FINAL REPORT

THE USE OF SOLAR ENERGY FOR HEATING AN ASPHALT STORAGE TANK

by

Marvin H. Hilton
Senior Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the the sponsoring agencies.)

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

August 1984
VHTRC 85-R5

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SUMMARY

A 10,000 gal. asphalt storage tank was equipped with a solar heating system and instrumented to determine its effectiveness over a 12.5-month period. An evaluation of the data indicated that the solar system conserved 25,126 kWh of electrical power during the monitoring period. At a cost of $0.0387 per kWh, savings of $972.24 were realized. A present-value analysis of the data indicated that the investment in solar energy systems to assist in heating asphalt is a favorable alternative to the conventional electrical heating system used by the Virginia Department of Highways and Transportation.

ADDITIONAL

METRIC CONVERSION FACTORS

To convert from	To	Multiply by
British Thermal Units, Btu	joules (J)	1.055×10^{3}
British Thermal Units, kBtu	" "	1.044×10^{6}
Kilowatt hour, kWh	" "	3.6×10^{6}
Degrees	Radians	1.745×10^{-2}
Gallons per minute	$\text{metre}^3/\text{sec.}$	6.309×10^{-5}

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INTRODUCTION

Due to the rising costs of energy during the past decade, there has been a need to conserve fuel and to lower operational costs wherever possible. One method of conserving energy and lowering costs in highway maintenance operations has been to use solar energy to assist in the heating of asphalt storage tanks. Several states have reported upon their use of solar energy for this purpose and say they have found it to be a viable alternative to other methods.(1,2)

In Virginia, solar energy has been used to heat several asphalt storage tanks which are normally heated by electricity. The first usage was on a tank located at the Volens maintenance headquarters in the Lynchburg District. The solar collectors utilized on this installation were fabricated in-house and the unit assembled by Virginia Department of Highways and Transportation personnel. A unique feature of this installation is that the asphalt is circulated through the collectors and the heat transfer is made directly to the asphalt as it returns to the storage tank. A second solar system was installed later at the Yellow Branch maintenance area headquarters, also in the Lynchburg District, and utilizes commercially available solar collectors to transfer heat to the asphalt storage tank. Neither of these first two installations were monitored to determine their efficiency and energy savings. Electrical energy usage as metered by the power company, however, indicated that savings in electricity costs were being realized. The third asphalt tank to be solar heated was an entirely new installation instrumented during its construction such that the solar energy contribution and backup conventional heating could be monitored. The installation was designed and assembled by personnel at the Lynchburg District office of the Virginia Department of Highways and Transportation. Monitoring of the installation was accomplished in cooperation with the U. S. Department of Energy and the Federal Highway Administration (FHWA) under Demonstration Project No. 52. Under this project, the costs of a solar system in excess of those of a conventional system were paid with federal funds. Since the funding contract required that the solar installation be monitored and that monthly reports be submitted for a period of one year of operation, the Virginia Department of Highways and Transportation requested that the Research Council perform the monitoring and reporting phases of the contract. This report represents the final report on the operation of the solar heated asphalt storage tank.

PURPOSE AND SCOPE

The primary purpose of the study was to determine the general operating efficiency and the amount of fuel and monetary savings that could be obtained by using solar energy to assist in the heating of a typical asphalt storage tank at a highway maintenance area headquarters. The typical tank used at these locations has a 10,000-gal. capacity and uses 12 kVA or 15kVA electrical units for heating the asphalt. In the application of solar heating, the basic tank size was maintained. Only the heating system was modified to accommodate the solar and backup systems. An additional purpose of the study was to determine if the solar heating installation was an economically sound investment.

The scope of the study was limited to the monitoring of the times, temperature, and flow of the heat transfer fluid through the solar system described below. There was no attempt to study the effects of varying the flow rates. The solar system was monitored over 1 year of operation. Because of several breakdowns of the monitoring equipment and other technical difficulties, the monitoring period was not continuous. A full year of monitoring, however, is reported for the period between May 1981 and January 1983.

PROJECT LOCATION AND GENERAL CLIMATIC CONDITIONS

The solar heated asphalt tank is located in Campbell County, Virginia, several miles south of Lynchburg on Rte. 682. The latitude of this location is approximately 37°25'. The average annual heating degree days for this region is approximately 4,150, assuming a 65°F. base temperature. The average daily temperature during the winter months (January, February, and March) is about 39.5°F., and during the summer (June, July, and August), it is approximately 76.5°F. The average annual percentage of possible sunshine is approximately 59%.(3) The average daily solar insolation during the winter months is approximately 950 Btu per square foot per day, and during the summer approximately 1,600 Btu per square foot per day. All the above averages, of course, vary from year to year and are only representative of what might be expected for the region.

DESCRIPTION OF THE SOLAR HEATING SYSTEM

The general layout of the solar heated asphalt storage tank is shown in Figure 1. Ten solar collectors, each having an area of 12.5 ft.^{2}, are fastened to the top of the storage tank at an angle of 50° to horizontal. The solar system was designed to be capable of supplying the total heating requirements of the storage tank under ideal conditions of solar insolation. An auxiliary electrical heating system, which is capable of supplying the total heating requirements when necessary, supplements the solar system as needed. The auxiliary heat is supplied by a 9 kW, thermostatically controlled emulsion heater.

The 10,000 gal. asphalt storage tank is approximately 10 ft.-6 in. in diameter and 15 ft.-6 in. high, and rests on a 20 ft.-2 in. concrete foundation. The solar heat transfer fluid is stored in the smaller 500-gal. tank shown in Figure 1. Attached to the side of the 500-gal. tank is the control box, which houses the auxiliary equipment, pumps, etc. Attached to the control box is an additional box which houses the monitoring control and recording equipment. A photograph of the completed installation is shown in Figure 2. Details of the design of the tanks, the heater coil for the asphalt tank, tank insulation, and the framing and mounting for the solar collectors are shown in the Appendix in Figures A-1 through A-7. Details concerning the commercially available solar collector panels are also given in Appendix A.

The flow schematic for the solar heating system is shown in Figure 3. Pumps A and A_1 move the water and antifreeze (Dowtherm SR-1 heat transfer fluid) solution from the storage tank to the solar collector panels. A differential thermostat (unit 9 in the electrical control layout shown in Figure 4) controls the operation of this system. Pumps B and C share a common intake of fluid which flows through the auxiliary emulsion heater. When the thermostat designated unit 5 in Figure 4 detects that the fluid in the solar storage tank is less than its set amount, the heat relay designated unit 4 activates the auxiliary heater. Pump B supplies the fluid that circulates around the pump used for drawing the asphalt from the storage tank. When the temperature at the asphalt pumps falls below its setting, the thermostat designated unit 2 in Figure 4 activates pump B. Pump C circulates the heat transfer fluid through the coil in the asphalt tank. The thermostat designated unit 3 in Figure 4 monitors the temperature of the asphalt. When the temperature falls below its predetermined setting, pump C is activated.

Although the solar storage tank is designed to hold 500 gal. of fluid, only 350 gal. were used.

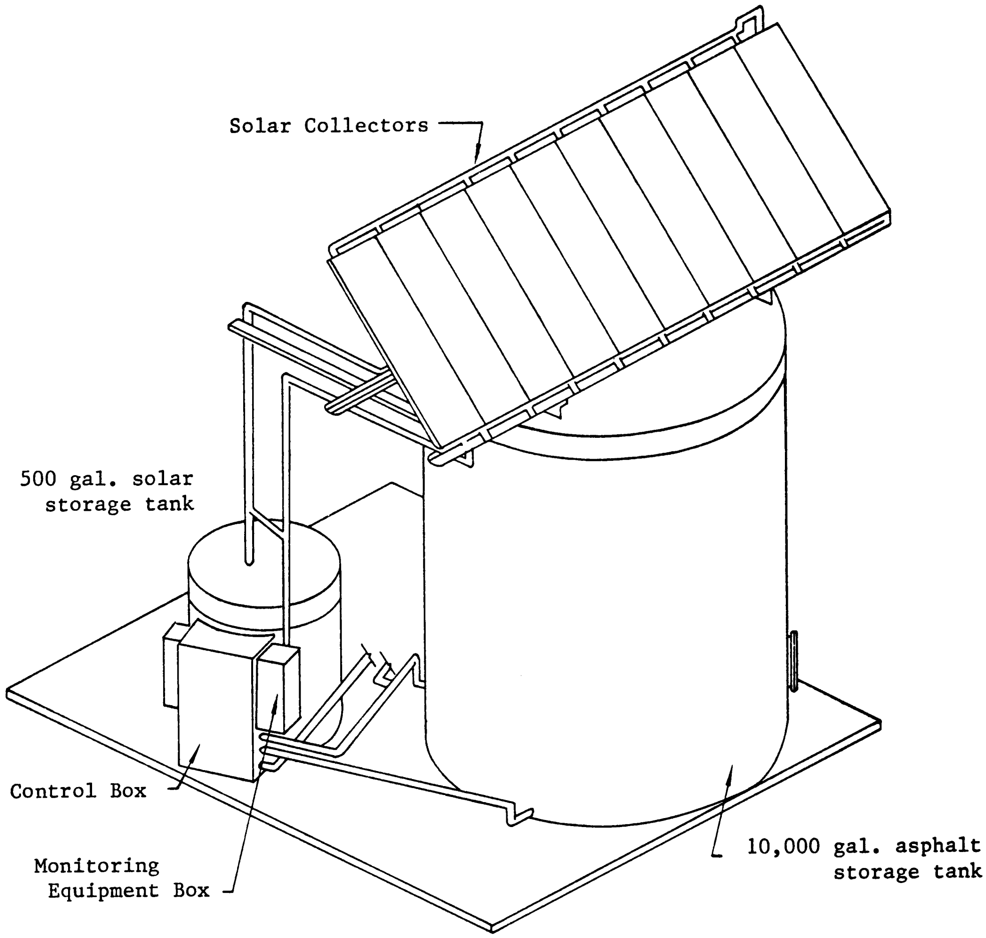

Figure 1. Schematic of the asphalt storage tank and solar heating system.

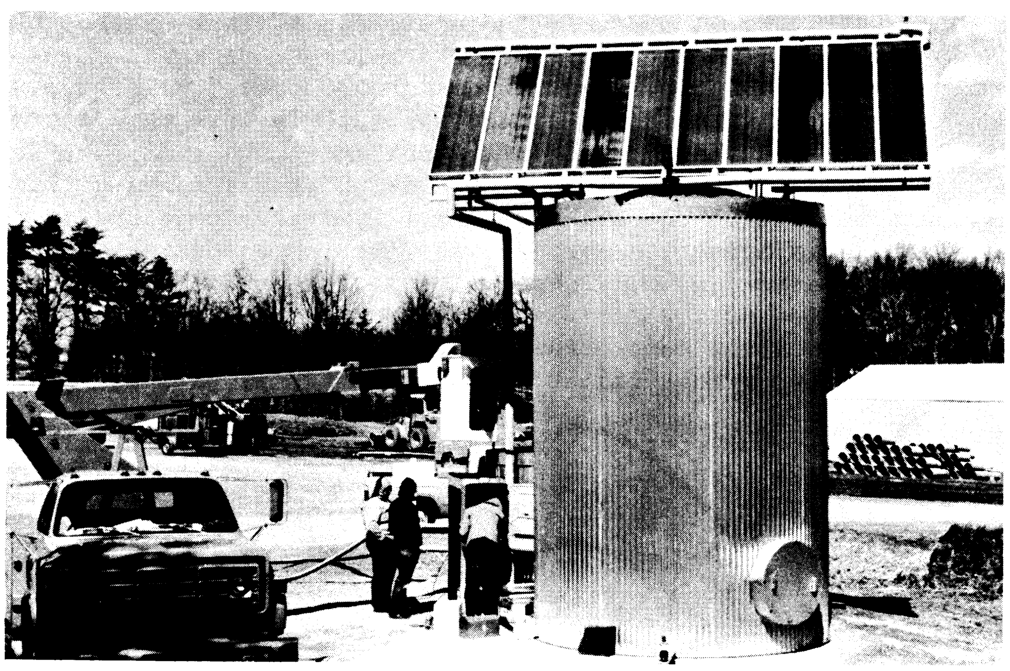

Figure 2. View of completed solar heated asphalt storage tank.

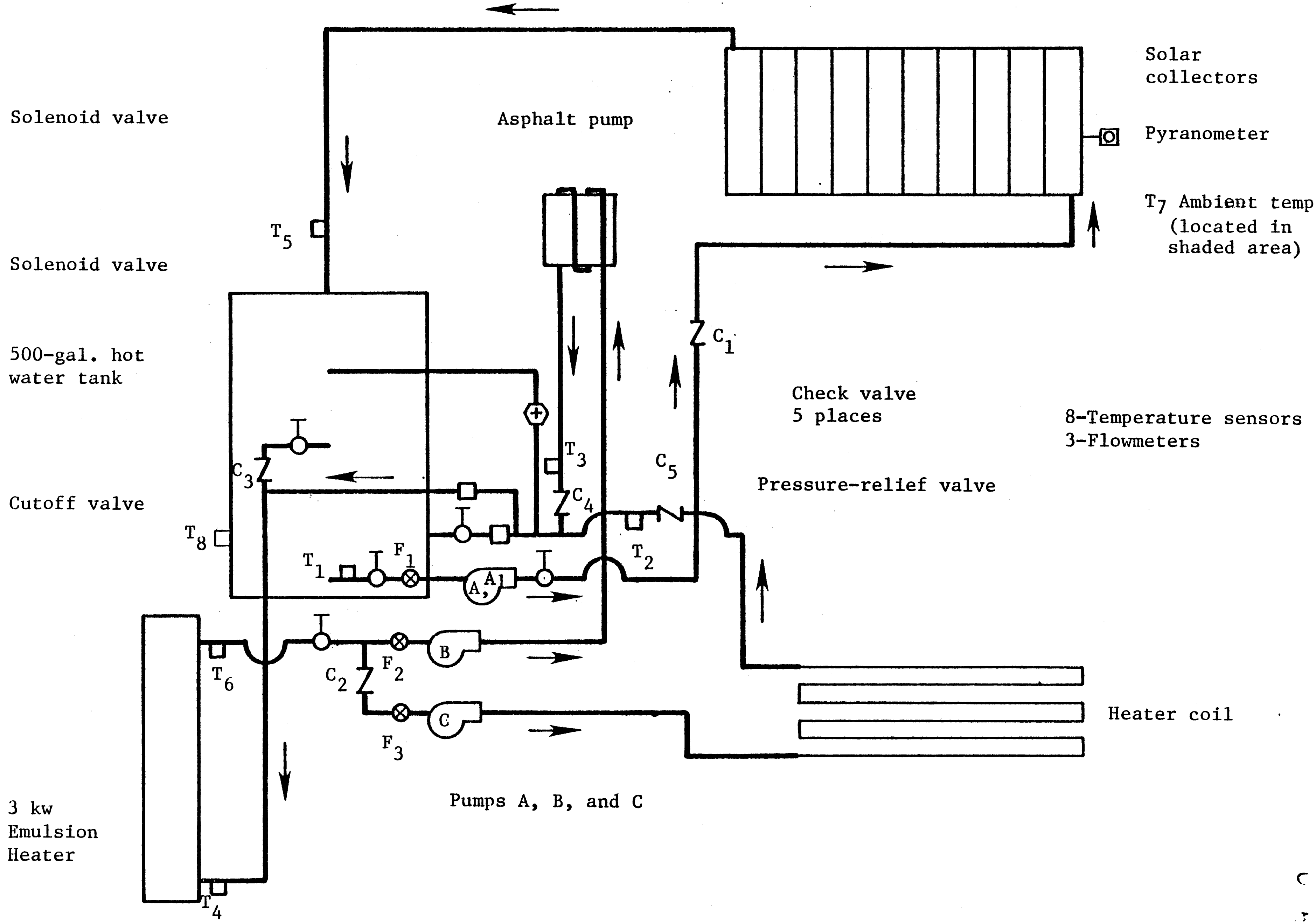

Figure 3. Flow schematic for solar heated asphalt storage tank.

