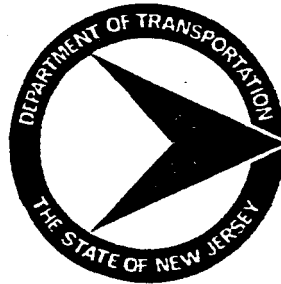


**SOLAR DOMESTIC HOT WATER SYSTEM
HARDING TOWNSHIP REST AREA BUILDING, I-287**

FINAL REPORT

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April 1988

**Prepared By
New Jersey Department of Transportation
Division of Research and Demonstration
Bureau of Transportation Technology Research
In Cooperation with
U.S. Department of Transportation
Federal Highway Administration**

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1. Report No. FHWA/NJ-88-011	2. Government Accession No. N.A.	3. Recipient's Catalog No. N.A.	
4. Title and Subtitle Solar Domestic Hot Water System Harding Township Rest Area Building, I-287		5. Report Date March, 1988	
		6. Performing Organization Code N.A.	
		8. Performing Organization Report No. 88-011-7799-11	
7. Author(s) Fuca, T. A. and Sasor, S. R.		10. Work Unit No. (TRAIS) N.A.	
9. Performing Organization Name and Address New Jersey Department of Transportation Division of Research & Demonstration 1035 Parkway Ave., CN600 Trenton, N.J. 08625		11. Contract or Grant No. DOT-FH-15-386	
		13. Type of Report and Period Covered Final Report Nov. 1982 - Nov. 1984	
12. Sponsoring Agency Name and Address New Jersey Department of Transportation Division of Research & Demonstration 1035 Parkway Ave., CN600 Trenton, N.J. 08625		14. Sponsoring Agency Code N.A.	
		15. Supplementary Notes Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration	
16. Abstract <p>A retrofit solar domestic hot water (DHW) system was designed and installed in a highway safety rest area building adjacent to I-287 in Harding Township, New Jersey. Monitoring instrumentation was included in the installation, and system performance was monitored for two years from Nov. 8, 1982 to Nov. 9, 1984. Since its installation the system has operated quite satisfactorily with only minor problems occurring. During the first year of operation the system provided a 77.6% solar contribution to the domestic hot water heating load. During the second year the solar contribution was 58.1%. This reduction was due primarily to leaks which developed in lavatory faucets during more than two months of operation, and increased hot water demand.</p> <p>A life cycle cost analysis based on actual costs and performance for the first two years of operation was performed. The results of the life cycle cost analysis indicate that for a 20 year life the cost of the solar system, including a backup system capable of supplying 100% of the DHW heating load, is slightly higher than the cost of a conventional system. However, the difference is judged not significant given inaccuracies in predicting future costs.</p> <p>Since the original involvement with the Harding Township rest area solar system, DHW solar systems have been installed in all five safety roadside rest area buildings in New Jersey.</p>			
17. Key Words Solar Energy, Solar Domestic Hot Water Systems, Life Cycle Cost Analysis, Solar Collectors, Performance Monitoring, Renewable Energy Sources		18. Distribution Statement No Restrictions	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 79	22. Price

ACKNOWLEDGEMENT

The authors would like to gratefully acknowledge those employee of the New Jersey Department of Transportation who participated in a cooperative effort to make this project a success, especially those in the Bureaus of Transportation Technology Research, Landscape Architecture, and Plant Engineering & Operations.

In particular the efforts of Joseph Flesch who faithfully monitored the system for two years are posthumously commended.

David Byers provided invaluable assistance during the initial planning and design stages of the project.

Special thanks are given to Janice Furda who typed the original manuscript of this report and William Crowell who performed the drafting work.

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SUMMARY AND CONCLUSIONS

A solar domestic hot water (DHW) system was installed in an existing safety roadside rest area building located adjacent to I-287 northbound, Harding Township, New Jersey. The DHW system included monitoring instrumentation so that system performance could be determined. Monitoring data was gathered for a two year period and an updated life cycle cost analysis was performed using the data.

The rest area building was retrofitted with a DHW solar system which was designed in-house by New Jersey Department of Transportation personnel. The system consists of four roof mounted solar collector panels which absorb heat from solar radiation. The heat is transferred through a nontoxic antifreeze solution flowing through the collector panels to a heat exchanger in a solar storage tank. Hot water is then available for use in the restrooms.

Control of the system is achieved through a differential temperature controller which automatically regulates the storage of heat in the solar storage tank. Instruments including a pyranometer with accumulating integrator, BTU meters, and kilowatt-hour meters were used to automatically accumulate system performance data.

The DHW system including the monitoring system was installed by a contractor for the low bid price of \$16,745. Installation was monitored and inspected by New Jersey Department of Transportation personnel and completed on time without any engineering change orders to the contract. No problems of any significance occurred allowing for the State's acceptance of the system on November 8, 1982 after a successful operational test period.

Performance monitoring of the DHW system extended over a two year period from November 8, 1982 to November 9, 1984. Raw data read directly from

the monitoring equipment was collected weekly for the second year. System performance indicators listed in Figure 2, page 20, were calculated from the collected data. Values of the performance indicators are included in Table 3, pages 22 and 23.

The solar system and monitoring system operated satisfactorily during the first year of operation with only minor problems occurring. The system provided a 77.6% solar contribution to the domestic hot water heating load during the first year. During the second year of operation the solar system and monitoring system continued to operate satisfactorily with only minor problems occurring. However, the solar contribution to the domestic hot water heating load dropped to 58.1%. The reduction in percent solar contribution was due primarily to leaks in lavatory faucets during more than two months of operation and measured at approximately 90 gallons per day, and secondarily because of increased hot water usage during the second year of operation. Without the leaks the solar contribution for the second year is estimated at 71%.

Since the solar contribution to the domestic hot water (DHW) heating load was 100% for four months during the first year of operation, it was decided to valve off the auxiliary electric hot water tank which served as a backup from the rest of the system so that a DHW system deriving its heat solely from solar panels could be evaluated. It was found that this one (solar) tank system operated more efficiently than the two (solar plus auxiliary) tank system and with less heat loss. Therefore, the auxiliary storage tank was permanently disconnected from the system and electric heating elements were installed in the solar tank to provide auxiliary heating as needed.

A life cycle cost analysis based on actual costs and performance during the first two years of operation was performed to update the life cycle study performed during design of the system. The cost of a conventional domestic hot

water heating system was compared to the cost of the solar system plus backup using FHWA guidelines. Equipment, electrical and maintenance costs were included in the analysis assuming a 20 year system life.

The results of the updated life cycle cost analysis indicate that for a 20 year life the present value cost of the solar system plus backup is approximately \$2,000 more than the costs of a conventional system. However, this difference is judged not significant given the inaccuracy in the underlying assumptions of the lifecycle cost analysis particularly when estimating several years into the future. Furthermore, it was determined that this difference is insufficient to indicate that solar heating of domestic water is not an economically feasible alternative to conventional hot water heating.

RECOMMENDATIONS

A solar domestic hot water (DHW) system with one storage tank containing a heat exchanger for transferring heat from the solar panels and electric heating elements for backup heating is recommended. This is the present configuration of the Harding solar system. Based on operational tests of a one tank (solar plus backup) versus a two tank (separate solar and backup tanks) system, it was found that the one tank system performed more efficiently with less storage tank heat losses.

It is further recommended that DHW systems be installed in all rest area buildings constructed. At present all five rest area buildings in New Jersey are equipped with DHW systems. Three systems have been installed as part of original construction and two have been installed as retrofits.

IMPLEMENTATION

During the second year of monitoring system performance, the solar domestic hot water system configured with only the solar heat exchanger tank in operation (i.e., without backup) was evaluated. As a result of the evaluation it was determined that a one tank configuration was more efficient for the solar domestic hot water system at the Harding rest area. Thus implementation of this result was accomplished by eliminating the existing electric hot water tank which served as a backup for the system and installing electric heating elements in the solar tank to serve as backup.

In 1984 New Jersey Department of Energy (NJDOE), Alternate Technology Unit personnel, who conducted seminars on solar domestic hot water system installation and operation, inspected the Harding rest area solar system. As a result NJDOE personnel applauded the Harding system as a "showcase" installation and one of the best in the State.

The solar system for the Harding Township rest area building was originally proposed in 1979 as a result of the Federal Highway Administration's Demonstration Project 52, Solar Energy for Highway Users. At that time other potential applications for solar energy were identified but more importantly interest in solar energy projects was generated within the New Jersey Department of Transportation. Because of this interest solar domestic hot water heating was incorporated into the construction plans for a new rest area building adjacent to I-80 in Knowlton, New Jersey. The design was accomplished by a consultant and it differed from the Harding system design. Construction was completed in November, 1982. Some overheating occurred in the Knowlton system initially, however after following the recommendations of New Jersey Department of Transportation, Division of Research and Demonstration, and New Jersey Department of Energy personnel, the problems were solved.

Another solar domestic hot water system was funded by the New Jersey Department of Energy and installed in the Deepwater rest area adjacent to I-295 just north of the Delaware Memorial Bridge. This retrofit system has been operating satisfactorily.

Along I-295 in Springfield Township, about 50 miles north of the Deepwater rest area and about five miles south of Bordentown, New Jersey, two identical rest areas are located on opposite sides of the highway. Solar domestic hot water heating was also incorporated into the design of these rest areas and the systems have operated satisfactorily.

The completion of the two Springfield rest area buildings brings the total number of solar domestic hot water installations for the New Jersey Department of Transportation to five. Thus since the original involvement with the Harding Township rest area system, solar domestic hot water systems have been installed in all five safety roadside rest area buildings in New Jersey.

INTRODUCTION

A retrofit solar domestic hot water (DHW) system was designed, installed and operated at the Harding Township rest area building adjacent to I-287, northbound in Morris County, N.J. The project was undertaken to reduce the high energy costs of heating domestic hot water by conventional means, and to conserve fossil fuel consumption. Solar energy is a nondepletable energy source which conserves fossil fuels, and it can be cost effective at the same time.

The objective of this project was to design a solar energy domestic hot water heating system and performance monitoring system, complete a life cycle cost study based on the design, prepare a monitoring plan for system evaluation, install the system, provide a public information display, monitor the system and evaluate its performance.

The Harding domestic hot water system was constructed utilizing funding from the Federal Highway Administration (FHWA) Demonstration Projects Division. Demonstration Project Number 52, Solar Energy for Highway Uses, was intended to encourage state highway agencies to use solar energy sources for highway related applications. The system was evaluated through the FHWA Highway Planning and Research (HPR) program.

The domestic hot water system was designed, installed and then monitored for two years from November 8, 1982 to November 9, 1984. The design, procurement and installation of the system were covered in detail in the interim report for the project. This final report summarizes the design and installation of the system and covers the monitoring and performance of the system including an updated life cycle analysis based on actual costs for the first two years of system operation.

DESIGN AND INSTALLATION

PROJECT DESCRIPTION

The Harding rest area is located adjacent to the northbound lanes of I-287 in Harding Township, Morris County, New Jersey. The rest area contains separate parking lots for light and heavy vehicles and contains a large picnic area. It is frequented by intra- and interstate tourists visiting the northwestern portion of the state and the historic Morristown area as well as by other travelers.

