SOLAR HOT WATER SYSTEMS IN MICHIGAN REST AREAS
Interim Report

MICHIGAN DEPARTMENT OF TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

SOLAR HOT WATER SYSTEMS IN MICHIGAN REST AREAS
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Frederick W. Harwood
Ron Holcom

Technology Laboratory Section
Materials and Technology Division
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Introduction

On December 13, 1976, Public Act 502 mandated that the Michigan Department of Transportation utilize solar energy systems, integrated with conventional systems, to heat water for highway rest areas and travel information centers.

Three such facilities have subsequently been built in Michigan with solar energy systems, which provide a portion of the energy to heat tap water. The first system—and subject of this report—was opened April 1981 on I 75 south of Bay City. The second, a travel information center, is located on US 23 south of Dundee, and the third on I 94 south of Battle Creek. The Department initiated a research project to evaluate these solar energy systems.

Data have been gathered at the I 75 (Bay County) rest area and this interim report is based on the monitoring of this system from March to June 1983 and January to March 1984. Data recording has only recently commenced at the I 94 facility, and will be analyzed and published in a subsequent report.

Solar Energy System and Monitoring Equipment

A Revere "Sun Pride" solar system was incorporated into the standard tap water system at the I 75 (Bay County) rest area. Figure 1 shows the plumbing layout, and Figure 2 is a schematic showing the water system with thermocouple and metering locations for sensing water temperatures and volumes.

The solar energy portion of the system consists of a 120-gallon solar water tank with an internal double-walled heat exchanger, four 35 by 77-in. solar collectors, and accompanying circulation system. The circulation system contains a liquid pump with an air purge, expansion tank, differential thermostat, and pressure gage. The solar system was filled with a 50/50 solution of propylene glycol and water.

The 120-gallon electric water heater is connected through an electric meter that measures only the energy to heat water.

System Problems

Data gathering began May 17, 1982 but complete analysis of the data was not possible until March 1, 1983 after valve 6 was closed to make the system more efficient, and a 4,500-watt electric heating element in the solar tank was disconnected to allow the tank water temperature to be colder and thus utilize more energy from the solar panels.

Complete and accurate data were gathered from March 1 through June 30, 1983 and January 9 through March 31, 1984. Several problems occurred between and after these periods including a leak in one of the

