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16. Abstract

This report describes a passive solar heating system for a 12,000 gallon asphalt storage tank. The solar system uses a thermosiphoning method with air as the heat transfer medium. The collectors were fabricated especially for the installation. As the air was heated in the collectors, the air moved up the collector into a duct surrounding the tank. The tank skin was used as the heat exchanger. As heat transfer occured the cooled air moved to the top of the duct around the tank and migrated down the opposite side of the tank, back into the collector to be reheated and recirculated. During periods of high solar flux, air temperatures of 200 degrees F were found and air velocities inside the duct were as large as 1 1/2 Fps. The asphalt temperatures were generally maintained around 130 degrees F during the summer months and dropped as low as 70 degrees F during the winter months. The asphalt heated was an emulsion. The design, plans, specifications ans construction costs are included.

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HEATING ASPHALT WITH A PASSIVE SOLAR UNIT

(Midland, Texas)

by

Kenneth D. Hankins
and
Bob Montieth

Research Report 272-1F

Research Study 1-10-81-272

Passive Solar Heating

Conducted by

Transportation Planning Division
Research Section
State Department of Highways
and Public Transportation

In Cooperation With The

U.S. Department of Transportation
Federal Highway Administration

August, 1984

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

The United States Government and the State Department of Highways and Public Transportation do not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGEMENTS

The research reported herein was conducted under the supervision of Mr. Jon P. Underwood, Engineer of Research and Development, and the general supervision of Mr. Phillip L. Wilson, State Transportation Planning Engineer.

The system was installed at the maintenance office and grounds at Midland, Texas in District 6 (Odessa). The district is under the general supervision of Mr. William A. Lancaster, District Engineer and the maintenance activities are under the supervision of Mr. Russell Neal.

Acknowledgement is given to:

Mr. Brad Hubbard, Mr. C. L. Goss, Mr. B. D. Cannaday, Mr. Doug Chalman, Mr. Randy Beck and Mr. James Wyatt for the technical support received during this study.

Personnel in the Transportation Planning Division for the review, proofreading and processing necessary for publication of this report.

Dr. G. C. Vliet and personnel with the College of Mechanical Engineering, University of Texas at Austin who assisted in developing the design concept and prepared the design for the solar system.

Mr. Terry Bryant, Maintenance Foreman in Midland County and the maintenance crew at the Midland office for assistance in the installation of the tanks and solar system and for the daily data collection after installation.

Mr. Bob Chamlee, Mr. Cliff Chamlee, and personnel with the Western Insulation Company for the fabrication, installation of the passive solar collectors, and for the interest shown in the project.

Mr. Edward Kristapones, Division Research Engineer with the FHWA for the interest and help received during this project. Mr. Kristaponis suggested the thermosiphoning design used in the system along with many materials items.

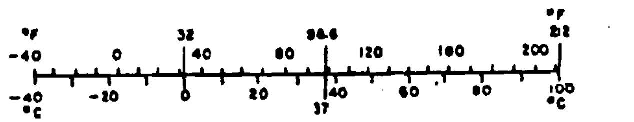
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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DEDICATION

This report is dedicated to James W. Strong, Senior Maintenance Engineer, State Department of Highways and Public Transportation, District 6 Odessa, Texas.

James W. Strong was born in Comanche, Texas July 20, 1927. He graduated from Texas Tech University in 1949 with a B.S. degree in Civil Engineering. James had a total of 21 years and 10 months with the State Department of Highways and Public Transportation, having begun his professional career in San Angelo as an Instrumentman. James also worked in the Big Lake and Sterling City residences before resigning in 1955. In 1965 James returned to the State Department of Highways and Public Transportation in Odessa as Senior Design Engineer, and later served as Assistant District Maintenance Engineer until his death on November 14, 1980.

Not only was James Strong a fine Civil Engineer respected by his friends and co-workers, he was also a dedicated worker in the community. James was a member of the Masonic Lodge, Scottish Rite Bodies, and Order of the Eastern Star. James was also a member of professional engineer associations for many years.

The passive solar heated asphalt storage tank was one of the last design projects of James Strong. In place of the usual rust-and-asphalt covered structure stands the mottled-white cylinder with a section of solar panels potruding from the side. Strong developed his design from an idea triggered from an issue of Mother Earth News. He worked with Kenneth Hankins of the Transportation Planning Division to obtain a grant for the project from the Department of Energy. His concept was different from the San Antonio and Lubbock districts solar heated asphalt tanks because it required no pumps or external power other than the sun and is thus a "passive" system.

Strong's experimental design was completed after his death by district maintenance workers under the direction of Supervising Maintenance Engineer Bob Monteith.

In a rugged countryside renowned for its wind and sun, Strong's passive, solar-heated asphalt tank is standing tall and silently compiling a record of efficient conversation of the Earth's most plentiful resource.

James W. Strong,
Senior Maintenance Engineer,
State Department of Highways
and Public Transportation
Odessa, Texas
July 20, 1927 - November 14, 1980

LIST OF FIGURES

LIST OF TABLES

I. BACKGROUND

The subject project was initiated in the summer of 1980 based on an idea proposed by personnel in District 6 (Odessa, Texas). The idea was to use passive solar techniques to heat an asphalt storage tank with no fuel costs, low initial costs and with little personnel monitoring needed. High temperatures were not desired, rather, temperatures were needed which would keep the asphalt sufficiently liquid to flow from the tank to a distributor without excessive time delays.

Contact was made with the Division Research Engineer with the Federal Highway Administration and later with the College of Mechanical Engineering at the University of Texas in Austin. After considerable discussion between the principles, a concept was developed of using air collectors and a thermosiphoning principle of operation. Based on this concept a design was performed by the College of Mechanical Engineering and plans and specifications were developed by the Department.

II. DESIGN INFORMATION

In the design concept, the asphalt storage tank was set horizontally on a permanent cradle with the bottom of the tank about ten feet above ground level. Air collectors were mounted near ground level, facing south, with east/west sun passage at an angle to the horizontal, but with the upper end of the collector fitting into a specially prepared socket connected near the bottom of the tank. The collectors were specially fabricated to provide the normal heat chamber under the glazing, but also with a return duct were interconnected with an open port along the bottom end of the collector(s). The collectors are positioned in a manner similar to solar collectors in active systems; however, the tanks must also be in the correct position to receive the collectors. Small "stand-offs" were attached to the tank exterior and a metal shroud placed around the tank to form an air duct completely around the circumferential portion of the tank. The collectors were butted against the tank in such a manner to form an air chamber or duct, which would allow air heated in the collectors to rise, lease the upper portion of the collector to enter the duct around the tank, travel around the tank, which would allow air heated in the collectors to rise, leave the upper portion of the collector to enter the duct in the lower portion of the collector. Therefore, following the thermosiphoning principle, the sun shines through a double layer of glazing and heats a color black absorber plate composed of expanded metal in the top chamber of the collector. The air around the absorber plate is heated, looses density and since the collector is tilted at an angle, migrates up the collector and out into the duct around the tank. A heat transfer occurs where heat from the air is transfered to and through the metal skin of the tank into the asphalt. The air in the duct is in turn cooled, increased in density, and by the time it reaches the top of the tank begins to fall toward the bottom of the tank on the side of the tank opposite entry. The air migrates out into the lower portion of the collector and is then forced into the upper chamber of the collector to be reheated and start another cycle. Thus the procedure forms a closed-loop air cycling system. The drawings on Plan Sheets 3 and 6 in Appendix B aid in understanding the concept.

The system design and report prepared by Dr. Vliet, may be found in Appendix A. The design procedure used a computer program to model the dynamic thermal conditions of the thermosiphoning air. The recommended design proposed 150 to 180 square feet of collector area, a tilt angle of about 45°, and using the metal skin of the tank, without extended surface fins, as the heat exchanger. It was decided to provide a series of parallel collectors which could be easily removed in case maintenance (such as removing and replacing deteriorated glazing) was needed. Eight collectors were invisioned, each with a length of about 10 feet and a width of 2-1/2 feet, for a total area of approximately 200 square feet.

Using the design information as a basis, plans and specifications were prepared. The plans may be found in Appendix B and the specifications in Appendix C.

III. CONSTRUCTION INFORMATION

Initially, District 6 in Odessa planned to use departmental forces to construct the system. However, this proved to be difficult because of the number of people available and the excessive workload. After several attempts at initiating work, it was decided to contract the work. The contract bidding was completed on May 13, 1983 with Western Insulation Company being the successful low bidder of three contractors bidding. The contract was for the fabrication and installation of the collectors as well as the preparation of the air duct around the tank with four inches of polyurethane foam insulation over the tank duct. The bid price was $7,750. Several minor modifications to the plans and specifications were made during fabrication and installation. However, one modification resulted in considerable extra work as follows:

> The interior edges of the collectors were required to have insulation consisting of precast polyurethane foam bats which are cut to fit and placed correctly in the collector shell. This seems to work well. However, foam bats were also required as the interior divider separating the upper heat chamber from the return air duct.
>
> In fact, to reduce weight, the bats were used as the divider rather than also using a metal shelf to hold the bats. Small channel members supported the bats. Several collectors had been fabricated before it was noticed that heat was causing the divider to lose shape and drop in the unsupported areas. A change was made and a fiberglass bat was used as the center divider. The collectors previously fabricated were reworked and modified to use the fiberglass as the separator rather than foam.

Figures 1, 2 and 3 show the collectors in various stages of fabrication at the Western Insulation Company shop. Figure 1 shows a collector without the glazing featuring the return port at the bottom end of a collector. The return port allows the cooler air from the duct on the lower portion of the collector to move into the heat chamber. The black web-like material in the right of the picture is the expanded metal of the heat absorber. Figure 2 shows the upper end of a collector. Note the insulation bats along the bottom and edges with the fiberglass divider separating the lower return duct from the upper heat chamber. The glazing is not in place. Figure 3 is very similar to Figure 2 except the collector has been completed. District 6 personnel fabricated the collector supports and Figure 4 shows these supports in place. Note the tank has received the circumferential duct and the tank duct and tank ends have been insulated with the sprayed foam. Figure 5 shows the collectors being installed. The collector is placed on the support rack, moved up so that the upper end of the collector fits through the socket and fits firmly against the gasket at the tank which separates the hot air chamber from the return duct. Caulking is applied as necessary between the collectors. When the collectors are in place the end member of the collector support rack swings up to hold the bottom of the collector preventing excessive vertical or horizontal movement. Figures 6 and 7 are two views of the completed system and Figure 8 shows a small container in a dump truck being filled from one of the first loads of asphalt in the tank.

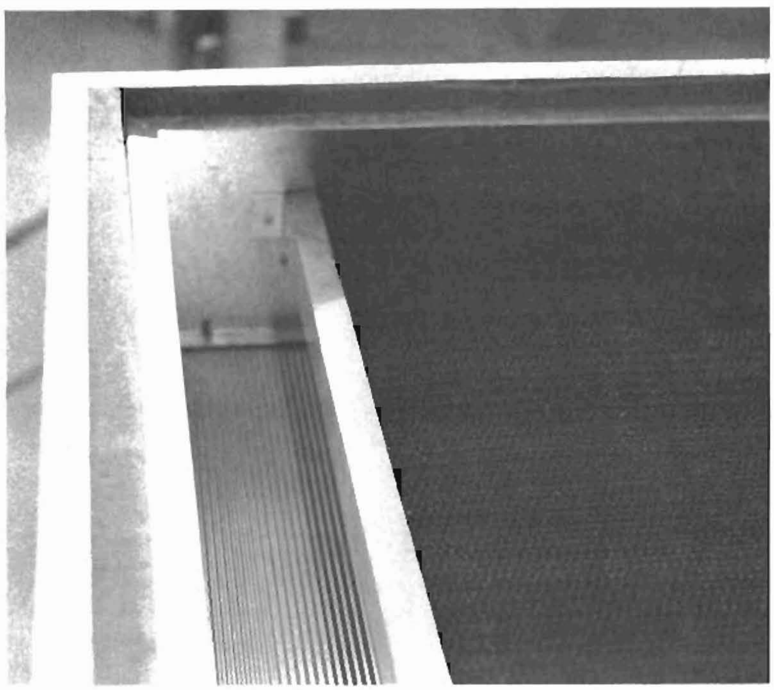


FIGURE 1. Collector in the Fabrication Process Showing the Return Port

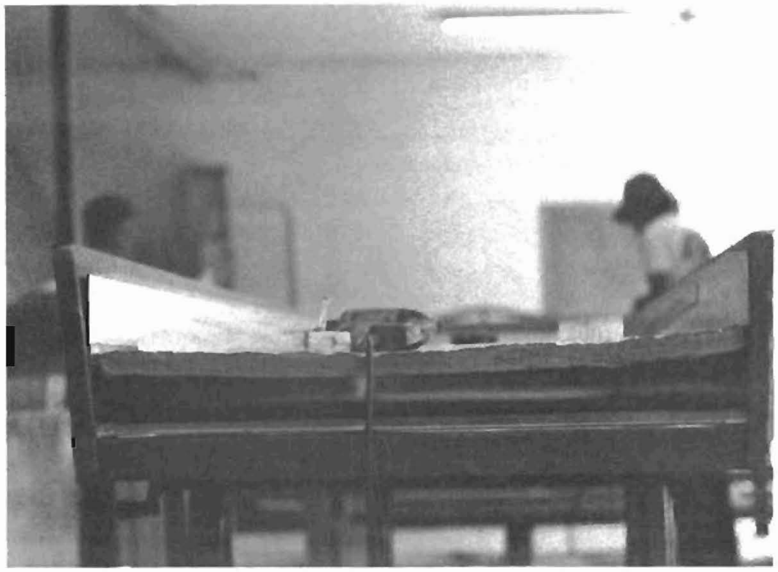


FIGURE 2. Collector Being Fabricated Showing Insulation

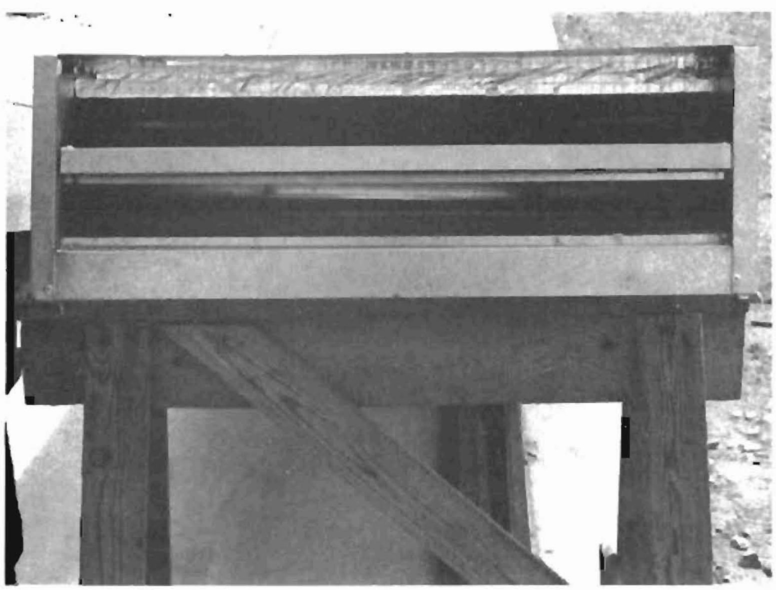


FIGURE 3. Completed Collector Showing the Ducts at the Upper End

FIGURE 4. Insulated Tank with Collector Racks

FIGURE 5. Installation of the Collectors

FIGURE 6. Oblique View of the Completed System

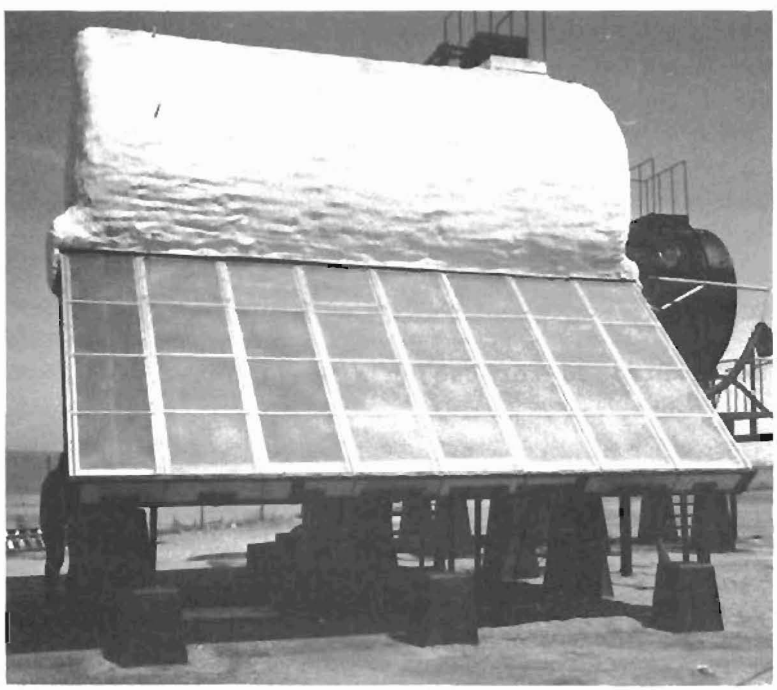


FIGURE 7. View of the Completed System

FIGURE 8. Asphalt Being Drained for Use on a Small Job

IV. COSTS AND OPERATION

The maintenance facility on which the passive solar system was installed had been recently completed and the tank used in the system was new. The tank was installed with the axis in an east/west position. The costs of the tank installation and painting will not be included with the system costs. As stated previously departmental forces fabricated the collector racks, and the contractor placed the circumferential duct, applied insulation, fabricated the collectors, and installed the collectors. The associated costs are:

Collector Rack Fabrication	$
Contract Costs	7,750
Total	$

Soon after completion the tank was loaded with about 6,000 gallons of emulsified asphalt. After a short time, asphalt was noted seeping near the lower portion of the socket at the collector/tank interface. The asphalt was off-loaded and after cleanup and investigation, it was found that the lower manhole cover needed additional tightening. Other than this initial incident the system has performed without trouble or attention.

V. TESTING

Performance data was collected on three different occasions and, in addition, District 6 personnel maintained a continuous record of temperatures throughout the observation period. The three special occasions generally consisted of obtaining temperature and duct air velocity readings during solar periods on two consecutive days.

Tests were conducted at the following times:

- November 8, 1983
- November 9, 1983

- March 13, 1984
- March 14, 1984

- July 24, 1984
- July 25, 1984

Testing Procedure and Equipment

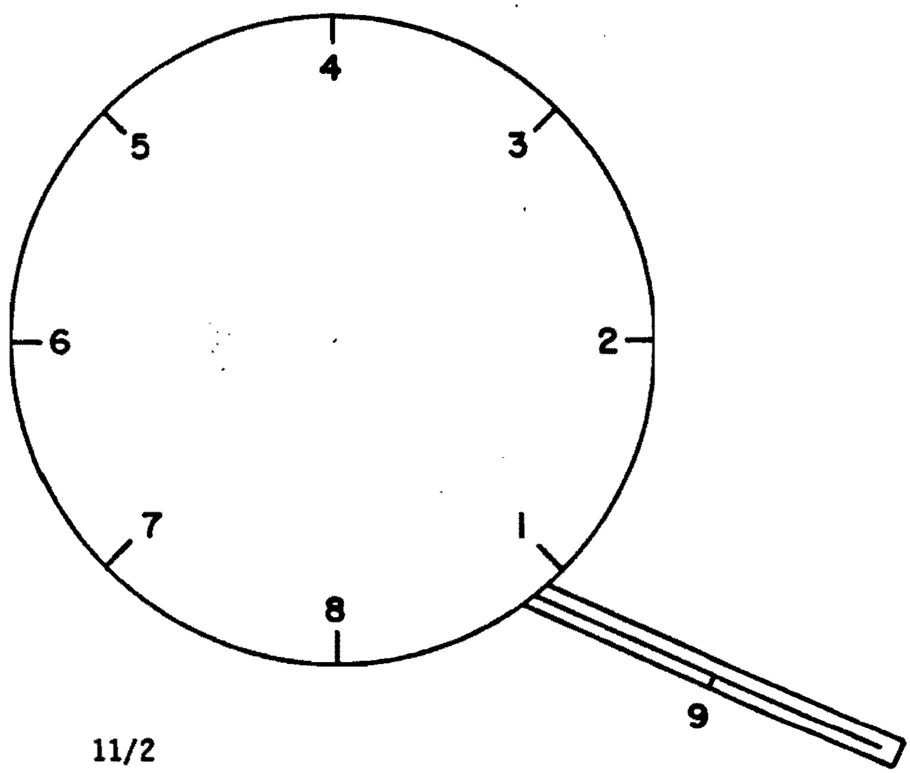
Dr. Vliet's design procedure developed estimates of temperature at several points around the circumference of the tank and in the heat and return ducts of the collector. It was decided to follow a similar procedure in obtaining temperature measurements. Figure 9 shows the location points (8 each equal angle) around the tank. Temperature was also collected in the return duct of the collector. District 6 personnel drilled small holes through the insulation and exterior skin of the circumferential duct at the measurement location points about two feet from the West end of the tank. Small PVC pipe inserts were installed so that temperature measuring probes could be inserted into the circumferential duct during testing. The pipe could be capped in non-testing periods.

Air Temperature Measurements

Cross Sectional Locations

The temperature measurement points will be at locations used by Dr. Vliet during the design of the system. To design the system, Dr. Vliet developed a "Basic" software program which calculated theoretical temperatures at various cross-sectional locations around the tank and collector. Measurements will be made at these locations and the program run so that theoretical and actual can be compared.