The rest area building was constructed in the summer of 1975 with a conventional 120 gallon electric hot water tank for supplying 16 wash basins in the restrooms. The building is 55 feet by 65 feet and 15 feet high with a flat roof. (See Photograph 1, page 9). Although situated in a wooded area, there are no trees in the immediate vicinity of the building to shade the roof.

The building was retrofitted with an active domestic hot water solar system. Solar radiation is absorbed by four roof mounted solar collector panels. Heat is transferred from the collector panels to a 120 gallon storage tank by non-toxic antifreeze fluid flowing through tubing in the panels and a heat exchanger coil in the storage tank. The heated water in the storage tank is then available for use in the restrooms. The operation of the energy storage system is controlled by a differential temperature controller. The existing electric hot water heater provides auxiliary heating to supplement solar heating during periods of high demand or when the solar system is not operating.

The solar hot water system was monitored and the data was analyzed monthly to determine various indicators of system performance. The main components of the monitoring instrumentation are a pyranometer, BTU meters and kilowatt meters.



PHOTOGRAPH 1

HARDING TOWNSHIP REST AREA BUILDING

SYSTEM DESIGN

The solar DHW system was designed in-house by New Jersey Department of Transportation personnel. The system was sized based on estimated maximum use of the rest area building during the tourist season which extends from spring to fall. Maximum usage was estimated at an average of 400 people per day, each using 0.6 gallons for a total of 240 gallons of hot water per day. It was assumed that the hot water would be supplied to the restrooms at a temperature of 100°F and the inlet temperature was assumed to be 50°F. Based on these assumptions the annual heating load was calculated to be 36.5 million BTU.

The determination of the number of solar collectors was made using the specifications of the Daystar Model 1600/TLS flat plate collector panels. The following data were also used:

- meteorological data for Trenton, New Jersey
- azimuth of due south
- collector tilt of site latitude minus 10°F
- collector inlet temperature at 108°F with 12°F rise across collector
- average ambient winter temperature of 36.8°F.

Table 1, page 11 includes the data used to calculate the monthly energy from a Daystar 1600/TLS collector panel. Examining total BTU demand for the rest area and comparing to the energy available for various numbers of collectors and associated costs the optimum collector sizing of four collectors was determined. It was calculated that 26.5 million BTU could be delivered and used by a four collector system. Monthly totals of BTU captured for a four collector system are presented in Table 2, page 12. Using the estimated annual heating load of 36.5 million BTU it was calculated that a solar system with four collector panels would supply 73% of the annual hot water demand for the rest area.

TABLE 1: MONTHLY ENERGY SUPPLY PER COLLECTOR

MONTH	INCIDENT ANGLE OF COLLECTOR (DEG)	COLLECTOR INLET TEMP. (°F)	ENVIR. TEMP. (°F)	TEMP. DIFF. (°F)	OPER. EFFIC.	CLEAR DAY X INSOLATION (BTU/SQ. FT)	X SQ. FT. PER COLLECTOR	X CLOUDINESS FACTOR	DAYS PER MONTH	MONTHLY ENERGY PER COLLECTOR (BTU/COLL)
JAN	30.00	108.0	32.0	76.0	.452	1656.69	21.1	.677	31	330,317
FEB	20.60	108.0	32.0	76.0	.456	2033.50	21.1	.639	28	348,412
MAR	10.00	108.0	41.0	67.0	.500	2306.56	21.1	.684	31	513,557
APR	1.90	108.0	51.8	56.2	.547	2415.24	21.1	.688	30	573,085
MAY	10.30	108.0	60.8	47.2	.583	2442.96	21.1	.710	31	657,869
JUN	13.45	108.0	69.8	38.2	.615	2434.41	21.1	.760	30	717,166
JUL	10.50	108.0	75.2	32.8	.635	2408.19	21.1	.786	31	782,015
AUG	2.10	108.0	73.4	34.6	.629	2350.89	21.1	.771	31	742,706
SEP	10.00	108.0	66.2	41.8	.603	2209.09	21.1	.804	30	674,707
OCT	20.70	108.0	55.4	52.6	.559	1951.47	21.1	.807	31	572,747
NOV	29.90	108.0	44.6	63.4	.510	1626.37	21.1	.768	30	400,932
DEC	33.45	108.0	33.8	74.2	.459	1475.06	21.1	.736	31	324,400

TOTAL YEARLY SUPPLY: 6,638,000

TABLE 2: MONTHLY BTU'S CAPTURED BY FOUR COLLECTORS

MONTH	DAYS	MONTHLY ⁽¹⁾ BTU DEMAND	BTU/COLL./MO. ⁽²⁾	BTU/4 COLL./MO.
JAN	31	3,098,760	330,317	1,321,268
FEB	28	2,798,880	348,412	1,393,648
MAR	31	3,098,760	513,557	2,054,228
APR	30	2,998,800	573,085	2,292,340
MAY	31	3,098,760	657,869	2,631,476
JUN	30	2,998,800	717,166	2,868,664
JUL	31	3,098,760	782,015	3,098,760 29,310 ⁽³⁾
AUG	31	3,098,760	742,706	2,970,824
SEP	30	2,998,800	647,707	2,698,828
OCT	31	3,098,760	572,747	2,290,998
NOV	30	2,998,800	400,932	1,603,728
DEC	31	3,098,760	324,400	1,297,600

TOTAL BTU'S DELIVERED AND USED: 26,522,340

(1)
$$\text{BTU demand per day} = \frac{400 \text{ tourists}}{\text{day}} \times \frac{0.6 \text{ gal.}}{\text{tourist}} \times \frac{8.33 \text{ BTU}}{\text{gal. } 1^{\circ}\text{F}} \times 100^{\circ}\text{F}(\text{T OUT}) - 50^{\circ}\text{F}(\text{T IN}) = 99,960 \text{ BTU}$$

(2) From Table 1

(3) BTU not collected - in excess of demand

A 20 year life cycle cost analysis (1980-2000) was performed prior to designing the solar system. The best available information on costs of a solar DHW system with a conventional backup system were compared to a conventional DHW system on an economically valid basis to determine the most cost effective system. System component life was assumed to be 20 years; the rate of return on investment and the fuel price escalation rate were assumed to be 10% per year; the maintenance inflation rate was assumed to be 7% per year. All comparisons were made on the present value of costs (1980).

The life cycle cost analysis indicated that when the solar system design was optimized for an average annual hot water usage of 36.5 million BTU, cost effectiveness was nearly achieved for a 20 year system life. A summary of the present value of 20 year costs is shown below:

	Conventional System	Solar System Plus Backup
Equipment Cost	\$1,595	\$10,345
Electric Cost	9,760	2,664
Maintenance Costs	—	1,715
TOTAL 20 YEAR COST	\$11,355	\$14,724

At the time of the preliminary life cycle cost analysis it was concluded that the difference in costs of a conventional system versus a solar system with backup could not be determined significant because of possible errors in preliminary estimates. Assumptions of hot water demand, maintenance requirements, electricity rates, etc., could not be determined accurately for more than a few years at best.

The FHWA gave their approval to design and install the Harding DHW solar system using the sizing determined in the life cycle cost analysis. Figure 1, page 14, is a schematic of the the solar system including the monitoring system.

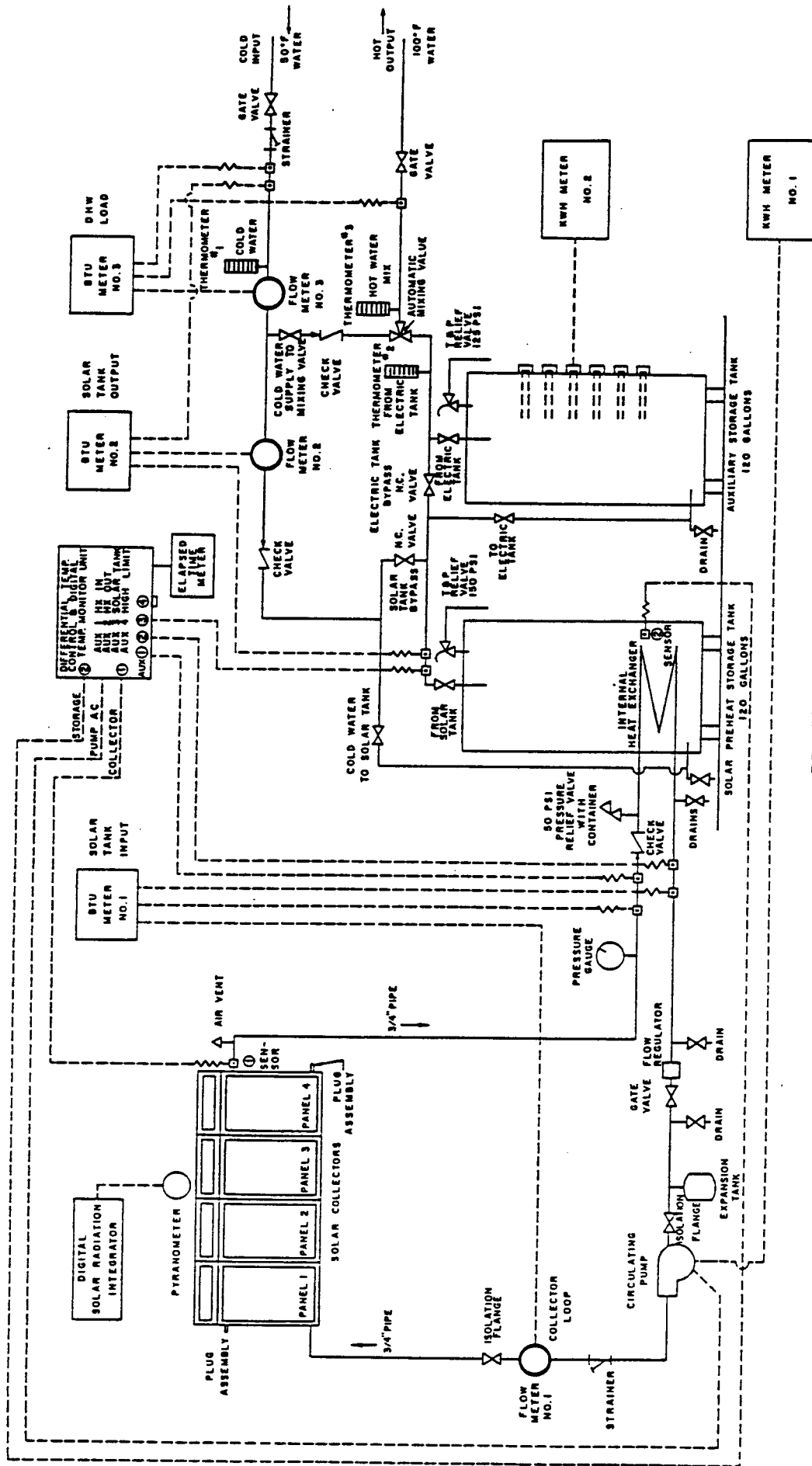


FIGURE 1
SOLAR DOMESTIC HOT WATER SYSTEM

Four flat plate solar collectors each face due south and are tilted 30° (40° latitude minus 10°) from the horizontal to maximize solar radiation captured during the summer, the time of maximum hot water usage. Each collector consists of a cover plate, absorber, insulation, piping, fittings, over-temperature heat rejection device and case. The cover plate is $3/16$ " tempered glass with a net aperture of 21.1 sq. ft. and designed to withstand a windload of 120 mph. The absorber is a black copper plate with $1/4$ " copper tubing connected to internal manifolds. Heat rejection panels provide over-temperature protection when the collector temperature reaches 225°F . A mechanically activated valve opens allowing heat from the antifreeze heat transfer fluid to be dissipated to the atmosphere.

