INSTRUMENTATION AND EVALUATION OF COMMERCIAL AND HOMEMADE PASSIVE SOLAR PANELS

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Abstract

The purpose of this project was to compare water-heating capacities of a commercial passive solar panel and a home designed passive solar panel. The home made solar panel consisted of six, 10 ft long parallel, ½ in. diameter PVC pipes with two headers and with no insulation. Both panels were placed on the east side roof of the author's house, therefore they received solar radiation during part of the day. The instrumentation consisted of seven thermocouples and a computer data acquisition system. Two identical, 20-gallon plastic tanks, one tank on each panel, were used for water storage. Two sets of comparative measurements were carried out. For the first set, the PVC solar panel pipes were white; for the second set, the PVC solar panel pipes were painted in black. For the white PVC system the maximum water temperature in the tank was slightly lower than the commercial solar panel tank water temperature. For the painted PVC system, the maximum water temperature in the tank was slightly higher than the commercial solar panel tank water temperature. In conclusion it can be stated that a simple homemade six-pipe, black PVC solar panel is superior to an expensive commercial solar panel. Although water tanks were not insulated, water temperatures in them have reached to about 100 deg-F in September. Such a system may be incorporated into one of the MET courses as a laboratory exercise to demonstrate basic principles of passive solar heating, calculation of heat losses, optimization, manufacturing techniques, creativity, etc.

Introduction

Solar water heating systems are extensively used for domestic hot water and swimming pool heating in warm climates [1-4]. Some of these systems even use heat collected in the attic of a house due to solar heating of the roof [1]. Some systems use solar cells to run a water pump to circulate water [3]. Since sun-tracking systems are complicated to implement, most solar panels are fixed at an optimum angle. If the system will be used for year-long heating, usually the angle is set for the winter optimum heating [5]. Optimum angle is a function of the geographic location where the panel will be used. At southern locations the solar panel angle with the horizontal will be larger. Systems could be designed with or without a circulation pump. Schematics of an active and a passive solar heating system are given in Fig.1 and Fig. 2 [6]. Water circulation in systems without circulation pump (passive systems) occurs due to density differences between the warm and the cold water (hot water rises, cold water sinks). Pipe sizes for natural circulation systems are larger to minimize pressure losses. Cost of a solar water heating system mostly depends on the type of the system. Freeze protected systems are more expensive since they require a pump and a secondary heat exchanger to move heat from an antifreeze solution to domestic hot water system. Since solar cells are very expensive, solar-pump systems are more expensive. As an example, a 40 gal capacity, passive water heating system with 32 square-ft solar collector area will cost about $1800 ($2700 with installation) [4]. Cost of the panel alone is $750.

Last summer the author wanted to design and install a passive solar, domestic hot water heating system for his house. Since solar collectors were expensive he wanted to test and see how a simple solar collector made of PVC pipes will perform. Department of Technology has a commercial solar collector panel on a portable solar water heater. The solar collector was removed from the unit and was used for the comparative measurements.

The purpose of this project was to compare water-heating capacities of a commercial solar panel and a home designed PVC, passive solar panel.

The Solar Collectors (panels)

The home made solar panel consisted of six, 10 ft long, parallel, ½ in. diameter PVC pipes with two headers and with no insulation. Pipes were spaced about four inches apart. The overall dimensions of the panel were about 25 inches by 10 feet. The commercial solar panel consisted of five 3 ft long and 3/8 in. diameter tubes between two 2.5 ft long headers. A black copper plate was attached across the parallel tubes to increase the effective surface area of the tubes. Combined system was placed inside a box with a Plexiglas window at the top and about three inches of fiberglass insulation at the bottom. Both panels were connected to two identical water storage and piping systems. Water tanks were 20-gallon trashcans. The top headers of the panels were connected to the topside of the tanks; the lower headers were connected to the bottom of the tanks to enhance natural circulation of water in the system. Since house did not have a sloped roof on the south side, both systems were placed on the east side of the house. The pitch of the roof was about 31 degrees with the horizontal. Figure 3-6 are some pictures of the configured system.