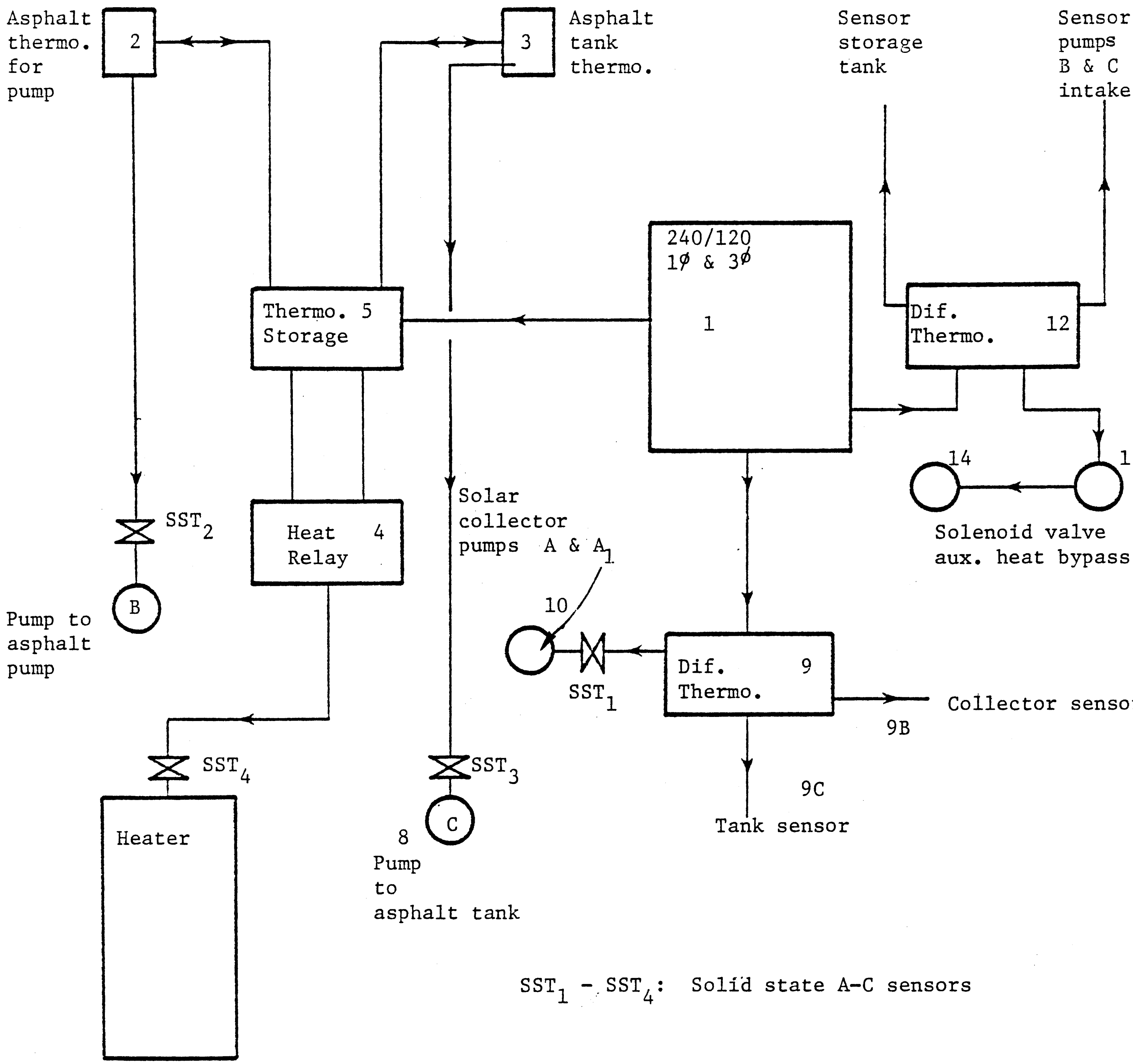

Figure 4. Electrical control layout for asphalt tank solar system.

A view of the interior of the control box that houses the 9 kW auxiliary emulsion heater and the solar pumps and other controls is shown in Figure 5.

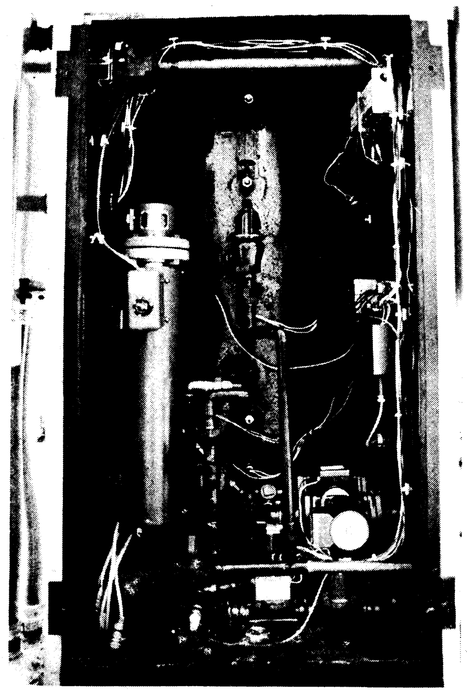

Figure 5. View of the interior of the control box.

INSTRUMENTATION

The monitoring system for the asphalt storage tank employed a microprocessor to control the monitoring rate of the various sensors. Eight temperature sensors were used to establish the heat transfer as gaged from the temperature differentials of the liquid. Ambient conditions were also monitored. Four voltage sensors were used to gage pump and auxiliary heater usage. In addition, three flow meters were used to establish the rate of flow of the heat transfer fluid in each of the three main loops of the system and a pyranometer was installed on the solar collector frame to measure the incidence of solar radiation. A digital cassette tape recorder was used to log the data and a tape player was used to play back the data for computer analysis.

The locations of all the temperature sensors, flow gages, and the pyranometer were shown earlier in Figures 3 and 4. The flow meters were located such that at least 10 in. of straight pipe upstream and 5 in. downstream were available to avoid turbulence at the sensors. In addition to the temperature sensors described above, an additional sensor was placed on the asphalt storage tank. The solid state A.C. sensors designated SST_1 - SST_4 in Figure 4 were connected to their respective monitoring devices through standard A.C. zip cords and 110 V A.C. outlets that paralleled the power sources for the devices. The temperature sensors, flow gages, solar incidence sensor, and the solid-state A.C. hardware elements monitored and recorded the following data:

1. The operational time of the auxiliary heater and each pump in the system.

2. The temperature differentials for each loop during the corresponding pump's time of operation. The temperature differentials for pumps A and A_1, B, and C were measured, respectively, by sensors T_1 and T_5, T_3 and T_6, and T_6 and T_2. Temperature sensors T_4 and T_6 were used to monitor the in-line heater.

3. Solar incidence.

The stabilized flow of the heat transfer fluid through each of the three loops was measured with a flow meter. These flow values were used as constants in determining the energy collected and used by the system. The electrical power consumption of the pumps and the in-line heater was determined based on the time that these units were operating over a given monitoring period.

MICROPROCESSOR FUNCTIONS

The microprocessor recorded the initial temperature at each pair of sensors for each of the loops and the in-line heater as described above in item 2. The temperature was recorded approximately 10 seconds after the pump for a particular circuit was activated and was rechecked and recorded along with the time when the temperature at a sensor changed by two degrees. Pyranometer readings were recorded and the values used to determine the amount of solar radiation during the transfer of energy from the collectors to the fluid. Therefore, the duration of collector activity and the solar incidence values were recorded by the microprocessor whenever the solar pump was active.

The ambient air temperature, T_7, was checked every 10 minutes and was recorded whenever a change of 2°F. occurred. Power failures were recorded at the time of power-off and power-on. The temperature of the asphalt was recorded each day, at anytime the asphalt pump was shutdown, and after the time-initiated daily circulation cycles. The solar storage tank temperature, T_8, was recorded at the initial start-up of the system and at the end of each day (midnight).

All of the data were collected and recorded on the cassette tape. A view of the monitoring and recording equipment is shown in Figure 6. The cassette tape deck was picked up and replaced every 2 to 3 weeks and the data brought in for readback and computer analysis.

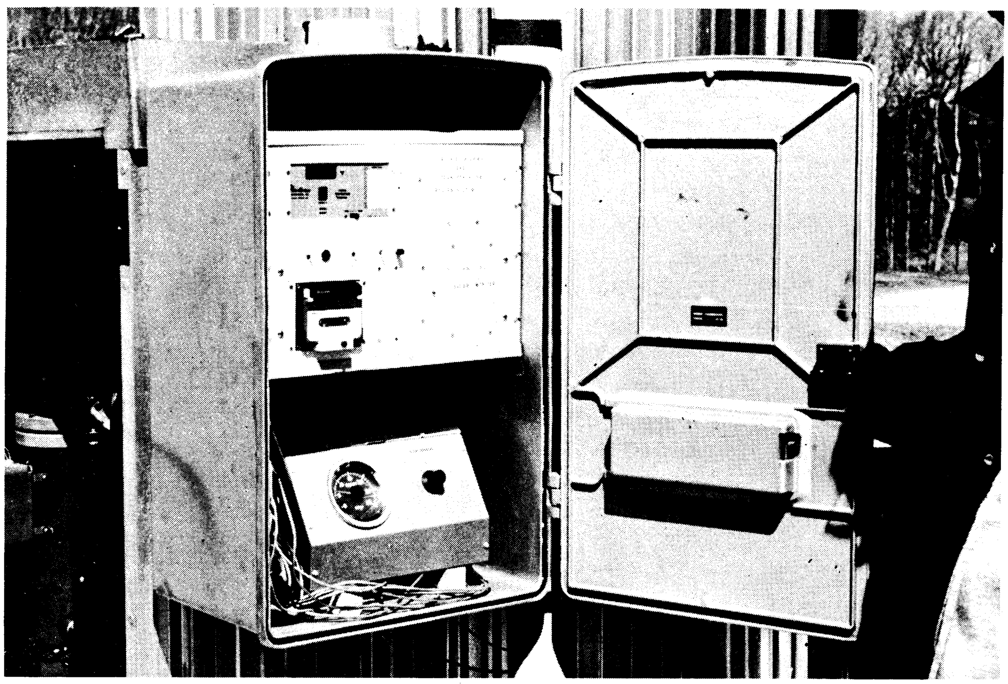

Figure 6. View of the monitoring and data recording equipment (top); flow meter (bottom).

DATA PROCESSING AND ANALYSIS

The data were analyzed on a CDC CYBER 172 computer using FORTRAN programs. The temperature differentials, flow values, and pump on-times were used to establish the amount of energy supplied by the solar collectors and the in-line heater, and the energy used to heat the asphalt and the asphalt pump. The solar intensity data provided the threshold levels for the operation of the collectors. Reference ambient temperatures were taken during all pump operations. With these data, the following items could be monitored or calculated.

1. Total solar insolation in the plane of the collectors

2. The energy transferred from the collectors to the fluid

3. Asphalt heating load

4. The solar energy contribution to the heating loads

5. The auxiliary heater's contribution to the heating loads

6. The fuel consumed by the auxiliary heating system

7. The operating energy for the electrical auxiliary heater and the pumps

8. The temperature of the stored asphalt

9. The electricity saved and operation costs saved

The majority of the daily and monthly data were summarized in reports generated by the CDC computer. A typical monthly summary report for October 1982 is shown in Figure 7. The development of this summary from the data collected is described under monthly performance calculations. In addition, the computer was programmed to develop graphical portrayals of the average daily values of the following:

1. Ambient temperature, °F

2. Irradiation, kWh

3. Collector activity, %

4. Solar energy added to the system, kBtu

5. Energy added, kBtu

6. Energy used, kBtu

7. Energy lost, kBtu

8. Electricity used, kWh

9. Solar contribution to useful energy

Examples of these graphs for the month of October are shown, respectively, in Figures B1 through B9 of Appendix B. Each graph shows the daily values for each day of the month of October. The integrated summary of much of these data is that given in the monthly performance report for the typical example shown in Figure 7. All of these monthly data, including those given in graphical form, were submitted to the FHWA as soon as they were processed.

By perusing the figures shown in Appendix B, one can quickly obtain a general view of the ambient temperature, available solar energy, solar energy utilized, total energy added, energy lost, etc., for each day of a given month.

The lower part of the monthly solar performance report lists the impact of the solar contribution to the heating of the asphalt. In addition, the calculated quantity of electrical energy and costs saving are provided for two methods of evaluation which are defined below.

Monthly Performance Calculations

The monthly performance reports, an example of which is shown in Figure 7, were developed from the data collected on the cassette tapes. Daily summaries identical to the monthly format shown could be generated when needed. The following calculations were programmed to be performed by the computer and printed out as monthly summaries of the performance of the solar system.

MONTHLY SOLAR PERFORMANCE REPORT FOR CONTRACT DOT-FH-15-370
ASPHALT STORAGE TANK - ROUTE 682 CAMPBELL COUNTY, VIRGINIA

OCTOBER, 1982

ENVIRONMENTAL FACTORS:

AMBIENT TEMPERATURE	IRRADIATION > 100	IRRADIATION USED
57.1 DEGREES F	1906.6 KWH	234.0 KWH
	SOLAR DUTY CYCLE	COLLECTOR ACTIVITY
	30.4 %	2.8 %

ENERGY ADDED TO THE SYSTEM:

SOLAR	INLINE HEATER	TOTAL
563.2 KBTU'S	1091.3 KBTU'S	1654.5 KBTU'S

ENERGY USED BY THE SINKS:

ASPHALT TANK	ASPHALT PUMP	TOTAL
1240.6 KBTU'S	231.6 KBTU'S	1472.3 KBTU'S

ELECTRICITY USED BY THE SYSTEM:

CIRCULATION PUMPS	INLINE HEATER	TOTAL
151.2 KWH	614.4 KWH	765.5 KWH

ENERGY LOST BY THE SYSTEM:

182.2 KBTU'S

TEMPERATURE OF THE ASPHALT:

101.7 DEGREES F

THERE WERE 0 POWER OUTAGES FOR A TOTAL DOWNTIME OF 0.0 MINUTES

IMPACT OF SOLAR CONTRIBUTION

	SOURCE METHOD	SINK METHOD
PORTION OF USEFUL ENERGY SUPPLIED BY THE SOLAR SYSTEM	32.7 %	26.6 %
CONVENTIONAL ENERGY SAVED	1918.6 KWH	1497.2 KWH
DOLLARS SAVED (.0387/KWH)	74.25	57.94

Figure 7. Monthly solar performance report for contract DOT-FH-15-370 asphalt storage tank -- Route 682 Campbell County, Virginia.

Temperature and Solar Insolation

The average monthly ambient temperature was calculated from the daily averages by relationships

$$A_T = \frac{\Sigma_1^N \dfrac{\Sigma_1^M T_A t}{24 \text{ hours}}}{N},$$

where

A_t = average ambient temperature,

T_A = ambient temperature,

t = number of hours at a given temperature,

M = number of temperature changes in a 24-hr. period, and

N = number of days.

The solar radiation used was computed by summing the kWh of solar energy available to the collectors while they were active. That is,

$$S_I = \Sigma_1^N \Sigma_1^M S_i t,$$

where

S_I = solar intensity,

t = time that solar intensity was at a given level during collector activity,

S_i = solar intensity during periods when the collectors were active, and

M = number of times the collector was active.

The activity of the collectors is related to the intensity of the solar radiation and was measured as the average daily percentage of activity over the monthly period.

$$C_A = \frac{\Sigma_1^N \Sigma_1^M \dfrac{t}{24}(100)}{N},$$

where

C_A = collector activity, in percent, and

M = number of times the collector was active.

Energy Added to the System

The amount of solar energy added to the system was monitored by measuring the temperature differential between the entrance and exit to the collectors and the flow rate through them.

$$S_E = \Sigma_1^N \Sigma_1^M F_S (T_o - T_i)t,$$

where

S_E = solar energy in Btu,

F_S = flow through the collectors

T_i = entrance temperature of fluid,

T_o = exit temperature of the fluid, and

t = time interval at a given T_i and T_o.

The energy supplied by the in-line heater was measured by monitoring the temperature differential across the heater and the flow through it.

$$H = \Sigma_1^N \Sigma_1^M F_H(T_o - T_i)t,$$

where

H = heater energy in Btu, and

F_H = flow through the heater.

Energy Used

The energy used by the asphalt tank was established by monitoring the temperature differential across the heat exchanger and the flow through it.

$$A = \Sigma_1^N \Sigma_1^M F_A(T_i - T_o)t,$$

where

A = energy used by the asphalt tank in Btu, and

F_A = flow through the tank.

The energy used to warm the asphalt pump was determined in the same general manner as that used to heat the asphalt tank.

$$P = \Sigma_1^N \Sigma_1^M F_p(T_i - T_o)t,$$

where

P = energy used to warm the pump in Btu, and

F_p = flow through the pump.

Electricity Used

The pumps that circulate the fluid run only during acquisition or use of energy. Therefore, the energy used by the pumps was determined for the time each was in use by the equation

$$C = \Sigma_1^N \Sigma_1^M W_X\, t_X,$$

where

C_X = circulation pump energy used in kWh,

W_X = rating of pump in Watts,

t = time the pump was on, and

X = pump number (Figure 3).

The in-line heater was used only when the solar system was not able to supply sufficient energy to meet the heating requirements of the sinks. The energy used by the heater was determined for the time that it was in use as

$$H = \Sigma_1^N \Sigma_1^M W_H t_H,$$

where

H = energy used by the heater in kWh,

W_H = rating of the heater in Watts, and

t_H = time the heater was on.

Energy Lost

The energy lost by the system was determined by summing the energy added and the initial reserve energy and subtracting the sum of the energy used by the sinks and the final reserve energy.

$$E_L = \Sigma_1^N KW_f(T_I - T_F) + (S_E + H - A - P),$$

where

E_L = energy lost by the system

W_f = weight of the solar fluid,

T_I = initial reserve temperature,

T_F = final reserve temperature, and

K = Btu conversion factor.

All of the factors in the above equation are daily values. Electricity consumption was not included in this calculation.

Temperature of the Asphalt

The temperature of the asphalt given on the monthly summary is an average of single daily temperature readings.

$$T_A = \Sigma_1^N \frac{T_a}{N},$$

where

T_A = average monthly temperature of the asphalt, and

T_a = daily temperature of the asphalt.

Solar Contribution

The impact of the solar contribution to the total heating requirements of the system can be viewed from two perspectives. The first was designated as the source method and considers the solar impact side of the system. This method assumes that all the solar energy is useful and could be converted directly into savings. The second method was designated the sink method and considers the output side of the system. The sink method assumes that the only savings derived from the solar energy is the energy used that is not provided by the in-line heater.

The portion of the useful energy supplied by the solar system as defined by the source method is given by

$$E_1 = \frac{\sum_1^N \frac{S_E}{S_E + H} \cdot (100)}{N},$$

and by the sink method, it is defined by

$$E_2 = \frac{\sum_1^N \frac{A + P - H}{P + A} (100)}{N},$$

where

E_1 = useful solar energy supplied in percent (source method),

and

E_2 = useful solar energy supplied in percent (sink method).

The conventional energies saved as determined, by the source and sink methods, respectively, are $\Sigma^N KS_E$ and $\Sigma^N K (A+P-H)$, where K is a Btu to kWh conversion factor. By multiplying the cost per kWh by each of these two expressions the power cost savings can be determined. These values, of course, are hypothetical savings and are based on the data obtained and the method of evaluation.