Two hot water storage tanks provide a total of 240 gallons of storage. The existing 120 gallon tank has an electric heating coil which serves as a backup heating source. An additional 120 gallon tank contains an internal copper heat exchanger coil which transfers heat from the solar loop to the domestic hot water. This tank is stone lined and insulated with closed cell foam with an R-value of 11. Both the existing and auxiliary storage tanks are insulated with thermal insulating blankets. Piping and valves are installed such that the DHW system can be operated with either or both tanks.

An antifreeze heat transfer fluid of non-toxic propylene glycol (52% by weight) protects the solar loop from freezing down to a temperature of minus 30°F . The specific heat of the fluid is 0.854 BTU/LB-Degree Fahrenheit. The fluid is capable of withstanding stagnation temperatures up to 350°F without chemical degradation, however the heat rejection panels on the solar collectors protect the antifreeze heat transfer fluid from excessively high temperatures (over 225°F).

A circulating pump forces the antifreeze heat transfer fluid through the solar loop which includes the solar collector panels and the heat exchanger in the solar storage tank.

A differential temperature controller provides automatic control of the solar loop circulating pump. When the temperature of the solar collector absorber plate reaches 20°F higher than the temperature of the solar storage tank, the circulating pump is turned on; when the difference in temperature is reduced to 5°F the circulating pump is turned off. The differential temperature controller contains a high temperature limiter which prevents the temperature in the solar storage tank from exceeding 180°F. In addition to collector and storage temperatures the differential controller also monitors four other temperatures at various points in the system. An elapsed time meter accumulates the total operating time of the circulating pump.

Various components are included in the solar hot water heating system such as valves, gauges, air vents, pressure release valves, drains, regulators and an expansion tank. Interior and exterior piping is insulated to limit piping heat loss; exterior piping is protected with a weatherproof outer casing.

Instrumentation to monitor the performance of the solar system is included in the system design. See Figure 1, page 14. The main components are a pyranometer, BTU meters and kilowatt-hour meters. The pyranometer measures the solar insolation in the plane of the solar collectors; accumulated solar insolation is read on an accumulating integrator connected to the pyranometer. One BTU meter monitors the solar thermal energy being supplied to the solar storage tank. As shown in Figure 1, page 14, thermistors monitoring input and output temperatures to the solar storage tank of the antifreeze heat transfer solution in the solar loop and a flow meter measuring the flow in the solar loop provide the input required for the BTU meter to calculate stored heat. A second

BTU meter monitors the thermal contribution to the domestic hot water heating load. Two thermistors monitor the temperatures of the cold water input and the solar storage tank water output and a flow meter is located in the cold water supply to the solar storage tank. A third BTU meter monitors the domestic hot water heating load demand. Two thermistors monitor the temperatures of the cold water input and the domestic hot water output and a flow meter is located in the cold water supply.

INSTALLATION

Detailed information on the installation of the solar domestic hot water system including installed equipment problems during installation, and inspection and testing of the system are contained in the project interim report which dealt primarily with the procurement and installation phases of the project. Specifications for the system are also contained in the interim report. A contract in the amount of \$16,745 was awarded by the New Jersey Department of Treasury to the low bidder, All Pipe and Heating Company of Succasunna, New Jersey for procurement and installation of the system. The installation was subcontracted to Solar Innovations of Flanders, New Jersey. Installation began in August 1982 and after a successful operational test period was accepted by the New Jersey Department of Transportation and the New Jersey Department of Treasury on November 8, 1982.

The manufacturer and model of each component in the system and its function and operation in the system is described in the interim report. Problems that occurred during installation of the system were considered minor and easily rectified. One kilowatt-hour meter was sent back to the manufacturer for repairs which delayed completion by about two weeks, a strainer was installed in the wrong location and a leak in the roof developed during installation of the solar panel support curb.

New Jersey Department of Transportation personnel monitored and inspected the installation of the system. Since the system was designed by Department personnel, added assurance of installing a system as specified and intended was realized. An operational test lasting over a month was performed during which final adjustments were made and Department operating personnel were instructed in the proper operation and maintenance of the system. The contractor provided a written guide for checking system operation, draining and filling the solar collector heat transfer loop, and maintaining the system.

Upon final acceptance of the system by the State, a one year system warranty and 5 year warranty on the solar collectors were issued to the State by the contractor. The installation was completed on time for the contracted amount without any engineering change orders.

SYSTEM PERFORMANCE

MONITORING

Routine monitoring of the solar domestic hot water system began on November 8, 1982 and continued for a two year period until November 9, 1984. For the first year of operation the system was monitored weekly; for the second year of operation the system was monitored every two weeks. Raw data was read directly from the monitoring equipment installed with the solar system.

Thermal energy in kBTU (1000s of BTU) was read directly from the three BTU meters located at various points in the system; flow in gallons was also read from the BTU meters. Thermal energy in kBTU/sq. ft. was read from the pyranometer's accumulating integrator. Temperature in degrees Fahrenheit was read from three in-line thermometers and from the differential temperature control and digital monitoring unit at six other points in the system. An elapsed time meter measured the on-time in hours of the circulating pump. These data were recorded on a "Weekly Monitoring Raw Data Sheet."

A Monitoring Plan was prepared to explain the process of calculating system performance indicators from the raw data; the Monitoring Plan is contained in the interim report. Twelve system performance indicators are defined in detail in the Monitoring Plan and are listed in Figure 2, page 20.

FIGURE 2
SYSTEM PERFORMANCE INDICATORS

E_{IN}	- Insolation incident in the plane of the collectors
E_S	- Solar thermal energy supplied to the preheat storage tank
eff_{OA}	- Overall efficiency in supplying solar energy
E_D	- Domestic hot water heating load
E_{SH}	- Solar thermal contribution to the domestic hot water heating load
$Q_{S.T. Loss}$	- Heat loss from preheat storage tank
$E_{AUX.}$	- Auxiliary thermal contribution to the domestic hot water heating load
$Q_{AUX. Loss}$	- Heat loss from auxiliary tank and piping between solar tank, auxiliary tank and mixing valve
$W_{AUX.}$	- Operating electrical energy for the auxiliary system
P	- Percent solar contribution to the domestic hot water heating load
W_{OP}	- Operating electrical energy for the solar energy system
W_S	- Electricity saved by solar hot water heating system

PERFORMANCE

The performance indicators listed in Figure 2 were calculated monthly during the two year monitoring period. Monthly monitoring reports were written containing a complete description of the operational status of the solar system, the performance indicators for the month and a description of significant performance indicators. In addition, savings in electric costs based on current rates were presented each month. Appendix A contains the operational status and description of significant performance indicators included in Monthly Monitoring Report Numbers 1 through 24 for the two year monitoring period.

Values of performance indicators contained in the Monthly Monitoring Reports are included in Table 3, pages 20 and 23. Yearly totals for the performance indicators are also included. "Hours Solar" on the table are the number of hours that the circulating pump was running and therefore the time during which solar heat was being stored in the auxiliary solar tank. "Hours Aux." on the table are the number of hours heat was being supplied to the existing tank from the electrical heating element.

For the first year of operation the domestic hot water heating load demand was 14,301 kBTU and the solar thermal contribution to that demand was 11,100 kBTU for a 77.6% solar contribution. The solar system and monitoring system operated satisfactorily for the entire first year of operation (366 days), however, data for only 333 days is included in Table 3, page 22.

Data for 33 days during the first year of operation was disregarded due to several minor problems. Since the site was visited weekly to collect monitoring data, the entire week's data was judged to be unreliable on four occasions. During month 3 a leak in the existing auxiliary electric water tank developed and the heating elements were shut-off until repairs could be made. Thus monitoring data was disregarded for a nine day period. During month 5 a new heating

TABLE 3

MONTHLY PERFORMANCE INDICATORS
11/08/82-11/08/83

MONTH	START DATE	DATA DAYS	E _{in} (kBTU)	E _s (kBTU)	EFF _{oa} (%)	E _d (kBTU)	E _{sh} (kBTU)	Q _{s.t.} loss (kBTU)	E _{aux.} (kBTU)	Q _{aux.} loss (kBTU)	W _{aux.} (kWh)	P (%)	W _{op} (kWh)	W _s (kWh)	USAGE RATE (\$/kWh)	ELEC. SAVED (\$)	HOURS SOLAR	HOURS AUX.
1	11/08/82	30	2085	683	32.7	1356	509	182	847	272	327.2	37.5	6.91	177	0.088	15.58	98.6	54.5
2	12/08/82	29	1869	469	25.1	786	347	149	439	173	174.0	44.1	4.93	134	0.086	11.52	65.5	29.0
3	01/06/83	17	1272	388	30.5	569	310	88	259	109	106.0	54.5	3.95	109	0.084	9.16	54.4	17.7
4	02/01/83	30	3177	1067	33.6	1222	841	205	381	251	187.7	68.8	8.67	272	0.085	23.12	122.8	31.3
5	03/03/83	27	3095	1081	34.9	1093	892	163	201	233	132.5	81.6	7.89	285	0.089	25.37	116.2	22.1
6	04/06/83	28	2844	1085	38.2	1381	970	132	411	214	179.0	70.2	9.54	307	0.087	26.71	138.3	29.8
7	05/04/83	28	3633	1425	39.2	1359	1137	263	222	223	132.9	83.7	11.57	354	0.089	31.51	167.1	22.2
8	06/01/83	28	4429	1870	42.2	1324	1503	377	-179	279	27.6	100.0	12.41	404	0.093	37.57	199.5	4.6
9	06/29/83	26	4277	1654	38.7	902	1128	448	-226	206	5.7	100.0	10.28	277	0.088	24.38	184.9	1.0
10	08/03/83	28	4105	1598	38.9	1004	1155	478	-151	244	21.5	100.0	11.54	311	0.085	26.44	196.3	3.6
11	08/31/83	34	4747	1902	40.1	1356	1385	497	-29	263	67.9	100.0	13.96	418	0.091	38.03	230.2	11.3
12	10/04/83	28	2746	1066	38.8	1949	923	212	1026	65	311.5	47.4	9.21	293	0.087	25.49	141.0	51.9
TOTALS		333*	38279	14288	37.3	14301	11100	3194	3201	2532	1673.5	77.6	110.86	3341	0.088	294.88	1714.8	279

* Data disregarded for 33 days

TABLE 3(continued)