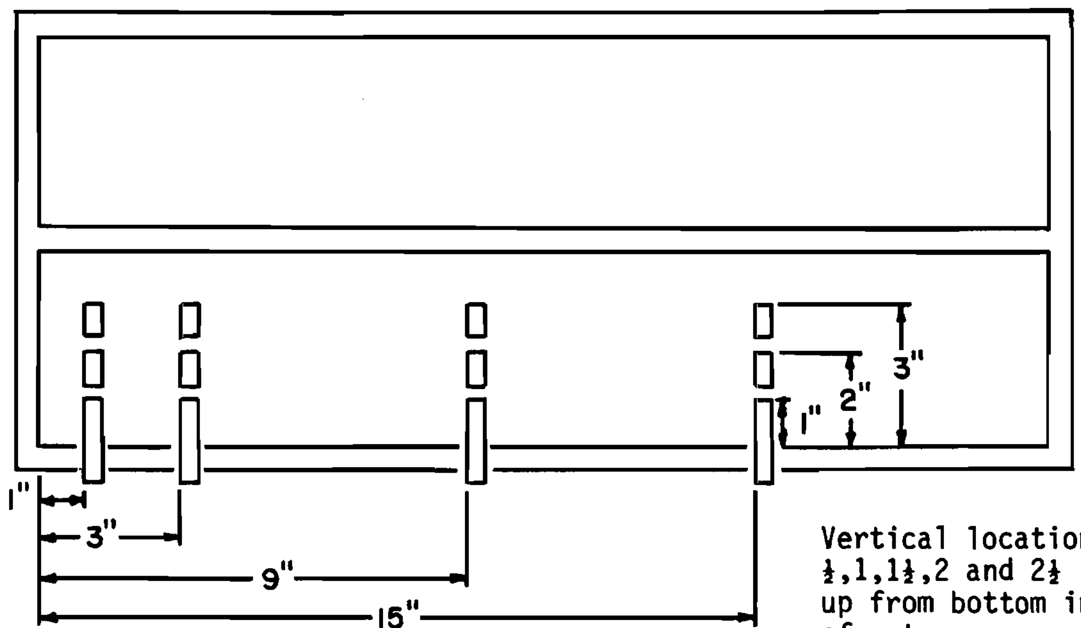
The velocity of the thermosiphoning air migrating from collector to tank to collector was measured only in the return duct of the collectors at location #9 as shown in Figure 9. It was assumed that this location would be indicative of the velocities at other locations. Measurements were made at several points on four collectors as shown in Figure 10.



11/2

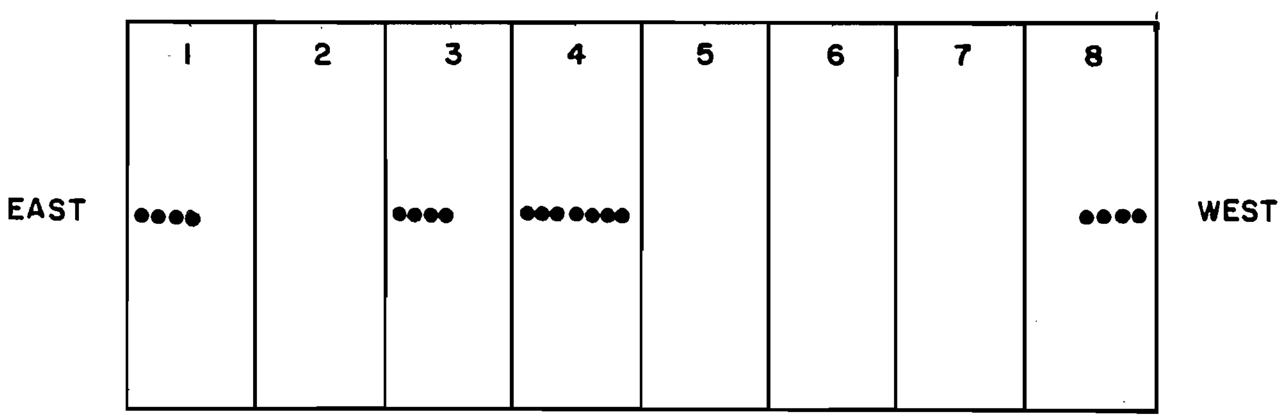
FIGURE 9 - Temperature Measurement Locations

Air velocity was measured at 5 locations vertically in the "return" part of the collectors.



Vertical locations are ½,1,1½,2 and 2½ inches up from bottom inside of return passage.

Measurements were obtained at collectors 1, 3, 4 and 8. Measurement locations are left to right on collectors 1 and 3 and right to left on collector 8.



Collector 4 will have 7 measurements horizontally from left to right as: 1", 3", 9", 15", 21", 27" and 29". Collectors 1, 3, and 8 will have 4 horizontal locations as shown in above sketch.

10 - Air Velocity Measurement Locations

Figures 11 and 12 are photographs taken during the testing period. Figure 11 shows several dial thermometers in place at test location #9. Figure 12 shows the air velocity measuring unit. The probe of the anemometer would be inserted in the same hole(s) as those being used by the dial thermometers in Figure 11.

The first series of temperature measurements were made with both (1) dial type, air conditioning thermometers and (2) a portable digital thermometer. A mercury thermometer was used to measure asphalt temperature through a thermometer well in the bottom of the tank. The portable digital thermometer had been previously calibrated to a reference at the Department and was then used as the interim reference for the subject work.

For the second series of tests two intergrated circuit (IC) temperature probes (AD 590's) were purchased. These probes were fitted with a power supply, a switch and a digital display. Using the switch, temperatures on one or the other could be read from the display. After the two day testing period the probes were installed permanently in location #1 (collector output temperature) and location #7 (return - near bottom of tank).

Finally, for the third series of tests, six additional IC temperature probes were purchased and seven of the probes were permanently installed at loctions #1 through #7. The eighth probe was installed in the well at the tank bottom to measure asphalt temperature. A rotary switch was provided so that the temperature on each of the eight probes could be read on the digital display mentioned previously.

It is difficult to find equipment that can accurately measure small air velocities. However, a unit was selected using a small diameter probe which could be inserted into a small hole through the collector skin and insulation. The probe could be manually positioned to permit measurements at various elevations in the duct. A power supply was provided and a digital voltmeter was used to measure and read the results in terms of voltage. The manufacturer of the equipment provided a correlation between voltage and air velocity. At the suggestion and urging of the FHWA the velocity measuring unit was recalibrated by placing the unit on a bicycle wheel with the spindle placed in a vise. The probe was placed at a known radius and the wheel with attached unit was rotated at several angular velocities. Using the angular velocity, a linear velocity was calculated and plotted against the voltage output for that speed. A room with zero air movement is needed, but generally, the manufacturer's correlation was repeated.

During the first data collection period the probe end of the velocity measuring equipment was rubbed along the exposed edge of the skin of the collector while the probe was being inserted into the duct. Unusual readings resulted ~~resulted~~ after the event. The unit was then recalibrated as explained above and found to produce inapplicable data. Close observation revealed the probe end was damaged. Data collection was suspended and the unit returned to the manufacturer for repair. The problem was explained to the manufacturer and a more durable probe was provided. This probe was used for the remaining studies; has been calibrated using the bicycle wheel several times; and seems to be performing well with repeatable results. Additional information about the testing equipment may be found in Appendix D.

FIGURE 11. View of Temperature Testing

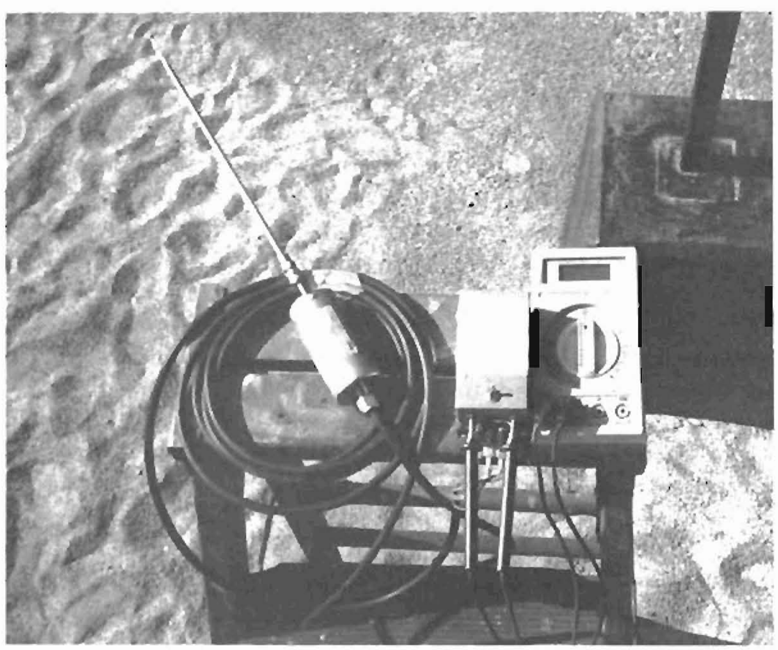


FIGURE 12. Air Velocity Measuring Equipment

Velocity Information

Initially, work was directed toward a study of the velocity patterns in the return duct of the collector. Air velocity measurements were obtained on collectors 1, 3, 4 and 8. The measurements were collected transversely across the collector return duct at the positions shown in Figure 10 and at five different elevations at each position also as shown in Figure 10. Typical velocity values at two locations of collector #4 are shown on Table I. Various and continually changing patterns were found. Temperature and velocity changes appear to be rapid and highly influenced by the solar flux available at any one instant in time. However, Figure 13 shows the best estimate of the flow pattern in the return duct when a relatively large velocity occurs. Note the larger velocities seem to be near the center and lower surface of the duct with the maximum at the center transversally, and about one inch above the bottom. Also, the weighted average velocity was calculated to be about two-thirds the maximum air velocity. The "weighting" was obtained by using the contour areas of a cross-section of a selected velocity. The maximum velocity found during the three testing periods was about 1-1/2 feet per second.

Temperature Information

Table II shows a list of typical temperature measurements. The measurements were obtained on July 24, 1984. Note during the early morning hours the temperature of the thermometer at tank location #1 is less than that at location #2. Some cooling of the asphalt must be occurring during this period but air velocities are normally zero at these times so it is doubtful if backsiphoning occurs. The tank could begin to receive some heating about 12:00- noon but the thermosiphoning is under way at about 1:00 P.M. The maximum out put temperature from the collectors on July 24 was 178°F.

TABLE I
VELOCITY MEASUREMENTS
PASSIVE SOLAR SYSTEM
NOVEMBER 8, 1983
(feet/sec.)

Time	Location	Distance of Probe Tip from Botton of Return				
		1/2"	1"	1-1/2"	2"	2-1/2"
2:30 PM	Collector #4	0.8	1.31	1.13	1.05	0.82
	* Position 15					
2:36 PM	Collector #4	0.7	0.9	1.0	0.9	0.8
	* Position 29					

*NOTE: Position 15 is 15 inches from the most easterly edge or in the center of the return duct of the collector. Position 29 is 29 inches from the most easterly edge of the collector or 1 inch from the most westerly edge of the return duct of the collector.

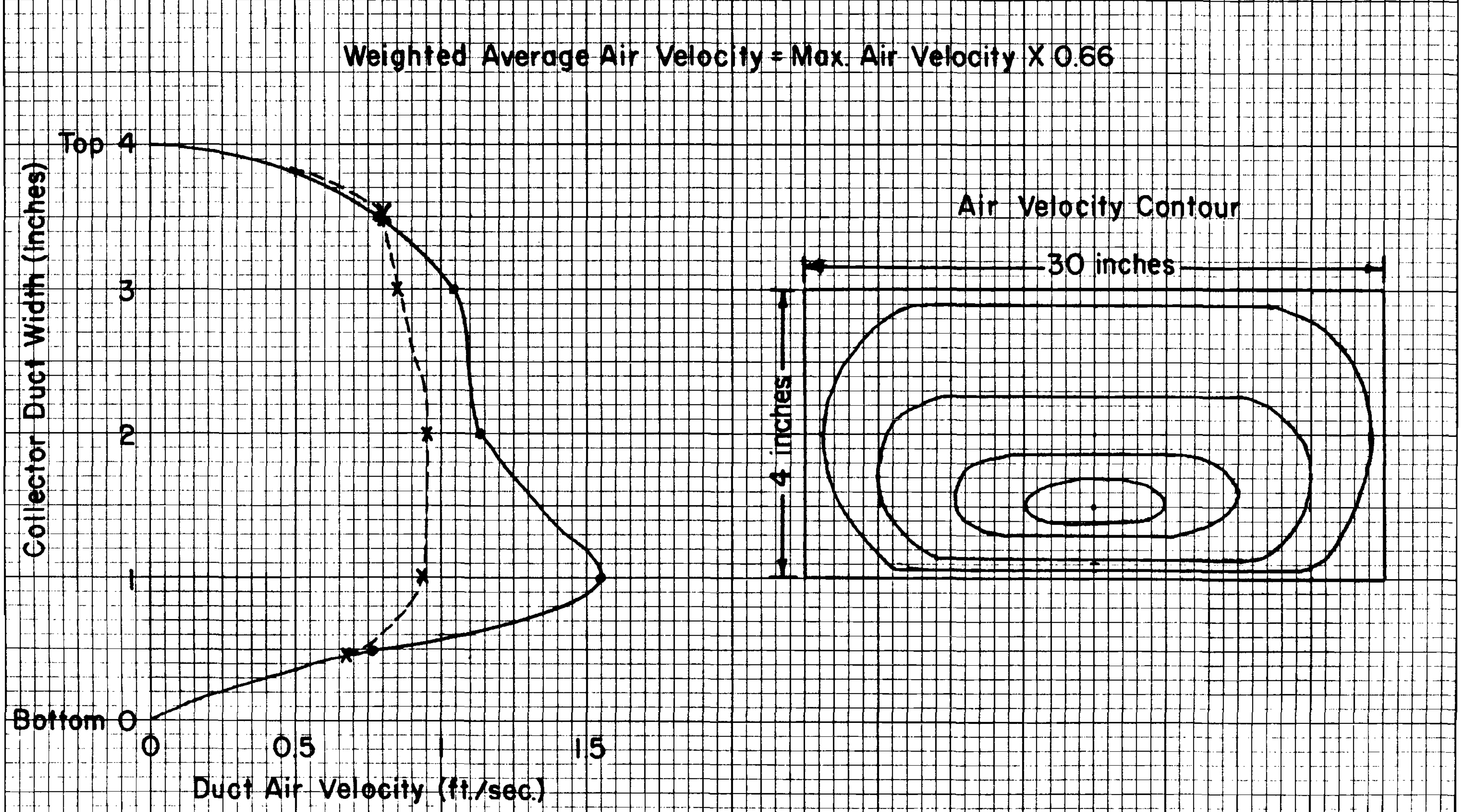


Figure 13 - Typical Air Velocity Patterns in Return Duct of Collector

TABLE II
TEMPERATURE
MEASUREMENTS
PASSIVE SOLAR SYSTEM
JULY 24, 1984
(°F)

TIME	Tank Location*							Asphalt	Air	Collector No.**				Remarks
	1	2	3	4	5	6	7	Temp.	Temp.	#1	#3	#4	#8	
11:13	121	134	130	127	131	129	124	130	93	100	94	104	100	
11:40	124	133	130	128	130	128	121	130	93	100	95	109	100	
12:33	137	140	135	131	134	131	132	130	85	107	95	119	102	High wind Dust in air
1:10	142	141	137	136	137	134	135	130	88	108	104	123	112	High Wind Less Dust
3:00	173	164	156	154	154	147	143	130	87	115	124	127	118	Sunny - Some Wind - No Dust
4:00	178	165	159	158	159	151	148	130	84	118	127	131	122	Sunny No Clouds or Dust
5:00	171	161	157	158	159	152	148	130	88	126	134	135	125	Sunny - Clear
5:10	172	161	157	157	158	151	148	130	87	125	133	134	123	Sunny - Clear
5:20	170	163	158	157	158	151	147	130	87	125	133	134	120	Sunny - Clear
5:30	169	163	157	156	157	151	147	130	88	125	132	133	120	Sunny - Clear
5:40	166	159	155	155	156	150	147	130	88	125	132	132	120	Sunny - Clear
5:50	164	162	156	154	155	149	147	130	90	125	130	132	130	Some Light Cloudiness
6:00	162	159	154	152	154	148	146	130	90	124	130	131	127	Sunny - Hazy
6:10	159	159	153	151	153	147	145	130	89	124	128	130	126	Sunny - Hazy
6:20	152	154	150	148	150	145	143	130	89	123	128	129	124	Ptly. Cldy.
6:30	150	152	148	146	149	144	142	130	88	120	127	127	120	Ptly. Cldy.

* Tank location numbers refer to circumferential locations around the tank as indicated in Figure 9.

** Collector No. refers to the individual collectors as numbered in Figure 10. The temperature measurements were obtained at location #9 and position 15 or in the center of the return duct of the collector. They are return temperatures. Temperatures at tank location #1 would be indicative of collector exit temperatures.

TABLE III
DAILY TEMPERATURE MEASUREMENTS

AT - ASPHALT TEMPERATURE
AAT - AVERAGE AMBIENT TEMPERATURE

DATE	TIME	#1	#7	#9 (Return Air)	AT	AAT	
11-09-83	5:00PM	146°	136°	120°	125°	- 52°	
11-10-83	2:30PM	197°	159°	140°	125°	- 48°	
11-14-83	3:00PM	185°	158°	140°	125°	- 65°	
11-15-83	4:45PM	179°	153°	140°	125°	- 50°	
11-16-83	8:30AM	112°	114°	below 50°	125°	- 37°	
11-16-83	2:08PM	200°	154°	140°	125°	- 70°	
11-17-83	2:40PM	208°	154°	143°	125°	- 60°	
11-18-83	2:50PM	189°	118°	98°	125°	- 63°	
11-21-83	2:20PM	179°	150°	135°	120°	- 61°	
11-22-83	9:42AM	108°	111°	82°	125°	- 42°	
11-22-83	2:00PM	173°	145°	125°	130°	- 63°	
11-23-83	4:27PM	138°	134°	129°	126°	- 45°	
11-28-83	4:10PM	08°	77°	130°	120°	- 37°	
11-29-83	1:30PM	122°	133°	125°	120°	- 48°	
11-30-83	9:00AM	88°	87°	below 50°	110°	- 29°	Tank empty
11-30-83	3:50PM	158°	136°	120°	125°	- 47°	Tank empty
12-01-83	8:30AM	Received new load (6000 gal.) 135°					
12-01-83	3:50PM	119°	121°	65°	135°	- 38°	
12-02-83	4:11PM	118°	114°	75°	130°	- 48°	
12-05-83	3:00PM	178°	154°	130°	130°	- 48°	
12-06-83	4:35PM	131°	146°	140°	125°	- 40°	
12-07-83	4:44PM	141°	137°	127°	125°	- 50°	
12-08-83	2:50PM	143°	145°	135°	125°	- 52°	
12-09-83	4:30PM	156°	148°	123°	120°	- 46°	
12-12-83	3:55PM	127°	141°	133°	120°	- 54°	
12-13-83	2:40PM	178°	149°	128°	120°	- 51°	
12-14-83	4:25PM	158°	143°	122°	122°	- 41°	
12-15-83	4:15PM	156°	140°	120°	120°	- 47°	
12-16-83	4:17PM	143°	113°	98°	115°	- 31°	10 Days temp
12-27-83	12:30PM	162°	102°	97°	75°	- 35°	from 6°F to
12-30-83	2:10PM	106°	109°	98°	80°	- 27°	26°F
01-02-84	4:10PM	74°	75°	65°	80°	- 40°	
01-03-84	3:20PM	108°	102°	52°	80°	- 42°	
01-04-84	3:05PM	164°	128°	110°	80°	- 49°	
01-05-84	3:25PM	176°	137°	125°	80°	- 46°	
01-06-84	2:10PM	164°	129°	105°	83°	- 52°	
01-09-84	3:15PM	126°	114°	93°	84°	- 49°	
01-10-84	2:45PM	128°	122°	87°	84°	- 37°	
01-11-84	3:15PM	132°	122°	108°	85°	- 43°	
01-12-84	2:40PM	155°	125°	100°	90°	- 42°	
01-13-84	3:20PM	115°	94°	57°	90°	- 34°	
01-16-84	3:45PM	63°	69°	50°	87°	- 30°	
01-17-84	1:50PM	54°	63°	49°	84°	- 34°	
01-18-84	1:10PM	54°	58°	50°	79°	- 22°	
01-23-84	3:34PM	181°	129°	110°	70°	- 45°	
01-24-84	3:00PM	178°	140°	124°	70°	- 43°	

TABLE III
(CONT.)

DATE	TIME	#1	#7	#19 (Return Air)	AT		AAT	
01-25-84	3:50PM	190°	153°	135°	120°	-	42°	tank almost empty
01-26-84	8:30AM	Received new loade 140°						
01-26-84	2:35PM	208°	152°	149°	110°	-	49°	
01-30-84	4:00PM	122°	124°	105°	125°	-	43°	
01-31-84	3:10PM	104°	108°	100°	125°	-	41°	
02-01-84	2:45PM	188°	147°	135°	125°	-	45°	
02-02-84	3:05PM	142°	124°	100°	124°	-	47°	
02-03-84	3:10PM	188°	140°	130°	120°	-	47°	
02-07-84	3:05PM	152°	147°	135°	120°	-	49°	
02-08-84	3:21PM	192°	143°	135°	124°	-	53°	
02-09-84	8:30AM	Received new load						
02-09-84	2:05PM	205°	155°	150°	130°	-	53°	
02-10-84	2:25PM	178°	147°	145°	140°	-	57°	
02-13-84	2:40PM	210°	149°	140°	126°	-	53°	
02-14-84	3:05PM	113°	142°	140°	125°	-	59°	
02-15-84	3:00PM	188°	148°	135°	130°	-	55°	
02-16-84	3:15PM	200°	167°	145°	125°	-	47°	
02-17-84	3:05PM	142°	145°	140°	110°	-	58°	
02-21-84	2:45PM	200°	145°	130°	115°	-	41°	
02-22-84	8:30AM	Received new load						
02-22-84	2:35PM	189°	155°	145°	130°	-	50°	
02-23-84	2:55PM	188°	157°	135°	125°	-	53°	
02-24-84	3:10PM	160°	157°	145°	125°	-	49°	
02-27-84	3:50PM	148°	144°	100°	110°	-	41°	
02-28-84	2:55PM	181°	149°	125°	120°	-	34°	
02-29-84	2:20PM	175°	137°	130°	125°	-	41°	
03-01-84	2:50PM	203°	146°	140°	120°	-	54°	
03-05-84	3:35PM	92°	97°	70°	115°	-	35°	
03-06-84	2:45PM	163°	137°	130°	110°	-	39°	
03-07-84	3:20PM	173°	141°	135°	115°	-	48°	
03-08-84	3:30PM	184°	151°	125°	110°	-	47°	
03-09-84	3:55PM	189°	143°	140°	110°	-	51°	
03-12-84	3:35PM	197°	151°	135°	110°	-	60°	
03-19-84	3:15PM	149°	128°	110°	110°	-	50°	
03-20-84	3:00PM	188°	152°	130°	105°	-	49°	
03-21-84	3:15PM	199°	145°	135°	115°	-	61°	
03-22-84	3:40PM	163°	128°	130°	115°	-	66°	
03-23-84	3:45PM	154°	132°	110°	115°	-	49°	
03-26-84	3:35PM	103°	106°	100°	110°	-	63°	
03-27-84	2:50PM	132°	107°	115°	110°	-	58°	
03-28-84	3:30PM	152°	127°	105°	105°	-	50°	
03-29-84	4:00PM	157°	137°	120°	105°	-	49°	
04-02-84	2:50PM	171°	119°	125°	105°	-	63°	
04-03-84	8:30AM	Received new load						
04-03-84	3:00PM	159°	141°	125°	110°	-	54°	
04-04-84	3:00PM	150°	148°	130°	110°	-	50°	
04-05-84	3:20PM	188°	145°	135°	110°	-	58°	
04-06-84	2:30PM	193°	106°	100°	110°	-	62°	

TABLE III
(CONT.)