The Instrumentation

The instrumentation consisted of seven thermocouples and a computer data acquisition system. The thermocouples were used to measure the inlet and the exit water temperatures of the solar panels, the water temperature at the mid points of the tanks and the ambient air temperature. The computer data acquisition system was used to record seven temperatures. Usually eight hours of data recording a day was more than sufficient. Due to the shade of the trees on the east side and the shade of the roof on the west side, the sun was only available for a period of about six hours.

The used data acquisition system consisted of a TDK 486-33 computer, a Data Translation [7] DT2805, low level, 12 bit data acquisition board and ASYST software. The board was connected to a DT707-T screw terminal box which supported thermocouple inputs with a reference junction occupying analog input channel "0". The throughput speed with single channel input on DT2805 is up to 6 KHz. The DT2805 has differential Analog to Digital Converter (ADC) inputs only. ADC gains on the board can be set by software for each channel. ASYST software was used for data acquisition, analysis and display. ASYST is a DOS based, high level programming language which can not be purchased any more. A picture of the data acquisition system is given in Fig. 7. The major specifications for the data acquisition board are given in Table 1.

Table 1. Major Technical Specifications for the DT2805 Data Acquisition Board.

Board	Resolution ADC/DAC	ADC Channels Differential	# of DAC Channels	Programmable Gains	I/O bits Port0/Port1
DT2805	12/12	8	2	1,10,100,500	8/8

The Comparative Measurements and Results

Two sets of comparative measurements were carried out. The white (unpainted) PVC pipe solar panel was used for the first set of measurements. The PVC solar panel pipes were then painted in black and they were used for the second set of measurements. A screen display of a typical run for unpainted (white) PVC solar panel is given in Fig. 8. As seen on the left hand side, middle rectangle of the graph, start time was about 10 A.M. Recording ended at about 4:55 P.M. The time interval between two successive data points, on the x-axis, was 4.8 minutes. Y-axis is the temperatures indicated by the thermocouples for measuring the ambient air temperature, the inlet and the exit water temperatures of the solar panels, and the water temperatures inside the tanks at their mid points. A graph of the same data is given in Fig. 9. Figure show that, a faster drop in the exit water temperatures is observed when panels were under shade at about 4:10 P.M. The temperature fluctuations seen in the figure were due to occasional clouds shading the panels. Panels were under shade until about 9:30 A.M. due to trees. A similar graph of a typical run for the black-painted PVC pipe-panel is given in Fig. 10.

As seen in Fig. 9, the exit water temperature from the commercial-panel was substantially higher than the white, PVC pipe-panel exit water temperature. The maximum water temperature in the commercial solar panel tank, at the mid point, was only slightly higher than the PVC solar panel tank water temperature. For the three days given in Table 2, the average water temperature rise in the PVC solar panel tank was about 7% less than the commercial-panel tank water temperature rise.

Table 2. Temperature Rise in the Water Storage Tanks, and the Average Percent Difference between the Pipe-Panel and the Commercial-Panel Tank Water Temperatures. The Pipe Panel was white (unpainted).

Date	Start and End Times	Commercial Panel Tank Temperature Deg-C	White Pipe Panel Tank Temperature Deg-C	Notes
8-15-04	9:00-17:00	43.6	41.2	Maximum Temp.
		18.8	18.7	Start Temp.
		24.8	22.5	Temp. Rise
			-9.27	% Difference in Temperature Rise
9-24	8:40-13:40	35.7	32.6	Maximum Temp.
		17.4	15.8	Start Temp.
		18.3	16.8	Temp. Rise
			-8.20	% Difference in Temperature Rise
9-25	9:00-17:00	37.4	34.8	Maximum Temp.
		19.4	17.6	Start Temp.
		18.0	17.2	Temp. Rise
			-4.44	% Difference in Temperature Rise
			-7.31	**Average % Difference in Temperature Rise**

As seen in Fig. 10, the exit water temperatures of both systems (commercial and pipe panels) were about the same when PVC pipes were painted in black. For the painted PVC solar system, the maximum tank water temperature in the tank, at the mid point, was slightly higher than the commercial solar panel tank water temperature. For the five days given in Table 3, the average water temperature rise in the painted, PVC solar panel tank was about 8% more than the commercial panel tank water temperature rise.