MONTHLY PERFORMANCE INDICATORS
11/09/83-11/09/84

MONTH	START DATE	DATA DAYS	E _{in} (kBtu)	E _s (kBtu)	EFF _{oa} (%)	E _d (kBtu)	E _{sh} (kBtu)	Q _{s.t.} loss (kBtu)	E _{aux.} (kBtu)	Q _{aux.} loss (kBtu)	W _{aux.} (kWh)	P (%)	W _{op} (kWh)	W _s (kWh)	USAGE RATE (\$/kWh)	ELEC. SAVED (\$)	HOURS SOLAR	HOURS AUX.
13	11/09/83	29	2170	732	33.7	3327	717	27	2610	-103	732.8	21.6	6.84	237	0.079	18.72	103.8	122.1
14	12/08/83	28	1889	494	26.2	3665	562	-60	3103	-140	866.7	15.3	5.14	192	0.078	14.98	78.2	144.5
15	01/05/84	28	2413	568	23.5	1203	443	103	760	156	272.8	36.8	5.75	156	0.072	11.23	88.7	45.5
16	02/02/84	34	2801	920	32.8	2254	855	70	1399	178	459.9	37.9	9.32	280	0.071	19.88	143.3	76.7
17	03/07/84	29	3510	1295	36.9	1859	1163	150	696	211	263.6	62.6	9.78	364	0.082	29.85	145.5	43.9
18	04/05/84	26	3150	1250	39.7	1437	1034	153	403	160	173.4	72.0	9.55	323	0.087	28.10	143.4	28.9
19	05/01/84	35	4299	1772	41.2	1952	1521	281	431	262	198.2	77.9	14.79	471	0.097	45.69	224.1	33.0
20	06/05/84	30	4494	1943	43.2	1583	1586	347	-3	239	71.9	100.0	13.62	477	0.099	47.22	227.8	12.0
21	07/05/84	33	4462	1849	41.4	1487	1458	370	29	49	27.2	98.0	12.96	444	0.090	39.96	222.7	4.5
22	08/07/84	31	4500	*	*	1548	1575	*	-27	57	0.0**	100.0	13.21	472	0.093	43.90	220.0	0.0**
23	09/07/84	28	3659	1433	39.2	1022	1064	378	-42	34	0.0	100.0	10.37	325	0.094	30.55	160.2	0.0
24	10/05/84	35	3257	1205	37.0	892	926	275	-34	36	0.0	100.0	10.47	296	0.091	26.94	157.7	0.0
TOTALS		366	40604	13461	37.3	22229	12904	2094	9325	1139	3066.5	58.1***	121.8	4037	0.086	357.02	1915.4	511.1

* Missing data

** Auxiliary tank disconnected August 8, 1984

*** Leaks caused E_d to be excessively high during months 13 and 14, thereby lowering P, the percent of solar contribution to the heating load demand. Assuming a more realistic value of E_d=1500 for months 13 and 14 would yield approximately 71% solar contribution.

element was installed in the auxiliary tank, and seven days of monitoring data was disregarded. During month 9 the circuit breaker for the solar loop circulating pump was mistakenly turned off by someone at the rest area; nine days of data were disregarded. By month 12 fluid pressure in the solar loop which had slowly been dropping reached the minimum allowable level and a defective air vent was replaced. Also, a defective temperature sensor in the solar loop which caused the circulating pump to run continuously for six days was replaced. A total of eight days of data was disregarded.

It was noticed that two hot water faucets in the men's lavatory began leaking at a significant rate during the end of month 12 causing the domestic hot water demand to increase.

It can be seen in Table 3, page 22 that during month 8 $E_{AUX.}$, the auxiliary contribution to the domestic hot water heating load, became negative. $E_{AUX.}$ is calculated by subtracting E_{SH} , the solar thermal contribution to the domestic hot water heating load, from E_D the domestic hot water heating load. A negative $E_{AUX.}$ indicates a net heat loss from the solar tank due to having a two tank system. More heat loss occurs in a two tank design than in a one tank design. A reduction in heat loss was experienced when the solar system was modified to a one tank system on August 6, 1984. See $E_{AUX.}$ for months 22, 23, and 24 in Table 3, page 23.

For the second year of operation the domestic hot water heating load demand was 22,229 kBTU. However, it should be noted that during months 13 and 14 leaking faucets which were measured to be approximately 90 gallons per day increased the total heating load by approximately 4,000 kBTU. The solar thermal contribution to the heating load was 12,904 kBTU which resulted in a 58.1% solar contribution for the year. The solar system and monitoring system operated satisfactorily for the second year of operation (366 days) and performance data is included in Table 3, page 23.

The leaks mentioned above were repaired during the first week of month 15 upon receipt of parts. The solar and monitoring system operated without any problems for the next several months.

During the second year of operation it was decided that a one tank system which derived heat solely from the solar panels would be evaluated during the summer months. During month 21 on July 12, 1984 the auxiliary (existing) electric hot water tank was valved off. It was expected that 100% of the domestic hot water heating load would be supplied by the solar loop since during the first year of operation the solar contribution to the load was 100% for four months (months 8 to 11). More significantly, as can be seen in Table 3, page 23, for months 21 - 24 heat losses, $Q_{S.T. Loss}$ from the solar tank and $Q_{AUX. Loss}$ from the auxiliary tank and piping between the solar tank, auxiliary tank and mixing valve, were reduced. As expected the one tank system operated with less heat loss and therefore more efficiently than the two tank system.

On August 6, 1984 the auxiliary electric hot water tank, although valved off, developed an irreparable leak. This tank was removed and after the successful operation of the one tank system it was decided that in lieu of a new auxiliary tank, electric heating elements would be installed in the solar tank to provide auxiliary heating as needed.

During month 22 a wire on BTU meter number 1, which measures E_S , the solar thermal energy supplied to the preheat storage tank, was disconnected. The wire was connected on September 5, 1984, however, the value of E_S is not included in Table 3 because some data was lost while the BTU meter was disconnected.

During month 24 on October 16, 1984 two 4,500 watt heating elements were installed in the solar hot water tank. As of this modification the solar tank with back-up electric heating elements provides the total domestic hot water requirement for the rest area.

LIFE CYCLE COST ANALYSIS

INTRODUCTION

This cost analysis, which has 1982 as its base year, is an updated version of the March 1980 life cycle cost analysis which was submitted to FHWA under Task A of the Work Plan in the demonstration project contract. This version includes actual equipment and installation costs for the solar domestic hot water system, and more accurate estimates of annual hot water demand in BTU, electricity usage rates, the electricity replaced by solar energy, and maintenance costs. These more accurate estimates were made based on monitored data for two years of system operation.

This life cycle cost analysis has been prepared in accordance with the USDOT Federal Highway Administration's Solar Demonstration Project Guidelines as outlined in the contract for this project (No. DOT-FH-15-386). A "life cycle cost analysis" is a form of economic analysis which will determine if a particular "solar" heating system is more economical than a comparable "conventional" heating system over the entire period of system life (20 years for this analysis). This type of analysis is realistic because it accounts for the time value of money.

In this analysis, the total cost of the conventional heating system will be compared to the total cost of the solar heating system PLUS the backup system. Total cost here will involve only equipment, installation, fuel and maintenance costs, and comparisons made on the present value of the costs. See Appendix B, page 75 for Federal Guidelines regarding built-in assumptions for this analysis.

The total cost of the solar heating system plus backup system will be calculated for a system designed to be installed with the original construction of

a facility. Thus, the equipment costs for the Harding Solar DHW system, which was a retrofit installation, will be adjusted to develop equipment costs for a system installed when a facility is first constructed.

The present configuration of the Harding solar system is recommended. Originally the Harding system was a two tank system using the existing 120 gallon electric hot water tank at the rest area for backup heating and a newly installed 120 gallon solar heat exchanger tank. During the second year of operation, the electric hot water tank developed a leak which could not be repaired. The Harding system was then modified to a one tank system with backup heating being done by electric heating elements installed in the solar heat exchanger tank. This configuration is working well and is more efficient than the previous two tank system because total storage tank heat losses have been reduced. This is why a system with one tank containing both a heat exchanger and electric heating elements for backup heating is recommended for solar DHW systems. It should be noted that this type of solar system still provides a backup heating system capable of supplying 100% of the hot water heating load if required.

COST OF CONVENTIONAL HEATING SYSTEM

The cost of a conventional electrical water heating system is defined as the present worth of the existing equipment including installation; plus 20 years of electric and maintenance expenses.

Equipment Costs (including installation) - The equipment required for the conventional water heating system is a 120 gallon water heater, which contains two 4,500 watt heating elements and thermostats, and an insulating blanket. The engineering and design work required for the conventional system is also included

in equipment costs. Accordingly, equipment costs are shown below; they include installation.

Equipment (including installation)

Engineering and design	\$800
120 Gallon water heater	950
Insulating blanket	50
<hr/>	
TOTAL	\$1,800

Electric Costs - To calculate these costs a 10% inflation rate is used for fuel costs, and a 10% rate of return on the investment per year is assumed as per Appendix B, page 75. Electric costs are calculated from an estimate of the average annual hot water demand at the rest area over 20 years. This annual demand is specified in millions of BTU which are then converted to kilowatt-hours of electrical power required per year using a conversion factor. Annual electrical cost is then calculated by multiplying kilowatt-hours times the electricity usage rate in cents per kilowatt-hour.

Disregarding months with significant faucet leaks and adjusting to a yearly basis, the hot water demand at the Harding Township rest area averaged about 16.5 million BTU per year for the first two years of operation of the solar water heating system (November 1982 - November 1984). Using 16.5 million BTU as the annual demand for base year 1982, and assuming annual demand will increase at an average rate of 5% per year for 20 years, the average annual hot water demand at the Harding Township rest area over the 20 year period is estimated at 30 million BTU. It is felt a 5% growth rate is realistic because demand at the rest area increased nearly 25% between the first and second year of operation, and in addition, demand is expected to significantly increase when the section of I-287 from Exit 38 to the New York State Thruway is opened.

Using the conversion factor 1 kilowatt-hour = 3,413 BTU's, the average annual hot water demand of 30 million BTU converts to 8,790 kilowatt-hours of electrical power required yearly from a conventional water heating system. To obtain the electric costs for the conventional system, an electricity usage rate must be applied to this power requirement. The electricity usage rate was obtained from New Jersey Power and Light's bills for the Harding Township rest area for the first two years of solar system operation (November 1982 -November 1984). These bills, which show a lump sum of both space and hot water heating, indicated an average electricity usage rate of approximately 9¢ per kilowatt-hour. Applying this usage rate to the conventional system, the annual electric cost to heat domestic water is (8,790 kilowatt-hours) x (\$0.09/kilowatt-hour) = \$790 for the conventional system.

Table 4 on page 30 shows electric costs for the conventional hot water heating system. The future worth of electric costs is listed in the second column for 20 years at a 10% inflation rate per year. The corresponding present worth value, at a 10% annual rate of return on investment, is listed in the third column. For example, in Table 4, \$790 invested in base year 1982 (the present year) at a 10% annual rate of return on investment for 14 years will be worth \$3,000 in future year 1996. The relationship between present and future worth is shown at the bottom of Table 4. The sum of present worth costs for 20 years is the basis for the systems comparison. Thus, total present worth electric cost for the conventional hot water system for the 20 year life is \$15,800.

Maintenance Costs - Only routine maintenance costs are assumed for the conventional electric hot water system. This routine maintenance, such as draining the hot water tank yearly, is estimated as 4 hours of labor at \$15 an hour for a total of \$60 a year.