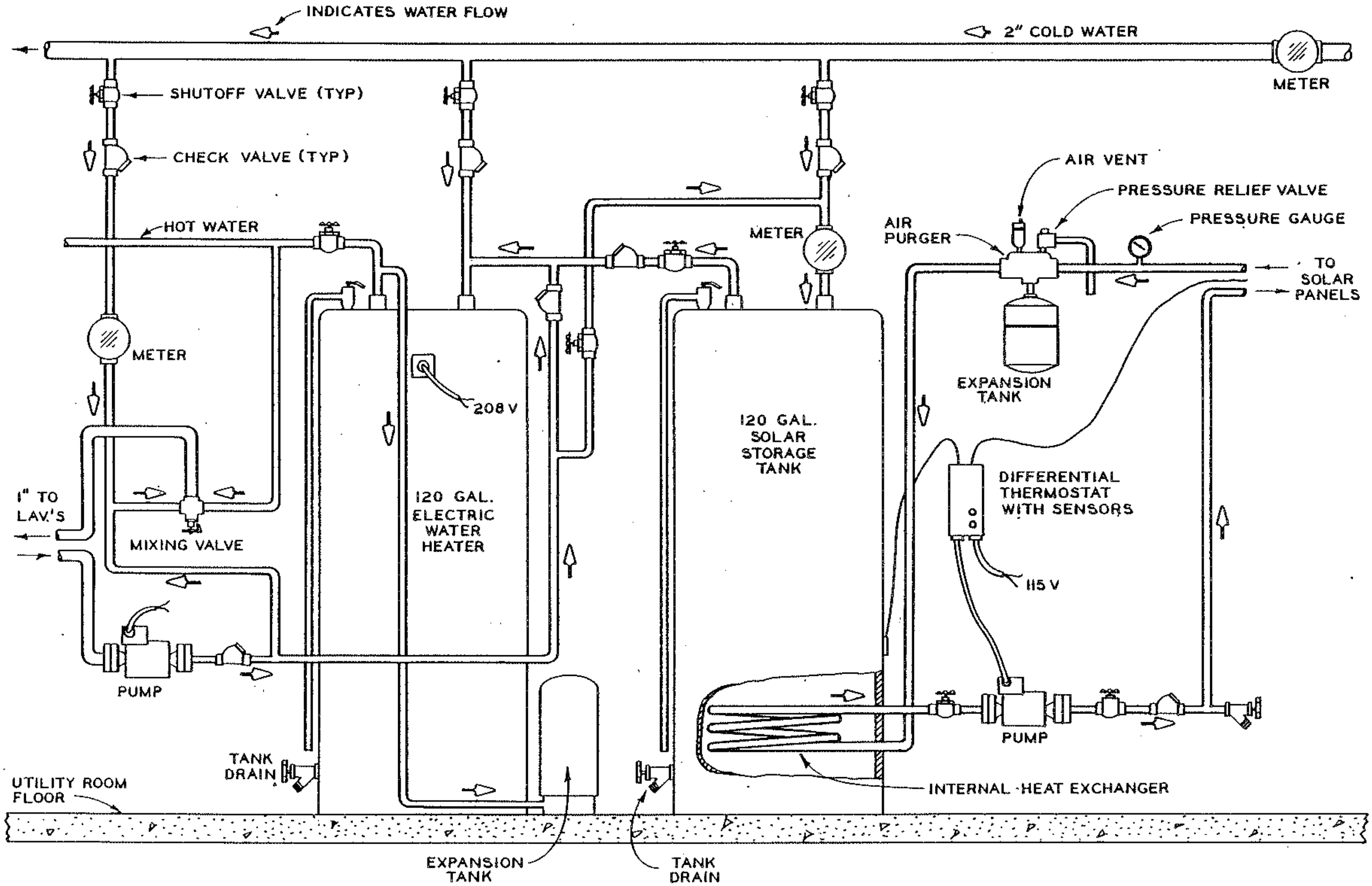

Figure 1. Diagram of hot and cold water system at Bay County rest area.