SUMMARY OF RESULTS

It was originally planned that the monitoring equipment would be operative for a continuous 1-year period. While the data reported here represent a period of approximately 12.5 months, the monitoring of a full winter season of operation of the solar heated asphalt tank was not achieved. Several malfunctions of the microprocessor resulted in the monitoring system being inoperative for long periods of time. On one occasion, and perhaps two, electrical storms in the area apparently created voltage surges that caused the monitoring system to break down. Since the asphalt storage tank is located approximately 80 miles from the researcher's home base, and since the cassette tapes and monitoring level were designed to collect data for a month without reloading, malfunctions on several occasions went undetected for several weeks. In addition, repair of the equipment had to await the availability of the electronics specialist and the delivery of replacement parts. As a result, the data that are reported are for two major periods of operation of the monitoring equipment. These periods were from May through November 1981 (less a 3-week period in September) and June 1982 through January 15, 1983 (less 11 days in December). Therefore, several of the colder months of the year were monitored within the two general periods that the data acquisition system was functioning. Although the project monitoring was to continue through the winter of 1983, no data were collected after a breakdown of the equipment on January 15.

As discussed earlier, monthly records of the daily operation of the solar system were developed graphically as illustrated in Figures B-1 through B-9 of Appendix B. All of these data were supplied to the FHWA demonstration projects office as they were developed. Since the quantity of data for the study is too voluminous to present here, only an overall summary of the monthly performance data follows.

General Data

The average monthly ambient air temperature and the average monthly temperature of the asphalt in the storage tank are given in Table 1. The monthly averages of the daily ambient temperatures ranged from 37.7° to 76.1°F. for those months for which data were collected. This range agrees very closely with the average temperatures expected for this region as discussed earlier. The monthly averages of the daily asphalt temperatures ranged from a low of 89.4°F. to a high of 116.6°F. Generally, the temperature of the stored asphalt was maintained between 95°F. and 100°F. Therefore, the temperature of the asphalt during the months of November, December, and January of 1982-1983 was considerably higher than that normally maintained.

The quantities of asphalt in the storage tank before, during, and after the monitoring period are shown in Figure 8. This graph was developed from logs maintained at the Timberlake maintenance area headquarters. As can be seen, the quantity of asphalt stored in the tank was quite variable during the course of the study. For the most part, the quantity was less than 6,000 gal. On two occasions the quantity dipped below 1,000 gal. for brief periods of time. Consequently, the energy required to maintain the asphalt temperature would be expected to be less than that which would have been required had the tank been filled closer to the 10,000-gal. capacity during the monitoring period.

Table 1

Average Monthly Ambient and Asphalt Temperatures

Year	Month	Average Ambient Temp., °F.	Average Asphalt Temp., °F.	Power Outages No.	Power Outages Time, hr.
1981	May	63.7	99.6	-	
	June	76.1	102.9	-	
	July	76.0	101.5	1	4.42
	August	73.1	109.2	2	25.58
	Sept. 1-9	70.4	101.9	1	7.87
	Nov.	48.2	87.1	-	
1982	June	69.7	101.5	1	0.03
	July	74.7	98.7	-	
	August	71.9	94.1	-	
	Sept.	66.1	89.4	-	
	Oct.	57.1	101.7	-	
	Nov.	48.3	115.2	-	
	Dec. 11-31	39.7	116.0	-	
1983	Jan. 1-15	37.7	116.6		

During the course of the study five power outages occurred (Table 1). Four of the five occurred in the first few months of monitoring. The last of these four occurred during a thunderstorm in early September of 1981 and probably was related to the monitoring equipment difficulties that followed. An additional outage was recorded in June of the following year after the microprocessor was replaced and the monitoring system reactivated. The total time lost to power outages during the period reported was 37.8 hours.

The flow rates used for the study were 5.7, 1.1, and 2.5 gal. per minute, respectively, for pumps A, B, and C as shown in Figure 3.

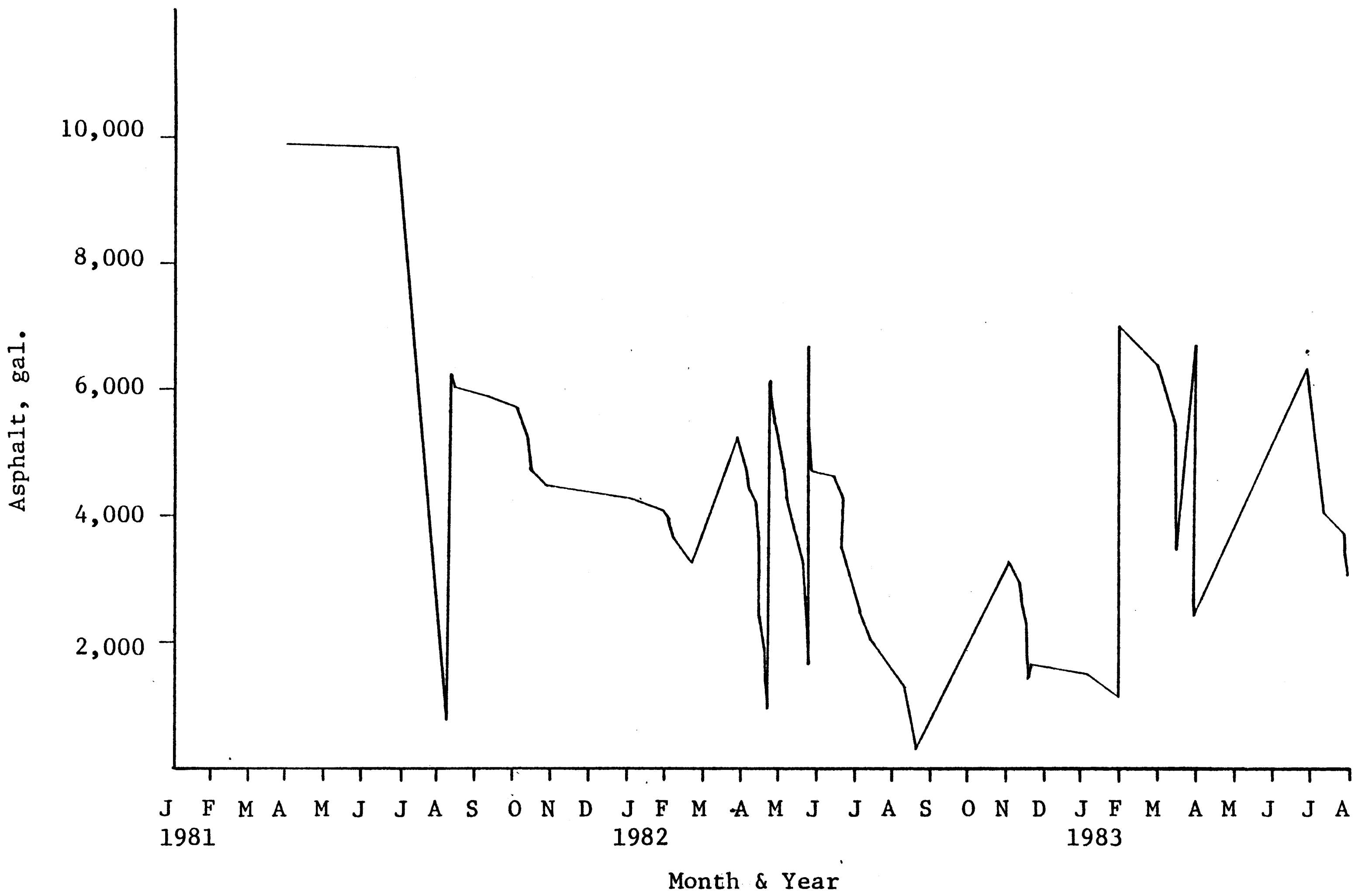

Figure 8. Quantity of asphalt in solar heated tank.

Energy Supplied to the Heating System

The energy supplied to the heating system is summarized in Table 2. For the period monitored, the solar system supplied a low of 65 kBtu (1,000 Btu) of energy between December 11-31 and a high of 1,025 kBtu in August of 1982. The low value for December was probably higher than that given, but the monitoring equipment was inoperative between the 1st and 11th of that month. For the total monitoring period of approximately 12.5 months, 8,921 kBtu of solar energy, S_E, were supplied to the system. The in-line auxiliary heater was not used at all for four of the months. The energy, H, supplied to the system by the auxiliary heater, therefore, varied between zero and a high of 1,567 kBtu during November 1982. The total energy added to the system by the auxiliary heater was 5,860 kBtu. Of the total energy supplied to heating the asphalt and the asphalt pump, the solar system supplied 60%. Although data for several of the winter months were not available, it is reasonable to assume that had the temperature of the stored asphalt been held in the 95°F. to 100°F. range the proportion of energy supplied by the solar system would have been higher. Therefore, even though several winter months were not completely monitored, the total solar contribution would have likely been very close to that determined here. Considering only the summer months of 1981 and 1982, respectively, 73% and 95% of the energy requirements were provided by the solar system.

Energy Used

The energy used for heating the asphalt and the asphalt pump is reported in Table 3. The energy requirements were generally higher during the colder months. The asphalt tank consumed 11,190 kBtu and the asphalt pump used 1,963 kBtu. The total energy used by the two sinks was 13,153 kBtu for the study period. This is approximately 11% less than the energy supplied by the solar system. While the difference between the energy supplied and the energy used cannot be directly accounted for, it is probably due to pipeline losses and slight variations in the flow rates as opposed to the values used in the calculations. At any rate, due to the complexity of the system and to the continuing change in the quantity of asphalt stored in the tank, the relationship between the two totals from Tables 2 and 3 would appear reasonable.

Table 2

Energy Supplied to the Asphalt Heating System

Year	Month	S_E kBtu*	Electrical Heater, kBtu	Total Added, kBtu
	May	862	259	1,121
	June	869	65	934
	July	941	43	984
1981	August	876	0	876
	Sept. 1-9	132	30	162
	Nov.	622	362	984
	June	745	0	745
	July	933	0	933
	August	1,025	0	1,025
1982	Sept.	892	198	1,090
	Oct.	563	1,091	1,654
	Nov.	299	1,567	1,866
	Dec. 11-31	65	1,295	1,360
1983	Jan. 1-15	97	950	1,047
	TOTALS	8,921	5,860	14,781

*kBtu = 1,000 Btu

Table 3

Energy Used by the Asphalt Tank and Asphalt Pump

Year	Month	Asphalt Tank, kBtu	Asphalt Pump, kBtu	Total Used, kBtu
1981	May	953	70	1,023
	June	641	51	692
	July	472	78	550
	August	326	88	414
	Sept. 1-9	69	22	91
	Nov.	1,225	197	1,422
1982	June	316	130	446
	July	345	103	448
	August	386	125	511
	Sept.	530	158	688
	Oct.	1,241	232	1,473
	Nov.	2,030	299	2,329
	Dec. 11-31	1,513	231	1,744
1983	Jan. 1-15	1,143	179	1,322
	TOTALS	11,190	1,963	13,153

Electricity Used

The kWh of electricity used by the circulation pumps, A, A_1, B, and C, and the in-line heater were measured in two ways. First, electrical usage was calculated from the power rating of the electrical units and the time that they were active during each month. Secondly, the electrical energy supplied to the asphalt storage tank system was metered by a regular power company meter. The kWh of electrical consumption calculated for the circulation pumps and the in-line heater and the total for these are presented in Table 4 along with the metered readings for each month. It can be noted that the total kWh as metered by the power company was about twice the calculated total (10,066 vs. 5,087). This difference is probably due to two factors. First, the difference reflects the efficiency of the pumps and in-line heater, since their energy output would not be expected to be the same as the energy input.

Secondly, the power consumed by the asphalt pump is not included in the calculated values. Therefore, some of the metered power reported in Table 4 would have been consumed by the asphalt pump. The power consumed by the pump was not included in the solar monitoring calculations since it would have been used in either a conventional or a solar heated system in the same manner. At any rate, the metered electrical consumption data were collected as a general backup and check on the operation of the monitored system. In general, the metered power consumption for each month shown in Table 4 is about twice that of the calculated as described earlier.

The metered electrical consumption increased markedly during late 1982 and early 1983. Whereas only 1,000 kWh of power were metered in November of 1981, for example, 2,104 kWh were metered in November of 1982. The calculated values for the electrical in-line auxiliary heater indicated a marked increase in usage during that same period. In reviewing the asphalt temperature data it appears that most of this marked increase in power consumption was related to a considerable increase in the temperature of the asphalt. Normally, the temperature of the stored asphalt is maintained in the 90°F. to 100°F. range. Between September 1982 and January 15, 1983, however, the temperature of the asphalt steadily increased from approximately 90°F. to 117°F. For each of the two general periods of data collection, the metered electrical consumption is compared to the temperature of the asphalt in Figures 9 and 10. While one would expect electrical consumption to increase somewhat in the fall of the year, these data show that the marked increase in power consumption was due in large measure to the increase in temperature of the stored asphalt. The metered and the calculated power consumption data are thus in good general agreement.

Table 4

Calculated vs. Metered electricity Used by
Pumps and In-Line Heater

Year	Month	Pumps, kWh	In-Line Heater, kWh	Total, kWh	Metered, kWh
1981	May	137	181	318	621
	June	127	45	172	300
	July	135	21	156	280
	August	90	0	90	295
	Sept. 1-9	38	16	54	100*
	Nov.	108	223	331	1,000
1982	June	145	0	145	-
	July	158	0	158	230
	August	158	0	158	234
	Sept.	151	109	260	432
	Oct.	151	614	765	1,531
	Nov.	106	948	1,054	2,104
	Dec. 11-31	69	761	830	1,644*
1983	Jan. 1-15	53	543	596	1,295*
	TOTALS	1,626	3,461	5,087	10,066

*Interpolated.

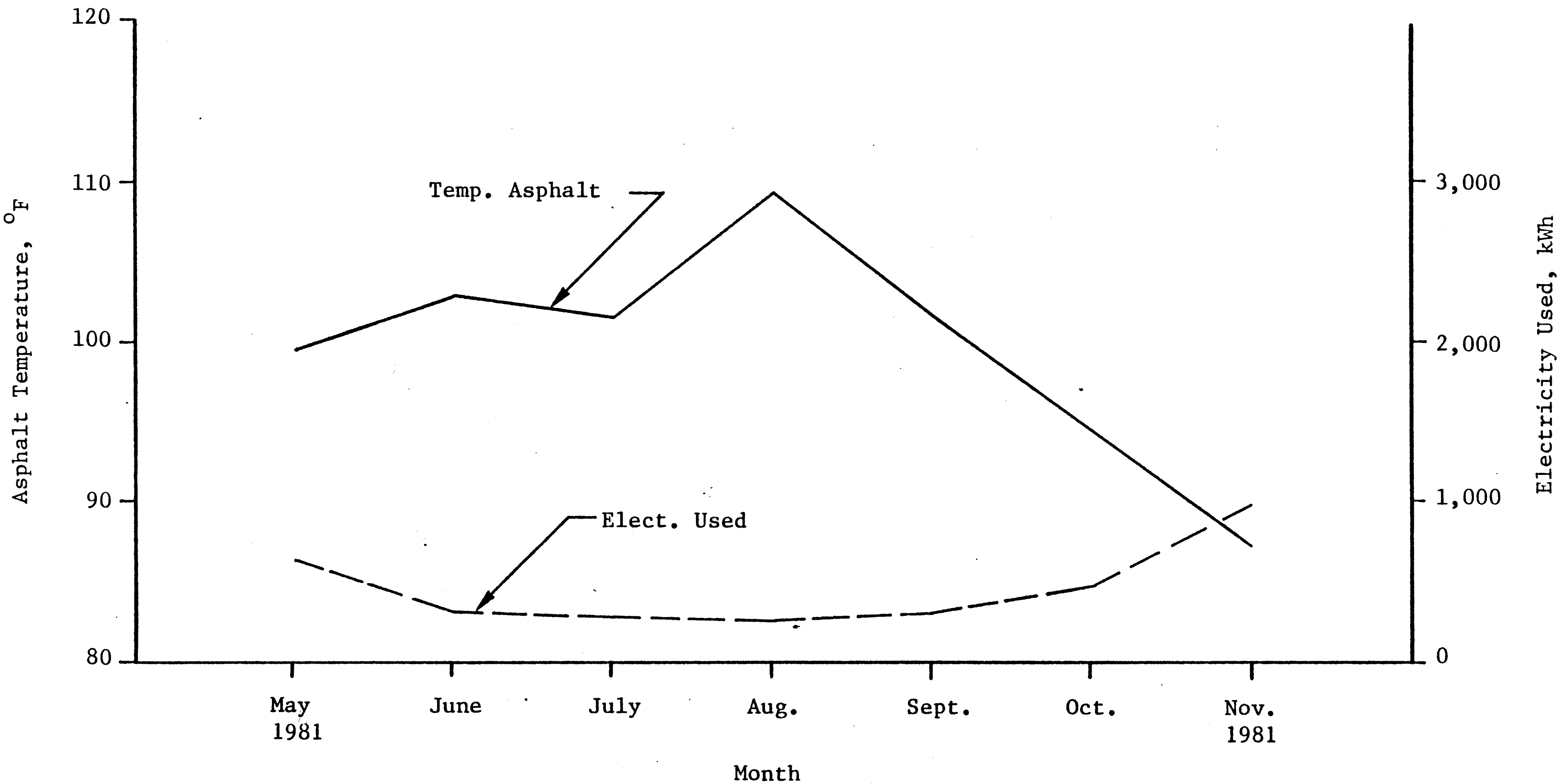

Figure 9. Average monthly temperature of asphalt and electricity used by Timberlake solar heated tank from May 1981 to Nov. 1981.