TABLE 4: CONVENTIONAL SYSTEM ELECTRIC COSTS

<u>Year</u>	<u>Future worth of electric cost @ 10% inflation/yr.</u>	<u>Present worth value @ 10% rate of return on investment</u>
1982		\$790
1983	\$ 869	790
1984	956	790
1985	1,051	790
1986	1,157	790
1987	1,272	790
1988	1,400	790
1989	1,539	790
1990	1,693	790
1991	1,863	790
1992	2,049	790
1993	2,254	790
1994	2,479	790
1995	2,727	790
1996	3,000	790
1997	3,300	790
1998	3,630	790
1999	3,993	790
2000	4,392	790
2001	4,832	790
2002	5,315	790

TOTAL PRESENT WORTH OF ELECTRIC COST FOR 20 YEARS = \$15,800.

PRESENT WORTH = FUTURE WORTH $\left(\frac{1}{(1 + i)^n} \right)$ $i = 0.10$ (10% rate of return on investment)
 $n =$ number of years

Table 5, page 32 lists maintenance cost for 20 years for the conventional hot water system. The future worth of the maintenance costs is listed in the second column for 20 years at a 7% rate of inflation per year. The corresponding present worth value, at a 10% annual rate of return on investment, is listed in the third column. Summing the third column, the present worth maintenance costs for the conventional hot water system for the 20 year life is \$910.

COST OF SOLAR HEATING SYSTEM

The cost of the solar domestic hot water (DHW) system is defined as all costs due to solar heating, plus the cost of the backup heating system. Costs for the retrofit solar DHW system installed at the Harding Township rest area will be used to develop estimates of the costs over 20 years of a solar DHW system installed at the time of original construction of a facility.

Equipment Costs (including installation) - Total equipment costs include the cost for engineering and design as well as the installed cost of the solar DHW system.

The cost for engineering and design was estimated as \$1,200 (50% more than for the conventional hot water system).

The installed cost for the retrofit solar DHW system at the Harding Township rest area was \$16,745. This amount includes equipment and installation costs. Of this amount, approximately \$4,800 was spent for monitoring equipment required for this research study but not required for a standard solar system. This brings to about \$12,000 the equipment cost for the retrofit solar DHW system at the Harding Township rest area. This equipment cost must be adjusted to obtain a value for the cost of a solar DHW system plus backup system installed with original construction of a facility rather than as a retrofit like the Harding system.

TABLE 5: CONVENTIONAL SYSTEM MAINTENANCE COSTS

<u>Year</u>	<u>Future worth of maintenance cost @ 7% inflation/year</u>	<u>Present worth value @ value @ 10% rate of return on investment</u>
1982		\$60
1983	\$ 64	58
1984	69	57
1985	74	56
1986	79	54
1987	84	52
1988	90	51
1989	96	49
1990	103	48
1991	110	47
1992	118	45
1993	126	44
1994	135	43
1995	145	42
1996	155	41
1997	166	40
1998	177	39
1999	190	38
2000	203	37
2001	217	35
2002	232	34

TOTAL PRESENT WORTH OF MAINTENANCE COST FOR 20 YEARS = \$910

PRESENT WORTH = FUTURE WORTH $\left(\frac{1}{(1 + i)^n} \right)$ $i = 0.10$ (10% rate of return on investment)
 $n =$ number of years

The present configuration of the Harding Solar system (one storage tank with both heat exchanger and backup heating elements) is recommended for the solar hot water system. Therefore equipment costs for the Harding solar DHW system as originally installed must be adjusted to arrive at the cost for the present configuration. Two adjustments will be made. Since a second storage tank with backup electric heating is not needed for the recommended configuration, piping costs for connection to this tank are subtracted from the original equipment costs. Secondly since electric heating elements for backup heating had to be purchased and installed in the solar heat exchanger tank, this cost will be added to the original equipment cost. The subtracted cost for connection to the second storage tank is estimated as \$500 while the added cost to install backup heating in the solar tank is estimated as \$300. Therefore, the \$12,000 in equipment costs as originally installed is adjusted downward by \$200 to arrive at \$11,800 as an estimate of the equipment costs for a solar DHW system plus backup system like that presently operating at the Harding rest area but installed when a facility is constructed.

Adding the cost for engineering and design (\$1,200) to the installed cost of the solar domestic hot water system, plus backup (\$11,800), a total equipment cost of \$13,000 is obtained.

Electric Costs - Electrical costs for the solar DHW system are calculated from the average annual hot water demand, the percentage of the demand satisfied by the electrical backup system, and the electricity usage rate.

As outlined on page 28, the average annual hot water demand at the Harding Township rest area is estimated as 30 million BTU. From two years of monitoring of the Harding solar system the annual percentage of the demand satisfied by the electrical backup system was about 32.5%. Using this

percentage, it is calculated that $(30 \text{ million BTU}) \times (0.325) = 9.75 \text{ million BTU}$ of the hot water demand will be met annually by the electrical backup system. This converts to 2,857 kilowatt-hours using the conversion factor, 1 kilowatt-hour = 3,413 BTU's. Thus, 2,857 kilowatt-hours of electrical power will be required annually for backup heating. The electricity usage rate at the Harding Township rest area from November, 1982 to November, 1984 was about 9¢ per kilowatt-hour. Therefore, the annual electric cost for the solar domestic hot water system is estimated as $(2,857 \text{ kilowatt-hours}) \times (\$0.09/\text{kilowatt-hour}) = \255 .

Table 6 on page 35 shows electric costs for the solar hot water system. Present worth calculations for 20 years are done in the same manner as for the conventional hot water system (see Table 4). An annual inflation rate of 10% is assumed for electricity usage rates, and a 10% annual rate of return on investment is also assumed. Accordingly, the total present worth electric cost for the solar domestic hot water system for the 20 year life is \$5,100.

Maintenance Costs - These costs will be based on the amount of maintenance on the solar DHW system at the Harding Township rest area. Only minor maintenance of the Harding solar system has been required since operation began in November 1982. For example, the types of maintenance required were repressurizing the solar loop, replacing an air vent, and replacing a temperature sensor of the system controller. Based on this experience, the following annual maintenance is assumed for the solar domestic hot water system.

<u>Annual Maintenance</u>	
- 8 hours of labor at \$15/hour =	\$120
- parts, antifreeze, etc.	40
<hr/>	
TOTAL	\$160

Thus the annual maintenance cost is estimated as \$160 for the solar DHW system.

TABLE 6: SOLAR SYSTEM ELECTRIC COSTS

<u>Year</u>	<u>Future worth of electric cost @ 10% inflation/yr.</u>	<u>Present worth value @ 10% rate of return on investment</u>
1982		\$255
1983	\$ 286	255
1984	315	255
1985	346	255
1986	381	255
1987	419	255
1988	461	255
1989	507	255
1990	557	255
1991	613	255
1992	674	255
1993	741	255
1994	816	255
1995	897	255
1996	987	255
1997	1,085	255
1998	1,194	255
1999	1,313	255
2000	1,445	255
2001	1,589	255
2002	1,748	255

TOTAL PRESENT WORTH OF ELECTRIC COST FOR 20 YEARS = \$5,100

PRESENT WORTH = FUTURE WORTH $\left(\frac{1}{(1 + i)^n} \right)$ $i = 0.10$ (10% rate of return on investment)
 $n =$ number of years

Table 7, page 37 lists maintenance costs for 20 years for the solar system. The future worth of the maintenance costs is listed in the second column for 20 years at a 7% rate of inflation per year. The corresponding present worth value, at a 10% annual rate of return on investment, is listed in the third column. Accordingly, summing the third column, the total present worth maintenance costs for the solar DHW system for the 20 year life is \$2,425.

LIFE CYCLE COST SUMMARY

Below is a table which summarizes all the information discussed in this analysis. The 20 year life cycle cost analysis indicates that the cost of the solar hot water system plus backup is about \$2,000 more than the cost of the conventional system.

	<u>Conventional System</u>	<u>Solar System Plus Backup</u>
Equipment Cost	\$1,800	\$13,000
Electric Cost	15,800	5,100
Maintenance Cost	900	2,425
TOTAL COST	\$18,510	\$20,525

This life cycle cost analysis is more accurate than the March 1980 analysis because it reflects actual equipment, electric, and maintenance costs for the solar DHW system operating at the Harding Township rest area. However, the \$2,000 cost difference between the evaluated systems is insufficient to indicate that solar heating of domestic water is not an economically feasible alternative to conventional hot water heating. This difference is not significant given the inaccuracy in estimating hot water demand, interest rates for investment, and inflation rates of electricity prices for more than a few years into the future.

TABLE 7: SOLAR SYSTEM MAINTENANCE COSTS

<u>Year</u>	<u>Future worth of maintenance cost @ 7% inflation/yr.</u>	<u>Present worth value @ 10% rate of return on investment</u>
1982		\$160
1983	\$171	155
1984	183	151
1985	196	147
1986	210	143
1987	224	139
1988	240	135
1989	257	132
1990	275	128
1991	294	125
1992	315	121
1993	337	118
1994	360	115
1995	386	112
1996	413	109
1997	441	106
1998	472	103
1999	505	100
2000	541	97
2001	579	95
2002	619	92

TOTAL PRESENT WORTH OF MAINTENANCE COST FOR 20 YEARS = \$2,425

PRESENT WORTH = FUTURE WORTH($\frac{1}{(1 + i)^n}$) $i = 0.10$ (rate of return on investment)
 $n =$ number of years

REFERENCES

1. Sasor, S. R., and Flesch, J., "Solar Domestic Hot Water System, Harding Township Rest Area Building, I-287," Interim Report, February, 1984, Report No. 84-013-7799.

APPENDIX A

MONTHLY MONITORING REPORTS NUMBERS 1 THROUGH 24

Operational status and description of significant performance indicators.
See Table 3, pages 22 and 23 for value of performance indicators.

MONTHLY MONITORING REPORT NO. 1

(November 8 - December 8, 1982)

This is the first of the monthly monitoring reports. Included is a summary of the operational status of the Harding Township Rest Area solar heating and monitoring systems, and a table listing the twelve indicators of system performance covered in the attached revised monitoring plan. The monitoring plan describes each of these performance indicators in detail, including the method of calculation. System performance is monitored using the instrumentation shown in the attached schematic diagram. The main components are a pyranometer, BTU meters, and kilowatt-hour meters.

Operational Status

For this period (30 days), both the solar heating and monitoring systems operated satisfactorily. Neither system had any downtime, nor was there any need for maintenance or repair work. The solar heating system operated for a total of 98.6 hours; the auxiliary electrical heating system, for 54.5 hours.

Performance Indicators

Page 2 lists the values of the indicators of system performance. Note that 32.7% of the incident solar energy was supplied to the preheat storage tank, and that 37.5% of the total hot water heating load was supplied by solar means. The electricity saved by the solar system was estimated as 177 kilowatt-hours which is equivalent to \$15.58 at a usage rate of 8.8 cents per kilowatt-hour.

MONTHLY MONITORING REPORT NO. 2
(December 8, 1982 - January 6, 1983)

This report includes a summary of the operational status of the Harding Township Rest Area solar heating and monitoring systems, and a table listing the twelve indicators of system performance covered in the revised monitoring plan. The monitoring plan describes each of these performance indicators in detail, including the method of calculation.