Table 3. Temperature Rise in the Water Storage Tanks, and the Average Percent Difference between the Pipe Panel and the Commercial Panel Tank Water Temperatures. The Pipe Panel was painted in black.

Date	Start and End Times	Commercial Panel Tank Temperature Deg-C	Pipe Panel Tank Temperature Deg-C	Notes
9-27	8:45-16:45	35.9	36.40	Maximum Temp.
		21.5	20.70	Start Temp.
		14.4	15.7	Temp. Rise
			9.03	% Difference in Temperature Rise
9-30	8:55-16:50	29.0	29.20	Maximum Temp.
		13.2	12.80	Start Temp.
		15.8	16.4	Temp. Rise
			3.80	% Difference in Temperature Rise
10-03	11:00-14:00	28.1	28.70	Maximum Temp.
		13.0	12.20	Start Temp.
		15.1	16.5	Temp. Rise
			9.27	% Difference in Temperature Rise
10-08	8:45-16:43	33.5	34.70	Maximum Temp.
		15.6	15.00	Start Temp.
		17.9	19.7	Temp. Rise
			10.06	% Difference in Temperature Rise
10-09	8:40-16:40	35.4	36.6	Maximum Temp.
		18.3	18.2	Start Temp.
		17.1	18.4	Temp. Rise
			7.60	% Difference in Temperature Rise
			7.95	**Average % Difference in Temperature Rise**

Conclusions

The results indicate that, such a simple PVC pipe-panel may be used to heat water up to about 100 deg-F. Heating capacity of a PVC solar water heating system may easily be increased by adding additional pipes. The process of heating can be maintained for a longer period of time if a similar panel is also used on the west roof of the house. Of course, the ideal location for the solar panels is the south side of the roof. For houses with an inclined (pitched) roofs on the south side commercial panels may be preferred since orienting a small, insulated panel is not difficult. Although orienting a PVC pipe-panel is also possible, pipes will require a larger support panel. A 4ft by 8ft plywood with appropriate supports may be used as the support panel. Even if the support panel is painted in black, due to convective cooling, the temperature of the support panel will not increase as much as the roof temperature will; therefore, the heating capacity of the PVC pipe, solar panel might decrease substantially.

The discussed system was an experimental setup. A permanent system should be designed using CPVC or metal pipes instead of PVC pipes. PVC systems are for cold water use only. The inlet water temperature to a domestic hot water heater may be increased if the solar water heater is used as a preheater. For such a system, water pressure in the solar panel and in the tank can be over 80 psi depending on the city or private well water supply pressures. The author's brief market survey showed that even uninsulated water tanks were more expensive than insulated gas or electric hot water heaters. Therefore buying an electric hot water heater and using it as a water tank will be a wiser choice. Since all domestic hot water heaters are insulated, one does not need to worry about insulation. One should, however, pay attention to sealing the tank properly so that rain or snow can not get into insulation to cause corrosion. If the tank is to be placed inside the attic space to minimize corrosion and for additional heat gain, proper precautions must be taken to eliminate possible water damage to the house if the tank or the pipes leak. When the solar system is connected to a domestic hot water heater, valves may be placed to use the system

(a). in stand-alone mode so that water in the solar panel water tank may be used, directly, for showers,
(b). as a preheater for a domestic hot water heater, and
(c). in isolation-mode so that the solar water heating system may be drained for winter in geographic locations where outdoor temperatures fall below 32 deg-F.

In conclusion it can be stated that a simple homemade six-pipe, black PVC solar panel is superior to an expensive commercial solar panel. It can also be said that painting the PVC pipes improved the temperature rise in the solar panel about 15%. Although water tanks were not insulated, water temperatures in the tanks have reached to about 100 deg-F in late September.