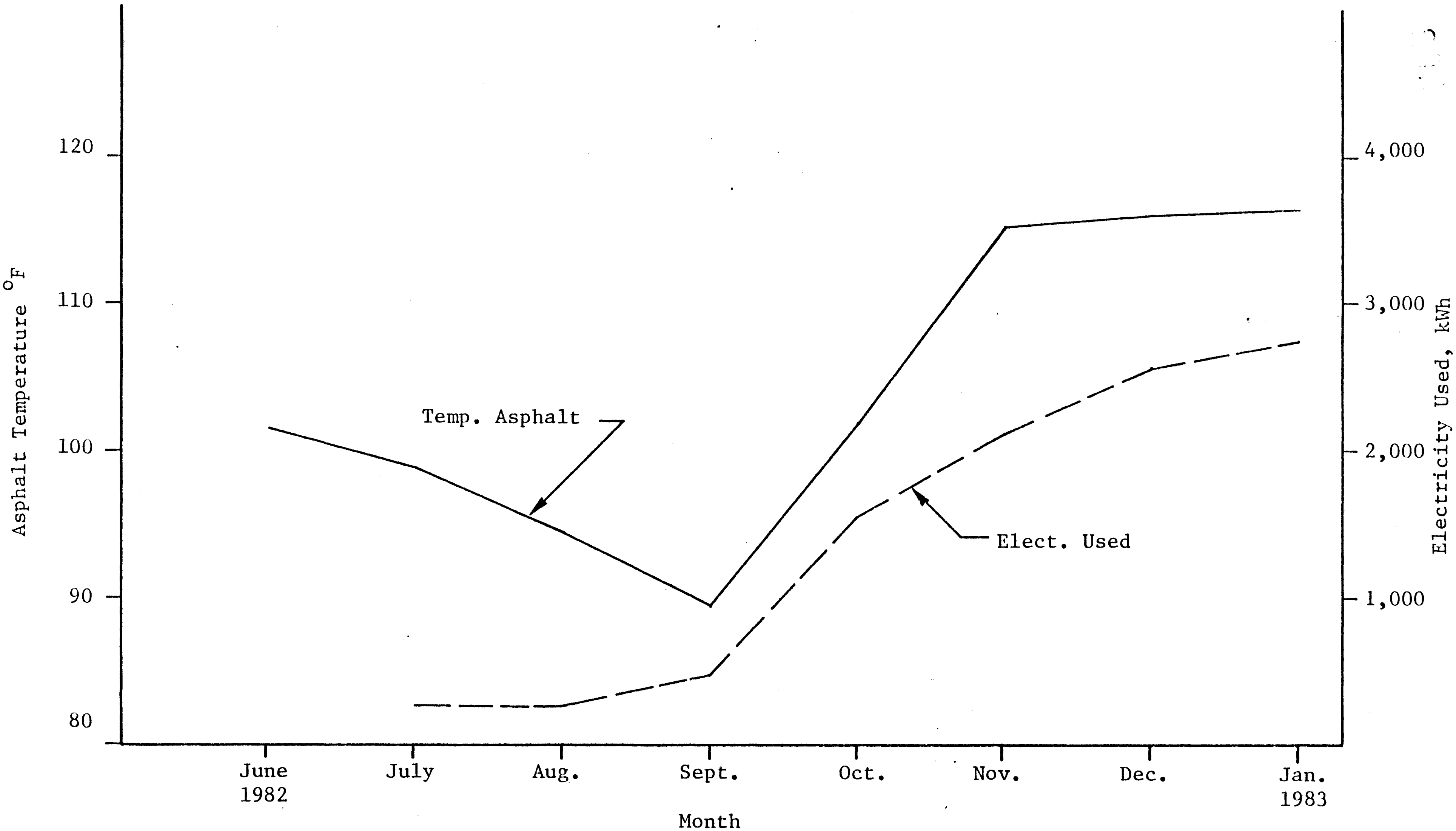

Figure 10. Monthly average temperature of asphalt and electricity used by Timberlake solar heated tank from June 1981 - Jan. 1983.

Savings in Energy and Money

As described earlier, the electrical energy saved by the solar system was calculated from two viewpoints. The results as determined by the source method are summarized in Table 5. This method of evaluation indicates that the solar system contributed 65.4% of the energy required by the facility during the period of study. A total of 30,360 kWh of electricity were saved as determined from this viewpoint. At the cost of $0.0387 per kWh prevailing in 1981 the savings for the approximately 12.5-month period would be $1,175.85.

The sink method results are summarized in Table 6. This method indicates that 70.7% of the solar energy was useful in contributing toward the heating requirements of the asphalt storage tank. A total of 25,126 kWh of electrical energy were saved as determined from this calculation. At the $0.0387 cost per kWh, $972.27 were saved over the approximately 12.5-month period.

While there is a moderate difference between the cost savings as determined by the two viewpoints, the sink method would appear to be the more realistic approach. The source method basically assumes that all the solar energy is useful. In the writer's view, it would appear likely that the system would not be able to utilize all the energy collected during the hot summer months. It can be noted from a comparison of the data in Tables 5 and 6 that the cost savings are much greater during June, July, and August as determined by the source method as opposed to the sink method. The more conservative sink method considers only the energy that was used during these warmer months rather than how much was made available by the solar system.

Finally, it should be noted that the cost of electrical power for this facility is now $0.049 per kWh. Therefore, the costs savings are now about 27% greater than those described above. While this increase has probably not occurred on an annual basis, it does indicate an annual increase of approximately 9% over the 3-year period.

Table 5

Savings in Energy and Money by the Source Method of Evaluation

Year	Month	Useful Solar Energy, %	Electrical Energy Saved, kWh	Savings*, Dollars
1981	May	72	2,934	113.53
	June	90	2,955	114.35
	July	90	3,203	123.94
	August	97	2,980	115.33
	Sept. 1-9	66	450	17.41
	Nov.	56	2,117	81.90
1982	June	97	2,536	98.12
	July	100	3,174	122.84
	August	100	3,491	135.08
	Sept.	86	3,036	117.49
	Oct.	33	1,918	74.25
	Nov.	16	1,017	39.36
	Dec. 11-31	4	220	8.51
1983	Jan. 1-15	9	329	12.74
	TOTALS	65.4	30,360	1,174.85

*For this calculation a kWh rate of $0.0387 was used. The rate being charged at the end of the study was $0.049 per kHw.

Table 6

Savings in Energy and Money by the Sink Method of Evaluation

Year	Month	Useful Solar Energy, %	Electrical Energy Saved, kWh	Savings*, Dollars
1981	May	76	2,607	100.88
	June	90	2,140	82.82
	July	90	1,729	66.92
	August	100	1,415	54.74
	Sept. 1-9	68	214	8.27
	Nov.	74	3,620	140.04
1982	June	100	1,521	58.85
	July	100	1,562	60.43
	August	100	1,746	67.55
	Sept.	84	1,671	64.67
	Oct.	27	1,497	57.94
	Nov.	28	2,599	100.58
	Dec. 11-31	25	1,535	59.40
1983	Jan. 1-15	28	1,270	49.15
	TOTALS	70.7	25,126	972.27

*For this calculation a kWh rate of $0.0387 was used. The rate being changed at the end of the study was $0.049 per kWh.

COMPARISON OF THE SOLAR HEATED TANK WITH A CONVENTIONAL ELECTRICALLY HEATED TANK

Since there were several breakdowns in the instrumentation installed on the solar heated asphalt tank, it was decided to generally compare that tank with a similar electrically heated tank located approximately 30 miles away at the Gretna area headquarters. This comparison was not a part of the original plan to study the solar heated asphalt tank at the Timberlake headquarters. However, it should give a broad view of the relative differences in the electrical energy consumption between the two installations, which both have 10,000 gal. storage tanks. The electrically heated tank near Gretna was chosen because it is one of the few tanks for which the power consumption is metered separately from that for other facilities at the area headquarters. In addition, it is relatively close to the solar heated tank that was investigated.

The information for the electrically heated tank was obtained from the records maintained at the resident engineer's office. These are the monthly electrical consumption quantities in kWh as billed by the electric utility and the date and amount of asphalt delivered and stored in the tank. Since the solar heated tank at the Timberlake headquarters was metered separately from the other facilities, it was possible to make a general comparison of the energy consumption of the two installations.

This comparison is shown for two different periods in Figures 11 and 12. Figure 11 shows the power consumption for May through November 1981. Although the electronic instrumentation on the solar installation was inoperative during October and part of September, the power consumption was recorded by the electric meter. For each of the months shown the solar heated tank consumed less power than did the electrically heated tank. Over the full 7-month period the solar heated tank used a total of 3,226 kWh of electricity, whereas the electrically heated tank used 14,400 kWh. Therefore, the solar heated tank used only 22% of the power consumed by the electrically heated tank. On the other hand, 10,968 gal. of asphalt were delivered to the electrically heated tank, whereas 5,537 gal. were delivered to the solar tank. While this information does not give a complete picture of the quantity of asphalt actually heated over the 7-month period, it does suggest that there was more activity at the Gretna tank and more asphalt was drawn off. Whether this would require more heating energy for the Gretna tank than that required for the Timberlake tank is difficult to assess. However, because of the substantial and consistent differences in the power consumption between the two tanks it is not likely that the difference in the quantities of asphalt delivered to the two tanks would have affected the net result; i.e., that the solar heated tank conserved substantial electrical energy over the 7-month period.

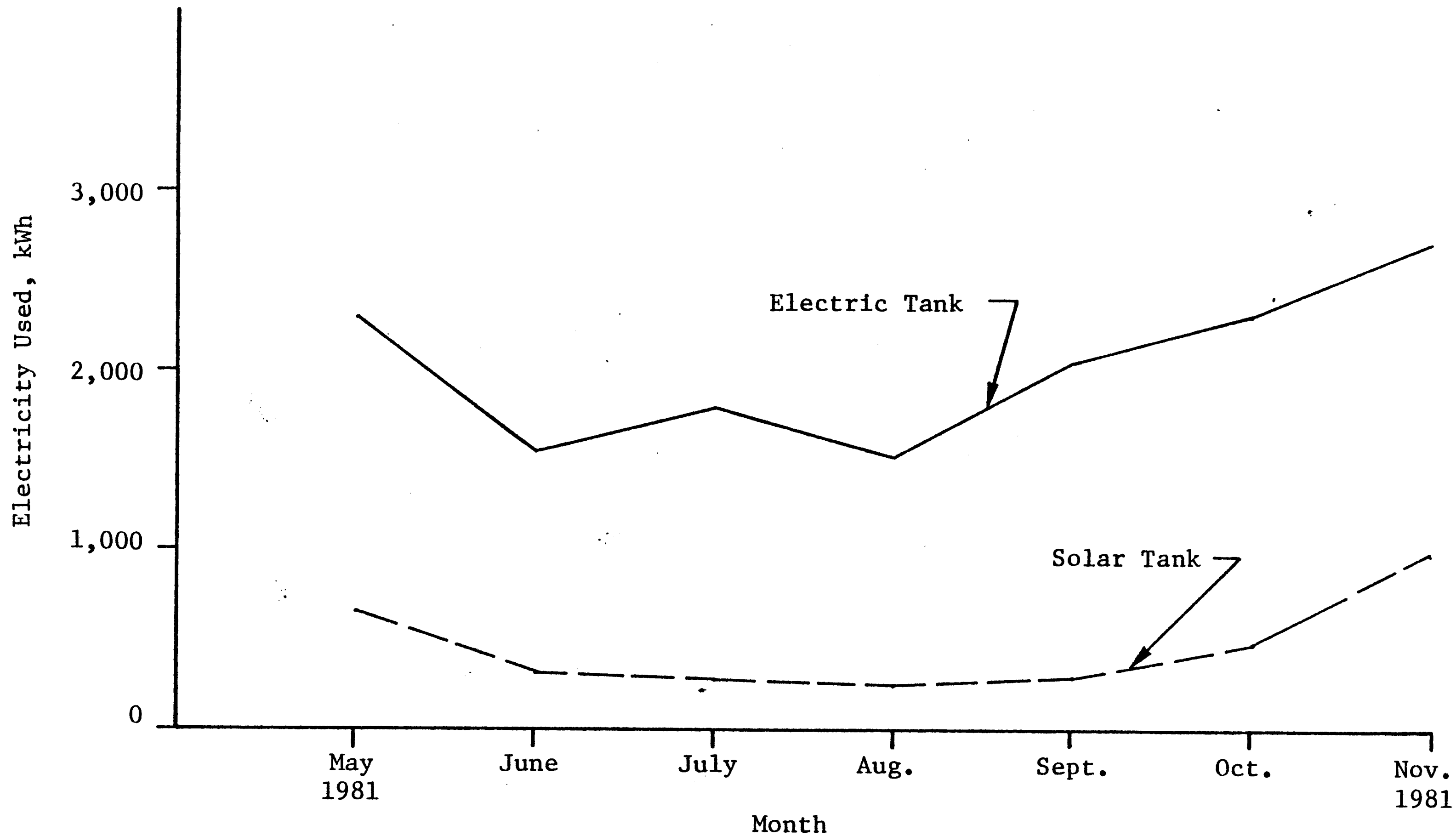

Figure 11. Comparison of total electricity used by two similar asphalt tanks — one solar heated (Timberlake), one electrically heated (Gretna). May 1981 - November 1981.

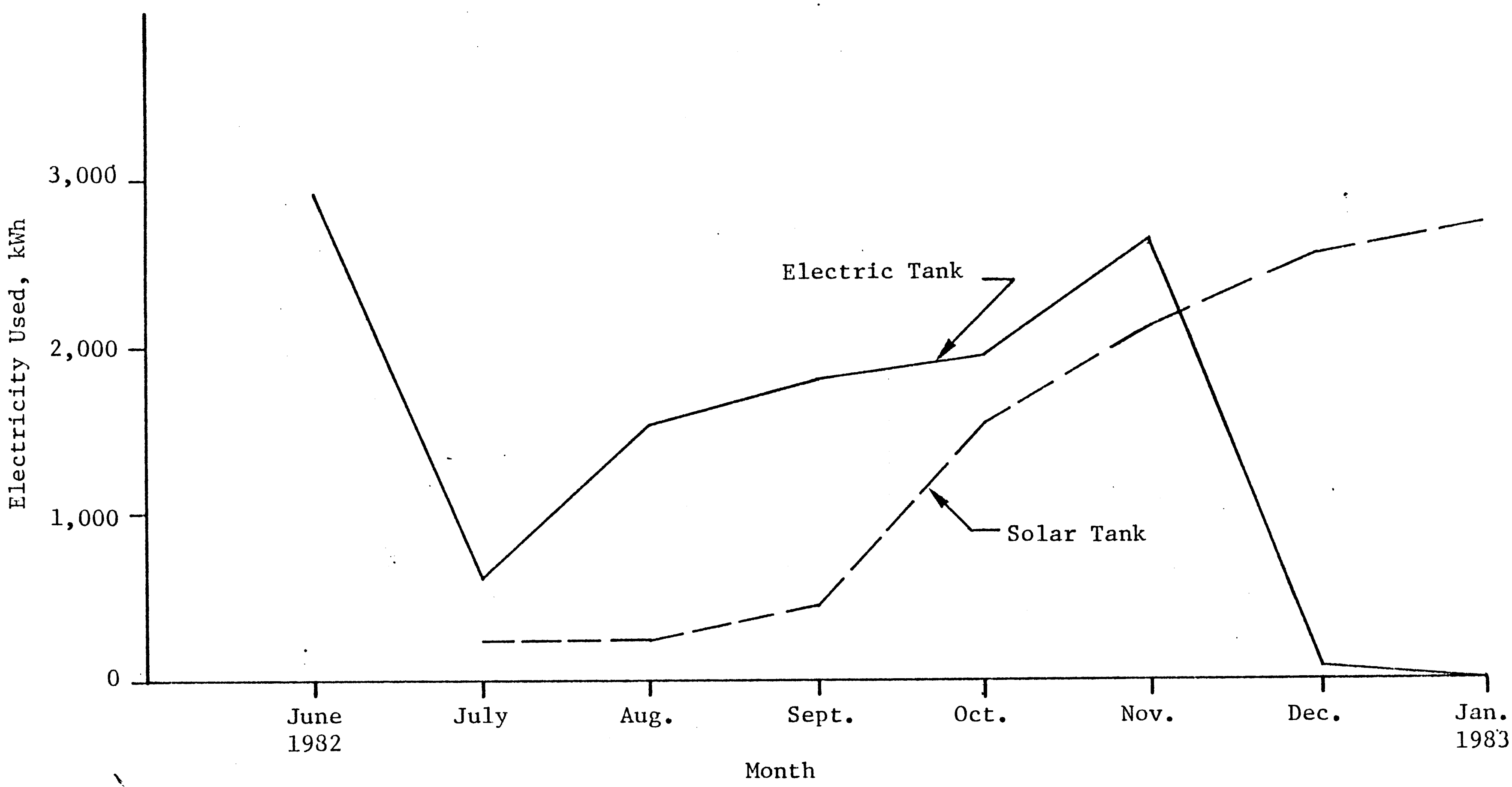

Figure 12. Comparison of total electricity used by two similar asphalt tanks — one solar heated (Timberlake) and one electrically heated (Gretna). June 1982 - Jan. 1983.

The second period for which the instrumentation on the solar heated tank was operational was between June 1982 and January 15, 1983. A comparison of the amounts of electricity consumed by the two facilities over this period is shown in Figure 12. It can be noted from these data that the solar heated tank consumed less energy than the electrically heated tank for all months except December and January. The data for these two months are really not comparable, however, because it is apparent that the electrically heated tank was, for all practical purposes, shut down during December and January when only 70 and 10 kWh were used. If these two months are excluded from the comparison, the Timberlake tank used 4,521 kWh between July and November, whereas the Gretna tank consumed 8,460 kWh. During this period, the solar tank used only 53% of the energy that the electrically heated tank used. During the period between June and January, 22,019 gal. of asphalt were delivered to the electrically heated tank, whereas 19,500 gal. were delivered to the solar heated tank. This would suggest that the asphalt usage was nearly the same for both facilities.

While the comparison for the second period does not indicate that the savings for the solar tank are as impressive as those in the first period, it should be noted that the temperature of the asphalt was maintained at a higher level in the solar tank during the latter part of 1982 than during the 1981 period. This reduced the efficiency of the solar system during 1982, as was discussed earlier.