Operational Status

For this period (29 days) both the solar heating and monitoring systems operated satisfactorily. Neither system had any downtime, nor was there any need for maintenance or repair work. The solar heating system operated for a total of 65.5 hours; the auxiliary electrical heating system, for 29.0 hours.

Performance Indicators

Page 2 lists the values of the indicators of system performance. Note that 25.1% of the incident solar energy was supplied to the preheat storage tank, and that 44.1% of the total hot water heating load was supplied by solar means. The electricity saved by the solar system was estimated as 134 kilowatt-hours which is equivalent to \$11.52 at a usage rate of 8.6 cents per kilowatt-hour.

MONTHLY MONITORING REPORT NO. 3

(January 6 - February 1, 1983)

A summary of the operational status of the Harding Township Rest Area solar heating and monitoring systems is given, and a table listing the twelve indicators of system performance described in the revised monitoring plan is provided. Problems which developed in the auxiliary system (electrically heated tank) caused unreliable values of performance indicators during the period January 12 - 21. Accordingly, results for this nine day period have not been included in this monthly report. Thus, this report covers the system's performance for the periods January 6 - 12 and January 21 - February 1, 1983.

Operational Status

From January 6 - February 1 the solar heating and monitoring systems operated satisfactorily with no need for maintenance or repair. However, during the period from January 12 -21, a leak developed near one of the 6000 watt elements of the electrically heated tank of the auxiliary system. On noticing the leak, rest area personnel turned off the heating elements of the tank. On January 18, maintenance personnel stopped the leak by making a temporary repair, and reenergized the heating elements. In so doing, they left the insulating jacket for the auxiliary tank partially open pending the arrival and installation of a new 6000 watt heating element.

MONTHLY MONITORING REPORT NO. 4

(February 1 - March 3, 1983)

Included is a summary of the operational status of the Harding Township Rest Area solar heating and monitoring systems, and a table listing the twelve indicators of system performance covered in the revised monitoring plan.

Operational Status

For this period (30 days) both the solar heating and monitoring systems operated satisfactorily. Neither system had any downtime, nor was there any need for maintenance or repair work. The auxiliary heating system also operated satisfactorily. The replacement 6000 watt heating element ordered for the auxiliary tank did not arrive, thus the insulating jacket of this tank was partially open for this entire monthly period. The solar heating system operated for a total of 122.8 hour; the auxiliary electrical heating system, for 31.3 hours.

Performance Indicators

Page 2 lists the values of the indicators of system performance. Note that 33.6% of the incident solar energy was supplied to the preheat storage tank, and that 68.8% of the total hot water heating load was supplied by solar means. The electricity saved by the solar system was estimated as 272 kilowatt-hours which is equivalent to \$23.12 at a usage rate of 8.5 cents per kilowatt-hour.

MONTHLY MONITORING REPORT NO. 5

(March 3 - April 6, 1983)

Included is a summary of the operational status to the Harding Township Rest Area solar domestic hot water heating system, and a table listing the twelve indicators of system performance covered in the revised monitoring plan. On March 22, a replacement 6000 watt heating element was installed in the auxiliary tank. (Note that it was decided to replace the existing element when a leak developed during the period January 12 - 21. A temporary repair was made at that time. See Monitoring Report No. 3.) This installation resulted in unreliable values of performance indicators for the period March 16 - 23. Therefore, results for this seven day period have not been included in this monthly report. Hence this report covers the system's performance for the periods March 3 - March 16 and March 23 - April 6; a total of 27 days.

Operational Status

From March 3 to April 6 the solar heating and monitoring systems operated satisfactorily with no need for maintenance or repair. However, as mentioned, on March 22 a replacement 6000 watt heating element was installed in the storage tank of the auxiliary system which necessitated that power to this tank be turned off. Though the repair was completed and the auxiliary tank was reenergized, the insulating jacket for this tank was still not closed by maintenance personnel because they did not

have the proper materials to do so. They have since ordered these materials.

Performance Indicators

Page 3 lists the values of the indicators of system performance. Notice that these performance indicators have been calculated for the 27 days from March 3 to 16 and March 23 to April 6. Performance from March 16 - 23 has not been included since the total system was not operating properly over this entire seven day period*; this resulted in unreliable values of performance indicators. Also recall that for this entire monitoring period the auxiliary tank was only partially covered by the insulating jacket. The auxiliary tank has insulation in addition to this jacket. For the 27 days, the solar heating system operated for a total of 116.2 hours; the auxiliary electrical system, for a total of 22.1 hours. Note that 34.9% of the incident solar energy was supplied to the preheat storage tank, and that 81.6% of the total hot water heating load was supplied by solar means. The electricity saved by the solar system was estimated as 285 kilowatt-hours which is equivalent to \$25.37 at a usage rate of 8.9 cents per kilowatt-hour.

*Meter readings are taken on a weekly basis.

MONTHLY MONITORING REPORT NO. 6

(April 6 - May 4, 1983)

This report is a summary of the operating status of the Harding Township Rest Area solar hot water heating and monitoring systems. Included is a table listing the twelve indicators of system performance covered in the revised monitoring plan. The monitoring plan describes each of the performance indicators in detail, including the method of calculation.

Operational Status

For the period shown above (28 days) both the solar heating and monitoring systems operated satisfactorily. Neither system was shutdown for any reason. The insulating jacket on the auxiliary storage tank was repaired by Maintenance personnel on April 20, 1983 and is secured properly and completely closed (see Monitoring Report No. 5). The solar heating system operated for a total of 138.3 hours; the auxiliary heating system, for 29.8 hours.

Performance Indicators

System performance indicator values are listed on page 2. Note that prior to April 20th the insulating jacket on the auxiliary system storage tank was not completely closed. As you can see 38.2% of the incident solar energy was supplied to the preheat storage tank, and 70.2% of the total hot water heating load was supplied by solar means. The electricity saved by the solar system was estimated as 307 kilowatt-hours which is equivalent to \$26.71 at a usage rate of 8.7 cents per kilowatt-hour.

MONTHLY MONITORING REPORT NO. 7

(May 4 - June 1, 1983)

This report includes a summary of the operational status of the Harding Township Rest Area solar heating and monitoring systems, and a table listing the twelve indicators of system performance covered in the revised monitoring plan. The monitoring plan describes each of the performance indicators in detail, including the method of calculation.

Operational Status

For this 28 day period both the solar heating and monitoring systems operated satisfactorily. Neither system had any downtime, nor was there any need for maintenance or repair work. The solar heating system operated for a total of 167.1 hours; the auxiliary heating system, for 22.2 hours.

Performance Indicators

Page 2 lists the values of the indicators of system performance. Observe that 39.2% of the incident solar energy was supplied to the preheat storage tank, and that 83.7% of the total hot water heating load was supplied by solar means. The electricity saved by the solar system was estimated as 354 kilowatt-hours which is equivalent to \$31.51 at a rate of 8.9 cents per kilowatt-hour.

MONTHLY MONITORING REPORT NO. 8

(June 1 - June 29, 1983)

This report includes a summary of the operational status of the Harding Township Rest Area solar heating and monitoring systems, and a table listing the twelve indicators of system performance covered in the revised monitoring plan. The monitoring plan describes each of the performance indicators in detail, including the method of calculation.

Operational Status

For this 28 day period both the solar heating and monitoring systems operated satisfactorily. The solar heating system operated for a total of 199.5 hours; the auxiliary heating system, for 4.6 hours.

Performance Indicators

Page 2 lists the values of the indicators of system performance. Observe that 42.2% of the incident solar energy was supplied to the preheat storage tank, and that 100% of the total hot water heating load was supplied by solar means. Note that E_{AUX} was negative for this period (-179 kBTU). This indicates that there was a net heat loss from the auxiliary storage tank which resulted in 4.6 hours of electric heating element operation. The solar heating system supplied to the auxiliary tank 1503 kBTU (E_{SH}) which exceeded the domestic hot water heating load demand ($E_D = 1324$ kBTU). It is probable that in a single tank storage

system (i.e. a system with no auxiliary tank but instead a solar storage tank with a built-in electric heating element), no auxiliary heat would have been required during this period.

The electricity saved by the solar system was estimated as 404 kilowatt-hours which is equivalent to \$37.57 at a rate of 9.3 cents per kilowatt-hour.

MONTHLY MONITORING REPORT NO. 9

(June 29 - August 3, 1983)

This report summarizes the operational status of the Harding Township Rest Area solar heating and monitoring systems. It also includes a table listing the twelve indicators of system performance covered in the revised monitoring plan (May 1983).

For the 35 day period, performance data is presented for only 26 days (July 8 - August 3) because power to the solar collector loop was mistakenly turned off apparently two days into the week of June 29 to July 8. The auxiliary electrical heating system remained energized; thus hot water was still supplied to the rest rooms. Power to the solar loop was restored (a circuit breaker was turned back on) by the site monitor during his visit on July 8. Since the system is monitored weekly, unreliable data resulted for the entire week of June 29 to July 8, and therefore performance for this period was deleted from this report.

Operational Status

The solar heating and monitoring systems operated satisfactorily for the 26 day period from July 8 to August 3. The solar heating system operated for 184.9 hours, while the auxiliary heating system operated for just 1.0 hour.

Performance Indicators

The values of the indicators of system performance are shown on page 3. Only data for the period July 8 to August 3 is included

for the reasons mentioned earlier. Approximately 38.7% of the incident solar energy was supplied to the preheat storage tank, and 100% of the total hot water heating load was supplied by solar means. Note that again the heat supplied by the solar water heating system to the heating load ($E_{SH} = 1128$) exceeded the domestic hot water heating load demand ($E_D = 902$ kBTU). E_D was considerably less than in the previous month due primarily to lower hot water usage and a higher cold water supply temperature. Thus once again, there was a net heat loss due to the auxiliary storage tank ($E_{AUX.} = -226$ kBTU).

The electricity saved by the solar system was estimated to be 277 kilowatt-hour which is equivalent to \$24.38 at a rate of 8.8 cents per kilowatt-hour.

MONTHLY MONITORING REPORT NO. 10

(August 3 - August 31, 1983)

This report includes a summary of the operational status of the Harding Township Rest Area solar heating and monitoring systems, and a table listing the twelve indicators of system performance covered in the revised monitoring plan (May 1983).

Operational Status

For the period (28 days) both the solar heating and monitoring systems operated satisfactorily. Neither system had any downtime, nor was there any need for maintenance or repair work. The solar heating system operated for a total of 196.3 hours; the auxiliary electrical heating system operated for a period of 3.6 hours.

Performance Indicators

Page 2 lists the values of the indicators of system performance. Note that 38.9% of the incident solar energy was supplied to the preheat storage tank, and that 100% of the total hot water heating load was supplied by solar means. Note that like the last two months (1) the percent solar contribution to the domestic hot water heating load was 100%, (2) the heat supplied by the solar heating system to the heating load ($E_{SH} = 1155$ kBTU) exceeded the domestic hot water heating load demand ($E_D = 1004$ kBTU), and (3) there was a net heat loss due to the auxiliary storage tank ($E_{AUX.} = -151$ kBTU).

The electricity saved by the solar system was estimated as 311 kilowatt-hours which is equivalent to \$26.44 at a usage rate of 8.5 cents per kilowatt-hour.

