UNPEPP 2002:

University-National Park Energy Partnership Program

Solar Water Heating System
Design and Installation Report

For the
Redwood Information Center
Orick, California

Redwood National Park
Schatz Energy Research Center
Humboldt State University

Prepared By:
Andrew Sorter
Kelly Miess

August 2002

Solar Water Heating System Design
Design and Installation Report

For the
Redwood Information Center
Orick, California

Prepared By Kelly Miess and Andrew Sorter
August, 2002

ABSTRACT:

This report details the successful design and installation of the solar water heating project completed by Schatz Energy Research Center interns Kelly Miess and Andrew Sorter for the Redwood Information Center (RIC) as part of the University National Park Energy Partnership Program (UNPEPP) for 2002.

Table of Contents

"Our relationship with your staff is truly one of our most rewarding partnerships."
Memo from Rich Schneider, Redwood National and State Parks Chief of Maintenance, to Peter Lehman, Schatz Energy Research Center Director

Introduction

Since 1997, the University-National Park Energy Partnership Program (UNPEPP) has teamed university students and faculty with National Park Service personnel to identify and develop sustainable energy use practices in the national parks. Projects focus on reducing fossil fuel use in accordance with the Park's "Green Energy" initiative. This association provides needed technical assistance to the Parks while offering valuable, real-world, educational experiences for students.

Partners Humboldt State University, Schatz Energy Research Center, and Redwood National Park selected the Redwood Information Center (RIC) at Redwood National Park, located in Orick, CA, as the project site for the UNPEPP 2002 partnership. HSU provided two student interns from the Environmental Resources Engineering department who were advised by SERC engineers and Redwood National Park staff in the necessary disciplines needed to complete the project. Our mandate was to design and install a solar water heating system to replace the electric water heater currently in use at RIC. Working through SERC, we conducted a site analysis that included site solar availability assessment, water usage and energy consumption data collection. We used the site data, research on contemporary solar water heating technologies, and an economic analysis to design the appropriate solar water heating system for RIC. With much help from SERC and Redwood National Park staff, we successfully designed, procured and installed the water heating system by August 7, 2002. The system has been providing nearly all of the hot water used at RIC from this date. After the installation, staff from the Redwood National Parks were given tours of the system and all were satisfied and proud of the system that they had a hand in implementing. The feeling of a "partnership" had truly been achieved.

Design Considerations

Heating water for domestic and industrial uses is one of the most energy consumptive processes. Water heating is second only to space heating in the amount of domestic energy consumed in developed countries and is estimated to account for 25% of the total energy consumption for a family of four living in the U.S. Fortunately, water heating is one of the oldest and most basic solar energy technology applications. Many important concepts should be explored when designing a solar water heating (solar thermal) system.

After studying the main categories of current solar water heating technology, we focused our attention on active, indirect systems. We made this choice because active systems tend to operate at much higher thermal conversion efficiencies than indirect systems. Furthermore, indirect technology was appealing because the chance of freezing is completely eliminated by using a glycol/water mixture working fluid. This was important because we wanted the system to operate year-round without burdening park staff with complications that could arise with freezing conditions. The next choice we had to make was the collector-type.

We configured our system with flat plate thermal panels because of the very durable design features that have made these collectors an industry standard. The modular design of these panels allows them to be easily serviced and the warranties offered by manufacturers insured a long system life (15-year warranty/30-year life design). The current alternative to flat plate panel technology is evacuated tube collectors. This technology was appealing because the vacuum tube collectors operate at a higher efficiency in limited solar environments. However, because of their vacuum tube construction, these collectors seemed too fragile for the marine and very public location of the RIC installation.

Assessing Solar Resource and Hot Water Load

Hot water demand, solar insolation, and the availability of an unobstructed solar window at the collector installation site are the three main factors for determining the viability of operating a solar water heating system at a specific location.