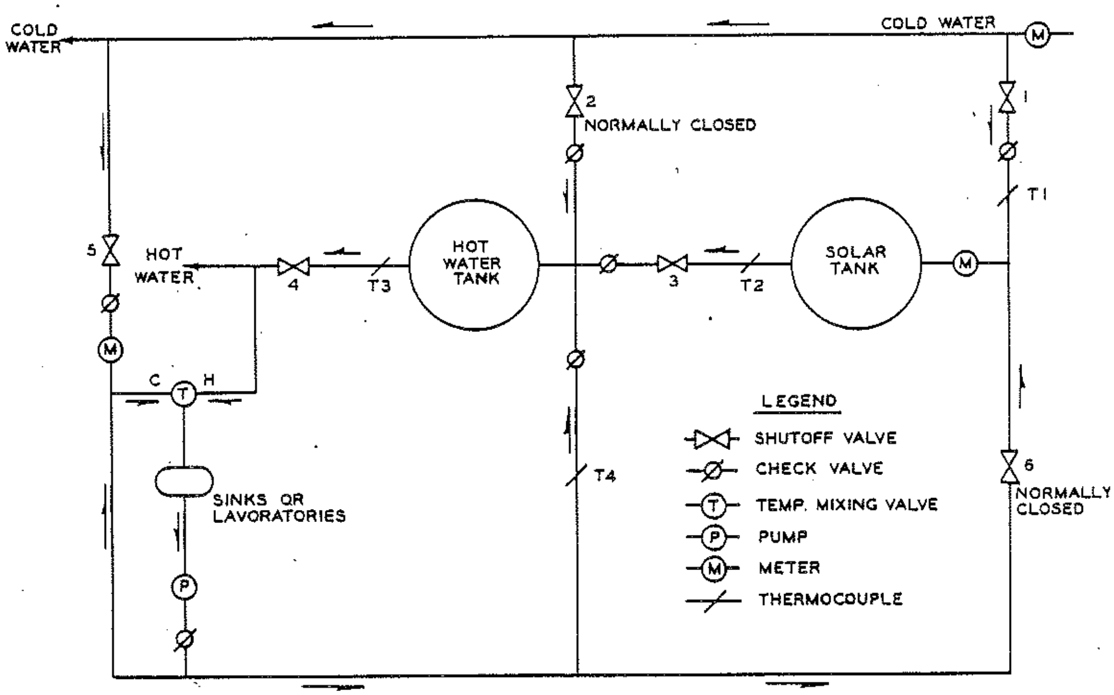

Figure 2. Schematic of hot and cold water system with thermocouples and water meters at Bay County rest area.

solar panels, a broken shaft on the solar pump, and a malfunction in the temperature recorder.

Data Collection

The rest area attendant read and recorded water meter readings and electric meter readings daily. The thermocouples were connected to a recorder that recorded temperatures every 30 minutes. As shown in Figure 2, water temperature readings were recorded for cold water (T1), solar tank water (T2), hot water (T3), and tempered water (T4). Outside air temperature was also recorded.

Counter switches were installed on the lavatory doors in an attempt to determine the number of persons using the rest area. Vandals destroyed the switches several times so this part of the study was abandoned.

Data Analysis

Data were entered into a computer for analysis. Daily values of electrical energy, total water, hot and cold tap water use, solar input energy, and solar stored energy were calculated by the computer. A typical daily graph showing semi-hourly values of the various water temperatures in the system, plotted by computer graphics, is shown in Figure 3. Monthly graphs were plotted of the daily electric energy, hot tap water volumes, and total hot and cold water volumes. Monthly graphs were also plotted of the solar, electric and total energy input, stored energy, and heat loss in the hot water system.

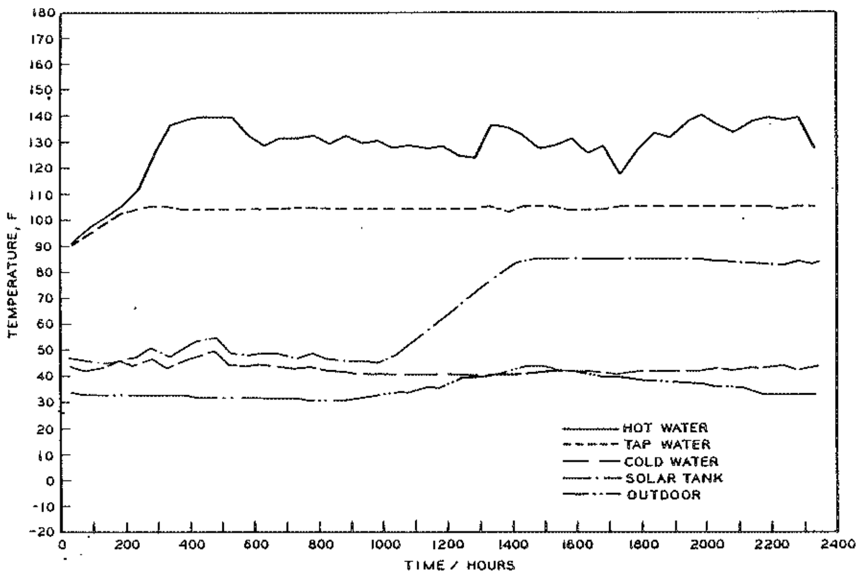

Figure 3. Daily temperature graph.