ECONOMIC ANALYSIS

In the original economic analysis the cost of the solar system was estimated to be $4,922 and the annual energy cost savings were estimated to be $501.41. The actual cost of the solar system was $7,438.05, including insulation of the tank. In order to recognize that some fringe benefits of alternative uses of irreplaceable fossil fuels exist, the Demonstration Projects Division of the FHWA has suggested that the savings of fuel costs be doubled for the analysis. Therefore, in the original analysis a figure of $1,002.82 was used as the annual energy cost savings. Using the more conservative sink method of analysis of the data obtained from this study, a total of $972.27 was saved over a 12.5-month period. By proportion, this would be equal to $933.38 annually, or $1,866.76 if doubled. The original escalation rate of 10% in the price of fuel was reasonable, since electricity costs have increased by 27% in the approximately 3 years since the facility was constructed. The original estimate of the payback period was 8.8 years when the doubled fuel costs savings were used as recommended.

The present analysis is based on the following:

Solar component life, n	=	20 years
Nominal interest rate, r	=	12% per year
Fuel price escalation rate, r_e	=	10% per year
Inflation rate (other than fuel), r_i	=	7% per year
Initial power cost per kWh	=	$0.0387
Assuming the power is generated by fossil fuels (2 x 0.0387)	=	$0.0774/kWh

The present value, PV, of the costs savings resulting from the solar system is

$$PV - A_s e^{-r_e} \frac{e^{n(r_e-r)}-1}{1-e^{-(r_e-r)}} - e^{-nr} (S_r - S_s),$$

where

A_s = annual energy costs savings = $1,866.76,

S_r = replacement costs of the solar system, and

S_s = salvage value of the initial solar system.

The replacement costs of the initial system at 7% annual inflation 20 years hence would be

$$S_r = 7{,}438.05\ (1 + 0.07)0^{20} = 28{,}782.91.$$

The salvage value, S_s, 20 years hence is assumed to be equal to the initial cost of $7,438.05. Accordingly, the present value of the savings resulting from the initial investment of $7,438.05 is $25,934 based on the values listed above. This would result in a payback period of 9.35 years for the initial investment.

The above analysis, as noted, used the recommended doubling of the fuel cost savings to account for the savings of irreplaceable fossil fuels. If only the direct electrical power costs savings are used for the present value analysis the results are still favorable. In this case, the annual energy cost saving, A_s, of $933.38 is used and the present value of the initial investment of $7,438 is $11,999. The payback period in this case would be 15 years.

MAINTENANCE COSTS

During the course of the study less than $100 was spent on maintenance of the solar system. This cost was due to the replacement of a valve in the plumbing of the solar system.

CONCLUSIONS

1. The use of solar energy to assist in the heating of asphalt storage tanks is a cost-effective means of saving both energy and dollars. For the solar heated asphalt storage tank monitored in this study, the most conservative evaluation of the data indicated that 25,126 kWh of power were saved over 12.5 months. At a cost rate of $0.0387 per kWh, this would yield a savings of $972.24 in power costs. The proportionate amount of savings for a 12-month period would be $933.58

2. Assuming a service life of 20 years for the solar components and interest at 12% per annum, a present value of $25,934 was yielded by the initial investment of $7,438. The payback period on the initial investment would be 9.35 years. In the analysis, the power cost savings were doubled to account for savings of irreplaceable fossil fuels. If only the direct electrical power costs savings are recognized, a present value of $11,999 with a payback period of 15 years would result. In either case, the investment in solar energy systems to assist in heating asphalt as opposed to the conventional electrical heating system is favorable.

3. The storage tanks are normally used to maintain the temperature of the asphalt in the 90°F. to 100°F. range. Had the temperature of the stored asphalt been maintained between 90°F. and 100°F. for the full monitoring period, the energy savings would have been greater. For approximately 3 months of the monitoring period the temperature of the asphalt was as high as 117°F.

4. A comparison of the metered electrical power consumption of the solar heated tank with that of a conventional electrically heated tank showed that the conventional system consumed considerably more power than did the solar assisted system. This comparison, in a general sense, supported the results obtained from the electronic monitoring installed on the solar heated asphalt tank.

RECOMMENDATION

One hundred seventy-three asphalt storage tanks are in use at the various maintenance area headquarters in Virginia. It is recommended that when new tanks are to be installed, or where older ones are to be replaced, that the solar-assisted heating system be considered. It has been estimated that approximately 25% of the storage tanks now in use are over 15 years old. Assuming that 25% (43) of the tanks now in use were solar heated and power savings of 25,000 kWh per year per tank were realized, $52,675 per year could be saved based on the current rate of $0.049 per kWh being charged at the Timberlake area headquarters.

ACKNOWLEDGEMENTS

Thanks are extended to B. W. Sumpter, then assistant district engineer in Lynchburg and now district engineer in Salem, and E. M. Mitchell, highway engineer, and Walter Eads, electrician, of the Lynchburg District for their assistance in conducting the study. The solar installation was developed and fabricated under the supervision of Mr. Mitchell.

The monitoring instrumentation for the study was developed and installed by Professor J. H. Aylor, of the University of Virginia. The computer programming used for the storage, retrieval, and reporting of the daily and monthly data was developed by Jerry Korf, research scientist with the Research Council, who also played a major role in developing the study and planning the instrumentation. Jennifer Ward, programmer/analyst with the Council, processed the data and assisted Mr. Korf with the computer programming. Jimmy French, technician supervisor, assisted with the data retrieval. The author gratefully expresses appreciation for the assistance of all these individuals.

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1. "A Solar Heated Asphalt Storage Tank," Technology Sharing Report FHWA-TS-78-207, U. S. Department of Transportation, Washington, D.C., August 1978.

2. Hankins, Kenneth D., "Using Solar Heating With Asphalt Storage -- Lubbock, Texas," Report No. 229-2F, Texas Department of Highways and Public Transportation, October 1981.

3. Solar Energy Handbook, Theory and Applications, Ametek, Inc., Chilton Book Company, Radnor, Pennsylvania, 1979.

APPENDIX A

STRUCTURAL DESIGN DETAILS OF THE SOLAR HEATED ASPHALT STORAGE TANK

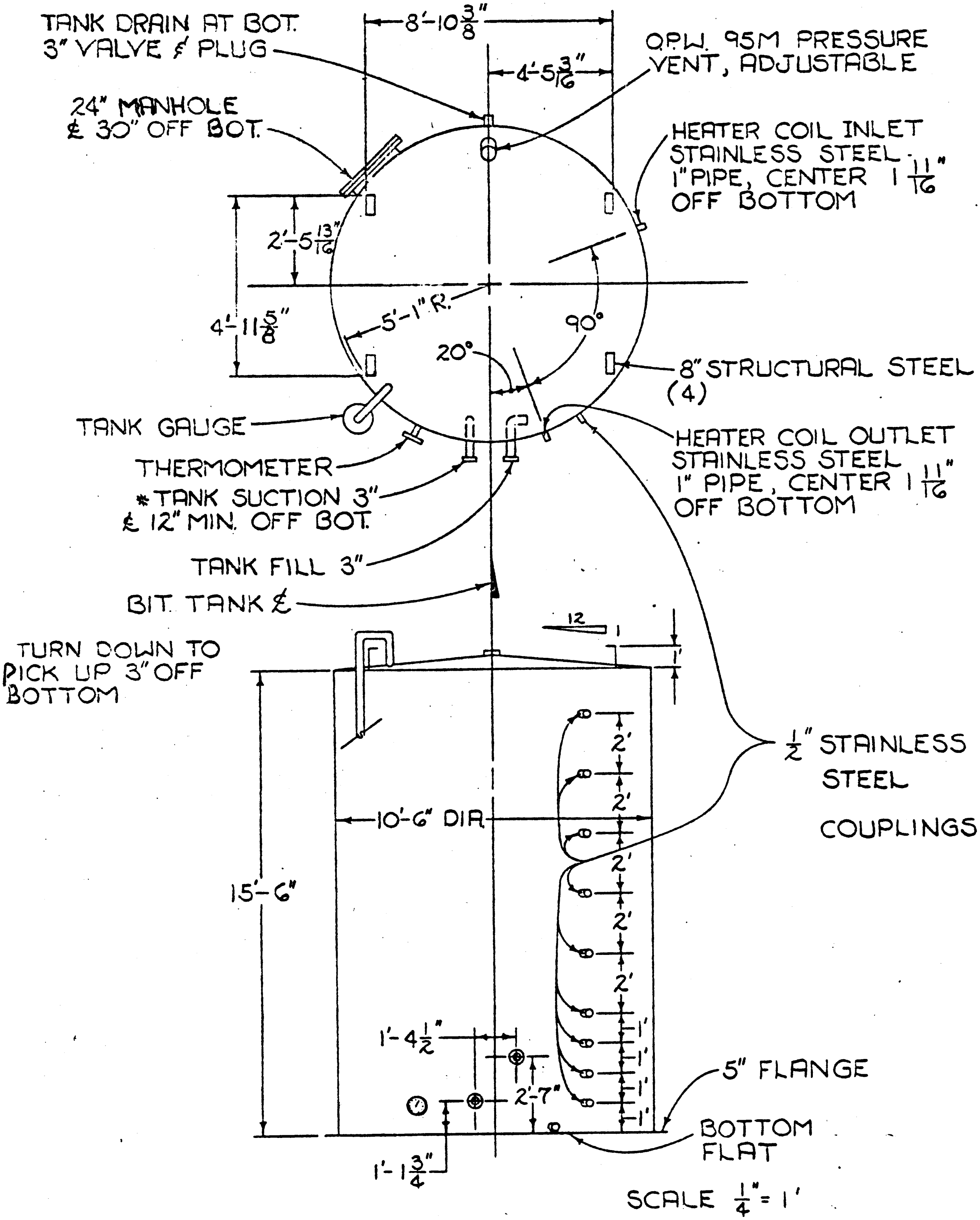


Figure A-1. Details of 10,000 gal. bituminous tank.

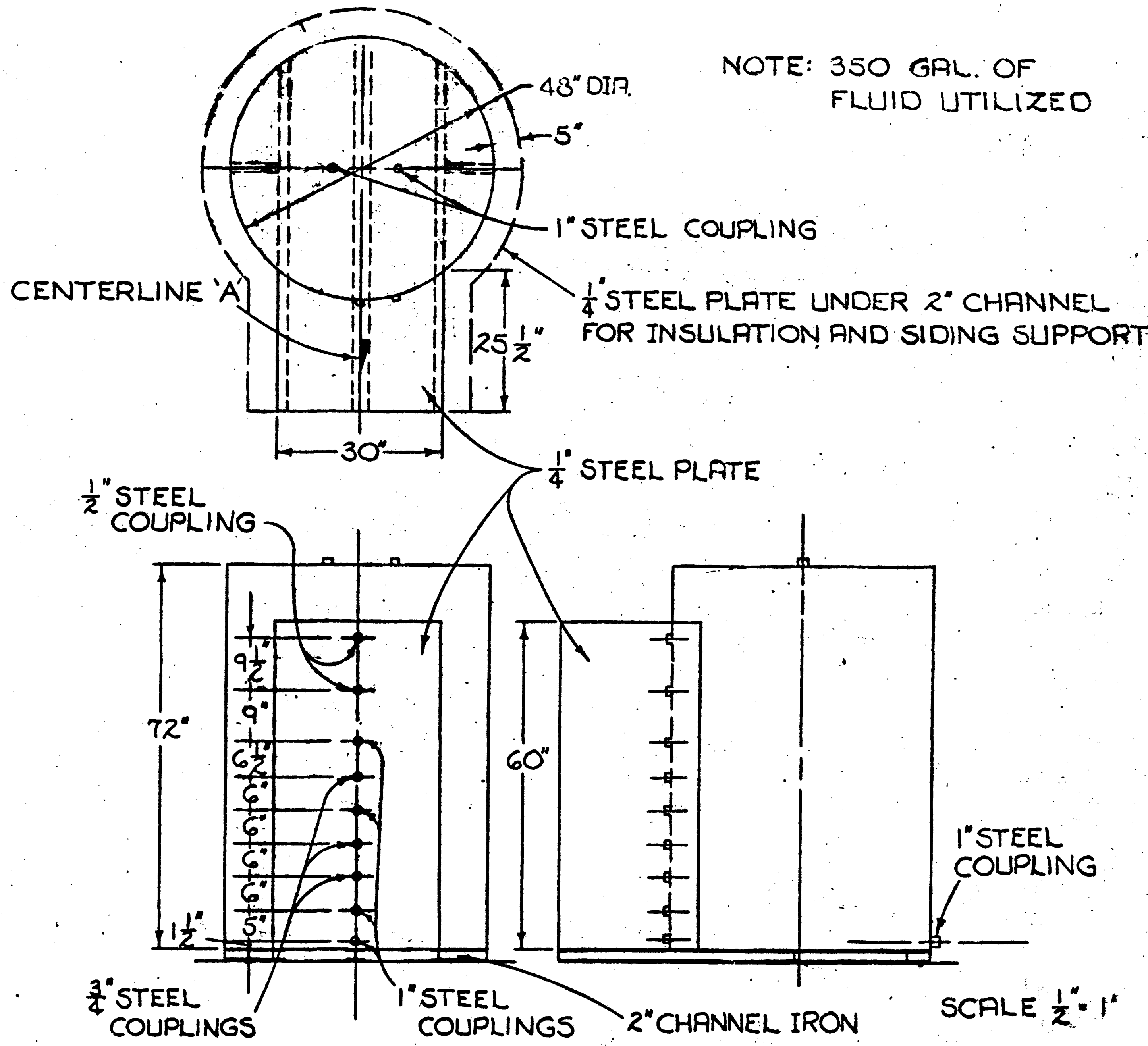


Figure A-2. Details of 500 gal. solar storage tank.

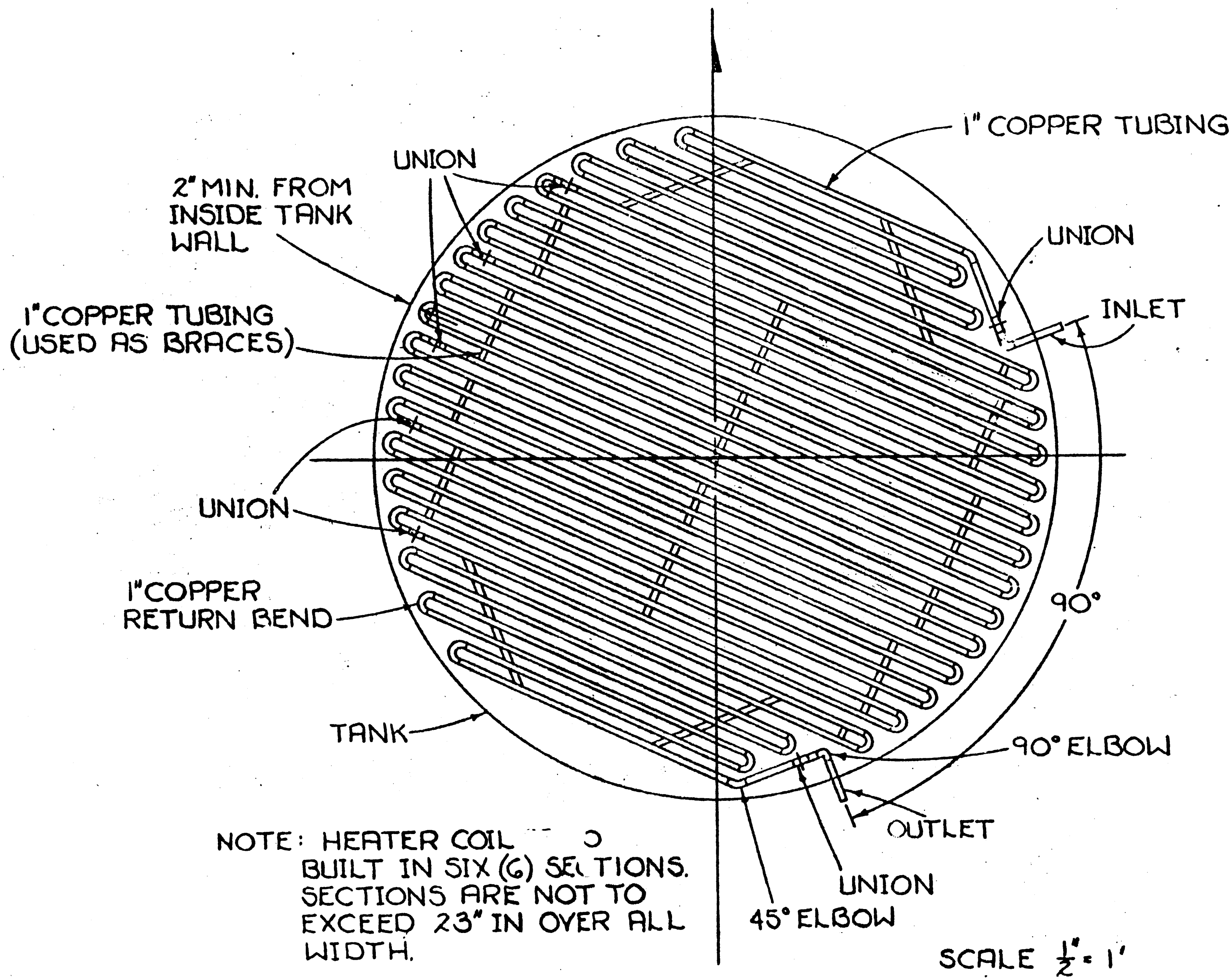


Figure A-3. Details of heater coil.