Estimating the hot water demand at RIC was achieved by measuring the energy use of the existing electric water heater. To facilitate this measurement, we placed a split-core current sensor around one leg of the wire for the existing electric water heater circuit. We then connected the split-core sensor to a data logger set to record current measurements at 30-second intervals. From these data, we established a profile of the use cycle of the water heater. The current data were measured over a period of two weeks (05/31/02 to 06/14/02). These dates correspond to a time of year that is representative of peak park visitation. Therefore, this time period was a good indicator of peak hot water usage. This estimation assumed that all energy used by the electric water heater was being used to heat incoming water, and did not include stand-by losses, thus making this estimation somewhat higher than the actual hot water usage at RIC. We also monitored the gross electricity use for RIC over the same period by recording daily energy meter readings. Comparing the measured water heater load to the gross electricity use at RIC allowed us to view the energy usage of the water heater as a percentage of RIC's total energy consumption. The above calculations yielded the result that the energy demand of the existing electric water heater was about 4.7 kWh per day, which is 4% of the total energy usage at RIC. This amount of energy use is equivalent to a 30-40 gallon/per day hot water demand. This figure was lower than we had expected, leading us to conduct an energy audit of the RIC building to determine a) whether the measured energy consumption of the water heater was accurate and b) where the majority of the energy was being consumed at RIC.

We conducted a complete electrical energy audit to provide a comprehensive accounting of electrical usage at RIC. The audit consisted of a walk-through accounting of all visible electrical loads. When possible, we obtained wattage ratings for specific appliance/electronic devices from manufacturer's specification labels. Where labels were not visible, we measured power requirements directly by using an instantaneous wattmeter or current sensors. Where this was impractical, we obtained wattages through manufacturers' websites or used generic wattage ratings for common electronics that we obtained from the Energy Efficiency and Renewable Energy Network (EREN). Specific appliance use estimates were obtained from RIC staff interviews and hard-wired appliance timers. We then categorized and subtotaled the observed electrical usage which is outlined in detail in the APPENDIX. The total monthly energy use accounted for in the energy audit was 3059 kWh. This usage was comparable to the average monthly usage calculated from RIC energy bills provided by park staff (Table 1). This indicated that our audit was a complete accounting of the energy use at RIC. The audit also confirmed that the electric water heater was only responsible for 4% of the total energy use at RIC (Figure 1)

Table 1: Summary of the energy bills for the Redwood Information Center (RIC) for 2001.

Month	Charge ($)	Total kWh
January	449.29	3370
February	353.41	3420
March	346.6	3310
April	329.24	3130
May	333.31	3170
June	452.36	3070
July	589.55	2820
August	484.77	2900
September	419.11	2500
October	445.37	2660
November	476.57	2850
December	394.1	2840
Average Monthly kWh		**3003**
Average Monthly Charge		**$423**

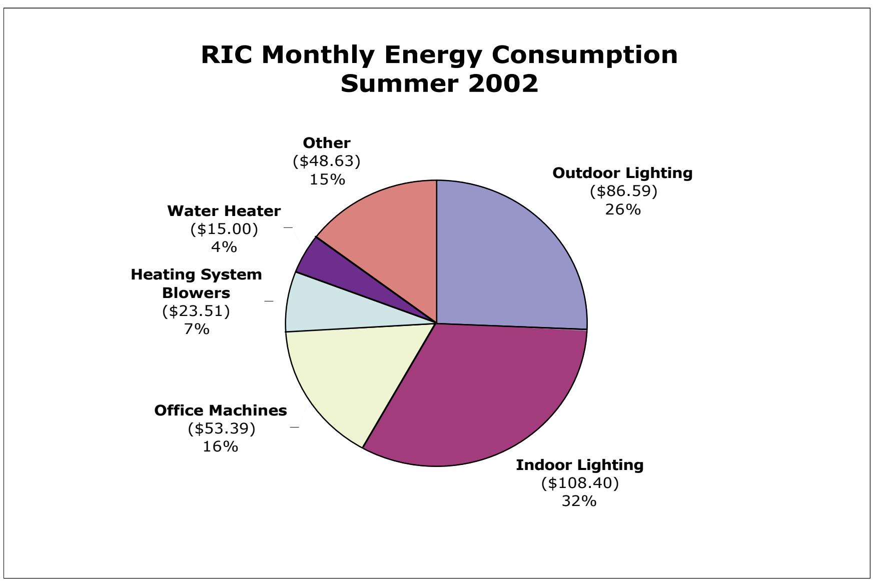

Figure 1: Pie chart of the results from the energy audit conducted at RIC.