References

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2. Solar Twin Ltd, 2nd Floor, 50 Watergate Street, Chester, CH1 2LA, England, UK. http://www.solartwin.com

3. SolarRoofs.com, 5840 Gibbons Dr., Carmichael, CA 95608, http://www.solarrofs.com

4. Solar Direct, 5919 21st. St. E, http://www.solardirect.com

5. MACS Lab, Inc., 2070 A Walsh Avenue, Santa Clara, CA 95050, http://www.macslab.com/optsolar.html

6. DOE Solar Energy Technologies Program: Residential and Commercial Water Heating http://www.eere.energy.gov/solar/sh_use_water.html

7. Data Translation, Inc., 100 Locke Drive, Marlboro, MA 01752-8528.

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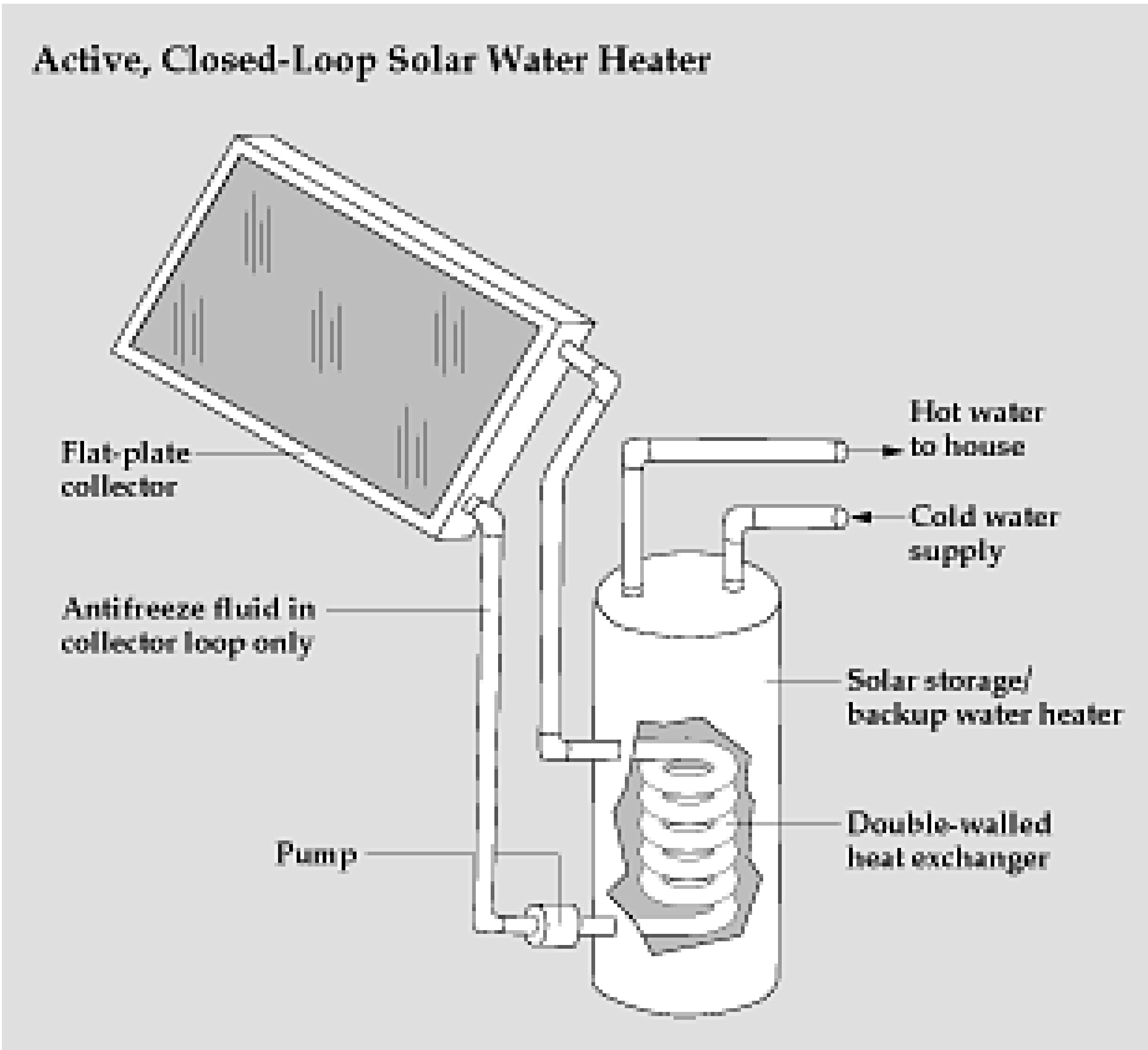