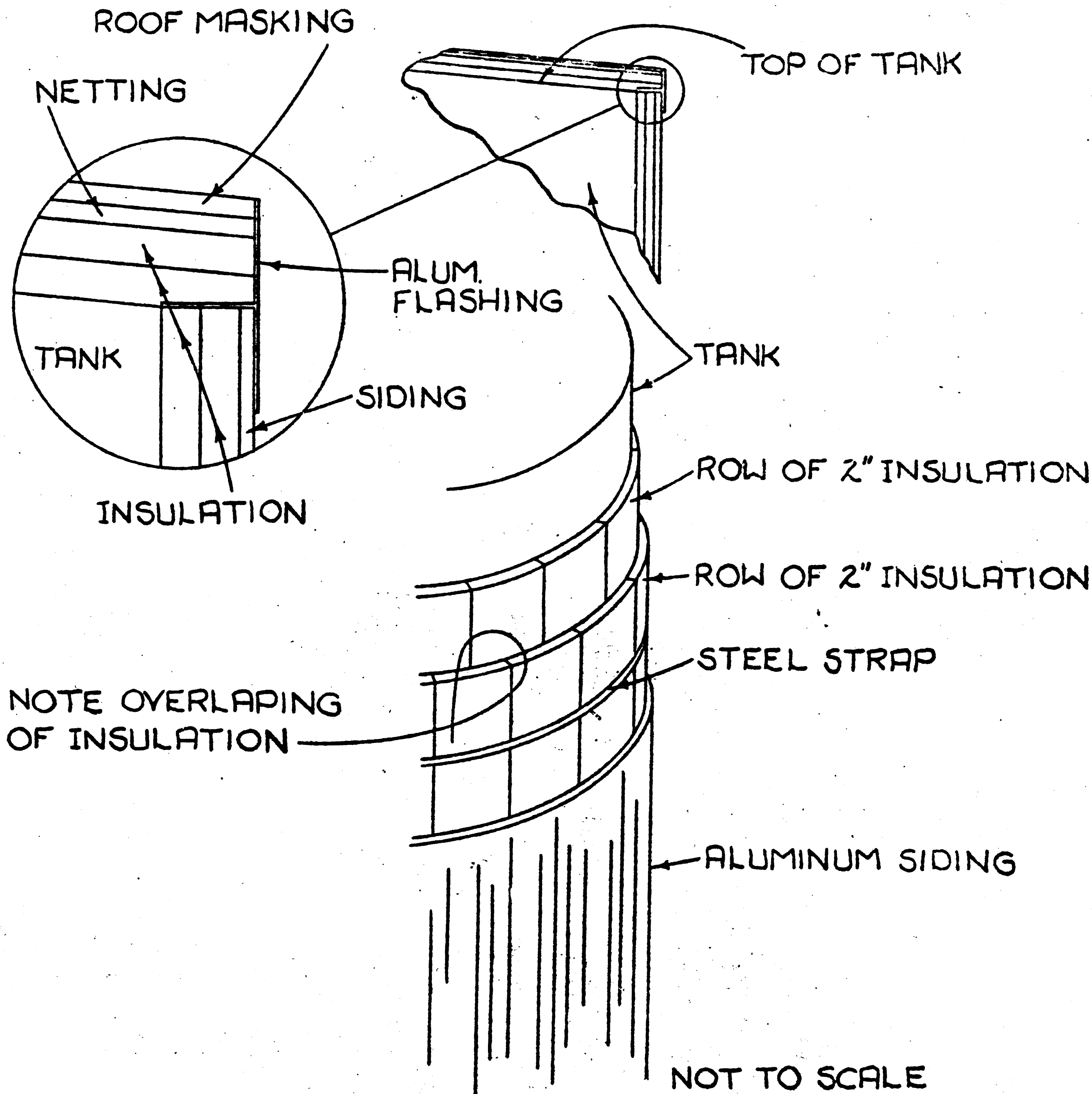


Figure A-4. Details for insulating the bituminous and hot water tanks.

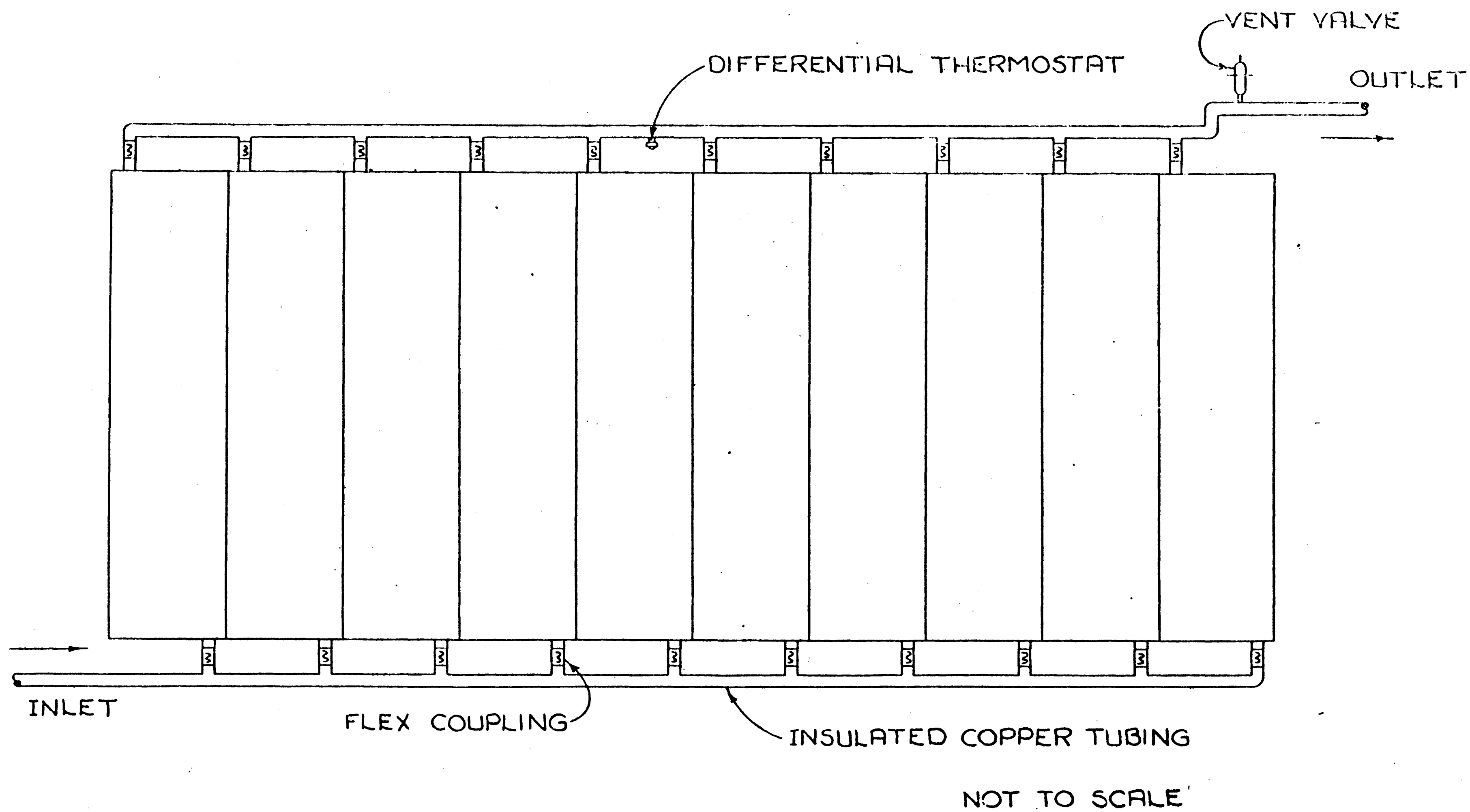


Figure A-5. Solar collector connections.

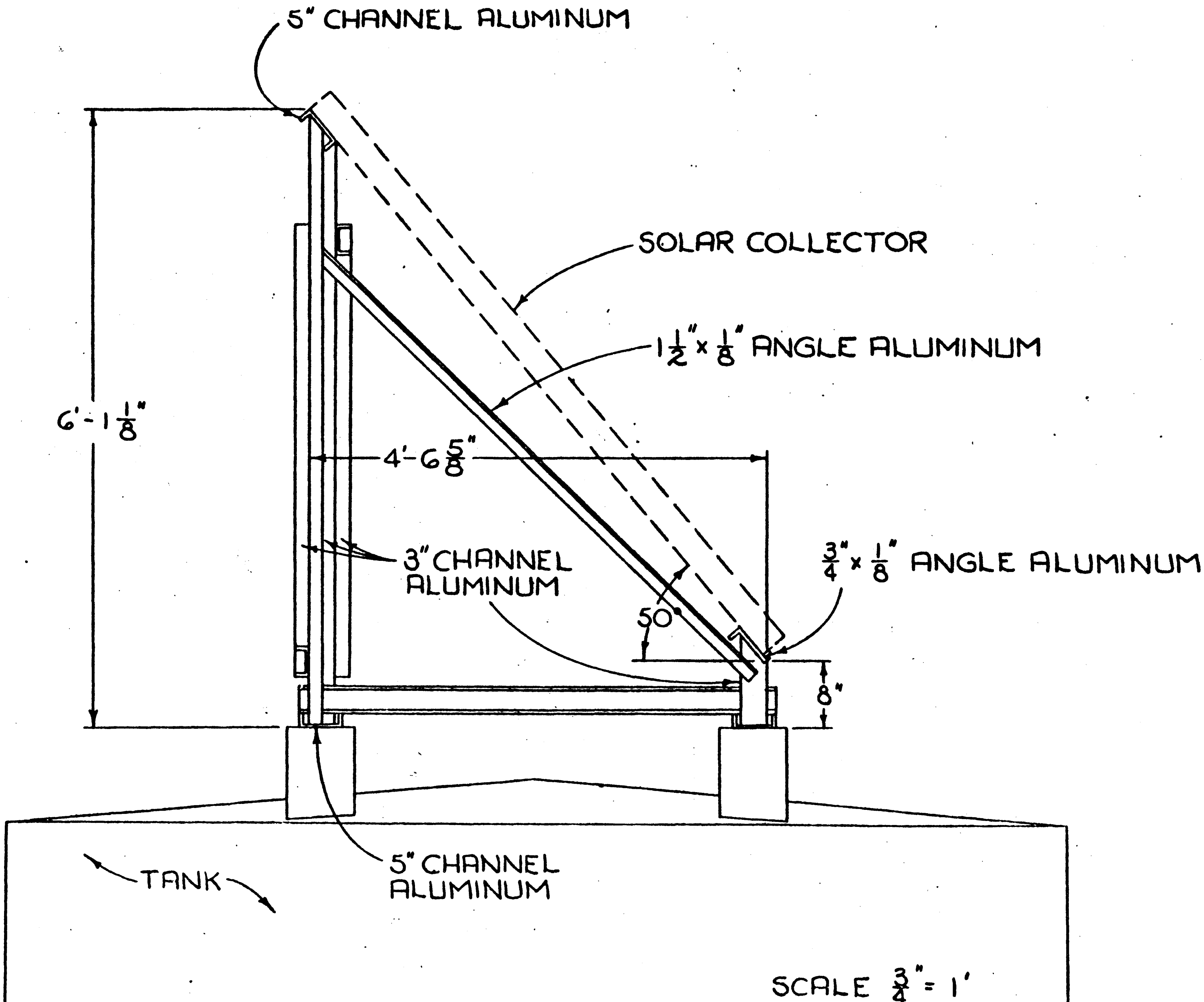


Figure A-6. Solar collector mounting frame (view looking east).

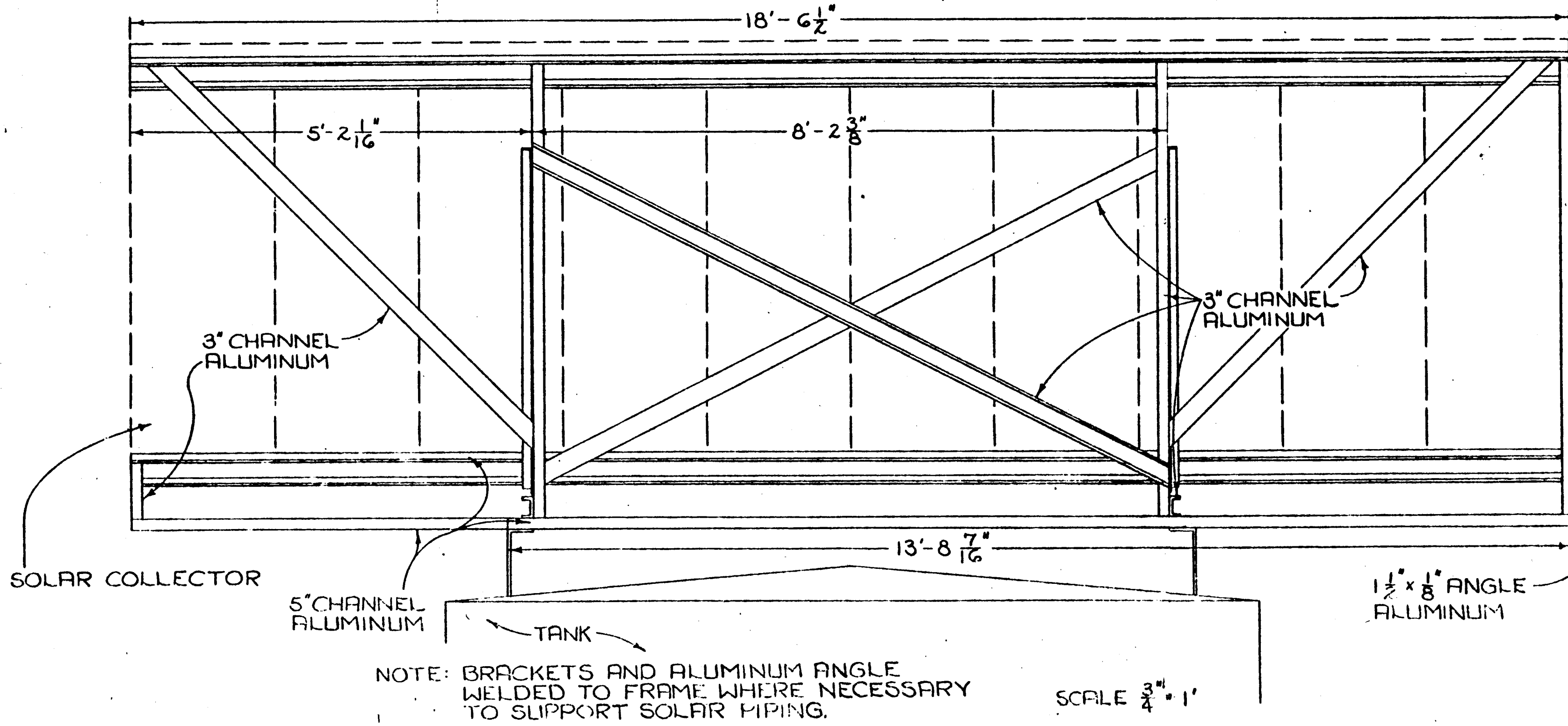
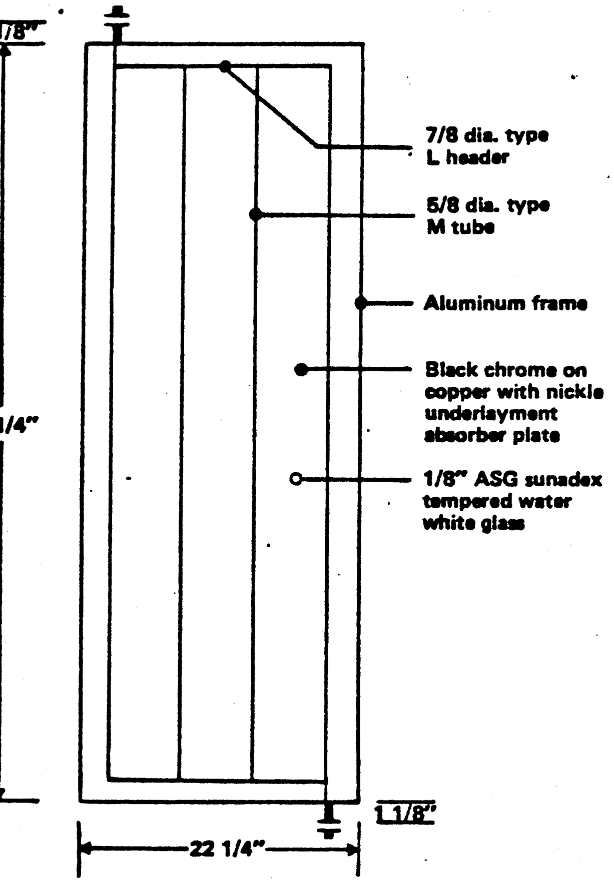


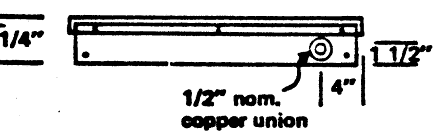
Figure A-7. Solar collector mounting frame (view looking south).

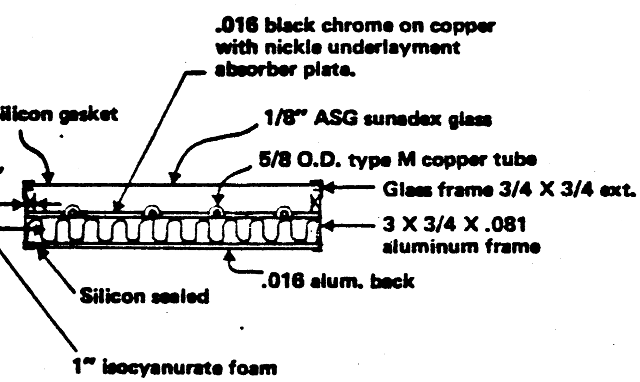
Virginia Solar Components, Inc.

Hwy. 29 South, Route 3, Rustburg, Virginia 24588 (804) 239-9523

VSC - 7HE COLLECTOR PANEL







FEATURES AND CONSTRUCTION

COVER: Single glazing: ASG sunadex 1/8 inch. Tempered, edges swiped. Double glazing: ASG Sun-A-Therm, 2 - 1/8 inch. Tempered, with no fog system. Total transmissivity: Single glazing 91.6%; Double glazing, 81.6%.

ABSORBER CONTAINER: Sides, aluminum extrusion; rear aluminum sheet .016 inches thickness, silicon bonded in place.