DATE	TIME	#1	#7	#19 (Return Air)	AT		AAT
04-09-84	2:45PM	197°	138°	130°	105°	-	70°
04-10-84	3:40PM	143°	125°	110°	110°	-	63°
04-11-84	3:35PM	182°	137°	135°	105°	-	69°
04-12-84	3:30PM	185°	155°	135°	115°	-	62°
04-13-84	3:45PM	185°	157°	140°	120°	-	70°
04-16-84	4:00PM	169°	147°	125°	120°	-	58°
04-17-84		Received new load					
04-17-84	3:00PM	201°	149°	145°	135°	-	67°
04-18-84	3:10PM	160°	129°	125°	125°	-	70°
04-19-84	3:00PM	190°	158°	145°	125°	-	71°
04-23-84	2:30PM	185°	154°	145°	125°	-	61°
04-24-84	3:30PM	152°	151°	155°	135°	-	74°
04-24-84	8:30AM	Received new load					
04-25-84	3:30PM	171°	147°	160°	145°	-	76°
04-26-84	3:00PM	134°	136°	175°	135°	-	73°
04-27-84	3:45PM	183°	159°	145°	130°	-	61°
04-30-84	8:30AM	Received new load					
04-30-84	4:30PM	190°	156°	150°	135°	-	65°
05-01-84	3:20PM	164°	148°	145°	140°	-	73°
05-02-84	3:55PM	177°	145°	145°	135°	-	74°
05-03-84	1:30PM	Received new load					
05-03-84	3:35PM	200°	162°	155°	150°	-	74°
05-04-84	3:40PM	189°	164°	160°	150°	-	79°
05-07-84	3:20PM	170°	149°	135°	140°	-	69°
05-08-84	3:00PM	190°	158°	145°	125°	-	58°
05-09-84	2:35PM	170°	150°	140°	135°	-	66°
05-10-84	4:05PM	194°	159°	150°	135°	-	78°
05-11-84	3:35PM	191°	167°	150°	130°	-	83°
05-14-84	3:40PM	147°	145°	135°	130°	-	74°
05-15-84	3:20PM	176°	140°	130°	110°	-	74°
05-16-84	3:45PM	130°	115°	65°	125°	-	68°
05-17-84		Received new load					
05-17-84	1:45PM	111°	119°	110°	125°	-	66°
05-18-84	3:35PM	129°	129°	110°	125°	-	70°
05-21-84	2:25PM	178°	149°	135°	125°	-	77°
05-24-84	3:15PM	160°	143°	145°	125°	-	80°
05-25-84	3:45PM	188°	147°	140°	125°	-	81°
05-29-84	3:45PM	174°	145°	130°	125°	-	65°
05-30-84	3:40PM	178°	142°	135°	125°	-	69°
05-31-84	3:40PM	179°	144°	140°	120°	-	73°
06-01-84	3:45PM	184°	146°	140°	120°	-	77°
06-04-84	3:30PM	171°	137°	135°	120°	-	73°
06-05-84	2:10PM	154°	133°	130°	120°	-	77°
06-06-84	3:30PM	151°	141°	135°	125°	-	78°
06-07-84	3:45PM	147°	137°	140°	120°	-	83°
06-08-84	3:40PM	170°	140°	140°	125°	-	83°
06-11-84	3:30PM	170°	142°	135°	125°	-	81°
06-12-84	3:35PM	180°	141°	135°	125°	-	81°

TABLE III
(CONT.)

DATE	TIME	#1	#7	#19 (Return Air)	AT	AAT
06-13-84	3:30PM	125°	134°	130°	125° -	79°
06-14-84	3:20PM	109°	124°	120°	125° -	74°
06-20-84	3:20PM	166°	132°	130°	120° -	80°
06-21-84	3:20PM	165°	135°	140°	120° -	82°
06-22-84	3:10PM	167°	137°	135°	120° -	81°
06-25-84	4:00PM	159°	139°	140°	125° -	86°
06-26-84	3:20PM	187°	142°	140°	125° -	88°
06-27-84	3:30PM	173°	148°	135°	125° -	83°
06-28-84	3:30PM	151°	135°	125°	125° -	80°
07-02-84	4:15PM	124°	119°	115°	125° -	75°
07-03-84	3:50PM	158°	139°	140°	120° -	81°
07-05-84	3:45PM	183°	147°	140°	125° -	83°
07-06-84	3:10PM	156°	137°	135°	125° -	84°
07-09-84	4:00PM	162°	143°	140°	125° -	82°
07-10-84	3:55PM	184°	145°	140°	125° -	84°
07-11-84	4:00PM	181°	147°	140°	125° -	85°
07-12-84	4:00PM	163°	143°	135°	125° -	81°
07-13-84	3:35PM	178°	144°	140°	125° -	80°
07-16-84	3:30PM	165°	143°	135°	125° -	82°
07-17-84	4:05PM	166°	142°	130°	125° -	79°
07-18-84	3:45PM	159°	139°	130°	125° -	82°
		Load Asphalt				
07-19-84	4:10PM	182°	154°	140°	125° -	84°
07-20-84	4:00PM	180°	153°	140°	125° -	84°
07-23-84	3:30PM	170°	148°	140°	130° -	83°

TABLE III
(CONT.)

DATE	TIME	#1	#2	#3	#4	#5	#6	#7	#9	Asph. Temp.	Avg. Ambient Temp.
07-26-84	3:25PM	184°	182°	162°	165°	164°	155°	148°	140°	127°	78°
07-27-84	3:45PM	191°	189°	175°	175°	173°	164°	155°	140°	126°	79°
07-30-84	3:20PM	148°	151°	146°	145°	147°	141°	138°	130°	128°	79°
07-31-84	2:20PM	165°	154°	147°	149°	151°	144°	139°	135°	127°	77°
08-01-84	3:45PM	143°	142°	136°	137°	138°	133°	131°	125°	126°	80°
08-02-84	3:30PM	166°	151°	148°	153°	155°	149°	143°	140°	125°	84°
08-03-84	3:25PM	158°	155°	150°	150°	151°	145°	141°	130°	125°	82°
08-06-84	3:15PM	182°	153°	150°	156°	160°	154°	147°	140°	124°	83°
08-07-84	3:25PM	117°	135°	135°	135°	137°	133°	129°	125°	123°	82°
08-08-84	2:20PM	117°	128°	125°	123°	126°	121°	118°	105°	123°	76°
08-09-84	3:30PM	166°	163°	154°	155°	155°	148°	139°	135°	121°	79°
08-10-84	3:30PM	114°	126°	124°	121°	125°	120°	116°	105°	120°	76°
08-13-84	3:20PM	Instruments	Inoperative	thru 09-17-84							
09-18-84	2:35PM	187°	163°	161°	162°	167°	162°	523°*	140°	127°	73°
09-19-84	3:35PM	191°	170°	169°	167°	173°	167°	528°*	145°	128°	72°
09-20-84	3:15PM	149°	149°	147°	146°	150°	143°	504°*	125°	128°	69°
09-21-84	3:30PM	193°	170°	162°	169°	170°	162°	520°*	145°	128°	72°
09-24-84	3:30PM	193°	165°	157°	166°	168°	161°	517°*	140°	126°	80°
09-25-84	2:55PM	114°	133°	129°	127°	123°	99°	466°*	45°	125°	67°
09-26-84	3:15PM	113°	118°	113°	110°	113°	106°	472°*	60°	149°	49°
09-27-84	3:10PM	169°	166°	153°	154°	153°	145°	502°*	125°	159°	58°
09-28-84	3:15PM	108°	117°	112°	108°	112°	101°	466°*	55°	117°	52°
10-01-84	3:15PM	184°	153°	145°	152°	155°	149°	506°*	130°	109°	
10-02-84	3:30PM	136°	125°	128°	132°	134°	132°	496°*	125°	110°	
10-03-84	3:25PM	90°	110°	109°	108°	112°	110°	473°*	85°	111°	
10-04-84	3:40PM	153°	138°	136°	142°	143°	137°	498°*	125°	109°	
10-05-84	3:10PM	156°	137°	136°	140°	141°	133°	493°*	120°	108°	
10-10-84	3:40PM	171°	148°	138°	143°	145°	137°	497°*	120°	114°	
10-11-84	3:15PM	171°	153°	144°	148°	148°	141°	501°*	125°	113°	
10-12-84	2:55PM	184°	168°	159°	164°	164°	156°	512°*	135°	113°	
10-15-84	3:30PM	191°	187°	172°	168°	166°	157°	517°*	135°	113°	
10-22-84	3:25PM	100°	104°	102°	100°	102°	94°	461°*	55°	107°	

* Equipment Malfunction

District Measurements

Table III contains temperature measurements obtained by District 6 personnel, generally on each working day. The date, time of measurement, location #1 (collector exit), location #7 return air, location #9 asphalt temperature, and average ambient air temperature are shown from November 9, 1983 through July 23, 1984. Locations #2 through #6 have also been included from July 26, 1984 through October 22, 1984.

IV. ANALYSIS

Figures 14 and 15 show time plots of both duct air velocities and temperatures for the second (March 13 and 14, 1984) and third (July 24 and 25, 1984) test periods. The asphalt temperature in the tank was about 110°F during the second test period and the ambient temperature varied from about 65°F in the morning to above 80°F in the afternoon. Collector output temperatures in the morning are above ambient but lower than the tank temperature. These temperatures were measured at location #1 and the values would indicate some reverse loss in energy from the asphalt. This loss is probably insignificant because the area for heat transfer would be small (a horizontal strip close to the top of the collectors). However, placement of the collector/tank socket closer to the bottom of the tank should be considered in future systems. The collector output temperature increases and is greater than the tank temperature before noon. The return temperature of the air in the duct was not plotted because of the clutter on the plot but temperatures 30° to 50°F lower than the output temperature can be envisioned during peak conditions. The third test period (Figure 15) shows somewhat similar conditions as those described above. The tank and air temperatures are somewhat higher as compared to the second test period and this seems to result in higher morning output temperatures even though the afternoon temperatures are about the same.

On all occasions some cloud cover was present. Generally the cloud cover was a slight haze but dense clouds occurred intermittently. The solar flux was not measured but reduced solar energy resulted from this cloud cover. The cloud cover or haze seemed to increase in the afternoon hours beginning about 2:00 P.M. (CST). The effects of this cloud cover and intermittent cloudiness can be seen in Figures 14 and 15. The plot points do not reveal the full effect of passing or intermittent cloudiness. Observations indicate almost immediate response when a cloud occurs and both exit temperature and duct air velocity are reduced. When the cloud passes, a rapid climb in values were observed.

A study of solar energy available to the system was performed by using Dr. Vliet's computer program found in Appendix A. The appropriate input variables were used, except separate runs were made while using different "solar flux values" and "hours of available sun". Comparisons of duct air temperatures calculated in the program were made with actual temperatures at corresponding locations around the tank. Figures 16 and 17 show plots of the calculated and measured duct temperature values for locations #1 (bottom of page) and #7 (top

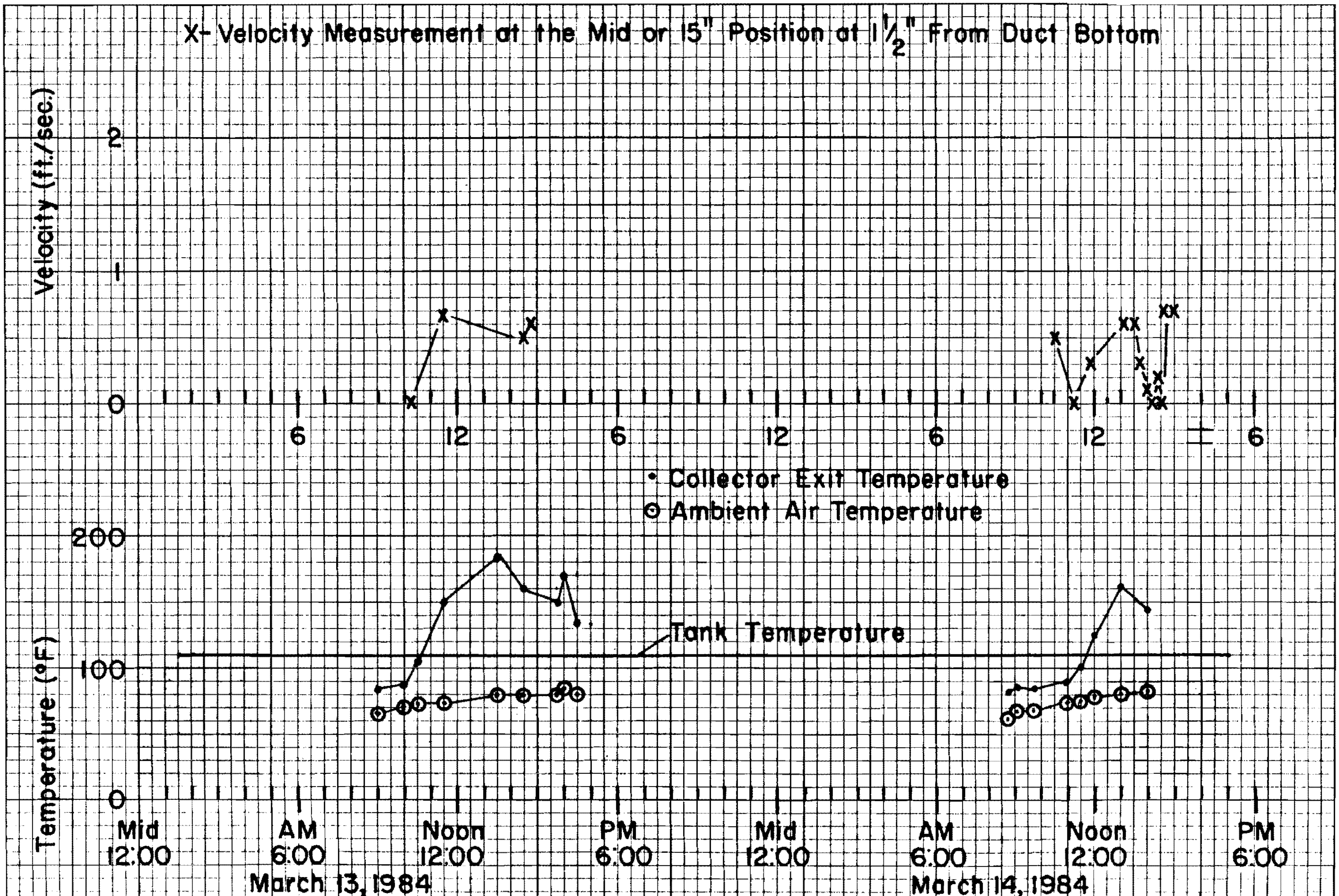


Figure 14 - Velocity and Temperature Measurements - March 1984

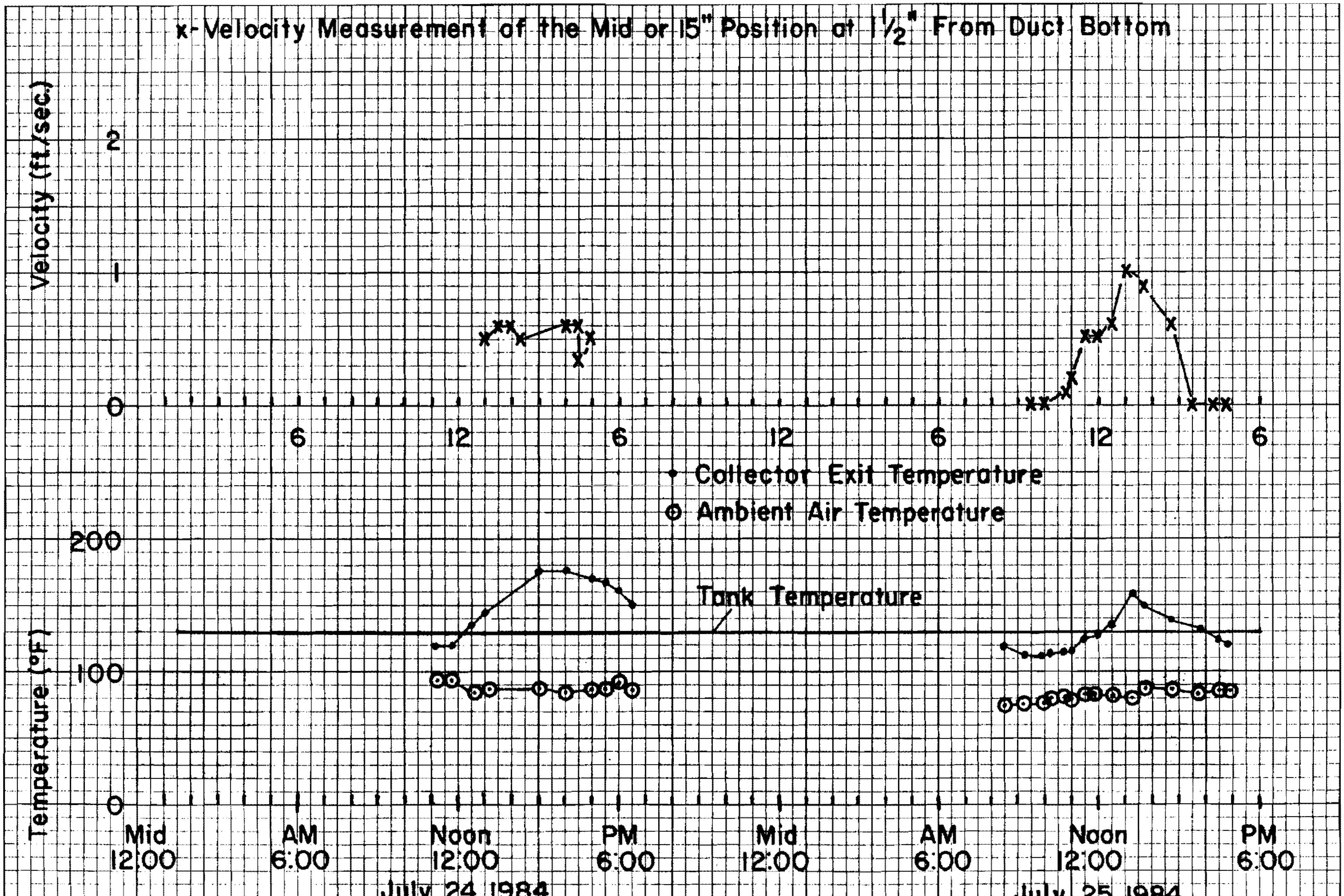


Figure 15- Velocity and Temperature Measurement - July 1984

on page). The time period of available sun for March was found to be approximately 10 hours whereas about 12 hours is available in July. The "solar flux values" used were 273,000 and 180 Btu/Hr-Ft^2. When comparing the collector exit temperatures at location #1, both figures 16 and 17 show the solar flux at the test periods to be between 200 and 273 Btu/Hr-Ft^2 as indicated on March 13. However, on March 14 cloudiness occurred about 1:00 to 2:00 PM. The temperature values at location #7, near the return to the collector, show the flux to be about 180 Btu/Hr. Ft^2 or lower. This could indicate there is a greater differential between temperature entering and leaving the tank duct and therefore a greater efficiency than expected. However it is believed that this difference between measured and calculated is more indicative of a temperature averaging process (since large temperature variations between reading periods at location #7 are not evident). It should be noted that the tank skin is not smooth and several appendages such as manholes exist at various locations around the tank. It would not be practical to model this effect in Dr. Vliets program. Therefore, it is believed that, given the unkown effects of cloudiness, there is a close relationship between the calculated and measured values. This relationship tends to verify both Dr. Vliets program as a design tool and the performance of the system. Another point of interest is the time of occurrence of peak temperatures. Particularly in July, the peak occurs in the afternoon at about 3:00 PM. This is because the tank is positioned slightly southeast/northwest and receives afternoon sun for a longer period.

VII. CONCLUSIONS AND RECOMMENDATIONS

It is concluded that the system performance responds to the needs originally established by the Odessa District of maintaining emulsified asphalt sufficiently liquid to flow from the tank without excessive time delays. The computer program developed by the College of Mechanical Engineering at UT Austin is applicable and can be used as a design tool. Given the effect of cloudiness in reducing available solar flux and the lack of instrumentation to measure this affect, the system seems to be performing as designed. The system has performed without need for attention or care - it just sets and does - as anticipated. Care will probably be needed in a few years in changing the glazing. The gasket between the collector and tank in the socket should be changed at that time. In future installations the connection between the collectors and the tank should be lower - at or near the bottom of the tank. The system is relatively inexpensive and the time for a return on expenditures should be small (estimated as 10 years).

It is recommended that additional installations be installed as needed and desired by districts in the State.