As can be seen in Figure 1, the majority of the energy consumed at RIC is used for indoor and outdoor lighting. By comparison, the water heater's contribution to the electrical load is very small. This led us to the conclusion that though replacing the electric water heater would decrease the energy consumption at RIC, addressing the power requirements of the lighting could yield even more significant energy savings. These design improvements would include daylighting, dimming ballasts triggered from photocells, and better seasonal timer management. These recommendations were made to the park staff, and could provide a basis for a future UNPEPP project.

The next step was for us to evaluate the amount of insolation that would be available at the installation site. We used a solar pathfinder to confirm that RIC had a completely unobstructed solar window. To measure the solar insolation at RIC, we installed a pyranometer in the northwest corner of the RIC service yard. We logged pyranometer data at 10-second intervals for two weeks. Because we had a relatively short window for recording site-specific data, we obtained solar data for Arcata, CA from the Renewable Resource Data Center (RRDC). These data summarize a typical meteorologic year based on 30-year average data. By comparing the measured data to the RRDC data, we were able to establish that the RRDC information was consistent with the conditions we would expect at RIC.

We next calculated the necessary collector area needed to supply the hot water demand. This required area varies throughout the year (Table 2). The orientations used in the calculation of collection area are based on two possible configurations. Ideally the collector would be mounted on a southern exposed roof, but because the roof of the RIC building is oriented east/west, the configuration options were limited to flush mounted on east facing roof (roof angle 18°) and oriented south (tilted off of the east facing roof) at a 41° angle (equal to latitude at RIC) (Figure 4).

Figure 4: Renderings of two collector configurations.

In order to reconcile differences in required collector area throughout the year, certain considerations must be made. If a system were designed to supply all of the hot water needed in January, it would be prone to serious overheating in the summer and would be very expensive. In contrast, if a system were designed considering only summer insolation levels, winter performance could be severely hampered. Therefore, an ideal solar water heating system is designed to supply 70-80% of the total yearly water-heating load. These systems tend to supply all of the water needed in summer months but require some supplemental heating during the colder, shorter, and darker fall and winter months.

With the insolation, loading and solar availability known, we were able to calculate the optimal collector area for the two orientations established for the RIC site.

We determined that the first configuration, consisting of a south oriented collector, tilted 41º from horizontal, required 42 ft^2 of collector area, so one standard sized 4’x10’ collector would be adequate. We calculated that the second configuration, consisting of an east-facing collector, “flush roof mounted” (18º from horizontal), required nearly 70 ft^2 of collector area, so at least two standard sized 4’x8’ collectors would be necessary.

The park staff decided that the flush mounted configuration was a more desirable option (even though it required twice the collector area of the “tilt mount” configuration) because they felt that a collector tilted off of the roof would negatively impact the aesthetics of the RIC building.

Design Recommendation

We based our final design recommendation on initial research and acquired site-specific data. From this information, we decided that an indirect, closed loop system was the most appropriate system for this installation. The main factors that influenced this decision were that the RIC site would have limited winter solar availability because of its foggy, coastal location, and that the potential for freezing conditions existed at the installation site. Indirect, closed loop systems provide freeze protection through the use of a glycol-water mixture working fluid. These systems also tend to operate at higher solar conversion efficiencies and would therefore be better suited for the somewhat limited solar conditions at RIC. We selected a flash or “on demand” propane-fired water heater as a backup for the solar water heating system. A schematic of the proposed system can be seen in the APPENDIX.

The flash water heater we chose for this specific configuration was an Aquastar 125-LPS. This flash heater is designed to operate with solar preheated water. The unit has sensors that allow it to determine the inlet water temperature and add only the amount of heat needed to boost water temperatures to the desired service temperature. If the inlet water temperature is at or above the desired service temperature, the burner is not activated, and the potable water passes through the unit un-boosted.