Figure 1. A Schematic of Active, Closed Loop Solar Water Heating System. Active, indirect systems are often used in climates with freezing temperatures [6].

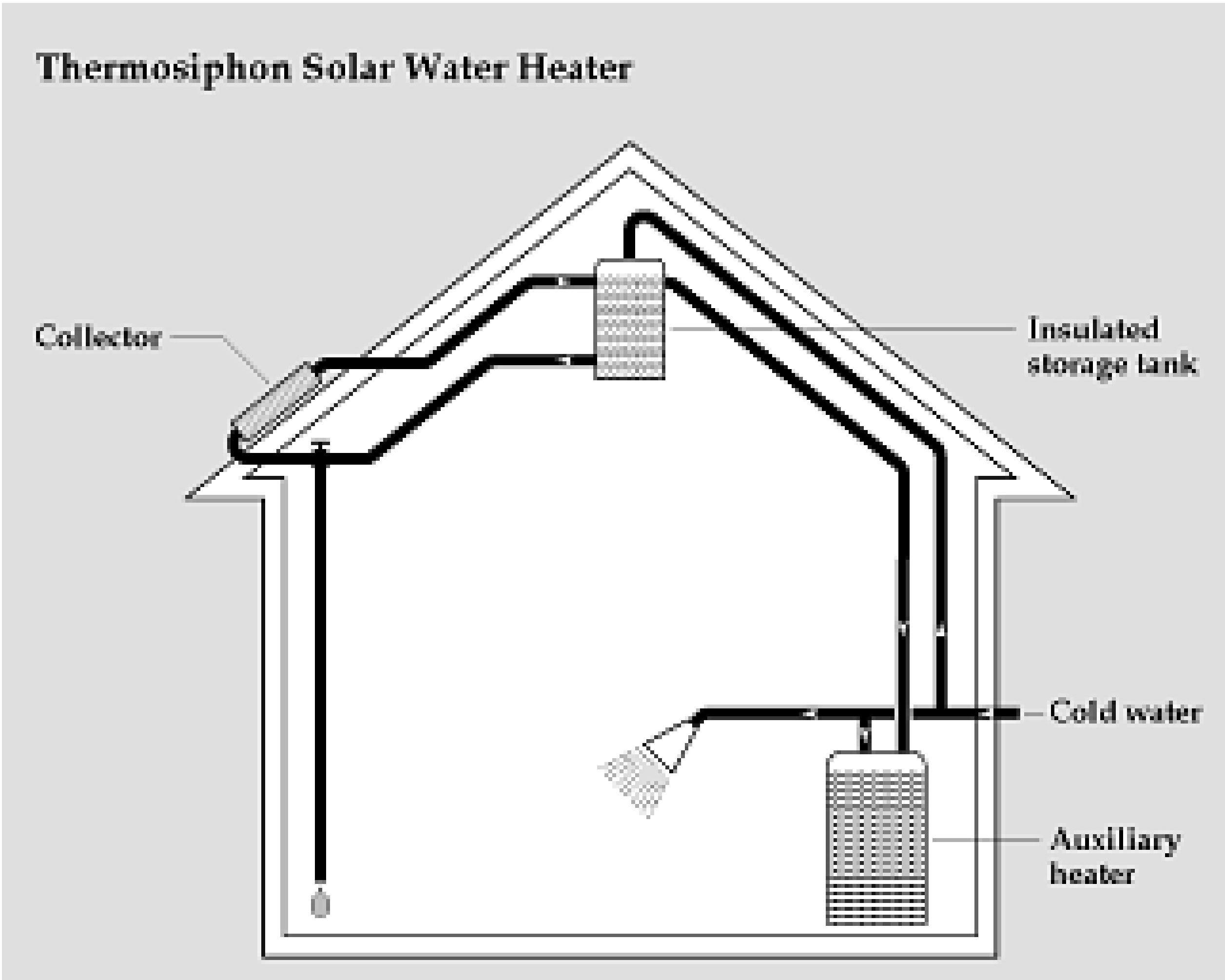

Figure 2. A Schematic of Passive Solar Heating System. Thermo-siphon systems are an economical and reliable choice [6].

Figure 3. The PVC Pipe Panel (left) and the Commercial Panel (right) Solar Collectors and the Water Tanks (top), as Installed.

Figure 4. The PVC Pipe Panel and the Commercial Panel Solar Collectors.

Figure 5. The Commercial Solar Panel with the Inlet Pipe and the Inlet Water Temperature Thermocouple Connections.

Figure 6. Water Tanks with the Inlet Pipe, the Outlet Pipe and the Mid-tank Water Temperature Thermocouple Connections.

Figure 7. The Data Acquisition System. The Screw terminal box is seen at the left hand side.