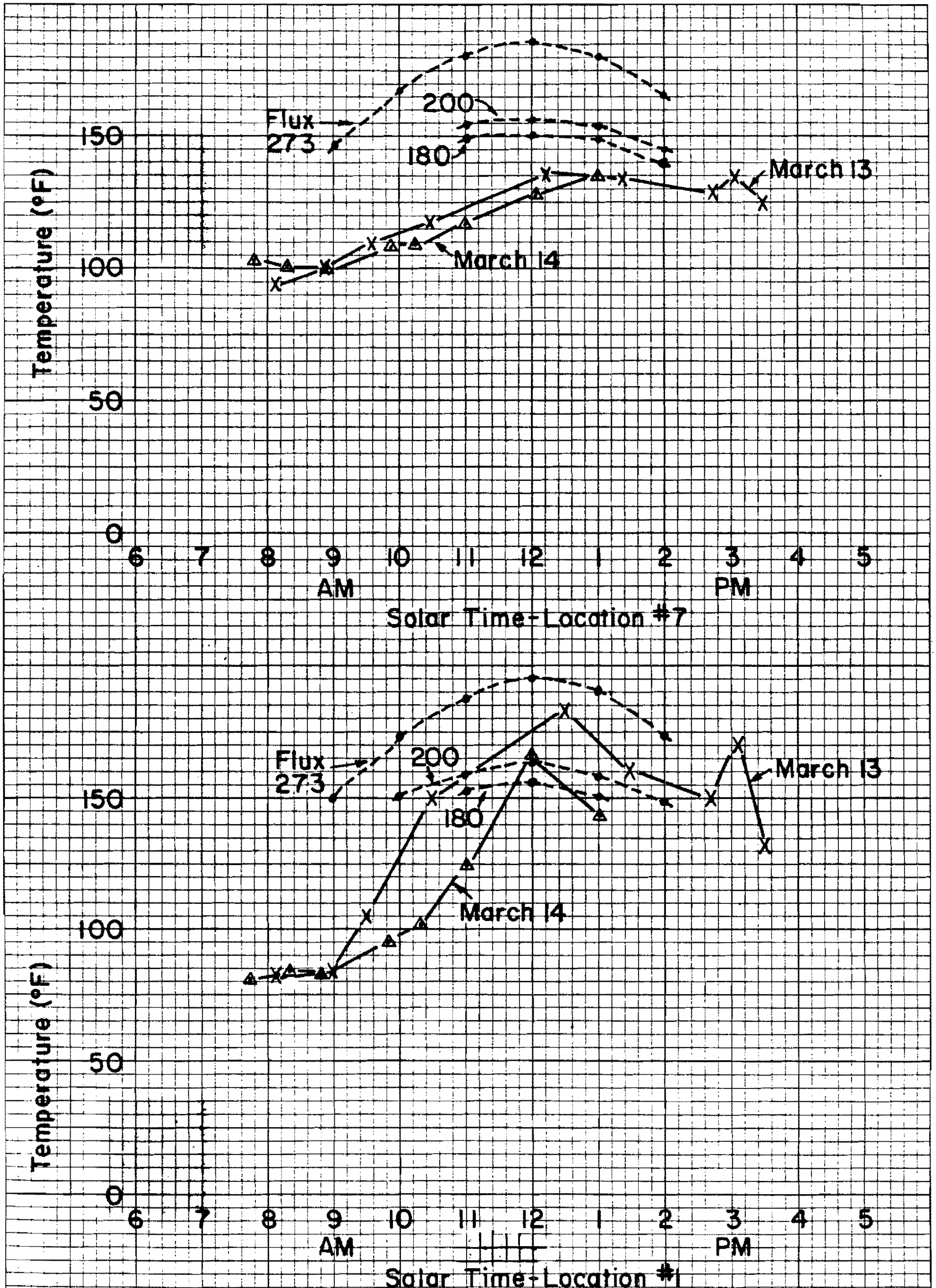


Figure 16-Comparison of Duct Temperatures for March 1984

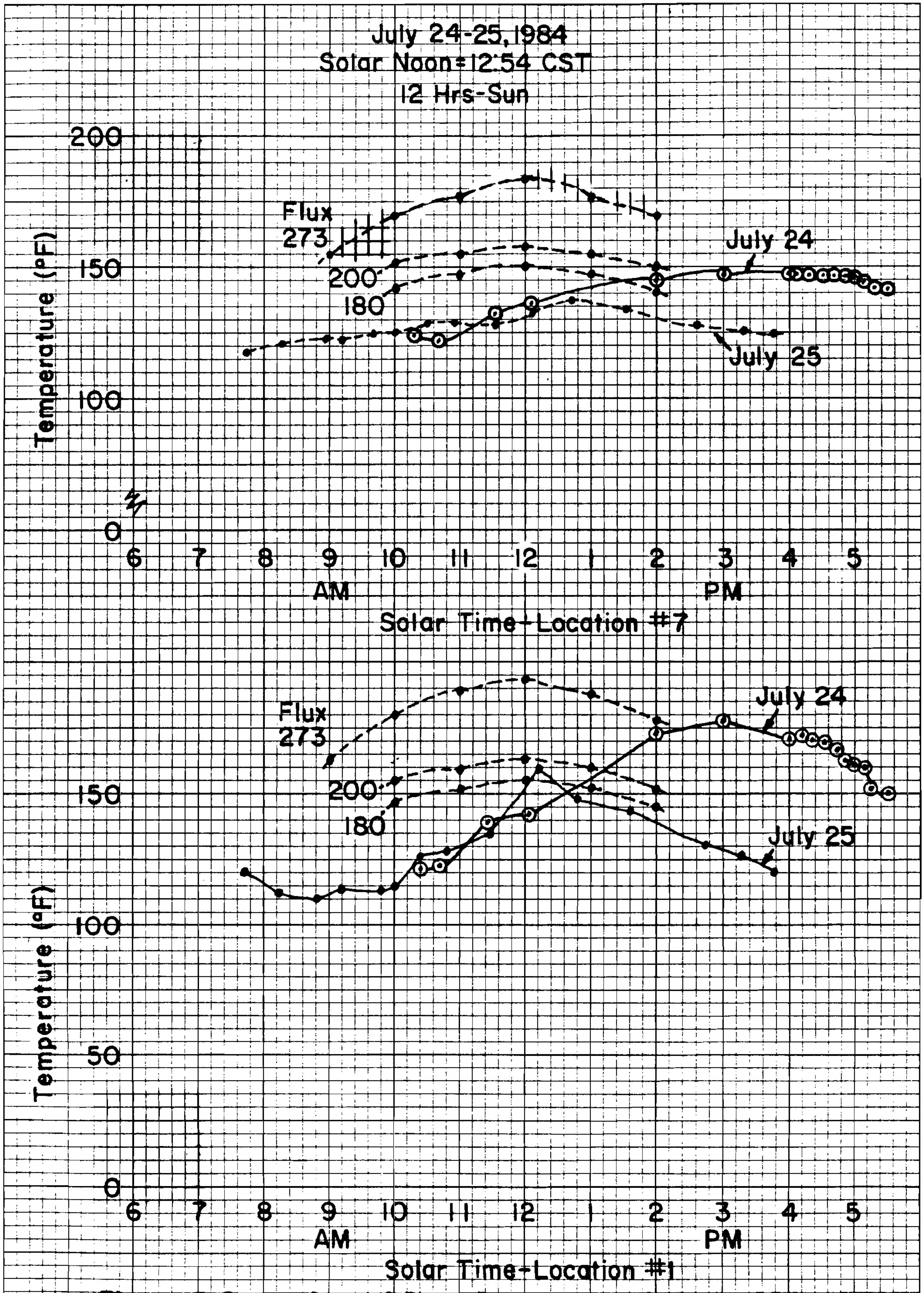


Figure 17-Comparison of Duct Temperatures for July 1984

LUBBOCK
BASED ON 1976 DATA

$$T_{NEW} = T_{OLD} - \frac{1}{83,300(.75)} Q_{IN} - 62.8(T_{OLD} - T_{AMB})$$

Time (Hour)	Q_{IN} BTU/Hr.	Aug. Ambient Temp. ° F	Old Temp.	New Temp.	Δ T	Q_{LOSS} 62.8(ΔT)	Result $Q_{IN}-Q_{LOSS}$	TEMP .000016(Result)
6		26.1	180	179.85	153.9	-9665		-0.15
7		28.7	179.85	179.70	151.15	-9492		-0.15
8		32	179.70	179.55	147.7	-9275		-0.15
9	9072	35.9	179.55	179.56	143.65	-9021	+ 51	+0.01
10	26964	40	179.56	179.85	139.55	-8764	+18,200	+0.29
11	37548	44.1	179.85	180.31	136.75	-8525	+29,023	+0.46
12	42588	48	180.31	180.86	132.31	-8309	+32,279	+0.55
13	42588	51.3	180.86	181.39	129.56	-8136	+34,452	+0.55
14	37548	53.9	181.39	181.86	127.49	-8006	+29,542	+0.47
15	26964	55.5	181.86	182.16	126.36	-7935	+19,029	+0.30
16	9072	56	182.16	182.18	126.16	-7923	+ 1,149	+0.02
17		55.5	182.18	182.05	126.68	-7956		-0.13
18		53.9	182.05	181.92	128.15	-8048		-0.13
19		51.3	181.92	181.79	130.62	-8203		-0.13
20		48	181.79	181.66	133.79	-8402		-0.13
21		44.1	181.66	181.52	137.56	-8639		-0.14
22		40	181.52	181.38	141.52	-8887		-0.14
23		35.9	181.38	181.23	145.48	-9136		-0.15
24		32	181.23	181.08	148.23	-9372		-0.15
1		28.7	181.08	180.93	152.38	-9569		-0.15
2		26.1	180.93	180.77	154.83	-9723		-0.16
3		24.5	180.77	180.61	156.27	-9814		-0.16
4		24	180.61	180.45	156.61	-9835		-0.16
5		24.5	180.45	180.29	155.95	-9794		-0.16
6		26.1	180.29	180.14	154.19	-9683		-0.15
7		28.7	180.14	179.99	151.44	-9510		-0.15
8		32	179.99	179.84	147.99	-9294		-0.15
9	9072	35.9	179.84	179.70	143.94	-9039		-0.14

TABLE IV

Hourly Temperatures in January

Lubbock
BASED ON 1976 DATA

$T_N = T_o - \frac{1}{83300(0.75)}$ $Q_{IN} = 62.8(T_o - T_A)$

Time (Hour)	Q_{IN} BTU/Hr.	Avg. Ambient Temp. °F	Old Temp.	New Temp.	ΔT	Q_{LOSS} 62.8 (ΔT)	Result $Q_{IN}-Q_{LOSS}$	Temp. 0.000016(Result)
6	0	67.205	180	179.887	112.795	-7083		-0.113
7	0	68.637	179.887	179.775	111.250	-6986		-0.112
8	0	70.500	179.775	179.665	109.275	-6862		-0.110
9	17892	72.669	179.665	179.844	106.996	-6719	+11,173	+0.179
10	26712	75.000	179.844	180.167	104.844	-6542	+20,170	+0.323
11	35532	77.331	180.167	180.632	102.836	-6458	+29,074	+0.465
12	35532	79.500	180.632	180.099	101.132	-6351	+29,181	+0.467
13	26712	81.363	181.099	181.426	99.736	-6263	+20,449	+0.327
14	17892	82.794	181.426	181.613	98.632	-6194	+11,698	+0.187
15	0	83.694	181.613	181.515	97.919	-6149		-0.098
16	0	84.000	181.515	181.417	97.515	-6124		-0.098
17	0	83.694	181.417	181.319	97.723	-6137		-0.098
18	0	82.794	181.319	181.220	98.525	-6187		-0.099
19	0	81.363	181.220	181.120	99.857	-6271		-0.100
20	0	79.500	181.120	181.018	101.620	-6382		-0.102
21	0	77.331	181.018	180.914	103.687	-6512		-0.104
22	0	75.000	180.914	180.808	105.914	-6651		-0.106
23	0	72.669	180.808	180.699	108.139	-6791		-0.109
24	0	70.500	180.699	180.588	110.199	-6921		-0.111
1	0	68.637	180.588	180.476	111.951	-7031		-0.112
2	0	67.205	180.476	180.362	113.271	-7113		-0.114
3	0	66.306	180.362	180.247	114.056	-7163		-0.115
4	0	66.000	180.247	180.132	114.247	-7175		-0.115
5	0	66.306	180.132	180.018	113.826	-7148		-0.114
6	0	67.205	180.018	179.905	112.813	-7085		-0.113
7	0	68.637	179.905	179.793	111.268	-6988		-0.112
8	0	70.500	179.793	179.683	109.293	-6864		-0.110
9	17892	72.669	179.683	179.862	107.014	-6720	+11,172	+0.179

TABLE V

Hourly Temperatures in July

	System #1	System #2	System #3	System #4
Initial Cost	$20,300	$16,590	$ 8,635	$ 6,835
Annual Heating Cost	97.80	253.00	880.80	16,030.56
1st Year	20,300	16,590	8,635	6,835
	98	253	881	16,031
Total	20,398	16,843	9,516	22,866
5th Year	20,300	16,590	8,635	6,835
	490	1,265	4,405	80,155
Total	20,790	17,855	13,040	86,990
10th Year	20,300	16,590	8,635	6,835
	980	2,530	8,810	160,310
Total	21,280	19,120	17,445	167,145
15th Year	20,300	16,590	8,635	6,835
	1,470	3,795	13,215	240,465
Total	21,770	20,385	21,850	247,300
20th Year	20,300	16,590	8,635	6,835
	1,960	5,060	17,620	320,620
Total	22,260	21,650	26,255	327,455
25th Year	20,300	16,590	8,635	6,835
	2,450	6,325	22,025	400,775
Total	22,750	22,915	31,660	407,610

TABLE VI

COST COMPARISON OF HEATING SYSTEMS

TABLE VII

COSTS ASSOCIATED

WITH THE

SOLAR AND AUXILIARY HEATING

COMPONENTS AND INSTALLATION

LUBBOCK

Heating and Data Collection Components:

Item	Quantity	Cost/Unit	Unit	Quantity Cost
Solar Collector Panels	6	$ 546.00	Each	$3,276.00
Circulator Pump	1	224.00	Each	224.00
Control Valves	2	35.00	Each	70.00
Air Vent	1	10.00	Each	10.00
Line Strainer	1	14.00	Each	14.00
Check Valve	1	14.00	Each	14.00
Flow Switch	1	29.00	Each	29.00
Heating Boiler	1	403.00	Each	403.00
Manual Switch	4	3.00	Each	12.00
24 Volt Transformer	1	50.00	Each	50.00
Differential Thermostat	1	30.00	Each	30.00
Safety Thermostat	1	30.00	Each	30.00
Double Throw - Double Pole Relays	4	10.00	Each	40.00
Heat Exchanger	1	300.00	Each	300.00
Expansion Tank	1	50.00	Each	50.00
Pressure Relief Valve	1	10.00	Each	10.00
3/4" Copper Tubing	180	0.55	Feet	99.00
Copper Elbow	15	0.72	Each	10.80
Copper Tee	17	1.33	Each	22.61
Copper Coupling	28	0.33	Each	9.24
3/4" Valves	2	5.00	Each	10.00
Tubing Insulation	180	0.50	Feet	90.00
(Differential) Thermostat	1	30.00	Each	30.00
Recording Thermometer	3	325.00	Each	975.00
Recording Pyranometer	1	1,000.00	Each	1,000.00
				6,808.65
Labor				3,500.00

Foundation:

Item	Quantity	Cost/Unit	Unit	Quantity Cost
P.C. Concrete	3	30.00	Cubic Yds.	90.00
½" Reinf. Steel	329	0.50	Feet	164.50
				254.50
Labor				200.00

APPENDIX A

PASSIVE SOLAR SYSTEM DESIGN

Passive Solar System Design

Solar Heated Asphalt Tank with Thermosiphon Air Collectors

G. C. Vliet

A design study has been conducted at the request of the Texas Department of Highways and the U.S. Department of Transportation to analyze and design a solar heating system for asphalt tanks using thermosiphon air collectors. A summary of the design approach and results follows.

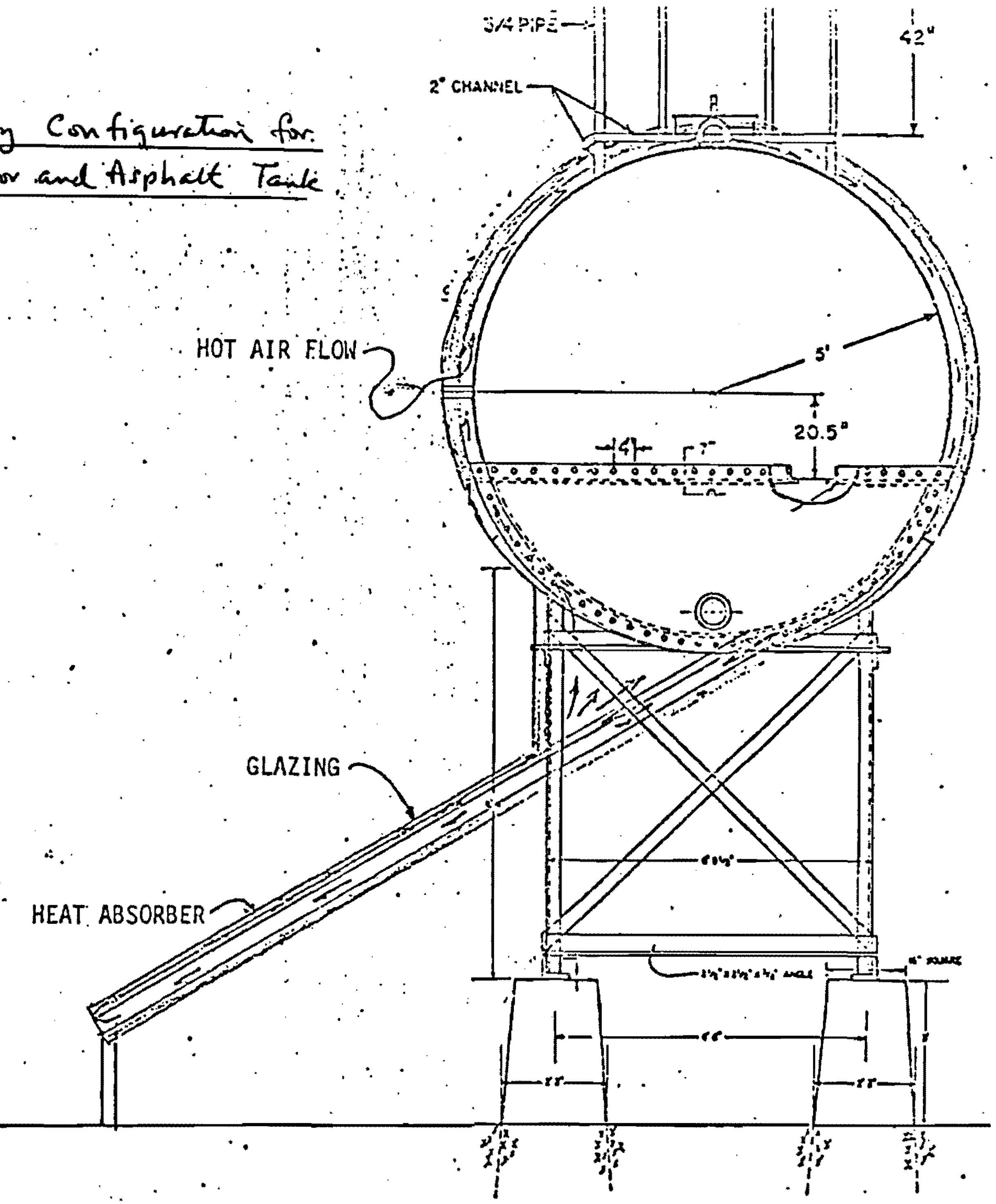
General:

The thermosiphon air solar collector appears to be ideally suited to the need for maintaining asphalt (emulsion) tanks in a range of temperatures such that the asphalt can be easily pumped from the tank (120 to 150°F) and such that the emulsion remains above the critical temperature of de-emulsification (~50°F). The asphalt tanks are approximately 10 feet diameter and 20 feet long (horizontal), with the bottom of the tank 10 feet above ground and the supporting framework about 6'-8 1/2" wide as shown in Figure 1. A preliminary concept of the location of the collector is also shown in Figure 1, where the air circulates around the tank underneath the thermal insulation blanket.

The thermosiphon air collector concept has several advantages: no active mechanical components, automatic (passive), no tank penetrations, and no corrosion or leaking problems. A possible disadvantage is the potentially low heat transfer (coefficients) involved with natural circulation; however, it has been found that the latter is not a problem and the concept appears to be quite attractive.

The configuration is typical of thermosiphon systems with the insulated tank located above the collector. The warm air from the

FIGURE 1 - Preliminary Configuration for Thermosiphon Air Collector and Asphalt Tank



ATTACHMENT A

collector circulates around the tank between the tank wall and the insulation. No tank penetrations are necessary with the design, and the tank heat transfer surface is reasonably large ($20 \times 10\pi$ + ends $\approx$ 1000 ft^2). So as to not interfere with the support structure and thus simplify the ducting attachment between the collector and tank, it was considered advisable to locate the top of the collector at the approximate bottom elevation of the tank, and about 3 1/2 feet out from the tank vertical center plane as shown in Figure 2. The optimum collector angle should be about 45^o (approx. latitude plus 15 degrees) since the seasonal load for this application is not unlike that for a solar heating and hot water application, for which this rule of thumb has been shown to be reasonable. The collector length, L_c, is of course a to be determined variable. The collector area $A_c = L_c \cdot W_c$ will affect the temperature range attained by the asphalt during different periods of the season. In addition to the collector area, the collector design configuration is also important. These two features will be addressed subsequently.