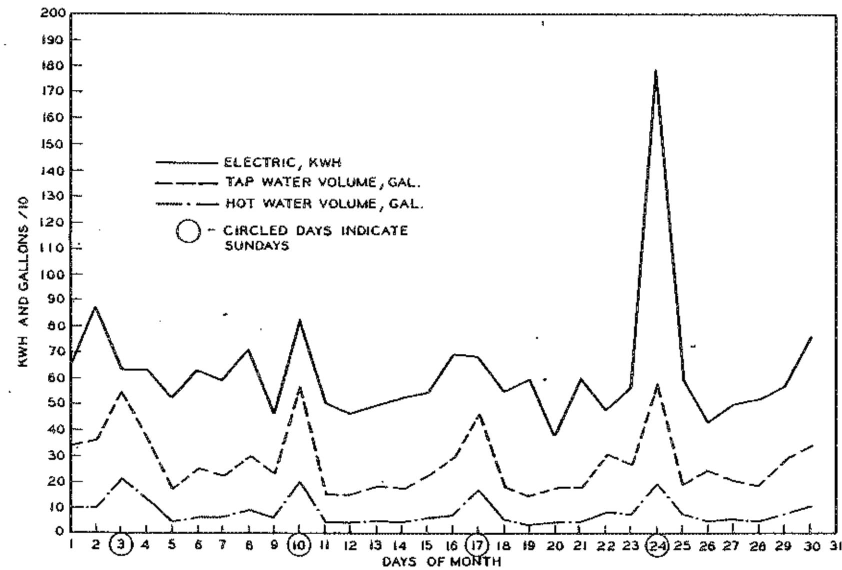

Figure 4. Monthly water volumes and electrical energy values.

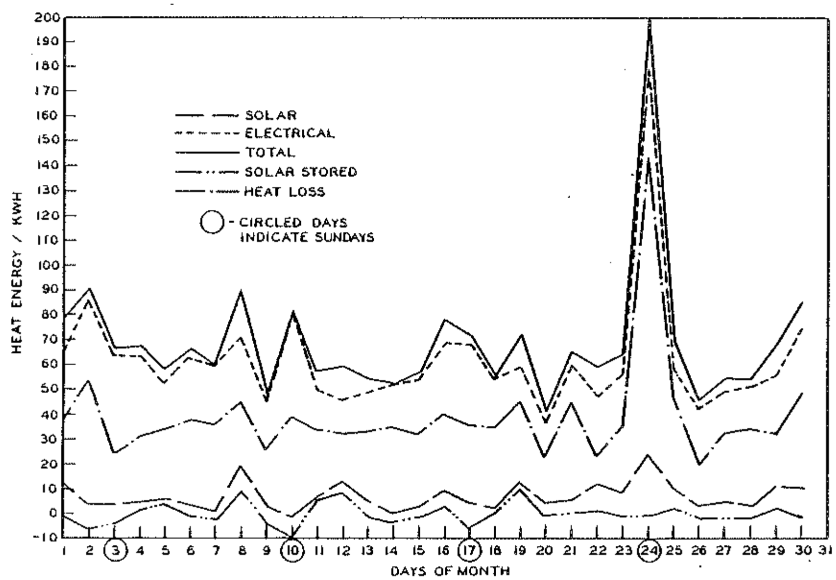

Figure 5. Monthly energy graph.

Daily graphs indicate the 'heartbeat' of the system. Information such as the availability of solar energy and the ability of the water heating system to keep up with the volume of tap water being used is readily accessible.

Sundays and holidays are generally days of high tap water use at this rest area (Fig. 4). A typical energy graph, Figure 5, shows this increase for total energy on Sundays and holidays. The heat loss in the hot water system was calculated as the difference between the total energy input and the energy needed to raise the cold water to tap water temperature. The average heat loss was approximately 35 kilowatt-hours of energy per day.

Daily water and energy usage were combined into groups of two or more days with each group representing an average high and an average low volume of tap water use per day. As a result, one high volume group and one low volume group made up approximately one week, except the 12 days from March 6 through 17, 1984, that were all low and averaged 159.8 gallons per day. On the Sundays of January 15 and 22, 1984, and March 18, 1984, only one day was used for high volume days. These groupings consolidated the data from 205 days to 57 groups. Tables 1 and 2 give the average tap water volumes and energy usage in these groups for the 1983 and 1984 data, respectively. These values were used to determine an average monthly total of city water and tap water volumes, solar, electric and total energy usage, and the dollar savings of electrical energy. This information is itemized in Table 3.