MONTHLY MONITORING REPORT NO. 11

(August 31 - October 4, 1983)

This report summarizes the performance of the Harding Township rest area solar domestic hot water and monitoring systems.

Operational Status

For this 34 day period, both the solar water heating system and the monitoring system operated satisfactorily. The solar water heating system operated for a total of 230.2 hours, and the auxiliary electrical heating system operated for 11.3 hours.

Performance Indicators

Page 2 lists the values of the indicators of system performance. Note that 40.1% of the incident solar energy was supplied to the preheat storage tank, and that 100% of the total hot water heating load was supplied by solar means. Like the last three months (1) the percent solar contribution to the domestic hot water heating load was 100%, (2) the heat supplied by the solar hot water heating system to the heating load ($E_{SH} = 1385$ kBTU) exceeded the domestic hot water heating load demand ($E_D = 1356$ kBTU), and (3) there was a net heat loss due to the auxiliary storage tank ($E_{AUX.} = -29$ kBTU).

The electricity saved by the solar domestic hot water system was estimated as 418 kilowatt-hours which is equivalent to \$38.03 at a usage rate of 9.1 cents per kilowatt-hour.

MONTHLY MONITORING REPORT NO. 12

(October 4 - November 9, 1983)

This report summarizes the performance of the Harding Township rest area solar domestic hot water and monitoring systems. For the 36 day period, performance data is presented for only 28 days (October 4 to 27 and November 4 to 9). System performance between October 27 and November 4 is not included in this report because for this 8-day period the solar hot water system operated improperly due to the problems mentioned below.

Operational Status

For the month, several minor problems developed in the domestic hot water system. First, in the solar collector loop, fluid pressure, which had been gradually decreasing since the start of operation, finally reached the minimum allowable for proper operation of the circulating pump. A defective air vent was discovered and after it was replaced the system was repressurized to the proper reading (30 psi at approximately 110°F) on October 27. This work was done by the subcontractor under the terms of the one year system warranty. Second, during the week of October 27 to November 3, the solar collector loop operated continuously (both day and night) for nearly six days even during periods (particularly overnight) when solar heat was not available at the collectors. This condition was caused by a faulty solar loop temperature sensor connected to the system controller. The sensor was replaced under warranty on November 4

by the subcontractor and normal operation resumed. Third, two hot water faucets are leaking at a significant rate. Steps have been taken to get the faucets repaired by DOT's maintenance personnel.

For the 28 days for which the performance indicators were calculated, the solar heating system operated for 141.0 hours, while the auxiliary heating system operated for 51.9 hours.

Performance Indicators

Page 3 lists the indicators of system performance for the period from October 4 to 27 and November 4 to 9 (28 days). Notice that 38.8% of the incident solar energy was supplied to the preheat storage tank. Approximately 47.4% of the total hot water heating load was supplied by solar means. The leaking of the two hot water faucets resulted in the highest hot water heating load demand ($E_D = 1,949$ kBTU) of the twelve months monitored. This record high demand coupled with a below average amount of solar insolation ($E_{IN} = 2,746$ kBTU) resulted in a twelve month high for the auxiliary thermal contribution to the domestic hot water heating load ($E_{AUX.} = 1,026$ kBTU). This explains the drop in percent solar contribution to the domestic hot water heating load from 100% last month to 47.4% for this month.*

The electricity saved by the solar domestic hot water system was estimated as 293 kilowatt-hours which is equivalent to \$25.49 at a usage rate of 8.7 cents per kilowatt-hour.

*Subsequent to this month, the hot water faucet leaks were stopped and the hot water heating load demand returned to normal.

MONTHLY MONITORING REPORT NO. 13

(November 9 - December 8, 1983)

This report summarizes the performance of the Harding Township Rest Area solar domestic hot water (DHW) and monitoring systems.

Operational Status

For the 29 day period covered by this report, both the solar heating and monitoring systems performed well. The solar heating system operated for a 103.8 hours; the auxiliary heating system for 122.1 hours. This was the first month in which the auxiliary water heating system operated for more hours than the solar system apparently due to the leaks mentioned below.

Performance Indicators

Page 3 lists the values of the indicators of system performance. Overall efficiency in supplying solar energy ($\text{eff}_{\text{OA}} = 33.74\%$) and the total solar energy supplied to the preheat storage tank ($E_S = 732 \text{ kBTU}$) remained at nearly the same levels as for the corresponding period of the previous year (Month No. 1).

Some of the performance indicators were affected by two leaking hot water faucets in the men's room. These leaks were significant (approximately 90 gallons per day) and apparently were responsible for the highest readings of DHW demand ($E_D = 3327 \text{ kBTU}$), auxiliary contribution to the DHW Load ($E_{\text{AUX.}} = 2610 \text{ kBTU}$), and operating energy for the auxiliary system ($W_{\text{AUX.}} = 732.8 \text{ kWh}$) for any of the thirteen months, as well as the lowest monthly

readings of percent solar contribution to the DHW load ($P = 21.6\%$, heat loss from the preheat storage tank ($Q_{S.T. Loss} = 27$ kBTU), and heat loss from the auxiliary tank and adjacent piping ($Q_{AUX. Loss} = -103$ kBTU).*

The electricity saved by the solar system was estimated to be 237 kilowatt-hours, which is equivalent to \$18.72 at a rate of 7.9 cents per kilowatt-hour.

Thus, the elevated DHW demand increased the solar thermal contribution to the DHW load ($E_{SH} = 717$ kBTU) and the electricity saved by the solar heating system (\$18.72) by 41% and 20%, respectively, from the previous year's values and reduced heat losses from the storage tanks and adjacent piping.

*The leaks, which were discovered at the end of last month, were stopped in January 1984. For January, most of the indicators returned to approximately the previous year's levels.

MONTHLY MONITORING REPORT NO. 14

(December 8, 1983 - January 5, 1984)

This report summarizes the performance of the Harding Township Rest Area solar domestic hot water (DHW) and monitoring systems.

Operational Status

For the 28 day period covered by this report both the solar heating and monitoring systems operated well. The solar heating system operated for a total of 78.2 hours; the auxiliary electrical heating system operated for 144.5 hours. Like last month, the auxiliary system operated for more hours than the solar system.

During this 28 day period two hot water faucets located in the men's room continued to leak at a substantial rate (90 gallons per day).*

Performance Indicators

Indicators of system performance are listed on page 3. Overall efficiency in supplying solar energy ($\text{eff}_{\text{OA}} = 26.2\%$) and the total solar energy supplied to the preheat storage tank ($E_{\text{S}} = 494 \text{ kBTU}$) remained at nearly the same levels as for the corresponding period of the previous year (Month No. 2).

*The leaks were stopped during the week of January 5 - 12, 1984.

Note that similar to last month, the two leaking hot water faucets significantly affected several indicators. Fourteen month highs were attained for DHW demand ($E_D = 3665$ kBTU), auxiliary contribution to the DHW load ($E_{AUX.} = 3103$ kBTU), and operating electrical energy for the auxiliary system ($W_{AUX.} = 866.7$ kWh); and fourteen month lows, for percent solar contribution to the DHW load ($P = 15.3\%$), heat loss from the preheat storage tank ($Q_{S.T. Loss} = -60$ kBTU), and heat loss from the auxiliary tank and adjacent piping ($Q_{AUX. Loss} = -140$ kBTU).

The electricity saved by the solar domestic hot water system was estimated as 192 kilowatt-hours which is equivalent to \$14.98 at a usage rate of 7.8 cents per kilowatt-hour.

The elevated demand increased the solar thermal contribution to the DHW load ($E_{SH} = 562$ kBTU) and the electricity saved by the solar heating system (\$14.98) by 62% and 30%, respectively, from the previous year's values. It also reduced heat losses from the storage tanks and associated piping.

MONTHLY MONITORING REPORT NO. 15

(January 5 - February 2, 1984)

This report summarizes the performance of the Harding Township Rest Area solar domestic hot water (DHW) and monitoring systems.

During the week of January 5 - 12, substantial leaks from two hot water faucets in the men's room were stopped by Department personnel. One faucet remains in use, while the other is shut-off pending replacement parts. Stopping these leaks, which amounted to about 90 gallons a day, had a considerable impact on DHW demand for this month, and consequently, hours of operation of the auxiliary heating system.

Operational Status

For this period (28 days) both the solar heating and monitoring systems operated satisfactorily. The solar heating system operated for a total of 88.7 hours; the auxiliary electrical heating system operated for 45.5 hours. The auxiliary system operated for nearly 100 fewer hours than for last month due to the large reduction in DHW demand which resulted from stopping the faucet leaks.

Performance Indicators

Page 3 lists the values of the indicators of system performance. Note that the overall efficiency in supplying solar energy ($\text{eff}_{\text{OA}} = 23.5\%$) fell to a fifteen month low; however, 36.8% of the total hot water heating load was supplied by solar means as

compared to 15.3% for last month when faucets were leaking significantly.

Stopping of these hot water faucet leaks produced a drop in DHW demand (E_D) to 1203 kBTU for this month from a fifteen month high of 3665 kBTU for last month. As mentioned, the lowered DHW demand resulted in nearly 100 fewer hours of operation of the auxiliary system than for last month, and accordingly the operating energy for this system ($W_{AUX.}$) fell to 272.8 kWh from last month's fifteen month high of 866.7 kWh. In addition, note that heat losses from the storage tanks and adjacent piping increased considerably.

The electricity saved by the solar system was estimated to be 156 kWh which is equivalent to \$11.12 at a usage rate of 7.2 cents per kilowatt-hour.

MONTHLY MONITORING REPORT NO. 16

(February 2 - March 7, 1984)

This report includes a summary of the operational status of the Harding Township Rest Area solar heating and monitoring systems. Also provided is a table listing the twelve indicators of system performance covered in the revised monitoring plan (May 1983).

Operational Status

For this 34 day period, both the solar heating and monitoring systems operated well. No maintenance or repair work was required during this time. The solar heating system operated for a total of 143.3 hours; the auxiliary electrical heating system was on for a period of 76.7 hours.

Performance Indicators

A look at the indicators listed on page 2 shows that 32.8% of the incident solar energy was supplied to the preheat storage tank, and 37.9% of the total hot water heating load was supplied by solar energy. For the corresponding month of the previous year (Month No. 4), 68.8% of the total heating load was provided by solar energy. The reduced solar contribution percentage for this month (P in table on next page) was primarily caused by less average daily solar insolation ($E_{IN} = 82.4$ kBTU/day as compared to 105.9 kBTU/day as compared to 40.7 kBTU/day for Month No. 4).

The electricity saved by the solar system was estimated as 280 kilowatt-hours. For a rate of 7.1 cents per kilowatt-hour, the savings is \$19.88.

MONTHLY MONITORING REPORT NO. 17

(March 7 - April 5, 1984)

This report includes a summary of the operational status of the Harding Township Rest Area solar heating and monitoring systems, and a table listing the twelve indicators of system performance described in the revised monitoring plan.

Operational Status

For this 29 day period both the solar heating and monitoring systems operated satisfactorily. The solar heating system operated for a total of 145.5 hours; the auxiliary electrical heating system operated for a total of 43.9 hours.