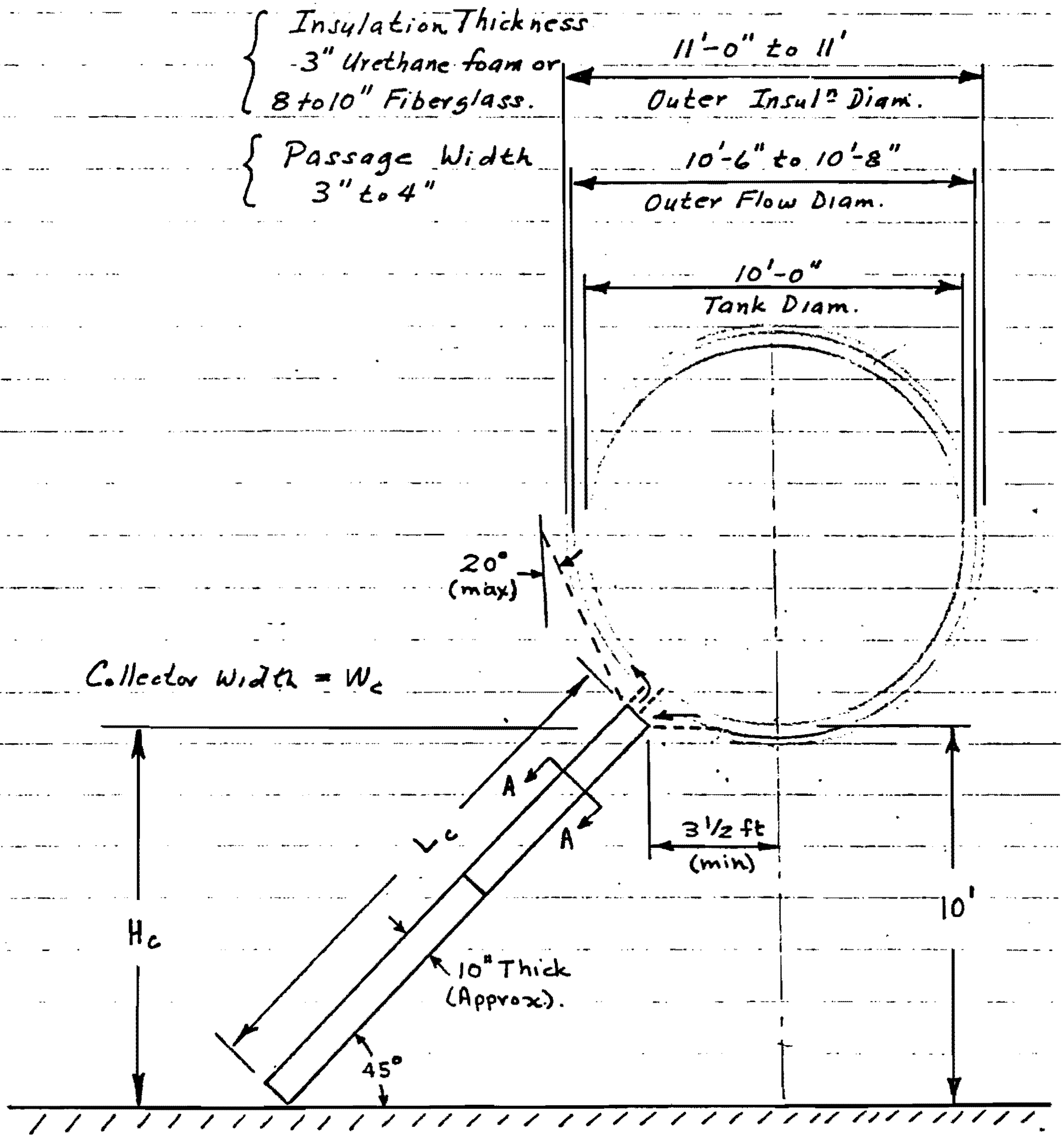
Since the flow is thermally driven, a computer program was developed to dynamically simulate the thermosiphon collector and tank (asphalt) with time. An undocumented listing of the program SOLAR written in BASIC language and the output listing of a sample run are included with this report as Appendix A.

Collector Design:

The collector design is a flat plate type with the return air from the tank flowing downward, then reversing its flow at the bottom of the collector to flow upward as it is solar heated. The return and supply streams are separated by an insulated wall. The back and sides of the

FIGURE 2.

End View of Solar Collector and Asphalt Tank

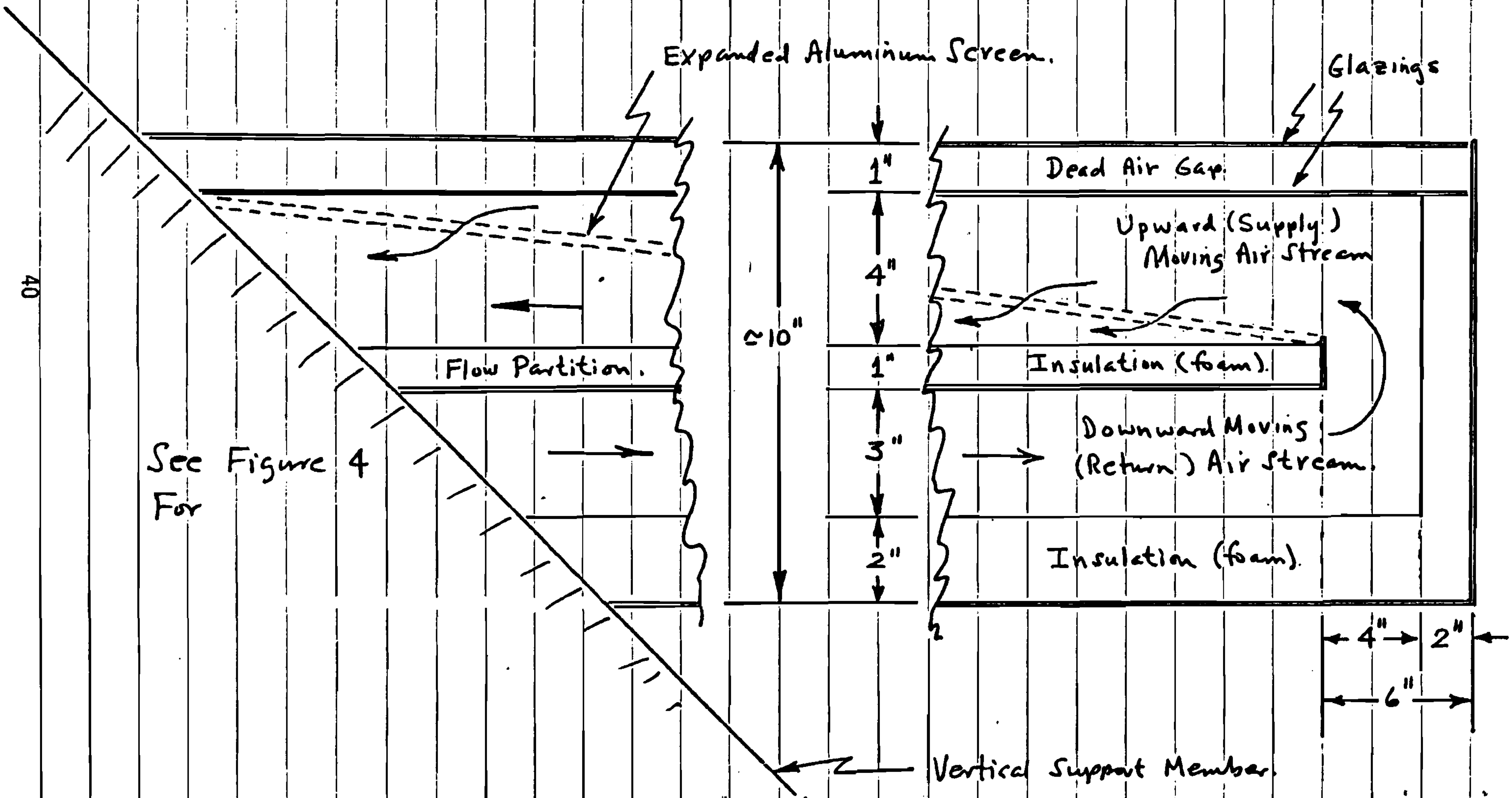


collector are also thermally insulated, while glazing is located on the front. Two basic absorber "plate" designs were considered: (a) an extended metal fin type absorber with a flat upper surface and finned under surface which extended into the upward moving air stream and (b) an expanded aluminum screen (filter) configured such that it serves as the solar absorber and the air passes through and is heated by it as it flows upward. A schematic of the extended fin type of configuration is shown in Figures B.1 and B.2 in Appendix B. This concept was rejected in favor of the expanded aluminum screen design for fabrication reasons.

A side view of the selected collector configuration using the expanded aluminum screen is shown in Figure 3, with the recommended dimensions indicated. The external insulation is the equivalent of 2 inches of urethane foam. The lower (return) and upper (supply) air passages are 3 and 4 inches thick respectively, the difference due to the presence of the expanded screen absorber running diagonally in the upper passage. Approximately a 4 inch (minimum) gap should be left at the lower end of the flow partition ot facilitate flow reversal. The glazing separation should be approximately 1 inch.

The recommended glazing is 35-40 mil Lascolite (or equivalent). The material is of moderate cost, has good transmission, has sufficient stiffness to not sag significantly for spans of 2 to 3 feet, is tough and easily fabricated. The expanded aluminum screen was recommended by personnel of the Dept. of Transportation and would be spray painted with a dull black paint. Calculations made on this configuration resulted in a collector efficiency defined by $F_R\ (\tau\alpha) = 0.65$ and $F_RU_L = 0.91$. This represents a collector a little better than that for the single

FIGURE 3 – SIDE VIEW OF THERMOSIPHON AIR COLLECTOR USING EXPANDED ALUMINUM SCREEN ABSORBER



glazed fin geometry collector discussed in Ref. (1).

The design for attachment of the collector to the tank and support is presented in Figure 4. Several discussions were held between this consultant and personnel of the Texas Dept. of Highways and the U.S. Dept. of Transportation regarding the collector design, the attachment of the collector to the tank and the tank insulation. Many of the details were covered in these discussions.

Computer Simulation

A computer code (see Appendix A) was developed to simulate dynamically the thermosiphon air collector and asphlat tank. The code is based on a physical model that divided the air annular passage around the tank into eight nodes (45^o each) and treated the collector as two nodes, one for the downward moving air and the other for the upward moving air. The heat transfer coefficient for the asphlat (Btu/hr ft^2 ^oF) in the tank was calculated from

$$h = - 0.25 + 0.0375\ T_a$$

where T_a is the asphalt temperature. This is based on natural convection heat transfer correlations and property data for asphalt emulsions. The above equation gives values that are considered to be conservative.

Heat transfer correlations in the air passages were based on accepted laminar or turbulent convective heat transfer correlations. It was found that turbulent flow prevailed, though the Reynolds numbers were not high (about 3000 to 5000 depending on conditions). Heat losses from the air passage through the insulation, and across the flow separator in the collector were accounted for during the collection

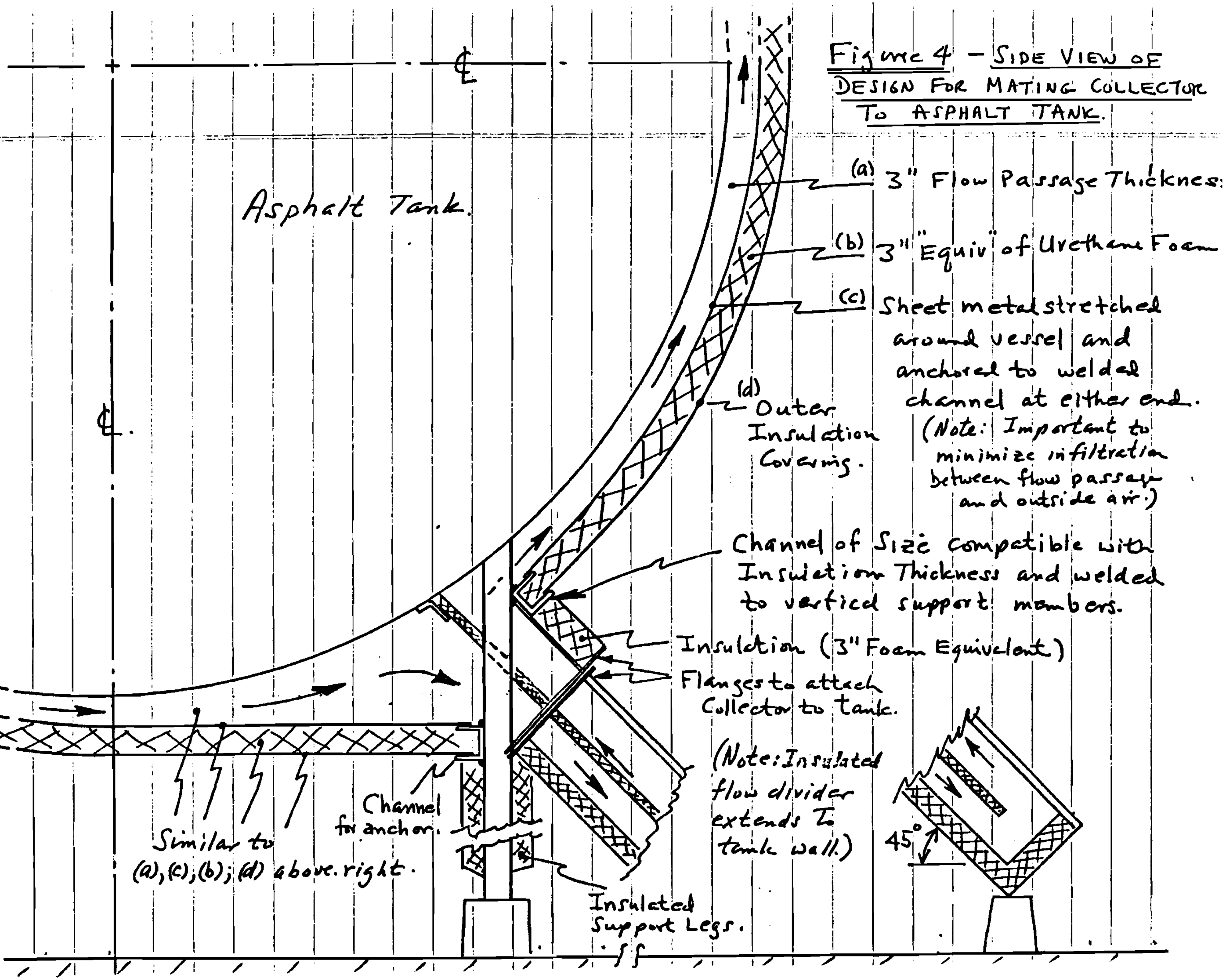


Figure 4 – SIDE VIEW OF DESIGN FOR MATING COLLECTOR TO ASPHALT TANK.

period. Losses from the asphalt through the insulated end of the tank were accounted for continuously and losses through the cylindrical surfaces of the tank were accounted for during non-collection periods.

The ambient temperature was assumed constant over each period of simulation. For January and July the average ambient temperatures used for Midland, Texas were 48 and 86^{o}F, respectively, Ref. (1). The insolation was assumed to be sinusoidal over a period of 10 hrs. for both the January and July periods examined. The same day length (10 hr) was used because during the summer the steep collector tilt results in an "effective" day length of about the same as in the winter. Data from Ref. (1) indicate that for Midland, Texas the daily insolation levels on a 45^{o} tilted surface were $\approx$ 1740 and 1750 Btu/day ft^2 for January and July respectively. Assuming a 10 hr. day for each period, the average peak (noon-time) insolation levels are 273 and 275 Btu/hr ft^2 respectively.

The model resulted in ten equations, with the unknown variables being the air temperatures of the ten nodes. The method of solution was to assume an air circulation flow rate and solve the set of ten simultaneous equations for the ten air temperatures. Using the resulting air temperatures, the net buoyant pressure differential around the loop was compared to the frictional pressure drop around the loop based on accepted pressure drop equations. The previously assumed flow rate was then corrected according to this difference and the ten equations resolved. This iteration procedure was continued until the net buoyant head and friction pressure drop agreed within a specified error. This steady state solution was assumed to be quasi-steady over a one hour time period during which the heat transfer to the asphalt was computed and assumed constant. The net temperature increase in the asphalt over the hour period was thus calculated, including the input from the collector and losses through the tank ends. During non-collection periods the heat losses from the tank were used to compute the decrease in asphalt temperature. Computations were done on an Apple II Plus computer.

Calculations were made with different collector areas for the two months of January and July to predict the approximate steady state temperature achieved by the asphalt as a function of collector area for each period. The results are presented in Table 1 and also in Figure 5. These results are based on the use of approximately 3.5 inches of foam insulation (or equivalent) on the tank.

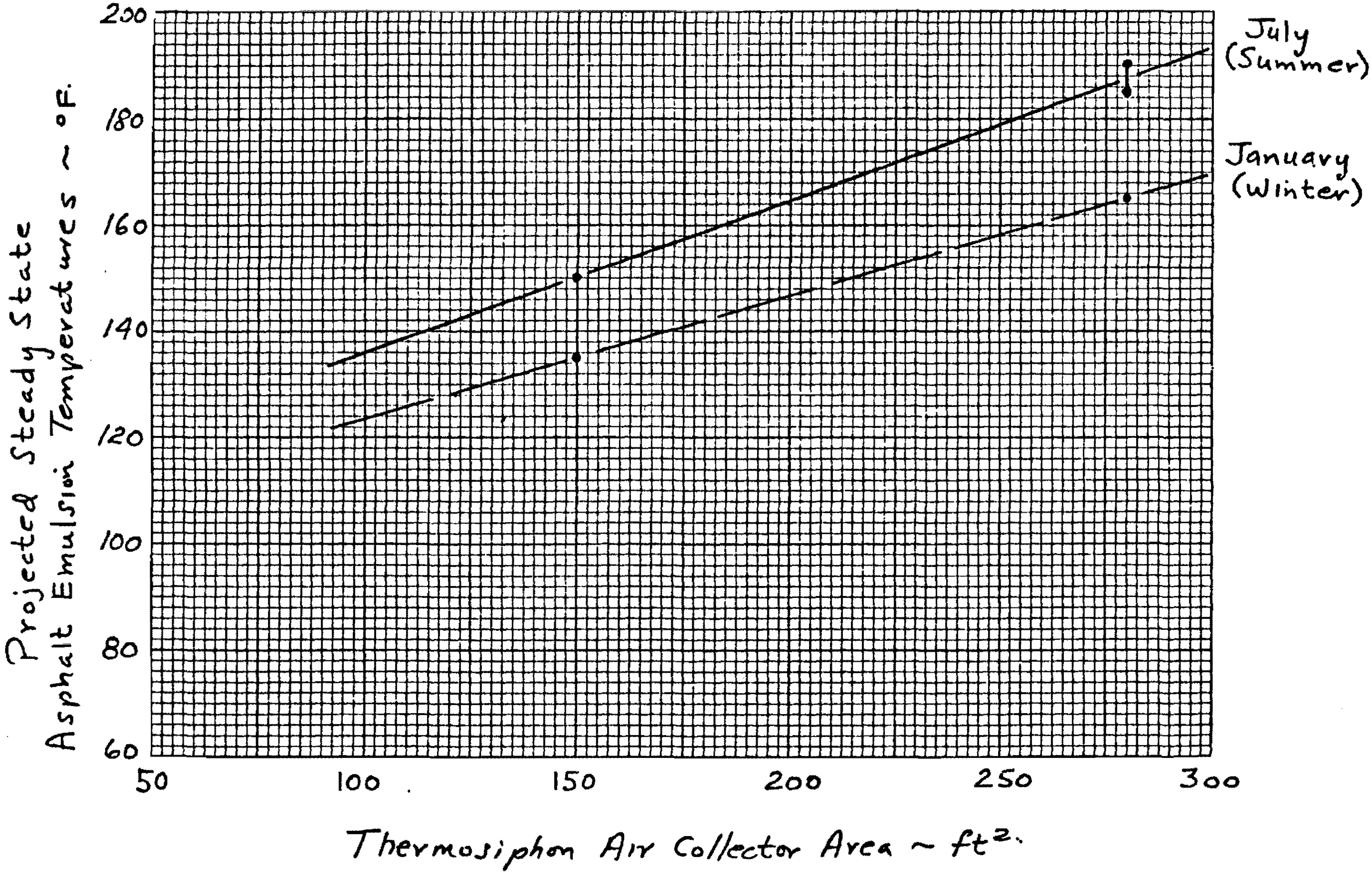
These calculations also showed that for an annular air passage gap around the tank of approximately 3 inches, the flow was sufficient to be turbulent. Thus the air side heat transfer coefficients were sufficiently large, that with the tank surface area available no extended surface (fins) on the tank is necessary.

Table 1 - Projected Steady State Asphalt Temperatures

Collector Area ft^2	Period	
	January	July
$10 \times 15 = 150ft^2$	135^oF	165^oF
$14 \times 20 = 280ft^2$	150^oF	$185 - 190^oF$

It was estimated initially that as much as 200 to $280ft^2$ of collector would be advisable; however, based on the results of Table 1, it is recommended that a collector area of 150 to 180ft^2 be used. The steady state temperatures of 135 and 165°F for winter and summer respectively for 150ft^2 of collector may suggest that a smaller collector area be used. However, to include some conservatism in heat losses from the tank, collector efficiency, and the fact that heating is less efficient with partially filled tanks, the 150 to 180ft^2 is recommended. Also, since this is the first of a kind (developmental) it is important to insure that the collector provide sufficient heat to the tank. If somewhat excessive temperatures are experienced, as will probably be the case in Spring and Fall, a manually adjustable shade on the collector will permit effective adjustment of collector area, and thus acceptable steady state asphalt temperatures.

FIGURE 5 - PROJECTED STEADY STATE ASPHALT EMULSION TEMPERATURES AS A FUNCTION OF COLLECTOR AREA AND TIME OF YEAR.



Reference:

(1) HUD Intermediate Minimum Property Standards for Solar Heating and Domestic Hot Water Systems, 1977, (HUD 4930.2).