Results

Rest areas have a different pattern of tap water use than homes or other public buildings. The pattern of use in the I 75 rest area is expected to be different than the use of the other two solar installations.

Daily averages of tap water volume increased from a low of 95.0 gallons in March 1983 to a high of 1,092.5 on Memorial Day weekend (Tables 1 and 2). High volumes of tap water occurred on Sundays and holidays. On these days and on some additional days the water heater did not have enough electric energy to keep up with demand.

Michigan does not get as much solar energy as other states farther from the Great Lakes or the Oceans, and farther south. The lakes and oceans cause more cloudy days to occur. As expected, more solar energy was available in June than in January. This is evident from Tables 1 and 2 under solar energy input.

The combination of rest area water use and solar energy variation, shows that in January a larger solar tank is required to provide necessary hot water storage for use on Sundays. The existing system uses up the solar heated water by 2:00 or 3:00 p.m. and the electric heater recovery rate is not adequate. In June, with heavy rest area use extending beyond

TABLE 1
AVERAGE TAP WATER VOLUMES AND ENERGY VALUES
(March-June 1983)

Dates		No. Days	Tap Water	Energy Input, KWH				Percent Solar
				Solar Stored	Solar Input	Electric Input	Total Input	
Mar.	1-3	3	150.0	1.23	3.42	46.00	51.88	6.6
	3-7	4	280.0	0.23	6.39	62.75	69.14	9.2
	8-11	4	132.5	-1.21	1.60	48.50	50.10	3.2
	12-14	3	296.7	0.23	10.39	63.33	73.74	14.1
	15-18	4	147.5	1.21	5.45	49.00	54.45	10.0
	19-20	2	275.0	-2.88	2.88	63.00	65.88	4.4
	21-24	4	95.0	1.96	3.50	43.75	47.25	7.4
	25-27	3	236.7	-2.91	4.90	54.67	59.57	8.2
	28-31	4	155.0	3.34	7.32	50.25	57.57	12.7
Apr.	1-4	4	405.0	-2.53	6.10	54.50	75.60	8.1
	5-7	3	213.3	0.15	3.19	58.00	61.19	5.2
	8-10	3	366.7	-1.15	7.10	66.33	73.43	9.2
	11-14	4	162.5	2.53	6.54	49.25	55.79	11.7
	15-17	3	323.3	-1.30	5.56	63.67	69.23	8.0
	18-21	4	165.0	2.30	6.27	52.50	58.77	10.7
	22-24	3	376.7	-0.15	14.92	93.67	108.58	13.7
	25-28	4	200.0	-0.58	5.78	50.25	56.04	10.3
Apr.	29-May 2	4	377.5	-1.67	8.78	58.50	67.53	13.0
May	3-5	3	183.3	2.91	7.18	53.33	60.51	11.9
	6-9	4	412.5	0.23	6.76	66.25	78.85	8.5
	10-12	3	206.7	0.38	7.45	47.00	54.45	13.7
	13-16	4	457.5	0.80	14.63	62.75	77.38	18.9
	17-19	3	240.0	-1.53	4.94	53.33	58.27	8.5
	20-23	4	515.0	2.01	10.94	69.76	80.69	13.6
	24-27	4	310.0	0.17	8.74	59.25	67.99	12.5
	28-31	4	1092.5	0.34	15.66	86.25	101.91	15.4
June	1-2	2	200.0	-3.33	1.56	39.00	40.56	3.8
	3-7	5	602.0	2.25	16.54	80.40	96.94	17.1
	8-9	2	180.0	-0.69	5.14	79.00	84.14	6.1
	10-13	4	980.0	0.40	27.93	48.75	76.68	36.4
	14-15	2	320.0	-0.46	9.63	53.00	62.63	15.4
	16-20	5	552.0	0.78	16.68	64.00	80.68	20.6
	21-22	2	325.0	-0.23	9.12	49.50	58.62	15.6
	23,24,27	3	453.3	-0.54	25.71	56.33	65.88	39.0
	28-29	2	345.0	3.10	9.58	56.00	65.58	14.6