AIR SPACE BETWEEN COVER AND ABSORBER: 1 1/8 inch above tube channel; 1 1/2 inch above absorber fin.

GASKETING MATERIAL: Compressible high temperature silicon sealed.

WEATHER PROOFING: Collector can be placed out in the weather without additional weather proofing.

FINISH ON ALUMINUM CONTAINER: Standard mill finish.

DIMENSIONS OF SURFACE MOUNTED COLLECTOR: Outside dimensions overall: 22 1/4 inch wide X 84 1/4 inch long X 3 1/4 inch thick. Effective absorber surface area = 12.5Ft^2.

ABSORBER: Copper sheet: .016 inches thick. Selective black chrome on nickle: minimum absorptivity, .93; maximum emissivity, .10. Manufactured by Berry Solar Products; durable to 400°F(305°C). Copper tubes: 5/8 inch O.D., 4 inches clear spacing, M type copper. Tube pattern: grid. Bond between tube and sheet: 95/5 solder, 270°wrap. Manifolds: 7/8 inch type L copper. Tube connections to manifold: 95/5 solder. Connection to external piping: 1/2 inch nom. copper union connection, nut and tail piece supplied. Manifold/Tubes pressure tested before leaving factory to 150 psi.

COLLECTOR INSULATION: 1.0 inch thick isocyanurate behind the absorber R=8. .5 inch isocyanurate on all inside edges of collector frame.

METHOD OF ANCHORING: Entire side and end of collector frame may be used for securing mounting brackets or flange clips to supporting structure. Screws or bolts should protrude no more than 1.0 inch inside collector.

WEIGHT PER PANEL: 59 lbs. filled; 55 lbs. empty (standard 2'X7' unit). The collector holds approximately .5 gallon of water.

RECOMMENDED FLOW RATE: .2 gpm per collector.

PRESSURE DROP: Negligible.

COLLECTOR COOLANT: Tap water recommended . . . pH to be controlled between 6.5 and 8, and the Ca. Mq count should be below 52ppm.

WARRANTY: Five year limited material and workmanship effective from date of purchase. See your local distributor for further information.

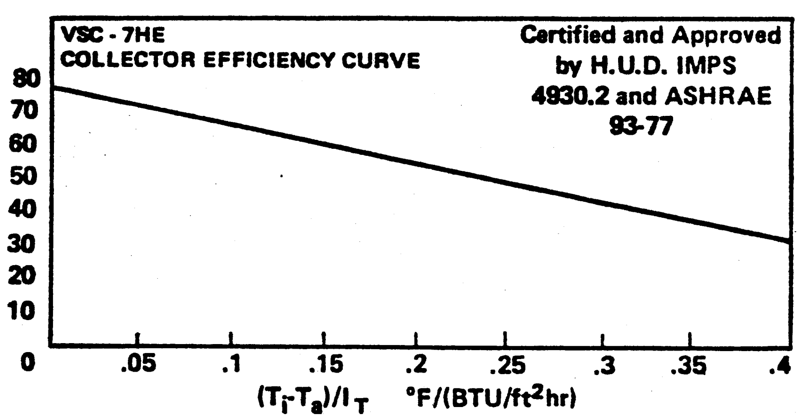


Figure A-8. Solar collector design details.