APPENDIX A

- Listing of Program SOLAR
- Sample Output

PROGRAM SOLAR: For Simulation of Solar Heated Asphalt Tanks with Thermosiphon Air Collectors

```
40  DIM A(11,12),UI(20),UO(20),AI(20),AO(20),CK(20)
50  DIM T(20),MU(20),RHO(20),RN(20),PF(20),PB(20),R(20),RR(20),AA(11,12)
90  FOR I = 1 TO 11
100 T(I) = 150.
120  NEXT I
1500  REM  CONSTANT PARAMETERS
1510 PI = 3.1416
1520 GC = 416793600.
1525  REM  GC IS IN UNITS (LBM-FT/LBF-HR^2)
1526  REM  IF "FULL" < 1.0 THEN ASSUMES TANK HALF FULL.
1527 FULL = 0.5
1530 KMAX = 100
1540 EC = 0.2
1545 CM = .1
1547 R = 10
1550 SUNT = 0.0
1555 DT = 1.0
1560 DAYS = 1.0
1565 DMAX = 2.0
1570 PR = 0.70
1580 CP = 0.24
1590 CO = .015
1595 TD = 1.0
1596 HG = 0.2
1597 CX = 0.67
1598 RA = 60
1599 AX = 2.0
1600  READ DIW,DOW,TO,T1,T2,LT,D11,W11,L11,D9,W9,H9,L9,DC,WC,LC,HC,SK,FK,
     QS,TI,HA,TA,C1,C2
1610  DATA  10,11,.008,.008,.25,20,.333,20,1,.333,20,10,11,.333,20,13,9,2
     5,.03,280,70,3,100,.7,1.2
1615  READ SHRS,DT,CTA
1617  DATA   12.,1.0,63000
1618 QMAX = QS
1990  PRINT "PLEASE ENTER THE FOLLOWING PARAMETERS - PUSH RETURN TO CONTI
     NUE"
1994  PRINT
1995  PRINT "***********************************"
1996  PRINT
1998  INPUT "ENTER TANK LENGTH (FT)";LT
2000  INPUT "ENTER ASPHALT TANK O.D. (FT)";DIW
2005 VT = PI * LT * (DIW ^ 2) / 4.
2006 CTA = CX * RA * VT
2007  IF FULL >  = 1.0 THEN  GOTO 2010
2008 CTA = 0.5 * CTA
2010  INPUT "ENTER FLOW CHANNEL I.D. (FT)";DOW
2020  INPUT "ENTER FLOW CHANNEL INNER WALL THICKNESS (IN)";TO
2025 TO = TO / 12.
2030  INPUT "ENTER FLOW CHANNEL OUTER WALL THICKNESS (IN)";T1
2035 T1 = T1 / 12.
2037  INPUT "ENTER THE TANK MATERIAL THERM. COND. (B/H-FT-F)";SK
2040  INPUT "ENTER TANK  INSULATION THICKNESS (IN)";T2
2045 T2 = T2 / 12.
2050  INPUT "ENTER THE TANK INSUL. THERM COND.(B/H-FT-F)";FK
```

```
2055  PRINT
2500  INPUT "ENTER COLLECTOR WIDTH (FT)";WC
2600  INPUT "ENTER COLLECTOR LENGTH (FT)";LC
2700  INPUT "ENTER COLLECTOR HEIGHT (FT)";HC
2720  INPUT "ENTER COLLECTOR SUPPLY CHANNEL I.D. (IN)";DC
2740 DC = DC / 12.
2760  INPUT "ENTER COLLECTOR RETURN CHANNEL I.D. (IN)";D11
2780 D11 = D11 / 12.
2800  INPUT "ENTER COLLECTOR INSUL. THICKNESS (IN)";TC
2820  INPUT "ENTER COLLECTOR INSUL. THERM. COND.(B/H-FT-F)";UCOW
2840 TC = TC / 12.
2860 UCOW = UCOW / TC
2900  INPUT "ENTER COLLECTOR PARTITION THICKNESS (IN)";TP
2920  INPUT "ENTER COLLECTOR PARTITION THERM. COND. (B/H-FT-F)";UWIC
2940 TP = TP / 12.
2960 UWIC = UWIC / TP
3000  INPUT "SOLAR COLLECTOR CONSTANT - C1";C1
3050  INPUT "SOLAR COLLECTOR CONSTANT - C2";C2
3299  PRINT
3300  PRINT "ENTER THE FOLLOWING STATE CONDITIONS"
3310  PRINT
3320  INPUT "MAXIMUM SOLAR FLUX INCIDENT UPON SOLAR COLLECTOR (BTU/HR-FT^
     2)";QS
3325 QMAX = QS
3327  INPUT "ENTER TOTAL SUN HOURS ";SHRS
3328  INPUT "ENTER NUMBER OF DAYS YOU WISH TO CYCLE OVER ";DMAX
3330  INPUT "AMBIENT AIR TEMPERATURE (F)";TI
3335  INPUT "EXTERNAL CONVECTIVE HEAT TRANSFER COEFFICIENT FOR THE SYSTEM
      (BTU/HR-F)";HA
3340  INPUT "ASPHALT TEMPERATURE (F)";TA
3350 QX = QMAX / (1.0 -  SIN (PI * (12. - SHRS) / 24.))
3355  HOME
3360  PRINT "THE PROGRAM IS RUNNI              NG"
3365  PRINT "*********************            ******"
3370 QQ = HA * AX
3372 AE = PI * ((DOW + T2) ^ 2) / 2.
3374 AZ = PI * (DOW + T2) * LT
3376 UC = 1.0 / ((1. / HA) + (T2 / FK) + (1.0 / HG))
3378 UE = 1.0 / ((1. / HA) + (T2 / FK))
3379 MH = 15000
3383 MDOT = 0.5 * MH
3386  IF DAYS > DMAX THEN  GOTO 13000
3387 SUNT = SUNT + TD
3388  IF SUNT > 24. THEN  GOTO 12500
3389 MH = 15000
3390 ML = 0.0
3393 QS = QX * (( SIN (PI * (SUNT - 6.) / 12.)) - 1.) + QMAX
3400  REM  CALCULATIONS START HERE
3605  IF QS <  = 0.0 THEN  GOTO 3710
3610 CEFF = C1 - ((C2 / QS) * (((T(10) + T(9)) / 2.) - TI))
3620  IF CEFF <  = CM THEN  GOTO 3700
3630  GOTO 3890
3700  REM  CALCULATE NO FLOW HEAT LOSS
3705  IF QS > 1. THEN  GOTO 3720
3710 QS = 0.0
3720 TA = TA - ((TA - TI) * ((UE * AE) + (UC * AZ) + QQ) * DT / CTA)
3731  PRINT
3750  PRINT "RELATIVE TIME: ";SUNT
```

```
3751  PRINT
3755  PRINT "INC. SOLAR FLUX (B/H-F^2)=";QS
3757  PRINT
3760  PRINT "NO FLOW CONDITION"
3762  PRINT
3765  PRINT "ASPHALT TEMPERATURE: ";TA
3767  PRINT
3768  PRINT
3770  GOTO 3387
3890 KOUNT = 0
3895  REM  START STEADY STATE ITERATION
3897  PRINT
3899 KOUNT = KOUNT + 1
3900  REM   CLEAR MATRIX
3901  FOR J = 1 TO R
3902  FOR I = 1 TO R + 1
3903 A(J,I) = 0.0
3904  NEXT I
3905  NEXT J
3906  IF KOUNT > KMAX THEN  GOTO 3915
3910  GOTO 3920
3915  PRINT "NO STEADY-STATE CONVERGENCE WITH SPECIFIED KMAX = ";KMAX
3917  STOP
3920  REM . CALCULATE GEOMETRIC PARAMETERS
3925 ACS = LT * (DOW - DIW)
3930 LFC = (PI / 16.) * (DOW + DIW)
3940 H1 = (((DOW + DIW) / 4.) * (1. -  COS (.393)))
3945 H2 = (((DOW + DIW) / 4.) * (1. -  COS (1.178))) - H1
3950 H3 = (((DOW + DIW) / 4.) * (1. -  COS (1.963))) - H2
3955 H4 = (((DOW + DIW) / 4.) * (1. -  COS (2.749))) - H3
3960 CA = LC * WC
3970  IF KOUNT < 2 THEN  GOTO 3990
3985  GOTO 4000
3990 MDOT = ((MH - ML) / 2.) + ML
4000  FOR I = 1 TO R
4010  REM  CALCULATE AIR DENSITY
4020 RHO(I) = 39.69 / (T(I) + 460.)
4040  REM  CALCULATE AIR VISCOSITY
4050 MU(I) = ((56.67 * (10 ^  - 6)) * T(I)) + .0406
4100  REM  CALCULATE AIR THERMAL CONDUCTIVITY
4110 CK(I) = (23.78 * 10 ^  - 6) * T(I) + .01326
4120  NEXT I
4190 RHO(9) = 39.69 / (0.5 * (T(9) + 0.5 * (3. * T(8) - T(7))) + 460.)
4200 RHO(10) = 39.69 / (0.5 * (T(10) + T(9)) + 460.)
4300  IF KOUNT = 1 THEN  GOTO 5900
4900  REM  ***CALCULATE FRICTIONAL PRESSURE DROP AROUND FLOW LOOP***
5000  FOR I = 1 TO 8
5005 RN(I) = (MDOT / ACS) * ((DOW - DIW) / MU(I))
5010  IF RN(I) > 1400. THEN  GOTO 5025
5015 FF = (12. * MU(I) * MDOT) / LT
5020  GOTO 5030
5025 FF = (0.0014 + (0.125 / (RN(I) ^ 0.32)) * MDOT ^ 2) / LT ^ 2
5030 PF(I) = ((FF * LFC) / (RHO(I) * (DOW - DIW) ^ 3)) / GC
5035  NEXT I
5110 I = 9
5115 D = D11 * 2
5120 A = D11 * WC
5125 LI = WC
5130 LFC = LC
```

```
5135  GOTO 5195
5140  REM  I=10
5145 D = DC
5150 A = (DC * WC) / 2.
5155 LI = WC
5160 LFC = LC
5195 RN(I) = (MDOT / A) * (D / MU(I))
5200  IF RN(I) > 1400. THEN  GOTO 5215
5205 FF = (12. * MU(I) * MDOT) / LI
5210  GOTO 5220
5215 FF = (0.0014 + (0.125 / (RN(I) ^ 0.32)) * MDOT ^ 2) / LI ^ 2
5220 PF(I) = ((FF * LFC) / (RHO(I) * D ^ 3)) / GC
5225 I = I + 1
5230  IF I > 10 THEN  GOTO 5237
5235  GOTO 5140
5237 FPT = 0.0
5240  FOR I = 1 TO R
5245 FPT = FPT + PF(I)
5250  NEXT I
5500  REM  ***CALCULATE BOUYANT PRESSURE FORCES AROUND FLOW LOOP***
5510 PB(2) = HC * RHO(9) * (1. / (0.5 * (T(9) + 0.5 * (3. * T(8) - T(7)))
     )) * (0.5 * (T(10) + T(9)) - 0.5 * (T(9) + 0.5 * (3. * T(8) - T(7)))
     )
5520 PB(3) = H1 * RHO(8) * (1. / (T(8) + 460.)) * (T(1) - T(8))
5525 PB(4) = H2 * RHO(7) * (1. / (T(7) + 460.)) * (T(2) - T(7))
5530 PB(5) = H3 * RHO(6) * (1. / (T(6) + 460.)) * (T(3) - T(6))
5535 PB(6) = H4 * RHO(5) * (1. / (T(5) + 460.)) * (T(4) - T(5))
5540 BPT = 0.0
5545  FOR I = 2 TO 6
5550 BPT = BPT + PB(I)
5555  NEXT I
5700  REM  CHECK ERROR CRITERION
5705 EPT = BPT - FPT
5708 EE = 0.5 * EC * (BPT + FPT)
5710  IF  ABS (EPT) < EE THEN  GOTO 11000
5712 MDOT = MDOT * (BPT / FPT) ^ 0.333
5715  IF BPT < FPT GOTO 5730
5720 ML = MDOT
5725  GOTO 5900
5730 MH = MDOT
5900  REM  EVALUATE HEAT TRANSFER COEFFICIENTS
5950  FOR I = 1 TO R
5960  IF I = 9 THEN  GOTO 6075
5965  IF I = 10 THEN  GOTO 6060
5970 D = (DOW - DIW)
5980 LI = LT
6005  IF RN(I) > 1400. THEN  GOTO 6020
6010 CHT = (4.364 * CK(I)) / D
6015  GOTO 6025
6020 CHT = (0.023 * (RN(I) ^ 0.8) * (PR ^ 0.333) * CK(I)) / D
6025 UA = 0.0375 * TA - 0.25
6028 UI(I) = 1.0 / ((1.0 / CHT) + (TO / SK) + (1.0 / UA))
6030 UO(I) = 1.0 / ((1.0 / CHT) + (( LOG ((DOW + T1) / DOW) / (2. * SK)) *
     DOW) + (( LOG ((DOW + T1 + T2) / (DOW + T1)) * DOW) / (2. * FK)) + (
     (1.0 / HA) * (DOW / (DOW + T1 + T2))))
6032  GOTO 6100
6060 D = DC
6065 LI = WC
6070  GOTO 6005
```

```
6075 D = D11
6080 LI = WC
6085  GOTO 6005
6100  NEXT I
9900  REM  STEADY STATE TEMPERATURE CALCULATIONS
9946 UI = (UI(1) + UI(8)) / 2.
9947 UO = (UO(1) + UO(8)) / 2.
9948 AI = (PI / 8.) * DIW * LT
9949 AO = (PI / 8.) * DOW * LT
9950  REM  LOAD MATRIX
9955 A(1,10) = MDOT * CP
9960 A(8,7) = MDOT * CP
9970 A(1,1) = ( - 0.5 * (MDOT * CP)) - (UO * AO) - (UI * AI)
9975 A(8,8) =  - (MDOT * CP) - (UO * AO) - (UI * AI)
9980 A(9,7) =  - 0.25 * ((2. * MDOT * CP) - (UWIC * CA) - (UCOW * CA))
9985 A(9,8) =  - 0.75 * ((UCIW * CA) + (UCOW * CA) - (2. * MDOT * CP))
9990 A(9,9) =  - ((MDOT * CP) + (UCOW * CA * 0.5))
9992 A(9,10) = (UWIC * CA * 0.5)
9994 A(10,7) =  - .25 * UWIC
9996 A(10,8) = .75 * UWIC
9998 A(10,9) =  - ((0.5 * C2) - ((MDOT * CP) / CA))
10000 A(10,10) =  - ((0.5 * C2) + ((MDOT * CP) / CA) + (UWIC * 0.5))
10010  FOR K = 1 TO 7
10015 A(K,K + 1) =  - (MDOT * CP) * 0.5
10020  NEXT K
10025  FOR K = 2 TO 7
10030 A(K,K) =  - (UO * AO) - (UI * AI)
10032  NEXT K
10035  IF FULL > = 1.0 THEN  GOTO 10040
10036 A(3,3) =  - (UO * AO)
10037 A(4,4) =  - (UO * AO)
10038 A(5,5) =  - (UO * AO)
10039 A(6,6) =  - (UO * AO)
10040  FOR K = 2 TO 7
10045 A(K,K - 1) = 0.5 * MDOT * CP
10047  NEXT K
10048  REM  LOAD CONSTANT ARRAY
10049  FOR K = 1 TO 8
10050 A(K,11) =  - ((UO * AO * TI) + (UI * AI * TA))
10051  NEXT K
10052  IF FULL > = 1.0 THEN  GOTO 10057
10053 A(3,11) =  - (UO * AO * TI)
10054 A(4,11) =  - (UO * AO * TI)
10055 A(5,11) =  - (UO * AO * TI)
10056 A(6,11) =  - (UO * AO * TI)
10057 A(9,11) =  - (UCOW * CA * TI)
10058 A(10,11) =  - ((C2 * TI) + (C1 * QS))
```

```
10059  REM   REARRANGE MATRIX
10060  FOR J = 1 TO R
10061  FOR I = 1 TO R + 1
10063 AA(J,I) = A(J,I)
10065  NEXT I
10066  NEXT J
10068  FOR I = 1 TO R + 1
10069 A(10,I) = AA(1,I)
10070  NEXT I
10072  FOR J = 1 TO R - 1
10074  FOR I = 1 TO R + 1
10076 A(J,I) = AA(J + 1,I)
10078  NEXT I
10080  NEXT J
10082  FOR J = 1 TO R
10083 AD = A(J,J)
10084  FOR I = 1 TO R + 1
10085 A(J,I) = (A(J,I)) / AD
10086  NEXT I
10087  NEXT J
10095  REM  GO TO 12000
10100  REM  MATRIX CALC. SOL.
10105  FOR J = 1 TO R
10110  FOR I = J TO R
10115  IF A(I,J) <  > 0 THEN  GOTO 10135
10120  NEXT I
10125  PRINT 'NOUNIQUESOLUTI ON '
10130  GOTO 13000
10135  FOR K = 1 TO R + 1
10140 X = A(J,K)
10145 A(J,K) = A(I,K)
10150 A(I,K) = X
10155  NEXT K
10160 Y = 1 / A(J,J)
10165  FOR K = 1 TO R + 1
10170 A(J,K) = Y * A(J,K)
10175  NEXT K
10178  FOR I = 1 TO R
10180  IF I = J THEN  GOTO 10191
10182 Y =  - A(I,J)
10185  FOR K = 1 TO R + 1
10187 A(I,K) = A(I,K) + Y * A(J,K)
10190  NEXT K
10191  NEXT I
10192  NEXT J
10194  FOR I = 1 TO R
10195 T(I) = A(I,R + 1)
10196  NEXT I
10198  GOTO 3895
```

```
11000  PRINT "THE STEADY STATE CONDITIONS ARE AS FOLLOWS:"
11005  PRINT
11010  PRINT "RELATIVE TIME:  ";SUNT
11011  PRINT
11012  PRINT "INC. SOLAR FLUX (B/H-F^2)=";QS
11015  PRINT "MASS FLOWRATE (LB/HR) ";MDOT
11020  PRINT "REY. NO.(1)=";RN(1)
11025  PRINT "REY. NO.(10)=";RN(10)
11030  PRINT "DELP ERROR =";EPT
11035  PRINT "DELP BUOY =";BPT
11050  FOR I = 1 TO R
11055  PRINT "T";I;" = ";T(I)
11060  NEXT I
11065 QP = 0.
11066  IF FULL >  = 1.0 THEN  GOTO 11070
11067 QP = (UI(1) * (T(1) - TA)) + (UI(2) * (T(2) - TA)) + (UI(7) * (T(7)
      - TA)) + (UI(8) * (T(8) - TA))
11068  GOTO 11080
11070  FOR I = 1 TO R - 2
11073 QP = QP + UI(I) * (T(I) - TA)
11075  NEXT I
11080 QAB = QP * AI
11085 TA = TA + (TD * (QAB - (((HA * AX) + (UE * AE)) * (TA - TI))) / CTA
     )
11089  PRINT
11090  PRINT "ASPHALT TEMP:  ";TA
11091  PRINT
11092  PRINT
11099  GOTO 3387
12500  REM  NEW SOLAR DAY
12520 DAYS = DAYS + 1.0
12525 SUNT = 0.0
12530  GOTO 3386
13000  END

]
```

SAMPLE OUTPUT

January Day
Collector: 15 x 10 = $150 ft^2$
$T_{asphalt} \Rightarrow 135^oF$ (Steady State)

```
 RUN SOLAR
PLEASE ENTER THE FOLLOWING PARAMETERS - PUSH RETURN TO CONTINUE

**********************************

ENTER TANK LENGTH (FT)20
ENTER ASPHALT TANK O.D. (FT)10
ENTER FLOW CHANNEL I.D. (FT)10.5
ENTER FLOW CHANNEL INNER WALL THICKNESS (IN).25
ENTER FLOW CHANNEL OUTER WALL THICKNESS (IN).03
ENTER THE TANK MATERIAL THERM. COND. (B/H-FT-F)26
ENTER TANK  INSULATION THICKNESS (IN)3.5
ENTER THE TANK INSUL. THERM COND.(B/H-FT-F).01

ENTER COLLECTOR WIDTH (FT)15
ENTER COLLECTOR LENGTH (FT)10
ENTER COLLECTOR HEIGHT (FT)7
ENTER COLLECTOR SUPPLY CHANNEL I.D. (IN)3
ENTER COLLECTOR RETURN CHANNEL I.D. (IN)3
ENTER COLLECTOR INSUL. THICKNESS (IN)2
ENTER COLLECTOR INSUL. THERM. COND.(B/H-FT-F).01
ENTER COLLECTOR PARTITION THICKNESS (IN)1
ENTER COLLECTOR PARTITION THERM. COND. (B/H-FT-F).01
SOLAR COLLECTOR CONSTANT - C1.65
SOLAR COLLECTOR CONSTANT - C2.91

ENTER THE FOLLOWING STATE CONDITIONS

MAXIMUM SOLAR FLUX INCIDENT UPON SOLAR COLLECTOR (BTU/HR-FT^2)273
ENTER TOTAL SUN HOURS 10
ENTER NUMBER OF DAYS YOU WISH TO CYCLE OVER 1
AMBIENT AIR TEMPERATURE (F)48
EXTERNAL CONVECTIVE HEAT TRANSFER COEFFICIENT FOR THE SYSTEM (BTU/HR-F)2.4
ASPHALT TEMPERATURE (F)135
THE PROGRAM IS RUNNING
*************************

RELATIVE TIME: 1

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 134.968421


RELATIVE TIME: 2

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 134.936854
```

RELATIVE TIME: 3

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 134.905298

RELATIVE TIME: 4

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 134.873754

RELATIVE TIME: 5

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 134.842221

RELATIVE TIME: 6

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 134.8107

RELATIVE TIME: 7

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 134.779189

RELATIVE TIME: 8

INC. SOLAR FLUX (B/H-F^2)=88.8346913

NO FLOW CONDITION

ASPHALT TEMPERATURE: 134.747691

RELATIVE TIME: 9

INC. SOLAR FLUX (B/H-F^2)=165.118709

NO FLOW CONDITION

ASPHALT TEMPERATURE: 134.716204

THE STEADY STATE CONDITIONS ARE AS FOLLOWS:

RELATIVE TIME: 10

INC. SOLAR FLUX (B/H-F^2)=223.653401
MASS FLOWRATE (LB/HR) 4394.1469
REY. NO.(1)=4451.88595
REY. NO.(10)=11863.3474
DELP ERROR =-1.25861868E-03
DELP BUOY =.0168069254
T1 = 154.429532
T2 = 153.278103
T3 = 152.143854
T4 = 151.082482
T5 = 150.032504
T6 = 149.054499
T7 = 148.082172
T8 = 147.181368
T9 = 147.823677
T10 = 155.042368

ASPHALT TEMP: 134.790806

THE STEADY STATE CONDITIONS ARE AS FOLLOWS:

RELATIVE TIME: 11

INC. SOLAR FLUX (B/H-F^2)=260.449704
MASS FLOWRATE (LB/HR) 4878.54012
REY. NO.(1)=4931.06745
REY. NO.(10)=13137.2884
DELP ERROR =-5.51090852E-04
DELP BUOY =.0210345612
T1 = 156.474039
T2 = 154.974026
T3 = 153.512506
T4 = 152.17134
T5 = 150.855586
T6 = 149.657423
T7 = 148.471893
T8 = 147.402581
T9 = 147.869933
T10 = 157.286314

ASPHALT TEMP: 134.915953

THE STEADY STATE CONDITIONS ARE AS FOLLOWS:

RELATIVE TIME: 12

INC. SOLAR FLUX (B/H-F^2)=273
MASS FLOWRATE (LB/HR) 5005.81792
REY. NO.(1)=5046.80743
REY. NO.(10)=13445.0982
DELP ERROR =-7.89138518E-04
DELP BUOY =.0218415527
T1 = 158.706662
T2 = 157.135098
T3 = 155.602188
T4 = 154.193096
T5 = 152.809534
T6 = 151.547084
T7 = 150.297328
T8 = 149.167339
T9 = 149.5917
T10 = 159.556402

ASPHALT TEMP: 135.055022

THE STEADY STATE CONDITIONS ARE AS FOLLOWS:

RELATIVE TIME: 13

INC. SOLAR FLUX (B/H-F^2)=260.449003
MASS FLOWRATE (LB/HR) 4920.43338
REY. NO.(1)=4972.57681
REY. NO.(10)=13248.0297
DELP ERROR =-1.12774191E-03
DELP BUOY =.020778458
T1 = 156.620611
T2 = 155.138159
T3 = 153.693193
T4 = 152.366423
T5 = 151.064404
T6 = 149.877914
T7 = 148.703728
T8 = 147.643746
T9 = 148.107604
T10 = 157.422954

ASPHALT TEMP: 135.179658

THE STEADY STATE CONDITIONS ARE AS FOLLOWS:

RELATIVE TIME: 14

INC. SOLAR FLUX (B/H-F^2)=223.652048
MASS FLOWRATE (LB/HR) 4591.20979
REY. NO.(1)=4673.72042
REY. NO.(10)=12453.673
DELP ERROR =-1.66762652E-03
DELP BUOY =.0176164076
T1 = 150.296309
T2 = 149.06928
T3 = 147.876961
T4 = 146.787277
T5 = 145.720479
T6 = 144.753681
T7 = 143.79825
T8 = 142.941508
T9 = 143.537388
T10 = 150.963139

ASPHALT TEMP: 135.262561

THE STEADY STATE CONDITIONS ARE AS FOLLOWS:

RELATIVE TIME: 15

INC. SOLAR FLUX (B/H-F^2)=165.116796
MASS FLOWRATE (LB/HR) 3819.31273
REY. NO.(1)=3934.83317
REY. NO.(10)=10487.6456
DELP ERROR =-2.4335127E-03
DELP BUOY =.0114660042
T1 = 139.969641
T2 = 139.191189
T3 = 138.442309
T4 = 137.767132
T5 = 137.111363
T6 = 136.526621
T7 = 135.951491
T8 = 135.446063
T9 = 136.343286
T10 = 140.397759

ASPHALT TEMP: 135.279386

RELATIVE TIME: 16

INC. SOLAR FLUX (B/H-F^2)=88.8323476

NO FLOW CONDITION

ASPHALT TEMPERATURE: 135.247306

RELATIVE TIME: 17

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 135.215238

RELATIVE TIME: 13

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 135.183182

RELATIVE TIME: 19

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 135.151137

RELATIVE TIME: 20

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 135.119105

RELATIVE TIME: 21

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 135.087084

RELATIVE TIME: 22

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 135.055075

RELATIVE TIME: 23

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 135.023077

RELATIVE TIME: 24

INC. SOLAR FLUX (B/H-F^2)=0

NO FLOW CONDITION

ASPHALT TEMPERATURE: 134.991092

APPENDIX B

Some sketches for the Finned Geometry Thermosiphon Air Collector

Figure B.1. – Extended Fin Surface (front end view).
(Cross-Sectional View (Section A-A) of Collector Assembly.)