We provided the National Park Service with cost estimates for the recommended system configuration from two manufacturers and several suppliers. The park staff chose the Heliodyne brand, Heliopak AC-16 system, an American Water Heater Co. solar storage tank, and an Aquastar 125B-LPS back-up heater. The Heliopak AC-16 consists of the following components:

- 2 GOBI 408 flat panel collectors
- Counterflow heat exchanger
- 2 Grundfos circulating pumps
- Expansion tank
- Miscellaneous fittings

Economic Analysis

As a check on the economic feasibility of this project, we performed a life cycle cost analysis on four system alternatives (Table 4) in order to compare each system's costs over 25 years (the expected lifetime of a solar hot water system). As a baseline comparison, we analyzed a simple replacement of the existing 18-year-old electric water heater. The second system consisted of a flash hot water heater only. The remaining two systems considered were solar systems with a flash water heater as a backup. One solar system was designed for flush mounting on the east-facing roof and required two 4' by 8' collectors. The other solar system was designed for south-facing, latitudinal tilt mounting and consisted of one 4' by 10' panel. In all other respects, the two solar systems were

Table 2: Summary of life cycle cost analyses

Item	Electric Water Heater	Flash Water Heater	Solar Flush Mount 2-panel & Flash Heater	Solar Tilt Mount 1-Panel & Flash Heater
Capital Equipment	$280	$1,100	$5,000	$4,300
Operation and Maintenance				
Labor	$1,800	$1,900	$2,300	$2,300
Materials	$0	$100	$100	$100
Energy Costs				
Electricity	$5,900			
Propane		$4,300	$1,300	$1,300
Repair and Replacement	$230	$100	$250	$250
Salvage	$30	$110	$500	$430
Total Life Cycle Cost	**$8,180**	**$7,390**	**$8,450**	**$7,820**

method[11].

The life cycle cost analysis indicated that all of the proposed configurations had nearly the same life cycle cost. Therefore the solar water heating system with a flash heater back-up was a feasible configuration that had not only approximately the same life cycle cost as the others analyzed, but as an extra economic advantage, protected the parks from the potential escalating utilities costs.

Installation Log

7/11/02: Received galvanized propane piping from Park plumber, Charlie Shay. Installed propane piping from access TEE to east wall of RIC. (12:00-4:30)

UNPEPP Intern Kelly Miess tightening down a propane plumbing connection.

Assessing the propane run under the Redwood Information Center

7/15/02: Due to the parks decision not to purchase a "power vent kit" for the Aquastar unit, the installation location of Aquastar was changed from the east wall of utility room to south wall. Modified propane piping runs to accommodate new location. Performed floor penetration at new location. (11:00-4:30)

7/16/02: Finished propane piping run through floor. Removed existing electric water heater. Measured ceiling and roof penetration sites. Checked for possible obstructions for these penetrations.

7/23/02: Removed existing plumbing to old electric water heater. Received storage tank and "Heliopak" module on site. Placed tank and began to assemble and plumb "Heliopak". Mounting hardware received was for tilt mount, so re-ordered proper mounting hardware. Placed drip pan under solar storage tank. Put tank on pressure treated blocks over drip pan.

7/24/02: With the aid of the park's boom truck, the collectors (crate and all) were placed on the roof at the RIC site. Crate was secured to the roof with straps and rope. Continued on the assembly of the solar loop.

Park Staff preparing to "boom" panels onto the roof at RIC.

UNPEPP Intern Andy Sorter guides the panels into place.

7/25/02: Solar loop on Heliopak completely plumbed.

7/26/02: Received mounting hardware for collectors. Placed and bolted collectors to the roof.

Kelly and Andy mounting the collectors.

Break Time!

7/29/02: Penetrated roof for collector plumbing. Plumbed collector supply and return. Installed roof jacks for penetrations. Sealed all bolt and plumbing holes with roof mastic roof and/or roof jacks.

7/30/02: Plumbed solar (glycol) loop.

7/31/02: Finished plumbing solar loop. Plumbed pressure relief valves. Began plumbing water loop.

8/1/02: Aquastar flash heater was delivered. Mounted Aquastar on wall. Installed extra screws required for earthquake zones.

8/2/02: Plumbed water loop to and from Aquastar.

8/5/02: Vented Aquastar heater. Installed all vent piping. Cut roof penetration, flashed vent pipe and secured chimney. Final propane hook-up to Aquastar completed.