Performance Indicators

Page 2 lists the values of the indicators of system performance. Observe that 36.9% of the incident solar energy was supplied to the preheat storage tank, and that 62.6% of the total hot water heating load was supplied by solar means. This month's percentage solar contribution, $P = 62.6\%$, was lower than for the corresponding month of last year (for Month No. 5, $P = 81.6\%$) mainly due to an increased average daily hot water demand (for this month, $E_D = 64.1$ kBTU/day; whereas for Month No. 5, $E_D = 40.5$ kBTU/day.)

The electricity saved by the solar system was estimated at 364 kilowatt-hours which is equivalent to \$29.85 at a usage rate of 8.2 cents per kilowatt-hour.

MONTHLY MONITORING REPORT NO. 18

(April 5, 1984 - May 1, 1984)

This report summarizes the performance of the Harding Township Rest Area domestic hot water and monitoring systems.

Operational Status

For the 26 day period ending May 1, 1984, the solar domestic water heating system and the monitoring system operated satisfactorily. The solar water heating system operated for a total of 143.3 hours, and the auxiliary electrical heating system operated for 28.9 hours.

Performance Indicators

Page 2 lists the values of the indicators of system performance. Approximately 39.7% of the incident solar energy was supplied to the preheat storage tank, and 72.0% of the total hot water heating load was supplied by solar means. Performance indicators for this month were nearly the same as for the corresponding month of the previous year (See Monthly Report No. 6, April 6 - May 4, 1983). For Month No. 6, the overall efficiency in supplying solar energy was 38.2%, and 70.2% of the total domestic water heating load was supplied by the solar heating system.

The electricity saved by the solar system was estimated at 323 kilowatt-hours. At a usage rate of 8.7 cents per kilowatt-hour, the savings is \$28.10.

MONTHLY MONITORING REPORT NO. 19

(May 1, 1984 -June 5, 1984)

Included in this report is a summary of the operational status of the Harding Township Rest Area solar heating and monitoring systems, and a table listing the twelve indicators of system performance described in the revised monitoring plan.

Operational Status

For the 35 day period ending June 5, 1984 the solar heating system and its associated monitoring equipment operated satisfactorily. The solar heating system operated for a total of 224.1 hours; the auxiliary electrical heating system operated for a total of 33.0 hours.

Performance Indicators

Page 2 lists the values of the indicators of system performance. Please note that the overall efficiency in supplying solar energy for this month was 41.2% which is slightly higher than the 39.2% calculated for the corresponding month of last year (See Monthly Report No. 7). However, the percent solar contribution to the domestic hot water heating load for this month was 77.9% which is lower than for Month No. 7 when P was 83.7%. This seeming contradiction is explained by the fact that this month's daily demand for domestic hot water was about 15% higher than for the corresponding period of last year (E_D was 55.8 kBTU/day for this month and 48.5 kBTU/day for Month No. 7).

The electricity saved by the solar system was estimated at 471 kilowatt-hours which is equivalent to a savings of \$45.69 at a usage rate of 9.7 cents per kilowatt-hour.

MONTHLY MONITORING REPORT NO. 20

(June 5, 1984 - July 5, 1984)

This report contains a summary of the operational status of the Harding Township Rest Area solar heating and monitoring systems. It also includes a table listing the twelve indicators of system performance described in the revised monitoring plan.

Operational Status

During this 30 day period both the solar heating and monitoring systems operated satisfactorily. The solar system operated for a total of 227.8 hours; the auxiliary electrical heating system operated for a total of 12.0 hours.

Performance Indicators

On the following page are values of system performance. Approximately 43.2% of the incident solar energy was supplied to the preheat storage tank as compared to 42.2% for the corresponding month of the previous year (Month No. 8). This month's percentage solar contribution to the water heating load was 100% which is equal to that of Month No. 8. For this month, domestic hot water demand, E_D , was 12% higher on a daily basis than for Month No. 8.

The electricity saved by the solar system was estimated as 477 kilowatt-hours. At a rate of 9.9 cents per kilowatt-hour, the savings is \$47.22.

MONTHLY MONITORING REPORT NO. 21

(July 5, 1984 - August 7, 1984)

This report summarizes the performance of the Harding Township rest area solar domestic hot water and monitoring systems.

Operational Status

During this 33 day period the solar heating system was modified as the auxiliary electrically heated tank was bypassed on July 12 through adjustment of the appropriate shut-off valves. Thus from this time forward the solar system was the only means of hot water heating; that is, there was no electrical backup system. Electrical power to the auxiliary tank was also shut-off. This modification was made to evaluate solar only operation with a one storage tank system.

Prior to July 12 the solar heating system operated for 49.5 hours while the auxiliary electrical heating system operated for 4.5 hours. For the rest of the month, the solar system operated for 173.2 hours while the auxiliary electrical system was off as mentioned.

The solar heating system and its associated monitoring equipment operated well for the month. However, on August 6 the auxiliary electrical tank developed a leak which could not be repaired (this tank was eventually removed from the rest area).

Performance Indicators

Page 3 lists the indicators of system performance. Please

note that the overall efficiency in supply solar energy for this month was 41.4% which compares to 38.7% for the corresponding month of 1983 (See Monthly Report No. 9). The percent solar contribution to the domestic hot water heating load was 98.0% which is slightly lower than the 100% calculated for Month No.9. Hot water heating load demand, E_D , was about 30% higher on a daily basis than for Month No. 9. Storage tank heat losses for this month ($Q_{S.T. Loss} + Q_{AUX. Loss}$) were about 50% less on a daily basis than for Month No. 9 apparently because of the switch to a one storage tank system on July 12.

The electricity saved by the solar sytem was estiamated as 444 kilowatt-hours which is equivalent to a savings of \$39.96 at a usage rate of 9.0 cents per kilowatt-hour.

MONTHLY MONITORING REPORT NO. 22

(August 7, 1984 - September 7, 1984)

This report summarizes the performance of the Harding Township Rest Area solar domestic hot water and monitoring systems.

Operational Status

Domestic water for this month (31 days) was heated only by solar energy. The auxiliary electrical system was off for the month and only one storage tank was in use. The solar water heating system operated well for a total of 220 hours for the month. However, there was a problem with the monitoring system as a wire was discovered disconnected from BTU Meter No. 1 on September 5. The wire was reconnected and BTU Meter No. 1 is now working properly, but some performance data was lost for the month.

Performance Indicators

Page 3 lists the values of the indicators of system performance. Indicators E_S , eff_{OA} , and $Q_{S.T. Loss}$ could not be accurately calculated for the month because of the problem mentioned with BTU Meter No. 1.

For this month, 100% of the domestic hot water heating load was supplied by solar means. This percentage is the same as that for the corresponding month of the previous year (Month No. 10). Domestic hot water heating load demand, E_D , was 39% higher on a daily basis than for Month No. 10. Note that the values of

$Q_{AUX. Loss}$ (57 kBTU) and $E_{AUX.}$ (-27 kBTU) are due solely to piping losses since the auxiliary electrical tank was bypassed for the month.

The electricity saved by the solar system was estimated as 472 kilowatt-hours which is equivalent to \$43.90 at a usage rate of 9.3 cents per kilowatt-hour. The savings for this month was considerably higher than for Month No. 10 in part because of the increased demand for domestic hot water.

MONTHLY MONITORING REPORT NO.23

(September 7, 1984 - October 5, 1984)

This report summarizes the performance of the Harding Township Rest Area solar domestic hot water and monitoring systems.

Operational Status

For this 28 day period, both the solar heating and monitoring systems operated satisfactorily. The solar heating system operated for a total of 160.2 hours. The auxiliary electrical heating system was off for this month, and only one storage tank was in use.

Performance Indicators

A look at the indicators on page 2 shows that the overall efficiency in supplying solar energy was 39.2% which is nearly the same as for the corresponding month of the previous year ($eff_{OA} = 40.1\%$ for Month No. 11). The percent solar contribution to the domestic hot water heating load was 100%; the same as for Month No. 11. Storage tank heat losses for this month ($Q_{S.T. Loss} + Q_{AUX. Loss}$) were 34% less per day than for Month No. 11 apparently because only one storage tank was in use. Note that the values of $Q_{AUX. Loss}$ (34 kBTU) and $E_{AUX.}$ (-42 kBTU) are the result of only piping losses because the auxiliary tank was bypassed.

The electricity saved by the solar system was estimated as 325 kilowatt-hours. At a rate of 9.4 cents per kilowatt-hour, the savings is \$30.55.

MONTHLY MONITORING REPORT NO. 24

(October 5, 1984 - November 9, 1984)

This report is a summary of the performance of the Harding Township Rest Area solar domestic hot water and monitoring systems during the time period shown above.

Operational Status

For this 35 day period, both the solar heating and monitoring systems operated satisfactorily. The solar heating system operated for a total of 157.7 hours. The auxiliary electrical system was off for the month and only the 120 gallon solar preheat storage tank was in use. On October 16 the second of two 4500 watt heating elements were installed in this storage tank; neither element was connected to power because electrical parts had to be ordered. Auxiliary electrical heating will now take place in the solar tank since as mentioned in Monthly Report No. 21, on August 6 the auxiliary electrical tank became inoperable due to a leak which could not be repaired.

Performance Indicators

These indicators are listed on Page 3. For Month No. 24 the overall efficiency in supplying solar energy was 37.0% as compared to 38.8% for the corresponding month of the previous year (Month No. 12). No further comparisons to this month are made because for Month No. 12 two hot water faucets were leaking at a significant rate.

The domestic hot water heating load was satisfied only by solar energy and that is why $P = 100\%$. However, there were instances noted when the water supplied to the rest rooms was only lukewarm. In fact, the average temperature of the rest room water was about 100°F which is more than 10 degrees less than that supplied for Months Nos. 22 & 23.

Note that the values of $Q_{\text{AUX. Loss}}$ (36 kBTU) and $E_{\text{AUX.}}$ (-34 kBTU) are due solely to piping losses since the auxiliary electrical tank was bypassed this month.

The electricity saved by the solar system was estimated at 296 kilowatt-hours. At a usage rate of 9.1 cents per kilowatt-hour, the savings is \$26.94.

APPENDIX B
FEDERAL LIFE CYCLE COST ANALYSIS GUIDELINES

Life cycle costing involves combining all costs throughout the project/system life, on an economically valid basis so the true, total costs can be compared for various projects/systems with the same technical performance. The system with the least life cycle cost is then the most life cycle cost effective. Alternative systems must be reduced to and compared on the same time frame.

The complete solar energy system cost shall include the costs of the backup system. The optimum solar percentage/fraction of the total load heating or power) shall be determined by comparing the life cycle costs of various solar energy system sizes (i.e., 40, 50, or 60 percent). This optimal solar energy system shall then be compared to a conventional energy system based on the life cycle costs. All comparisons shall be made on the present value of the costs with the following assumptions/conditions:

Solar component life is 15-20 years

Other component life is 20 years

Rate of return on investment is 10 percent per year

Fuel price escalation rate is 10 percent per year

Inflation rate (other than fuel) is 7 percent per year

To recognize that there are some forgone benefits of alternative uses of irreplaceable fossil fuels, the price of fossil fuels should be doubled for this analysis.