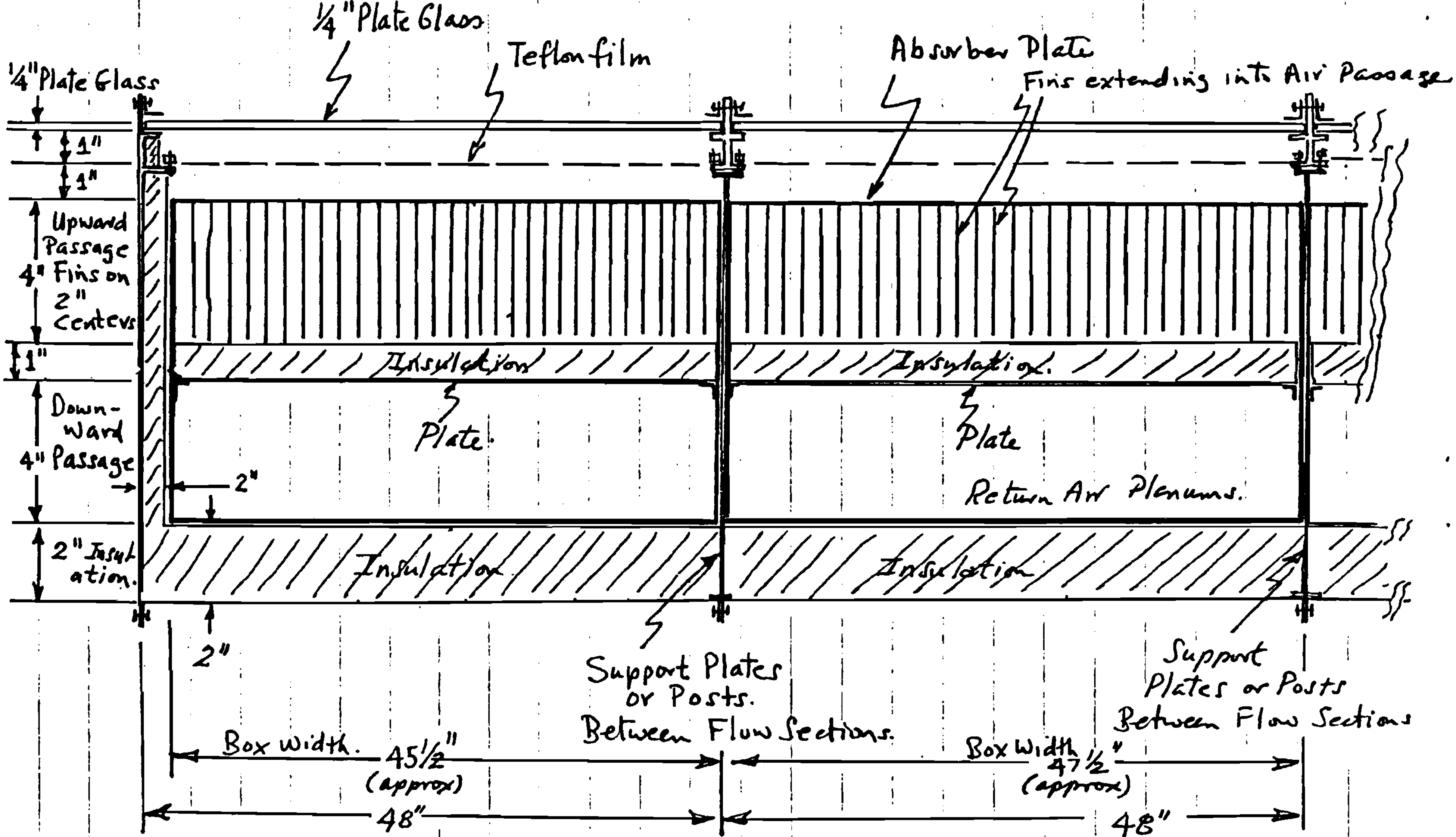
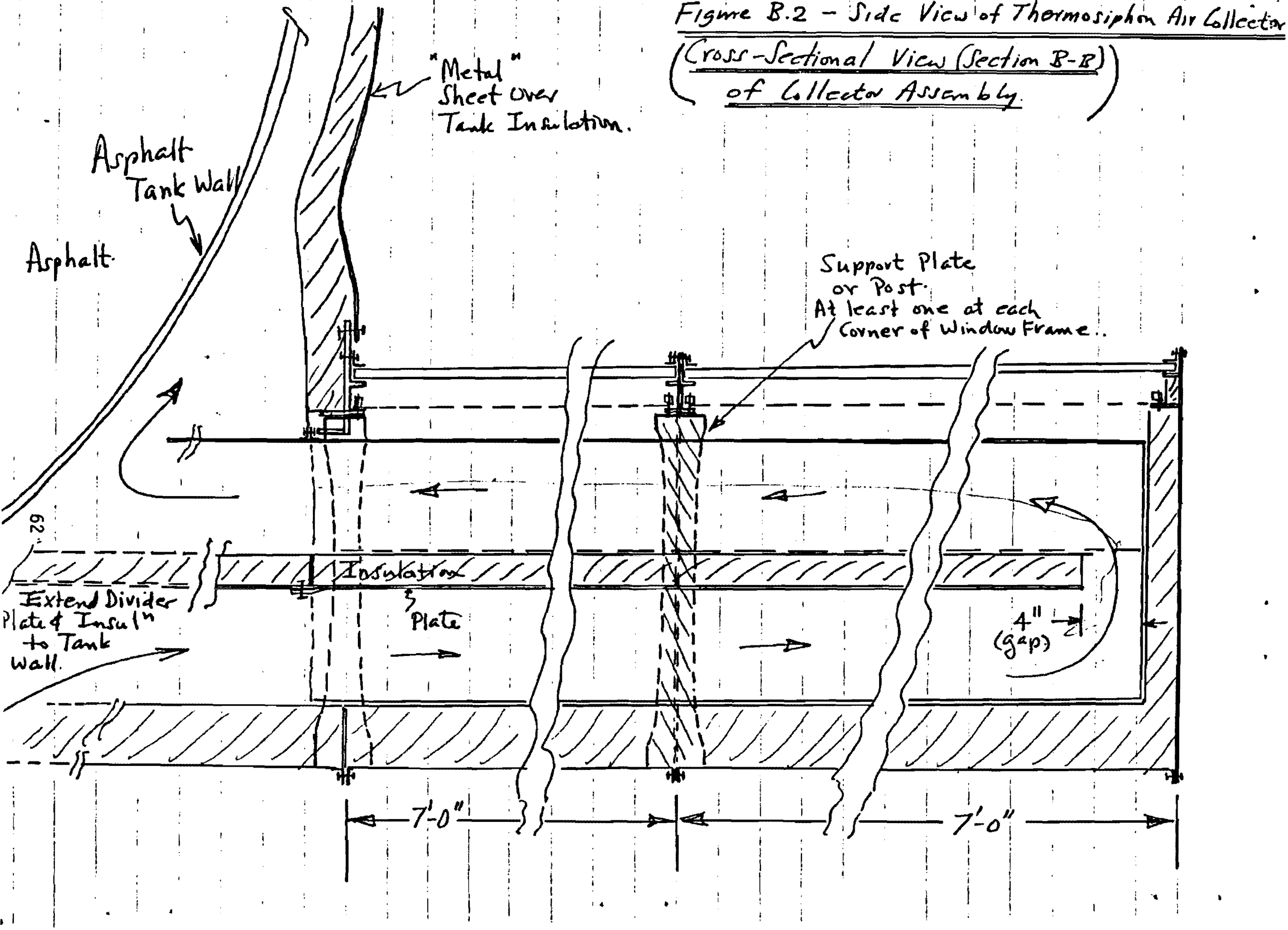


Figure B.2 – Side View of Thermosiphon Air Collector

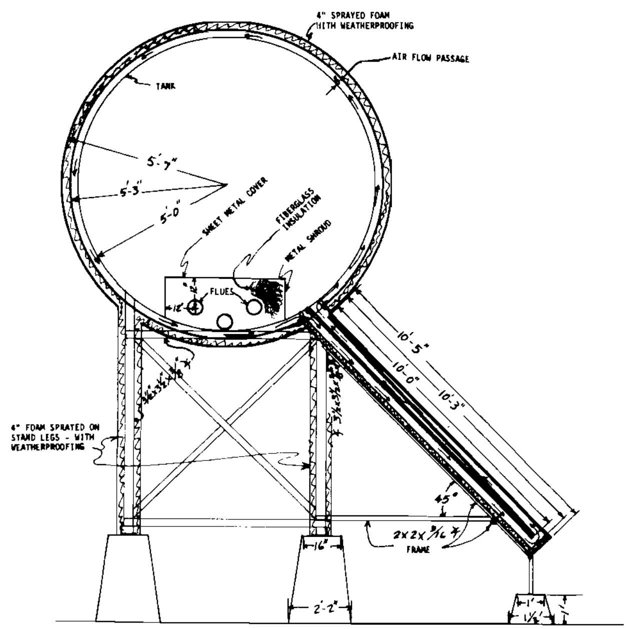
(Cross-Sectional View (Section B-B) of Collector Assembly)

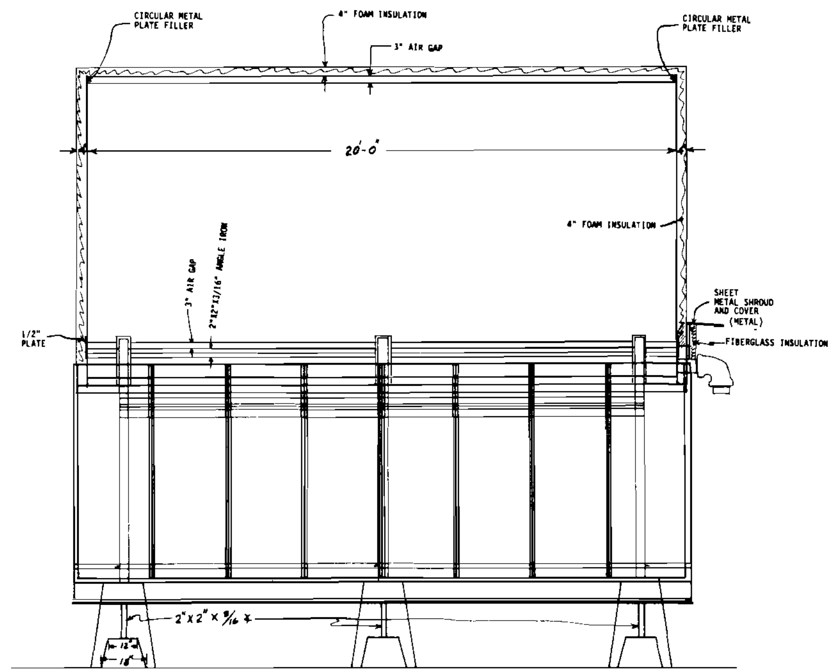


DISTRICT 6
MIDLAND - ODESSA
PASSIVE SOLAR HEATING SYSTEM
AIR THERMAL - SIPHONING

GENERAL LAYOUT

SITE:
MAINTENANCE YARD
MIDLAND COUNTY
NEAR AIRPORT
AT IH 20 AND
FM 1369



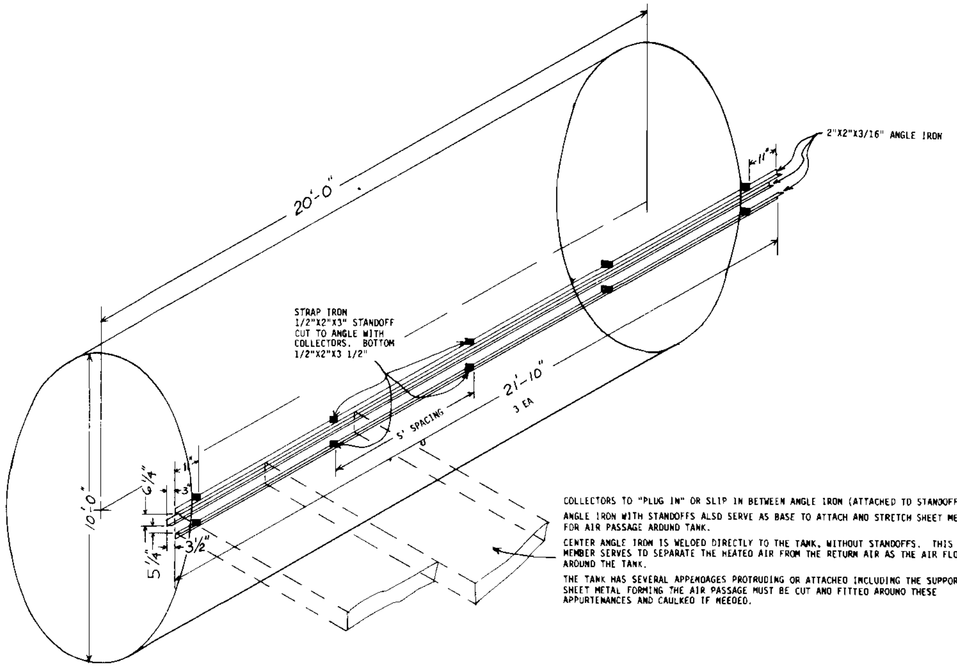


272 1
6 MIDLAND IH 20

DISTRICT 6
MIDLAND - ODESSA
PASSIVE SOLAR HEATING SYSTEM
SCHEMATIC OF COLLECTOR SOCKET
WHICH IS ATTACHED TO THE TANK

(OBLIQUE VEIW)

NOTE: TANK ROLLED SLIGHTLY COUNTERCLOCKWISE TO ENHANCE THE OBLIQUE VIEW

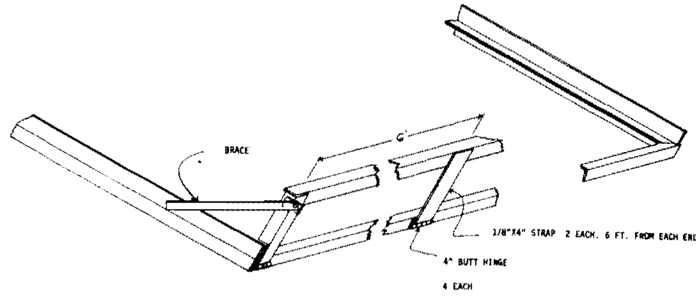


COLLECTORS TO "PLUG IN" OR SLIP IN BETWEEN ANGLE IRON (ATTACHED TO STANDOFFS).
ANGLE IRON WITH STANDOFFS ALSO SERVE AS BASE TO ATTACH AND STRETCH SHEET METAL FOR AIR PASSAGE AROUND TANK.
CENTER ANGLE IRON IS WELDED DIRECTLY TO THE TANK, WITHOUT STANDOFFS. THIS MEMBER SERVES TO SEPARATE THE HEATED AIR FROM THE RETURN AIR AS THE AIR FLOWS AROUND THE TANK.
THE TANK HAS SEVERAL APPENDAGES PROTRUDING OR ATTACHED INCLUDING THE SUPPORT. SHEET METAL FORMING THE AIR PASSAGE MUST BE CUT AND FITTED AROUND THESE APPURTENANCES AND CAULKED IF NEEDED.

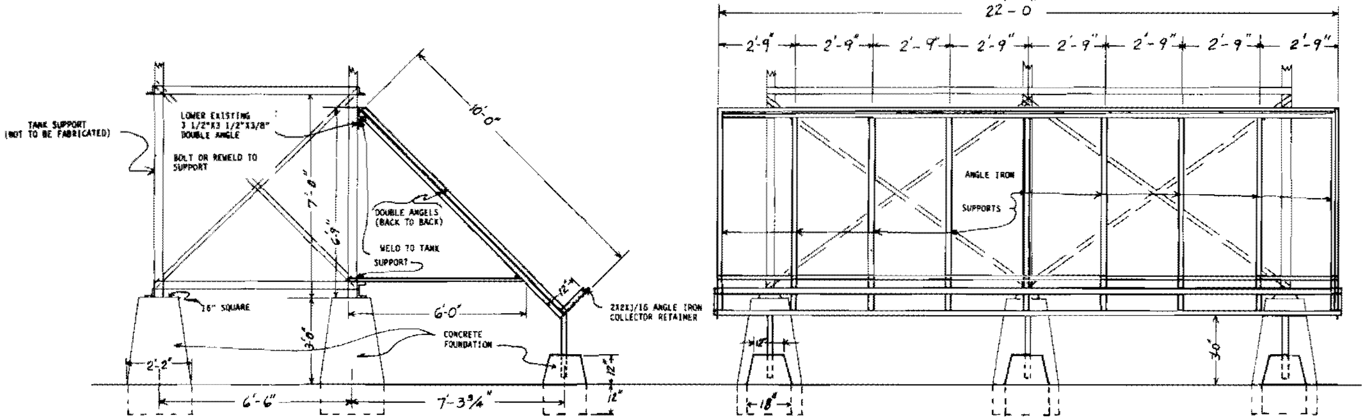
6 MIDLAND 272 2 IH20

DISTRICT 6
MIDLAND - ODESSA
PASSIVE SOLAR HEATING SYSTEM
AIR THERMAL - SIPHONING

COLLECTOR SUPPORT FRAME



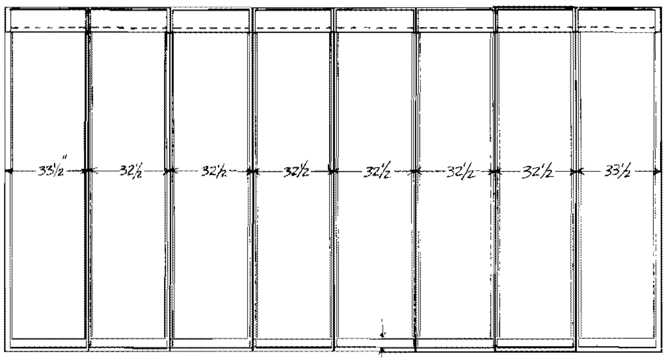
1. COLLECTOR SUPPORT FRAME IS BASICALLY FABRICATED FROM 2"X2"X3/16" ANGLE IRON.
2. COLLECTORS ARE RETAINED AT THE TOP BY THE TANK SOCKET AND AT THE BOTTOM BY THE ANGLE IRON RETAINER SHOWN.
3. OUTER ANGLE IRON IS FLAT SIDE OUT TO FORM A RACK FOR THE COLLECTORS. INTERIOR ANGLE IRON SUPPORTS ARE FLAT SIDE TO THE COLLECTORS.