APPENDIX B

TYPICAL MONTHLY ENERGY DATA FOR THE OPERATION OF THE SOLAR HEATED ASPHALT STORAGE TANK

MONTHLY SOLAR PERFORMANCE REPORT FOR CONTRACT DOT-FH-15-370
ASPHALT STORAGE TANK - ROUTE 682 CAMPBELL COUNTY VIRGINIA

OCTOBER, 1982

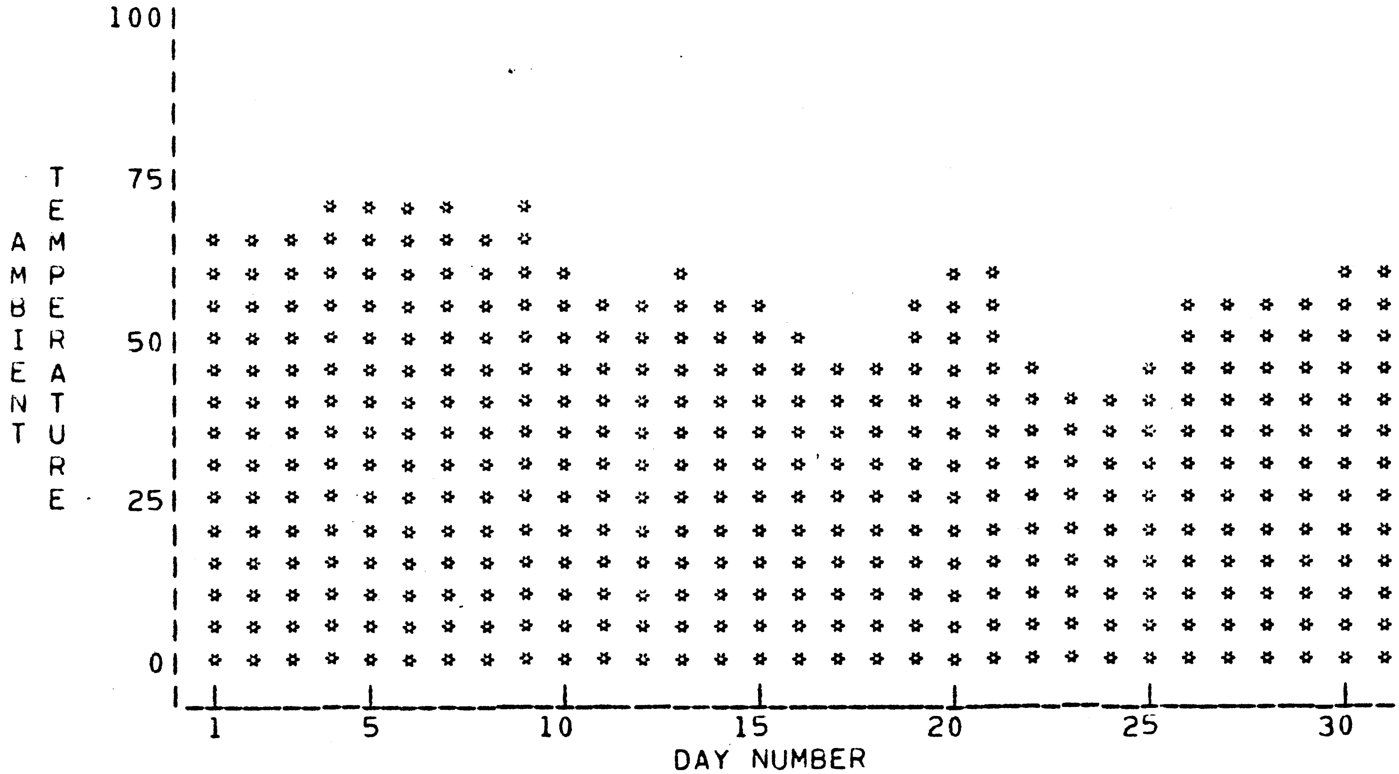


Figure B-1

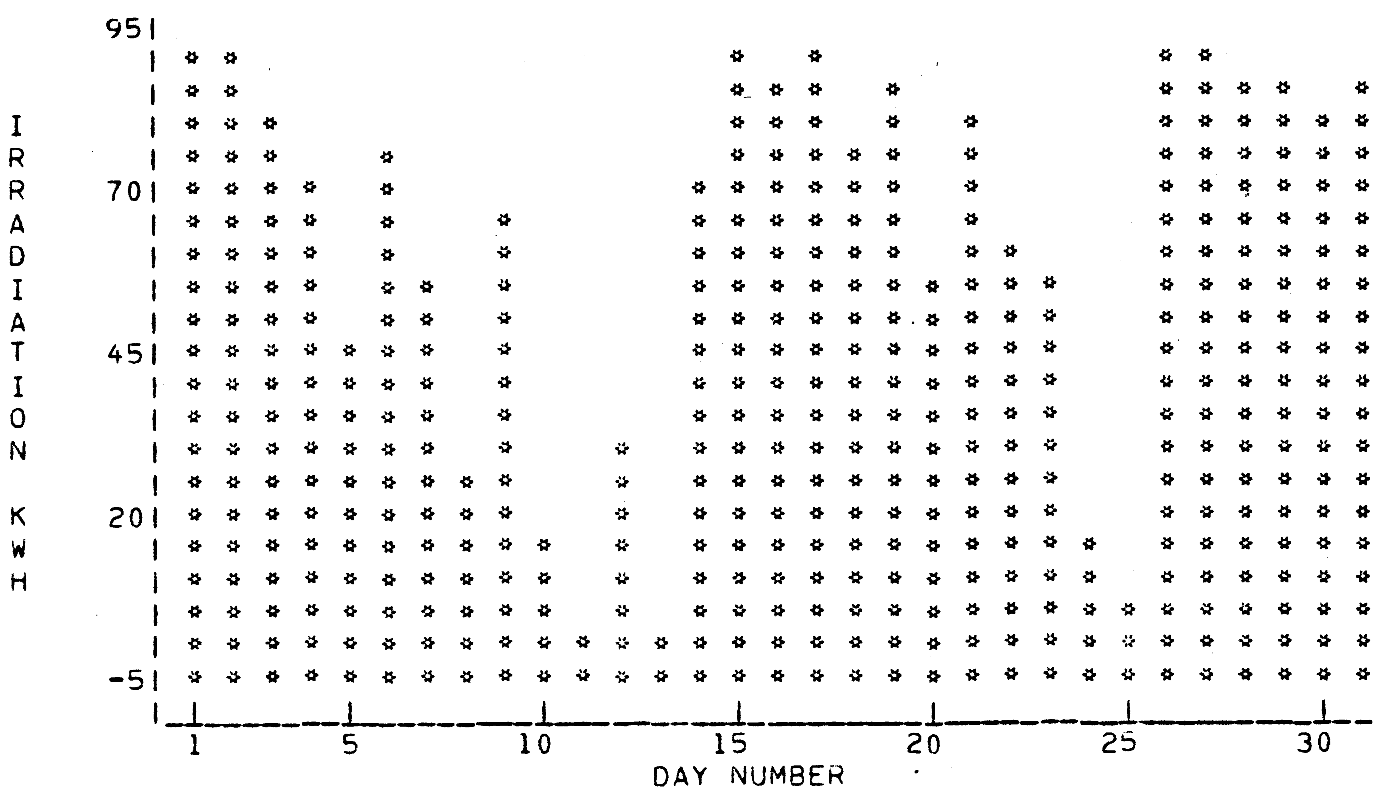


Figure B-2

MONTHLY SOLAR PERFORMANCE REPORT FOR CONTRACT DOT-FH-15-370
ASPHALT STORAGE TANK - ROUTE 682 CAMPBELL COUNTY VIRGINIA

OCTOBER, 1982

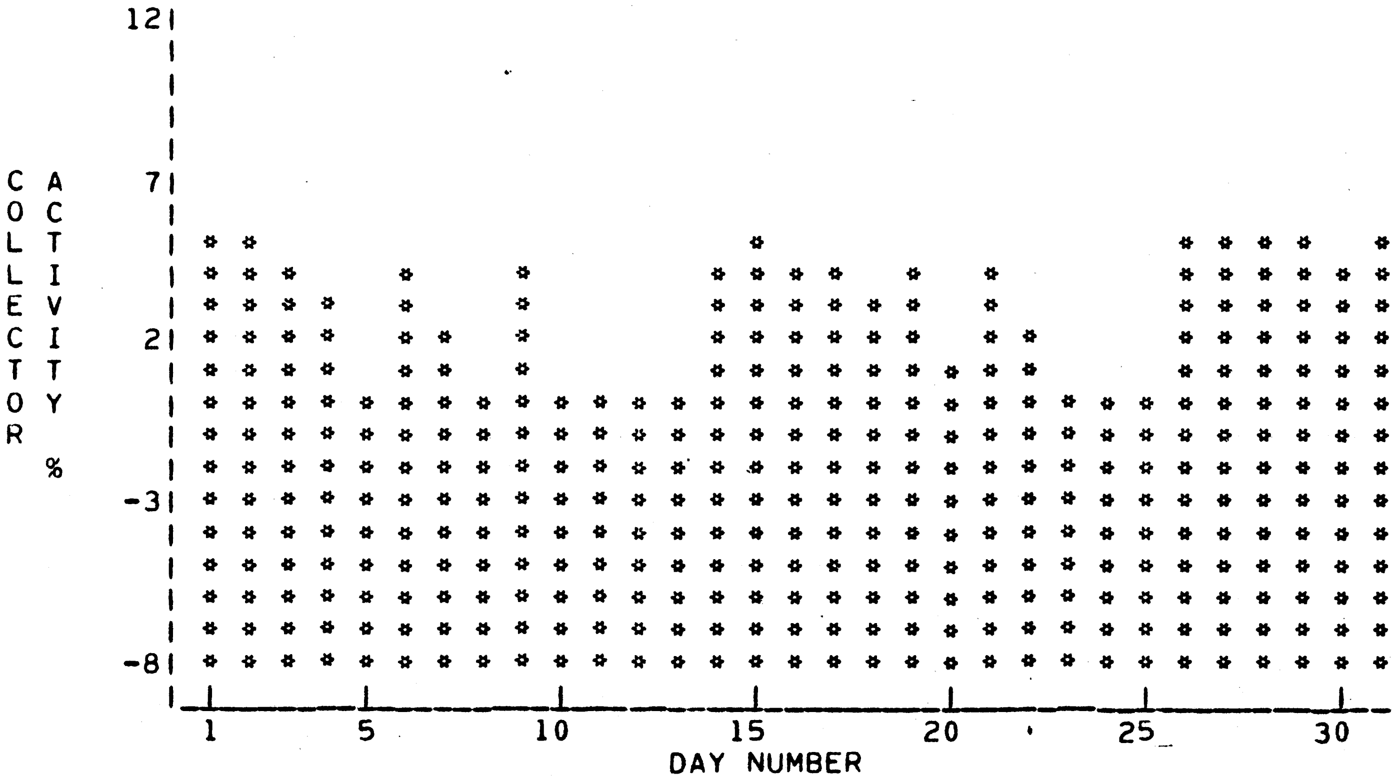


Figure B-3

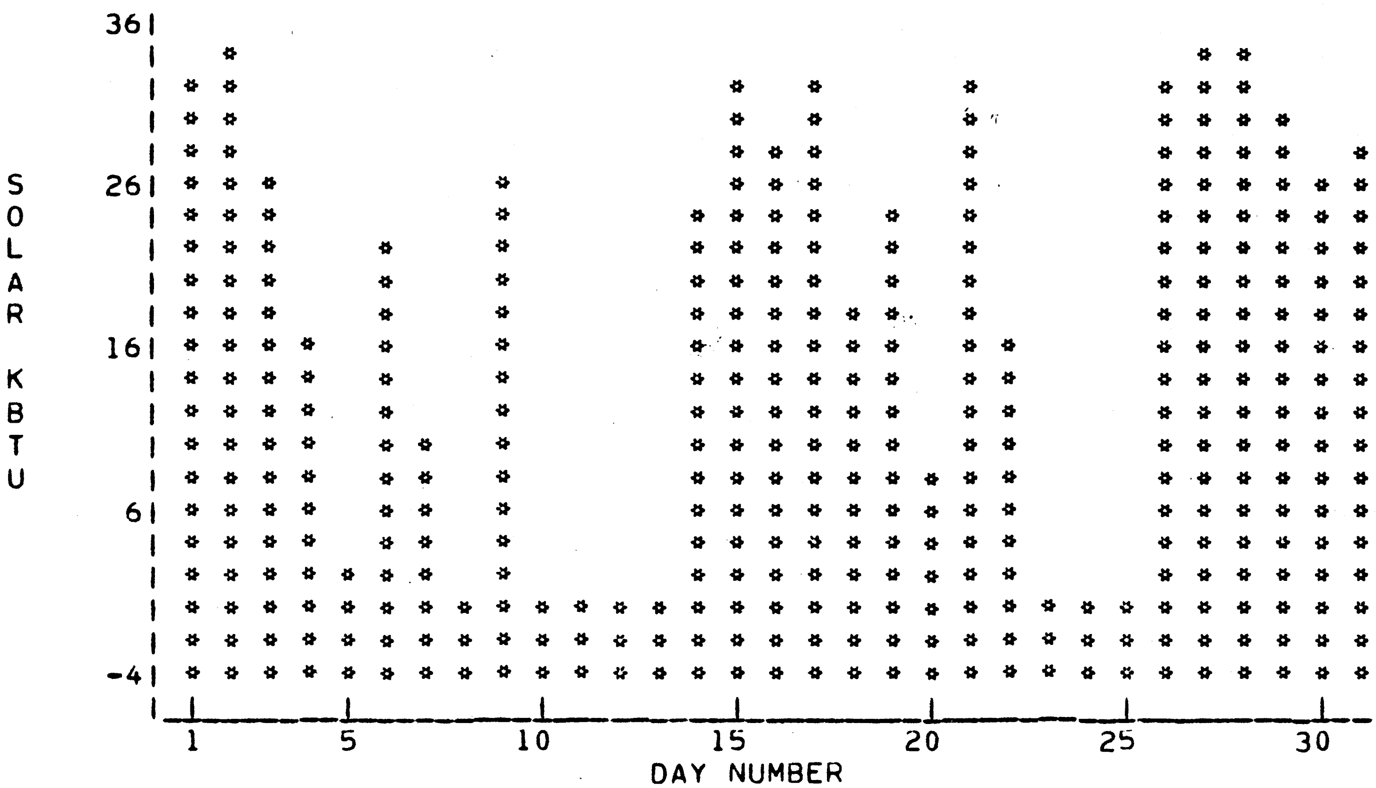


Figure B-4

MONTHLY SOLAR PERFORMANCE REPORT FOR CONTRACT DOT-FH-15-370
ASPHALT STORAGE TANK - ROUTE 682 CAMPBELL COUNTY VIRGINIA

OCTOBER, 1982

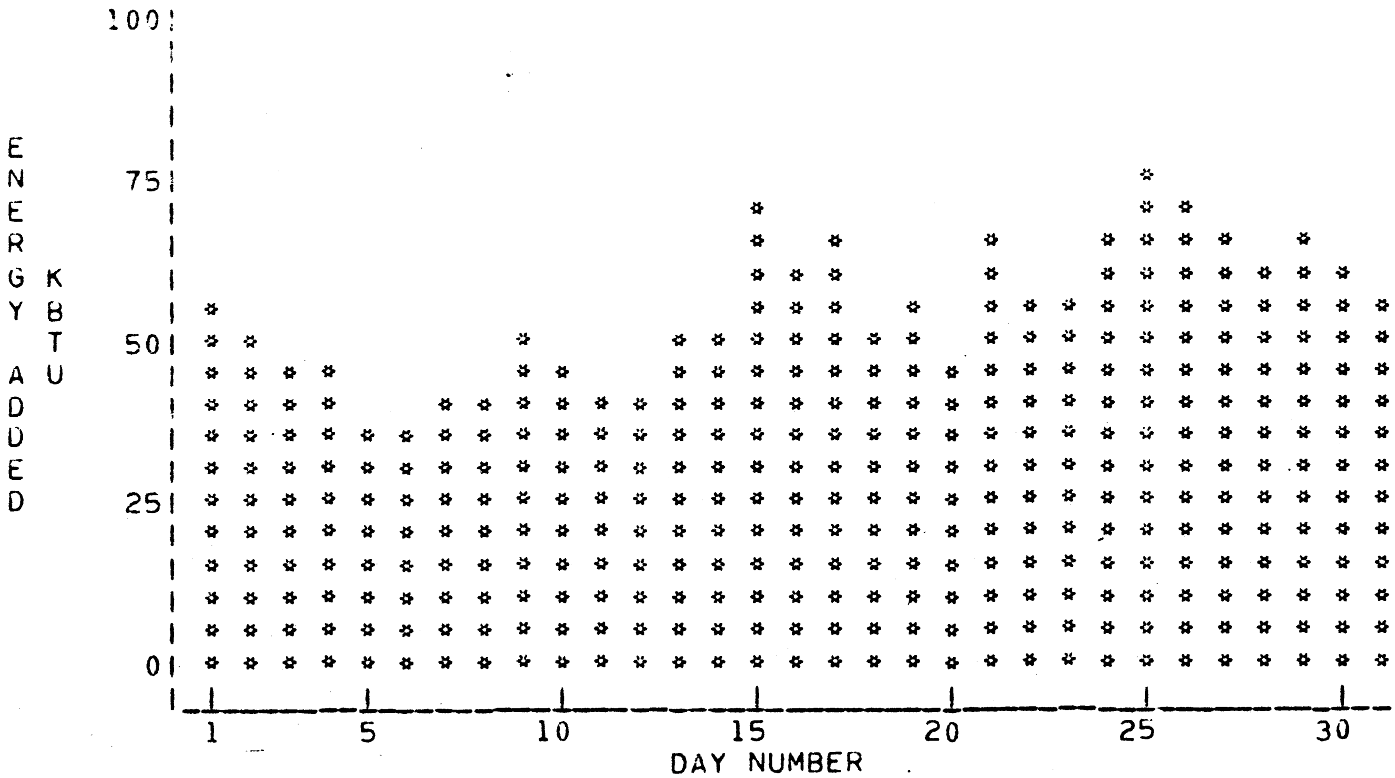


Figure B-5

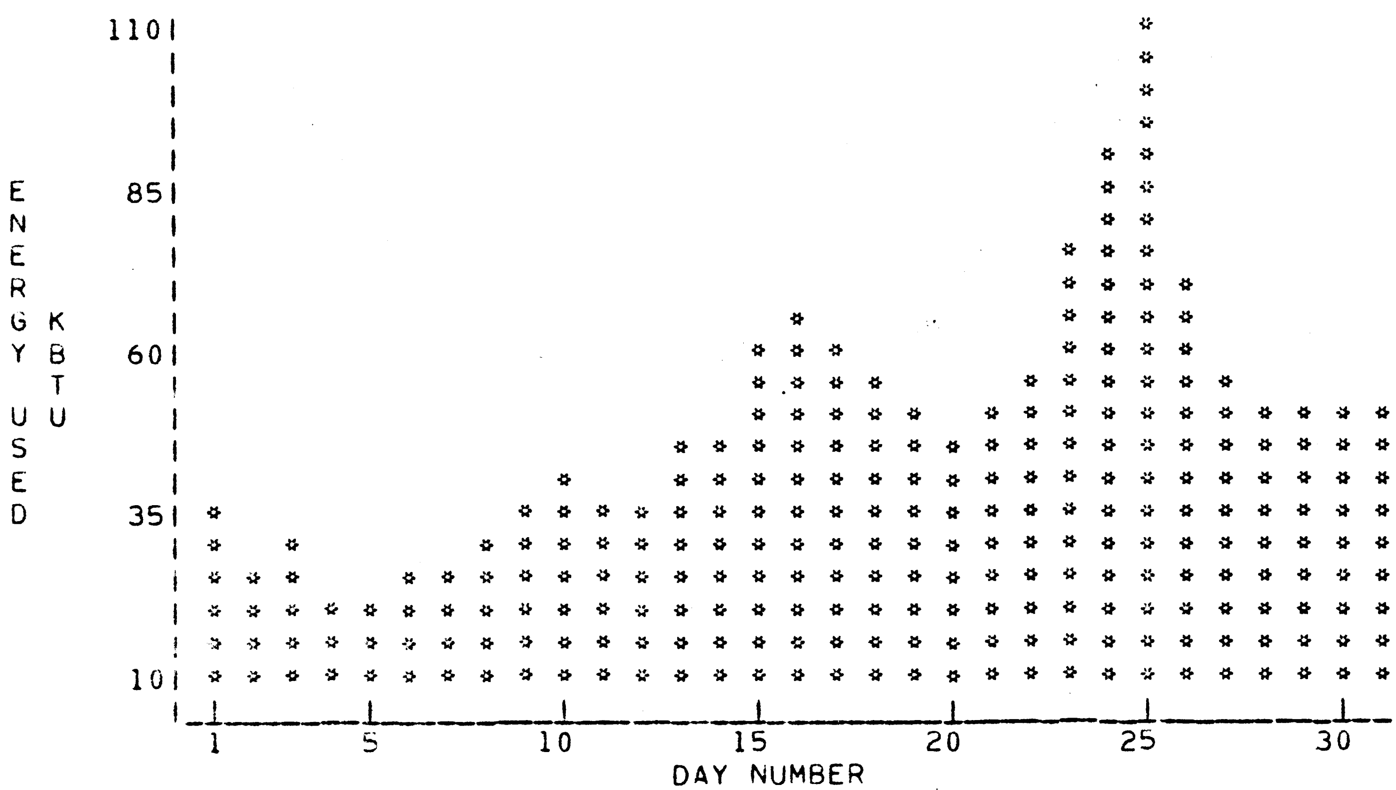


Figure B-6

OCTOBER, 1982

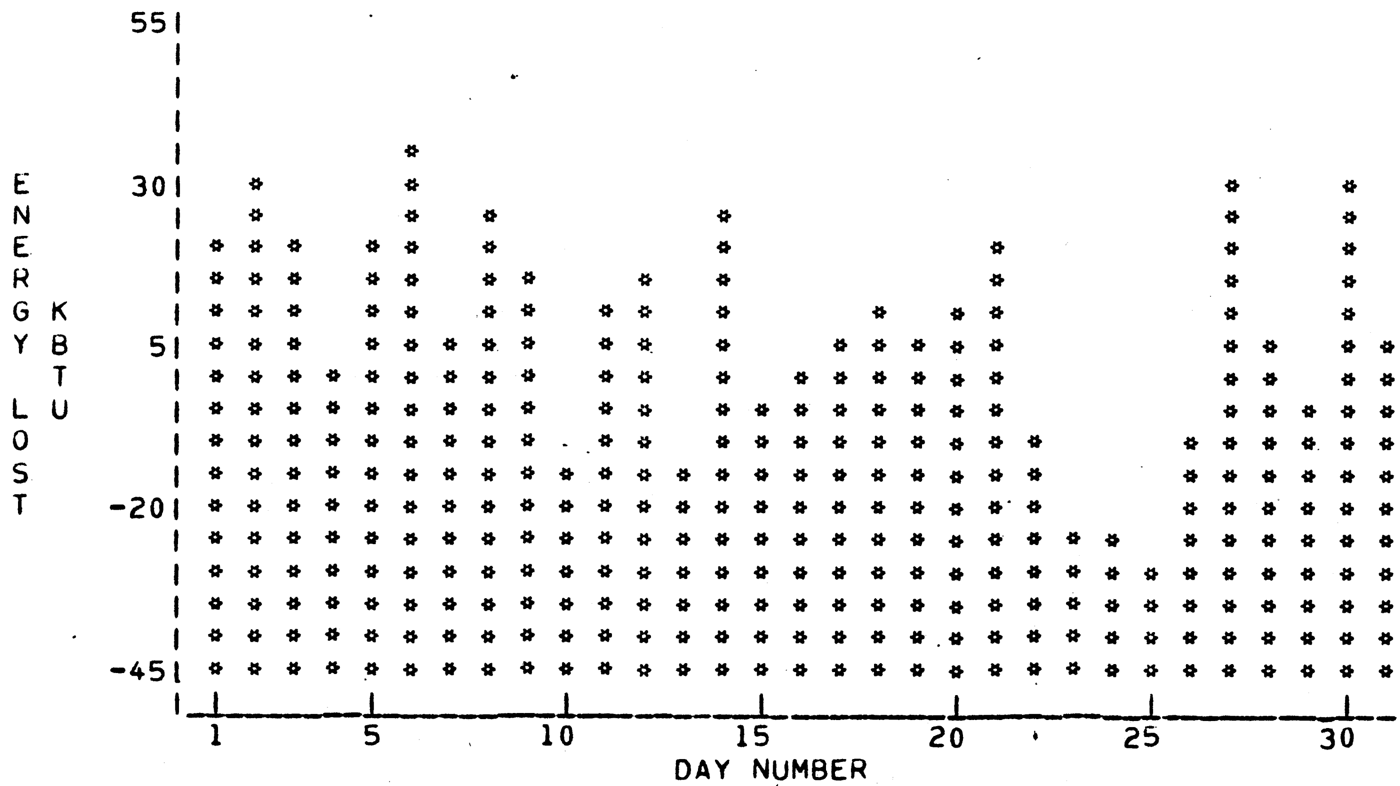


Figure B-7

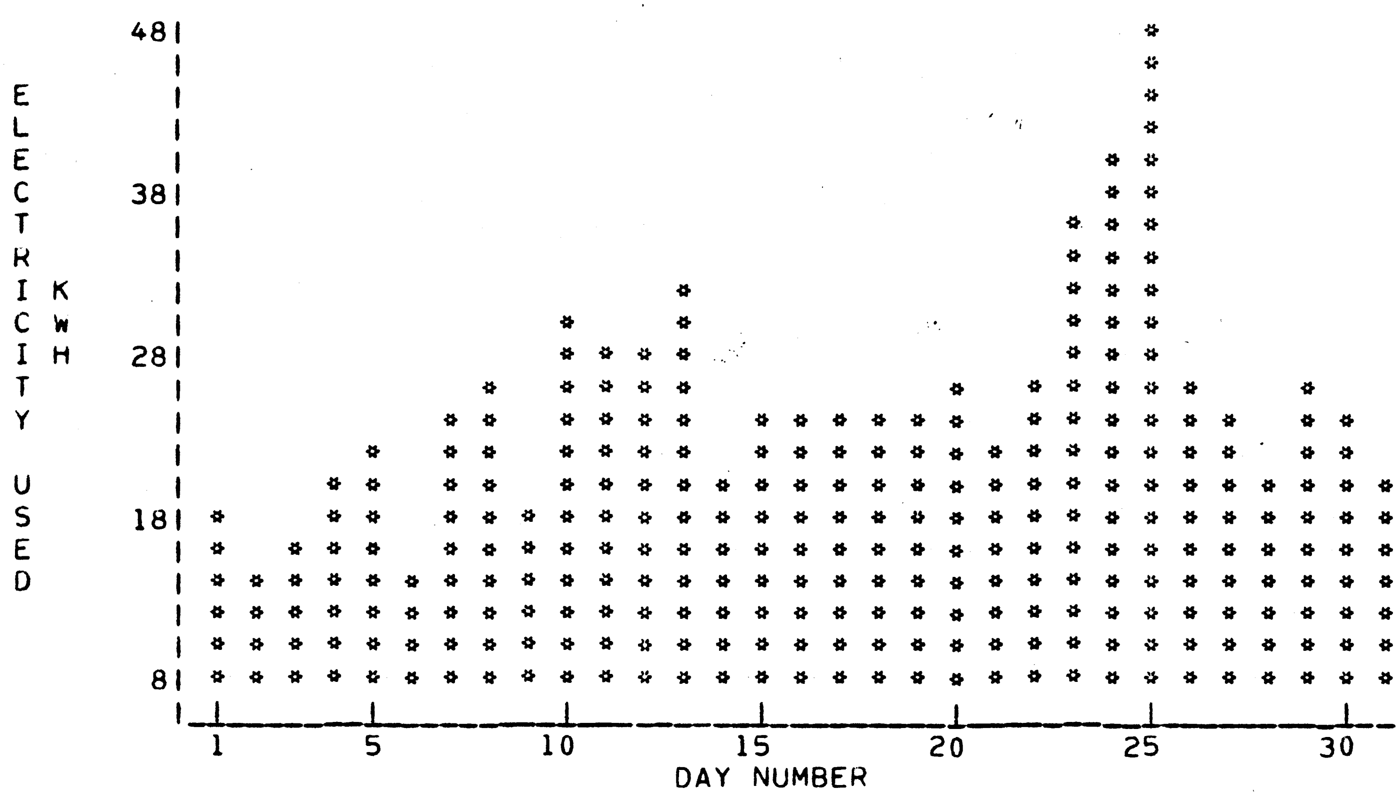


Figure B-8

MONTHLY SOLAR PERFORMANCE REPORT FOR CONTRACT DOT-FH-15-370
ASPHALT STORAGE TANK - ROUTE 682 CAMPBELL COUNTY VIRGINIA

OCTOBER, 1982

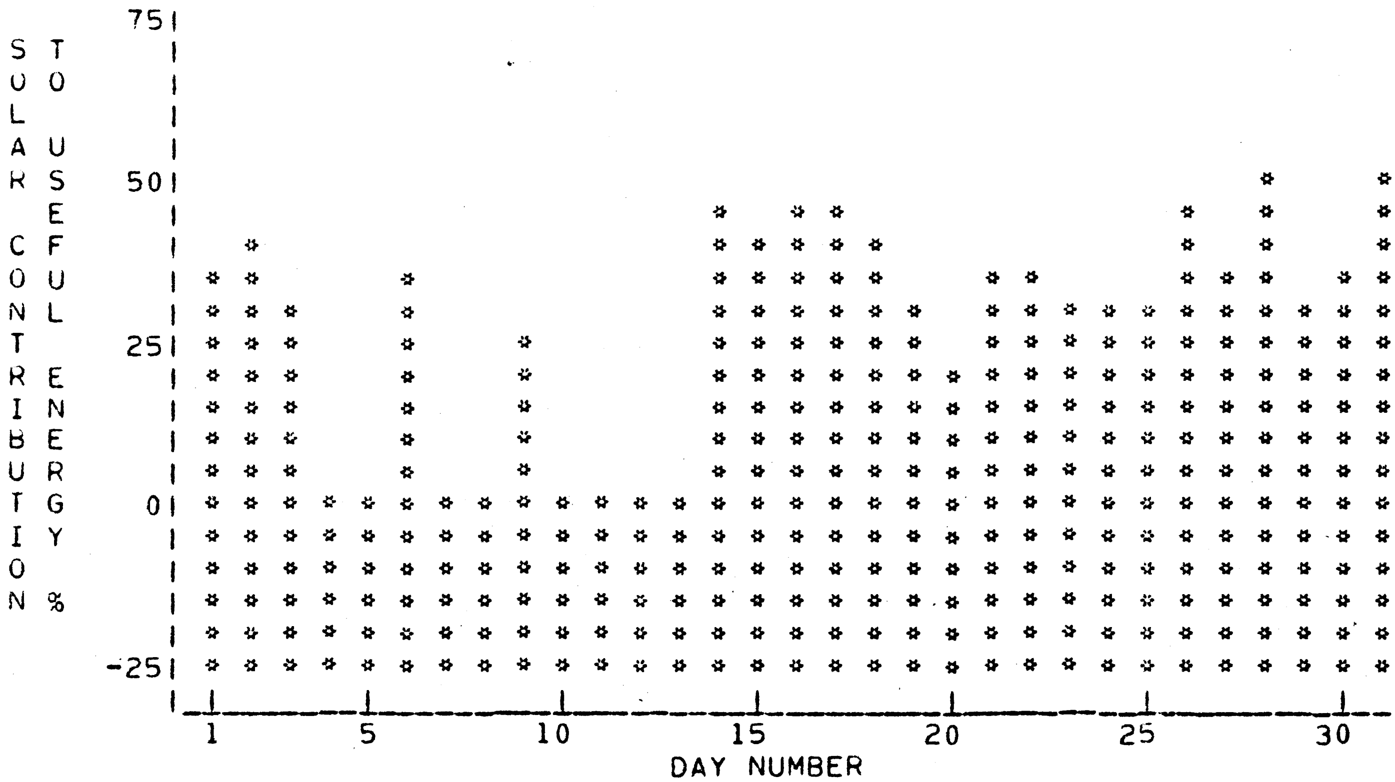


Figure B-9