TABLE 2
AVERAGE TAP WATER VOLUMES AND ENERGY VALUES
(January-March 1984)

Date	No. Days	Tap Water	Energy Input, KWH				Energy Output KWH	Percent Solar
			Solar Stored	Solar Input	Electric Input	Total Input		
Jan. 15	1	570.0	-1.61	1.09	60.00	61.09	49.53	1.8
16-21	6	146.7	0.00	1.04	49.00	50.04	16.93	2.1
22	1	420.0	-1.15	0.46	69.00	69.46	41.70	0.7
23-27	5	148.0	0.64	1.85	46.00	47.85	17.20	3.9
28-30	3	416.7	-1.69	0.20	59.00	59.20	36.51	0.3
Jan. 31-Feb. 2	3	120.0	2.22	3.68	44.33	48.01	14.05	7.7
Feb. 3-5	3	263.3	-1.61	0.11	55.33	55.44	29.99	0.2
6-10	5	150.0	0.92	3.56	45.20	48.76	17.68	7.2
11-13	3	423.3	1.38	6.06	61.67	67.73	46.81	8.9
14-18	5	152.0	-1.93	2.12	39.60	41.72	16.65	5.1
19-20	2	490.0	3.45	16.53	66.50	83.03	58.70	19.9
21-23	3	176.7	-0.08	6.18	44.67	50.85	21.00	12.1
24-26	3	493.3	-3.07	2.81	62.33	65.14	53.48	3.3
Feb. 27-Mar. 1	4	125.0	2.24	5.36	43.00	48.36	14.70	11.1
Mar. 2-5	4	270.0	-1.26	3.49	55.25	58.74	31.78	5.9
6-17	12	159.8	0.17	4.77	46.42	51.19	19.34	9.3
18	1	320.0	-4.14	0.74	62.00	62.74	39.15	1.1
19-22	4	127.5	2.88	4.77	41.75	46.52	15.54	10.2
22-26	4	290.0	0.69	13.33	57.75	71.08	35.56	18.8
27-29	3	126.7	-1.00	3.82	32.33	36.15	15.42	10.6
30-31	2	245.0	-6.32	1.54	49.00	50.54	26.33	3.0

Sunday because of vacations, a larger area of solar panels would be required to gather more solar energy. In this case, the solar energy would be used as generated with little needed for storage.

Tables 1 and 2 list the percentage of solar energy used to heat water in the rest area for the 57 groupings of days. As would be expected, the percentage increased from January to June. This occurred even though the use of tap water almost quadrupled.

The dollars saved on electrical energy did not justify the installation of the solar energy system in the I 75 rest area. This solar system cost $13,000 to install. Table 3 shows the dollars saved each month for electricity. The total of these values is $109.49 for the six-month period, which would amount to about $220 per year. Based on an interest rate of 10 percent, a savings of $1,500 per year would be required to amortize the cost of this system over a 20-year period.

Table 4 shows an estimated efficiency of the solar hot-water system. The percent of possible sunshine available at the Bay County area was

TABLE 3
MONTHLY VALUES
Water Volume; Solar and Electrical Energy

Date	Total Water, gals	Tap Water, gals	Solar KWH	Electrical KWH	Total Energy, KWH	Solar Energy, Percent	Savings, Dollars
Mar.	151,700	5840	154.37	1635	1789.37	8.6	12.65
Apr.	137,300	8180	212.53	1862	2074.53	10.2	16.36
May	201,500	13940	310.28	1941	2251.28	13.8	30.71
June	191,400	16050	364.59*	1639*	2003.59	18.2	36.09
Jan.	226,300	6440**	39.58**	1535	1574.58	2.5	2.79
Feb.	192,700	7190	124.57	1444	1568.57	7.9	11.32
Mar.	189,100	5990	172.72	1458	1630.72	10.6	11.79

* The days June 25, 26, and 30 were not included in the monthly value. The recorder paper ran out June 25 and wasn't replaced until June 27. Electricity to the water heater was off June 30.