Final installation of the Aquastar Flash Heater

8/6/02: Finished all water piping. Pressure tested all piping loops. Flushed entire system with water to clean out all piping. Filled system with water and ran system for the first time for approximately two hours. Continued to monitor piping for leakage. Drained system.

8/7/02: Filled system with 40% glycol in water mixture. Installed sensor wires. Insulated all glycol and hot water piping. Got system operational—monitored function throughout day. Received final check-off from Park carpenter Jim DeShon on all roof penetrations.

8/8/02: Finalized sensor wire placement. Installed piping labels. Received final project check-off from buildings and maintenance supervisor, Steve Carlson and Park plumber Charlie Shay.

8/9/02: Received final project check-off from Schatz project supervisors Angi Sorenson and Richard Engel. Installed thermo sensors and data loggers for long-term data collection.

Project receives final check-off from park staff and SERC Engineer Richard Engel.

Andy and Kelly happy with a job well done.

Actual System Installation Cost

The actual cost of main components and incidental plumbing/construction supplies can be seen in Table 5.

Table 5. Actual System Installation Cost Breakdown

ITEM	COST PER UNIT	# OF UNITS	TOTAL COST
HELIOPAK W/ (2) 4X8 COLLECTORS	$2,839.00	1	$2,839.00
HELIODYNE CAL CODE KIT	$105.00	1	$105.00
80 GALLON TANK W / HEAT EXCHANGER	$619.00	1	$619.00
ON-DEMAND WATER HEATER	$599.00	1	$599.00
3/4" TYPE M COPPER PIPING	$0.75	60	$45.00
3/4" COPPER FITTINGS	$0.35	100	$35.00
3/4" GALVANIZED PIPING	$0.72	30	$21.60
3/4" GALVANIZED FITTINGS	$0.35	25	$8.75
5" TYPE B VENT PIPING	$3.46	11	$38.06
5" TYPE B VENT FITTINGS	$11.69	3	$35.07
3/4" FOAM INSULATION	$0.30	60	$18.00
CRATING AND SHIPPING	$250.00	1	$250.00
MISC. SMALL PARTS			$200.00
TOTAL			$4,813.48

Conclusion

Since August 7, 2002, the solar water heating system designed and installed for the Redwood Information Center has been providing nearly all of the hot water being used at the facility. Temperature sensors have been installed in key locations throughout the system, and a pyranometer has been installed in the plane of the flat plate collectors. These instruments are connected to data logging equipment, and these data will be used to create a profile of the general operation and performance of the system over the next year.

The UNPEPP 2002 Redwood Information Center Solar Water Heating Project offered the Schatz interns the opportunity to take an engineering project from the initial research and design stages to the actual hands-on installation of the configured system. Performing such tasks as data acquisition and analysis, economic analysis, oral presentations, f-chart modeling, interpretive signage design, as well as all of the construction and plumbing activities associated with the system installation, the interns acquired and applied a broad range of applicable engineering skills. With the energy expertise offered by the engineering staff of the Schatz Energy Research Center and the construction knowledge shared by Park staff, the interns were able to cultivate both the theoretical and practical skills needed to complete renewable energy project design and installation.

References

[i]Lunde, Peter J., Solar Thermal Engineering- Space Heating and Hot Water Systems. John Wiley and Sons- New York, 1980.

[ii]Sandia National Laboratories. Stand Alone Photovoltaic Systems- A Handbook of Recommended Design Practices. National Technical Information Service. Springfield, VA. 1988.

APPENDIX

September 7, 2002

Director Lehman
Schatz Energy Research Center
Humboldt State University
Arcata, CA 95521

Dear Peter:

I would like to thank you for your assistance with the installation of the new solar hot water system at the Redwood Information Center, Redwood National & State Parks. Richard Engel and Angi Sorensen, Research Engineers, were instrumental in the design, scheduling and installation of the system. The Schatz Energy interns, Andy Sorter and Kelly Miess can be proud of their active participation in the development of this energy-saving solar system. The project was finished ahead of schedule and within the budget.

We also look forward to the installation of energy conservation systems at the Wolf Creek Outdoor School in Humboldt County. The Regional Energy Coordinator for the Pacific West Region, Steve Butterworth, is very interested in the project and may visit the site during installation.

Rich Schneider
Chief of Maintenance
Redwood National & State Parks