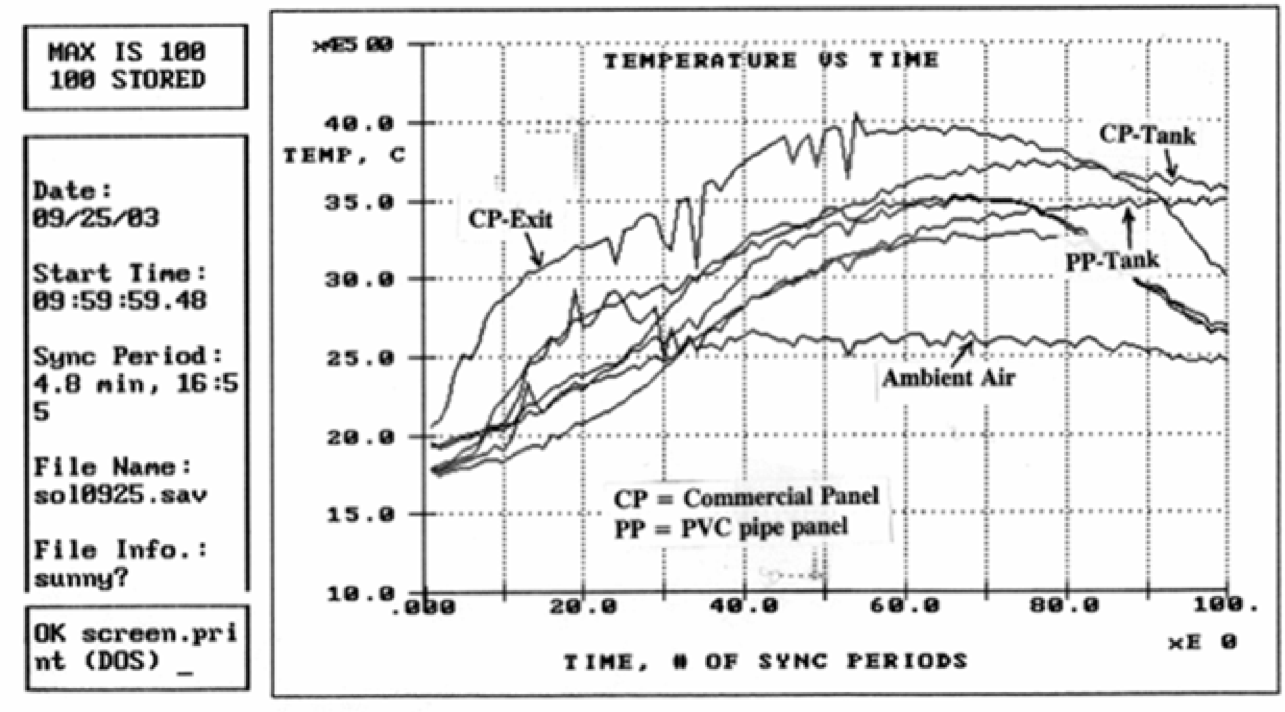

Figure 8. A Screen Print of a Typical Data Recorded on September 25 between 9:59 A.M. and 4:55 P.M. using White (unpainted) PVC, Solar Pipe-Panel.

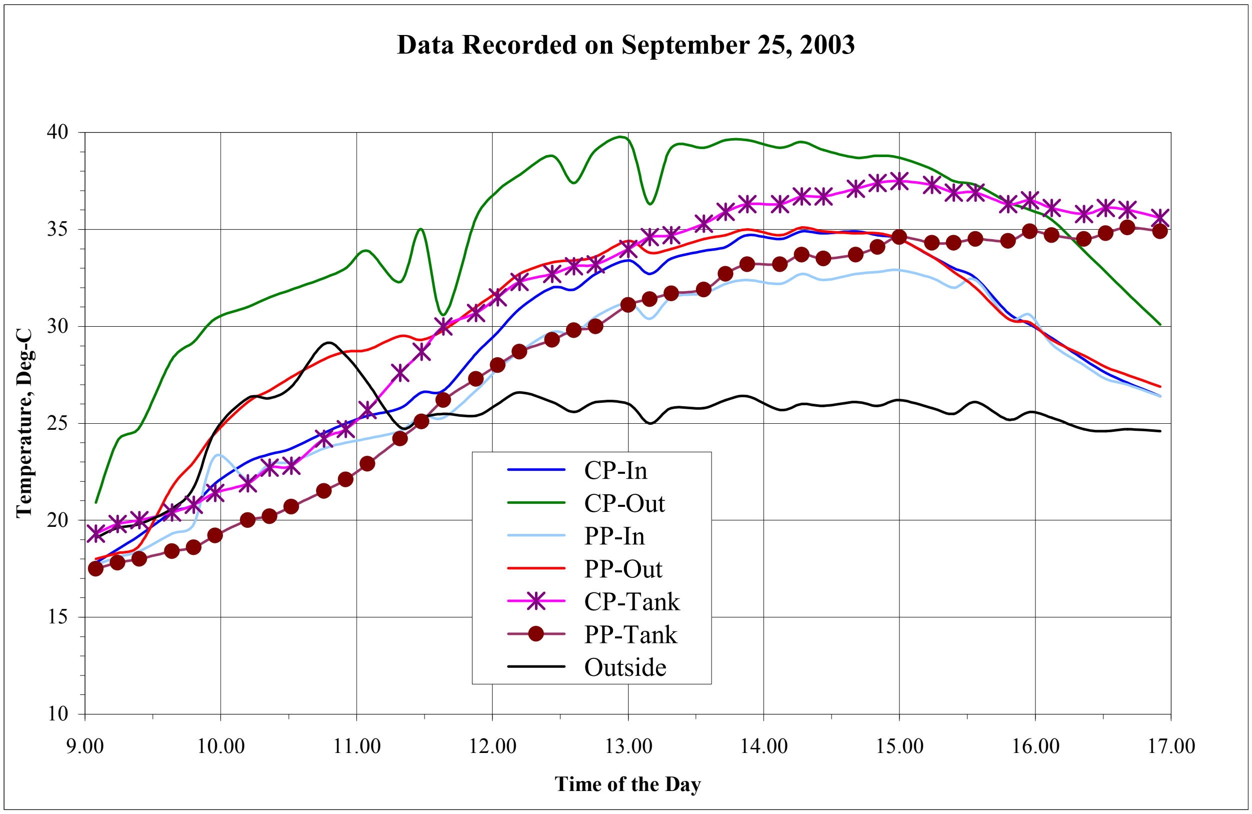

Figure 9. A Plot of a Typical Data Recorded on September 25 between 9:59 A.M. and 4:55 P.M. using the White PVC Pipe-Panel. The maximum pipe-panel tank water temperature is less than the commercial-panel maximum tank water temperature.

