportunities for many students beyond the two interns. Adjusting the thermostat setting resulted in an immediate and significant reduction in electricity use, and installation of the solar electric and solar thermal systems resulted in further savings. In addition to saving energy and money, the UNPEPP project created opportunities to teach students and park personnel about resource conservation and renewable energy technologies. Students who attended WCOS during the project period were aware of the interns' activities and the environmental monitoring equipment, and one group was even treated to a presentation from Matt and Steve. They discussed solar energy technologies, demonstrated the Solar Pathfinder™ as shown in Figure 13, and answered the students' questions. The UNPEPP project also created a unique educational experience for the ERE students who participated in the installation of the grid-connected PV system in September 2002, and a feature in the park's fall 2002 *Green Stew* newsletter ensured that all personnel learned about the renewable energy and efficiency upgrades.

Figure 13. Matt Rhode demonstrates the Solar Pathfinder™ to students at Wolf Creek Outdoor School.

In the third year, the interns assumed responsibility for all aspects of the engineering project, from the initial research and design stages to the actual hands-on installation and system testing. In the project planning phase, SERC staff had envisioned the interns assisting park personnel with the installation, but the actual experience was even more fulfilling. Although they were technically SERC employees, the interns were valuable members of the park team as well. Their relationship with park staff was based on mutual benefit and respect, and they were given unprecedented access to the RIC facility throughout the project period and entrusted with full responsibility for the installation. Park personnel authorized the interns to make purchases on the park's account at the local hardware store and provided all necessary materials, equipment, and support, including use of a boom truck. All parties agreed that the project was a great success. In a memo to the SERC director, Chief of Maintenance for RNSP Rich Schneider said, "Our relationship with your staff is truly one of our most rewarding partnerships."

Future Plans

Future plans for the SERC-RNSP partnership include developing educational materials for RIC and WCOS and identifying a project for summer 2004. In early 2004, SERC staff began working on interpretive materials to educate visitors about solar thermal technology and the system at RIC. These materials include a sign and tri-fold brochure and are based on the preliminary designs created by Andy and Kelly. SERC and RNSP continue to seek funding to develop educational materials for WCOS as well. This project will include an energy module to supplement the existing environmental curriculum and interpretive signs for the solar thermal and solar electric systems. At the time of this writing, SERC was also preparing to submit a proposal to UNPEPP for a summer 2004 project. SERC engineers were consulting with Steve Carlson, Buildings and Utilities Supervisor for RNSP, to select from the potential projects he had identified. SERC and RNSP hope to be involved in many more successful UNPEPP projects in the years to come.

Conclusions

The University-National Park Energy Partnership Program creates service learning opportunities for university students throughout the United States and contributes to sustainable energy use practices in national parks. Through this program three teams of two Humboldt State University Environmental Resources Engineering students have gained valuable experience managing engineering projects that allowed them to use their classroom training in a real-world context. Under the supervision of Schatz Energy Research Center engineers, they worked directly with Redwood National and State Parks personnel in each of three summers to identify energy conservation measures and design renewable energy systems. They acquired relevant data, developed preliminary designs within the given constraints, and selected the preferred alternative in consultation with park staff. These projects provided both personal and professional rewards to the students in addition to reducing the park's reliance on fossil fuels and educating staff and visitors about renewable energy.

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