** Values for days 1 through 8 were obtained from 1983 data.

TABLE 4
MONTHLY INSOLATION (SOLAR ENERGY) ANALYSIS
AT BAY COUNTY REST AREA

Year	Month	Theoretical Solar Energy Available KWH	Average Possible Sunshine, Percent	Average Possible Solar Energy, KWH	Solar Energy Utilized	
					Energy, KWH	Estimated Efficiency, Percent
1983	March	1379.22	40	551.69	154.37	28
	April	1513.92	55	832.66	212.53	26
	May	1684.88	55	926.68	310.28	34
	June	1680.60	60	1008.36	364.59	36
1984	Jan.	821.00	35	287.35	39.58	14
	Feb.	1064.80	45	479.16	124.57	26
	March	1379.22	40	551.69	172.72	31

multiplied by the theoretical solar energy available for clear sky conditions at the Bay County latitude (1, 2). Estimated efficiency was calculated using the product of the above computation and the solar energy values obtained from Table 3. This is an estimated value because even with zero percent sunshine there can be varying amounts of radiation received by the solar panels depending upon the thickness of the cloud cover.

The data taken at Bay County rest area agree with the results of nine antifreeze systems reported by Colorado State University (3). This was a literature review and included many solar systems throughout the United States. The average daily efficiency of these nine systems was 32 percent.

Department Experience Maintaining Solar Systems

The solar system in the I 75 rest area has had two problems that had to be resolved. A solar panel on the roof developed a hole and had to be repaired, and the circulation system pump failed and had to be replaced.

Solar systems require specially trained technicians to maintain them, as they are more complicated than a standard hot water system. Solar systems should be checked after electric power failures to see if any liquid has boiled out of the system or if leaks have developed due to high pressures. The Department's Maintenance personnel from Lansing, with the assistance of District MDOT personnel, have made repairs on the Bay County rest area solar system.

Solar systems need to be monitored more carefully than standard hot water systems. A solar system can become inoperative for long periods without detection because the primary electrical part of the system provides enough energy to heat the water during high use days.

In the Bay County rest area hot water was not available on many occasions even though no complaints were received from users of the facility. The hot water system in this rest area needs more electric energy in the system to prevent this. A tempering valve system that shuts the cold water off completely when the hot water is below the tempering valve setting would help to remedy part of this problem. A further modification that would improve the system is to provide larger electric heating elements in the hot water tank.

Recommendations

1) Construction of solar hot water systems in rest areas or tourist information centers should be discontinued until final analysis and evaluation of existing solar systems are completed.

2) Recirculating systems and tempering valves in existing non-solar hot water systems should be eliminated because of their inefficiency. Smaller, quick recovery hot water tanks under or near each bank of

lavatories would be a more efficient way to provide tempered water to the sinks.

3) The data presented in this report can be used to better estimate hot water needs and more efficient water systems in future rest areas and tourist information centers.

4) Attendants at those rest areas containing solar systems should check them daily to make certain the liquid in the system is pressurized. This will indicate if leaks have developed and/or if liquid has boiled out of the system. If the pressure is approaching zero, competent maintenance personnel should be contacted.

REFERENCES

1. U.S. Department of Commerce, National Climatological Data Center, "Local Climatological Data, Flint, Michigan," June 1983.

2. Fridgen, Cynthia, Mrozowski, Tim, and Zarka, Jim, "First Solar Catalog for Michigan," Department of Energy Grant published 1984.

3. Lof, G.O.G., and Karaki, S., "System Performance for the Supply of Solar Heat," Mechanical Engineering, Vol. 105, No. 12, Pg. 32-47, December 1983.