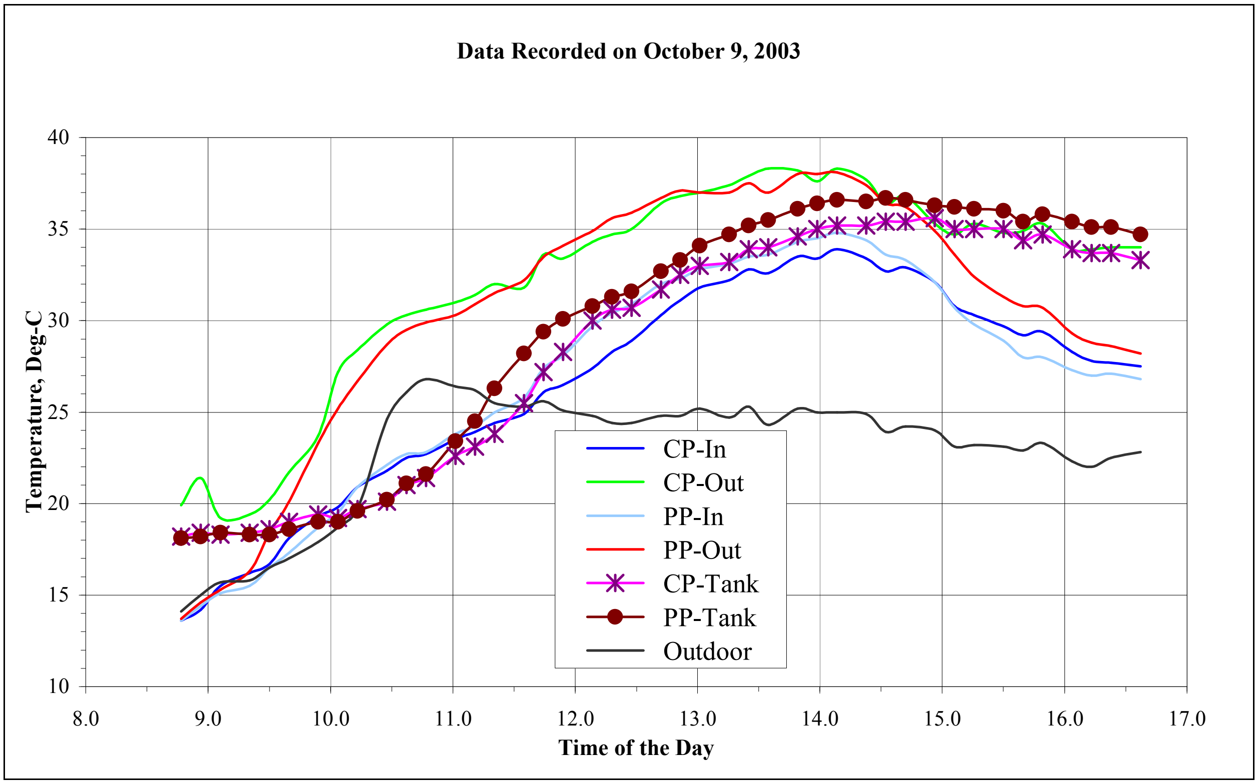

Figure 10. A Plot of a Typical Data Recorded on October 9, 2003, between 8:42 A.M. and 4:37 P.M. using Black-Painted PVC Pipe-Panel. Superiority of the pipe-panel is seen from the higher tank water temperature.