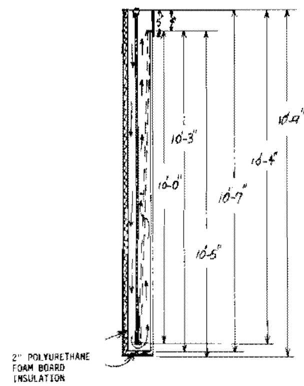


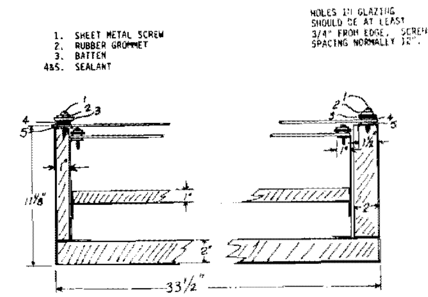
272 3
6 MIDLAND IH20

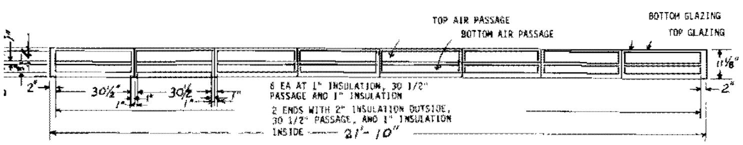
DISTRICT 6
MIDLAND - ODESSA
PASSIVE SOLAR HEATING SYSTEM
AIR THERMAL - SIPHONING

COLLECTOR DETAIL

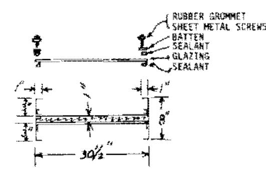


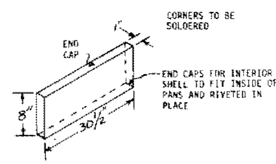






DETAIL INTERIOR SHEEL





INTERIOR SHELL (INDIVIDUAL COLLECTORS)

COMPOSED OF TWO CHANNEL MEMBERS FORMED FROM SHEET STEEL (1"X8") HELD TOGETHER BY SEVERAL SHORT LENGTHS OF WIDE CHANNEL (1 1/2X30 1/2") SPACERS FORMED OF SHEET STEEL. ONE INCH OF FOAM INSULATION PLACED ON WIDE CHANNEL TO FORM THE RETURN AND HEATING DUCTS. FOAM SHOULD BE SEALED TO CHANNEL MEMBERS TO PREVENT AIR PASSAGE BETWEEN DUCTS. LENGTH OF 1"X8" CHANNEL MEMBERS IS 10'-7".

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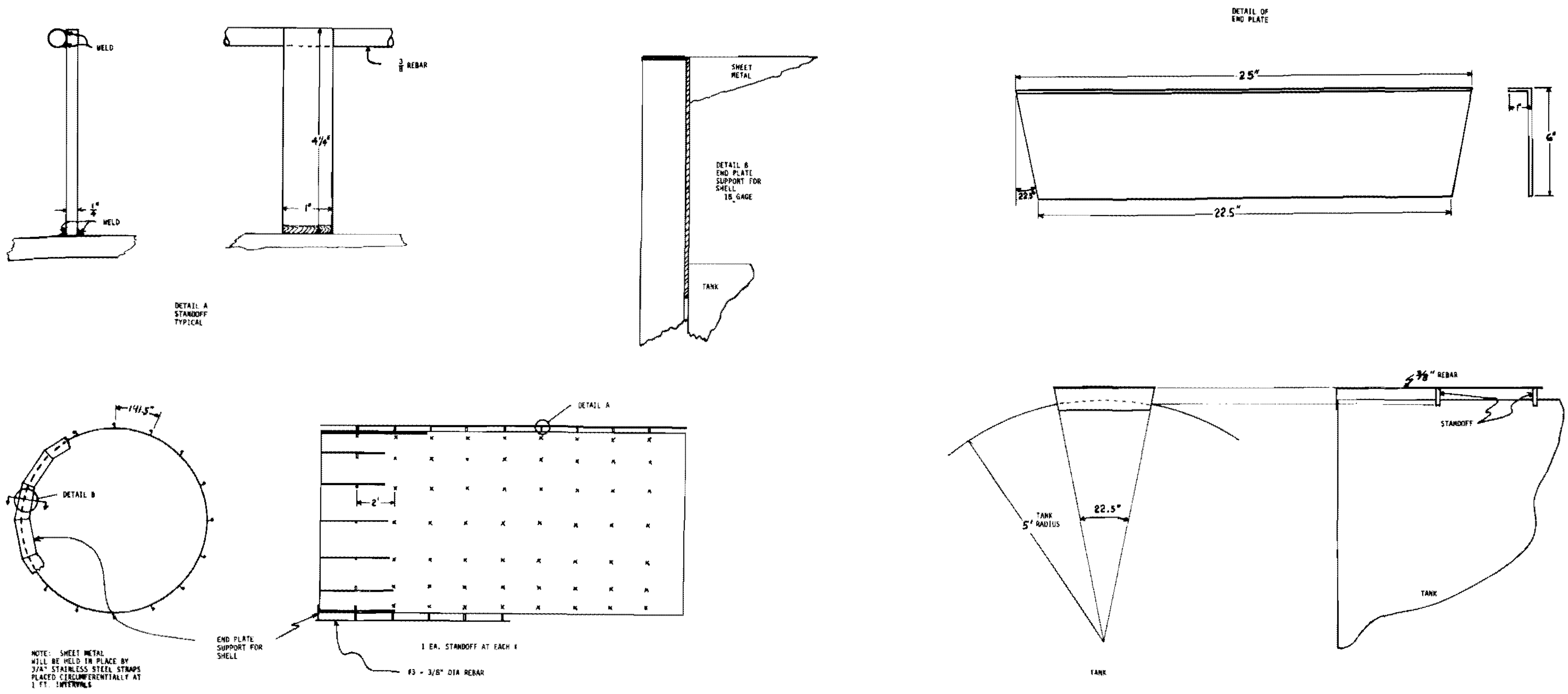
6 MIDLAND 1H20

DISTRICT 6
MIDLAND - ODESSA
PASSIVE SOLAR HEATING SYSTEM
AIR THERMAL - SIPHONING

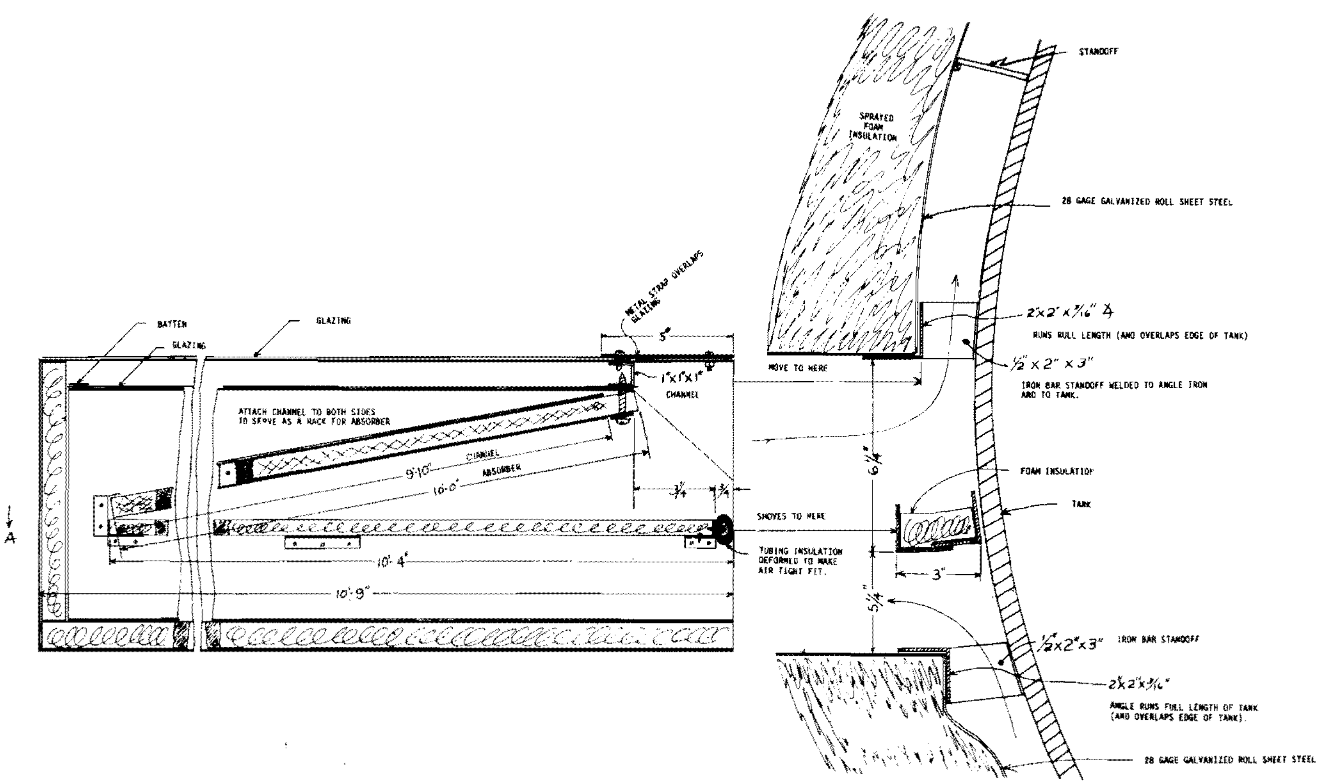
DETAIL END PLATES
AND STANDOFFS



272 5
6 MIDLAND IH20

DISTRICT 6
MIDLAND - ODESSA
PASSIVE SOLAR HEATING SYSTEM
AIR THERMAL - SIPHONING

DETAIL OF COLLECTOR AND GLAZING CONSTRUCTION



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6 MIDLAND IH20

GENERAL REQUIREMENTS

1. The Contractor shall observe and comply with all federal, state and local laws, safety and health regulations, ordinances, and all ordinances and all regulations which in any manner affect the conduct of the work.

2. In order to insure the safety of the traveling public, the Contractor shall coordinate all work with the District Engineer, or his designated representative, and shall place warning signs in accordance with the Manual on Uniform Traffic Control Devices.

3. The proposal shall be accompanied by a Proposal Guaranty of the character and in the amount as indicated in the proposal.

   The proposal guaranty of the low bidder may be retained until after the contract has been awarded, executed, and bonds made. Proposal guaranty of all except the low bidder will be returned within 72 hours after the bids are opened.

4. When the amount of the contract is $25,000 or less, a performance bond and payment bond will not be required.

   When the contract amount is greater than $25,000, and within 15 days after written notification of award of the contract, the bidder shall execute and furnish to the Commission the contract, with (1) a performance bond and (2) a payment bond each in the full amount of the contract price, executed by a surety company or surety companies authorized to execute surety bonds under and in accordance with the laws of the State of Texas.

   The (1) performance bond and(2) payment bond are to be furnished as a guarantee of the faithful performance of the work and for the protection of the claimants for labor and material.

   Should the bidder to whom the contract is awarded refuse or neglect to execute and file the contract and bonds within 15 days after written notification of the award of the contract, the proposal guaranty filed with the bid shall become the property of the State, not as a penalty, but as liquidated damages.

5. Until the award of the contract is made, the State reserves the right to reject any or all proposals and to waive such technicalities as may be considered for the best interest of the State. The award of the contract, if it be awarded, will be to the lowest reasonable bidder.

6. Contracts will be approved and signed under authority of the State Highway and Public Transportation Commission.

7. The Contractor agrees to accept full responsibility for any and all damages, including damage to State right-of-way, as a result of his operations thereon. The Contractor further agrees to promptly repair any such damage in accordance with the District Engineer's instructions.

8. The Contractor shall provide the State with the Department's Certificate of Insurance covering the below listed insurance coverages prior to the initiation of any work.

   A. Worker's Compensation Insurance
      Amount - Statutory

   B. Comprehensive General Liability Insurance
      Amounts - Bodily Injury $300,000 each occurrence
      Property Damage $25,000 each occurrence
      $100,000 for aggregate

   C. Comprehensive Automobile Liability Insurance
      Amounts - Bodily Injury $100,000 each person
      $300,000 each occurrence
      Property Damage $ 25,000 each occurrence

   The State shall be included as an "Additional Insured" by Endorsement to policies issued for coverages listed in B and C above. A "Waiver of Subrogation Endorsement" in favor of the State shall be a part of each policy for coverages listed in A, B, and C above. A certified copy of these Endorsements shall be attached to the Certificate of Insurance. Deductible policies will not be permitted.

9. The Contractor agrees to save harmless the State from any and all claims and liability due to the acts of the Contractor's employees and the operation of his equipment. The Contractor also agrees to save harmless the State from any and all expenses, including attorney fees, incurred by the State in litigation or otherwise resisting such claims or liabilities as a result of the Contractor's employees' activities. Further, the Contractor agrees to protect, indemnify and save harmless the State from and against all claims, demands and causes of action of every kind and character brought by any employee of the Contractor against the State due to personal injuries and/or death to such employee resulting from any alleged negligent act, by either commission or omission on the part of the Contractor or the State.

10. The Contractor will confine all opeations to daylight hours with no work performed on Sundays or State observed holidays unless otherwise authorized by the District Engineer or his designated representative.

11. All equipment operating on State right-of-way shall be licensed in accordance with the laws of this State.

12. The District Engineer, or his designated representative, will notify the Contractor by letter to begin operations, with work to begin within ten (10) days after such notice.

13. All operations must meet the approval of the District Engineer or his designated representative. Failure by the Contractor to begin the work within the time specified or failure to perform as herein specified shall be cause for immediate suspension of the work and possible cancellation of the contract or declaration of default.

Should the Contractor not carry out the work in an acceptable manner, the District Engineer, or his designated representative, may give notice in writing to the Contractor and his Surety of delay, neglect, or default, specifying the same. If the Contractor does not comply with the directives within a period of 10 days after said notice, the surety company shall make arrangements for completion of the work.

14. When the quantity of work to be done or of materials to be furnished under any major item of the contract is more than 125 percent of the quantity stated in the proposal, then either party to the contract, upon demand, shall be entitled to revised consideration on that portion of work above 125 percent of the quantity stated in the proposal.

    When the quantity of work to be done or of materials to be furnished under any major item of the contract is less than 75% of the quantity stated in the proposal, then either party to the contract, upon demand, shall be entitled to revised consideration on the work performed.

    A "Major Item" shall be construed to be any individual bid item included in the proposal that has a total cost equal to or greater than 5 percent of the total contract cost. The total contract cost shall be computed on the basis of the proposed quantities and the contract unit prices.

15. The Contractor will not be permitted to assign, sell, transfer, or otherwise dispose of the contract or any portion thereof, or his rights, title, or interest therein without the approval of the State Highway and Public Transportation Commission. The Contractor will not be permitted to sublet any portion of the contract without the approval of the Engineer. No sub-contract will, in any case, relieve the Contractor of his responsibility under the contract and bond. Written consent to sublet, assign or otherwise dispose of any portion of the contract shall not be construed to relieve the Contractor of any responsibility for the fulfillment of the contract.

16. Payments to the Contractor for services rendered will be made based upon the submission of State Form 132, State Department of Highways and Public Transportation Monthly Statement, properly completed and documented by Department personnel.

SPECIAL PROVISIONS TO THE GENERAL REQUIREMENTS

For this Maintenance Contract, these Special Provisions amend, replace or delete Items of the General Requirements:

Item 7 is amended to include the following:

All damages which are not repaired by the Contractor will be repaired by State Forces at the Contractor's expense. All expenses charged by the State for repair work shall be deducted from the Contractor's estimate.

Item 12 is deleted in its entirety and not replaced.

Item 13 is replaced by the following:

Abandonment of Work or Default of Contract. If the Contractor fails to begin the work within the time specified; or fails to perform the work with sufficient workmen and equipment; or has insufficient materials to insure the completion of the work within the contract time; or shall perform the work unsuitably; or shall neglect or refuse to remove materials or perform anew such work as may have been rejected as being defective or unsuitable; or shall discontinue the prosecution of the work without authority; or shall become insolvent or be declared bankrupt; or shall commit any act of bankruptcy or insolvency; or shall make an unauthorized assignment for the benefit of any creditor; or from any other cause whatsoever shall not carry on the work in an acceptable manner, the Engineer may give notice in writing to the Contractor and his Surety of such delay, neglect, or default, specifying the same. If the Contractor within a period of seven (7) calendar days after such notice shall not proceed in accordance therewith, then the State shall, upon written notice from the Engineer of the fact of such delay, neglect, or default and the Contractor's failure to comply with such notice, have full power and authority, without violating the Contract, to take the prosecution of the work out of the hands of the Contractor and to appropriate or use any or all materials and equipment on the ground as may be suitable and acceptable, and enter into an agreement for the completion of the Contract according to the terms and provisions thereof or use such other methods as in his opinion may be required for the completion of the Contract in an acceptable manner. All costs and charges incurred by the State, together with the costs of completing the work under Contract, shall be deducted from the money due, or which may become due, the Contractor. In case the cost so incurred by the State shall be less than the amount which would have been payable under the Contract if it had been completed by the Contractor, the

Contractor will be entitled to receive the difference. In case such cost shall exceed the amount which would have been payable under the Contract, then the Contractor and the Surety shall be liable and shall pay to the State the amount of such excess.

Item 17 is added as follows:

The State Shall have the right to audit the books and records of the Contractor during the hours of the normal workday.

Item 18 is added as follows:

Definition of Terms: Engineer. For the purpose of the Contract, "Engineer" will mean the Engineer-Director of the State Department of Highways and Public Transportation or his authorized representative.

GENERAL DESCRIPTION OF THE SYSTEM

This specification includes two general items. The first item involves the fabrication of the eight solar collectors. The second item is concerned with the installation of sheet metal around the circumference of an asphalt stroage tank to form an air duct.

The collectors to be fabricated and installed by the contractor will be a portion of a larger solar heating system which is designed to heat a 12,000 gallon asphalt storage tank. The heating system uses a passive or "no fan" method of moving the heated air. This method uses the thermo-siphoning principle in that the air when heated by solar energy in the collectors will become less dense and rise. The heated air will leave the collectors and enter a passageway or duct surrounding the asphalt tank. The passageway or duct is to be fabricated and installed by the contractor. A heat transfer occurs where heat is transferred from the air through the tank walls to the asphalt. In turn the air cools. As the air cools it becomes more dense and tends to drop on the opposite side of the tank where the air will enter the bottom duct of the collector. The air will fall to the lower portion of the collector and enter the upper duct of the collector to be reheated again. Therefore a closed air circulatory system is formed. Since the cooler air tends to be lower in the system, reverse cycling at night will be nil or minimized.

GENERAL DESCRIPTION OF WORK ON THE SOLAR COLEECTORS

The contractor shall furnish all material, equipment, shipping and labor required to fabricate and install the passive solar collectors as shown and described in the plans, specifications and special provisions included herein. The work to be accomplished will be the fabrication of eight solar collectors which in general will be composed of sheet metal, a polyurethane foam board insulation, an expanded metal filter material, and a clear fiberglass material used as glazing. The sheet metal will be bent or treated to form an enclosure and the foam board will be the insulation to prevent or reduce heat transfer between the solar heated air in the collector and the surrounding air. The heat absorber plate will be formed from the expanded metal filter material and collectors will be double glazed using the clear fiberglass material.

After fabrication of the collectors, the contractor shall fit the upper end of the collectors into the Collector Socket which has previously been installed on the tank by the owner. The collectors shall be fitted in such a manner that a closed air circulatory system is formed with no leaks or air transfer between the internal air circulation system and the ambient air. If caulking or other compounds are needed this material shall meet the specifications found in Section 6 of this document. In addition, the contractor will also place the collectors in the Collector Rack which has previously been fabricated and installed near the tank by the owner. The collectors shall be fitted in the Collector Rack in such a manner that little space occurs between the sides of the collectors. The contractor shall caulk along the top and bottom of the sides of the collectors,or along the openings between the collectors to reduce ambient air entry between the sides of the collectors. The caulking shall meet the specifications found in Section 6 of this document.

Note the collectors will be fabricated and installed as individual units. When the collectors are installed, the air in each collector is in an individual system, however, when the air flows out of the collectors, the air is in a common duct surrounding the tank.

The collectors shall be placed and attached to the rack in such a manner as to prevent movement of the collectors in the rack during periods of variable or high winds.

SOLDERING AND SHEET METAL WORK FOR THE SOLAR COLLECTORS

Art. 1. SCOPE OF WORK: The contractor shall furnish all labor, materials services, equipment and incidentals required to complete all work under this section as shown on plans and as specified.

This work shall include the fabrication of the collector housing, both exterior pan and end cap along with the interior shell. Fixtures such as angle and channel members may be fabricated from the sheet metal or purchased as structural members.

Art. 2. SHEET METAL WORK: All workmanship shall be strictly first class in every respect and any defective or careless work shall be removed and properly replaced by the Contractor. The various sections shall be uniform, joints at corners and angles shall be carefully mitered or fitted and the different sections accurately fitted and secured with sheet metal screws of adequate size. Rather than sheet metal screws, cold (blind pop type) riveting may be used to secure the various sections. A metal brake capable of accepting eight foot lengths will be used when bending the sheet metal to the form shown on the plans or specifications.

Art. 3. SOLDERING: Soldering shall be performed by personnel proficient in the work. Connections shall be clean and free of contaminants. A high quality solder having a melting point of 500^{o}F or higher will be used. All corrosive type materials used in connection with soldering shall be neutralized, cleaned, or removed from the sheet metal to prevent corrosion.

Art. 4. MATERIALS: All sheet metal shall be 24 gage and shall be galvanized. Thicker sheet metal may be accepted if approved by the Owner.

INSULATION FOR THE SOLAR COLLECTORS

Art. 1. SCOPE OF WORK: The contractor shall furnish all labor, materials, services, equipment and incidentals required to complete all work under this section as shown on the plans and as specified.

This work shall include the fabrication of the insulating material found on the bottom, sides, and end of the outer pan of the collectors. Also, the insulation placed in the interior shell forms the separation between the heating and return ducts of the collector.

Art. 2. INSULATION WORK: All insulation work shall be first class in every respect and any defective or careless work shall be removed and properly replaced by the Contractor. The various components shall be cut to accurate dimensions and the pieces fit closely together. Gaps greater than 1/16 inch will not be permitted. The insulation material shall be a rigid type foam sheet or bat with a foil backed moisture barrier on a least one side. The insulation shall be attached to the adjacent sheet metal using a mastic glue.

Art. 3. MATERIALS: The insulation shall be composed of polyurethane foam. The urethane material shall have a K factor of approximately 0.13 Btu/ft^2, hr, ^{o}F, inch, a tensile strength of approximately 52 psi and a density of 2.5 pcf $\pm$ 0.2 pcf. Variations in K factor, tensile strength, or density may be accepted if approved by the owner.

The mastic glue shall be capable of withstanding temperatures in excess of 250^{o}F without debonding. The glue shall be applied in such quantities as to permanently bond the insulation material to the sheet metal.

The glue shall be the following or equivalent.

General Electric
Silicone Glue
No. GE 2573-01D

CAULKING FOR THE SOLAR COLLECTORS

Art. 1. SCOPE OF WORK: The contractor shall furnish all labor, materials, services, equipment and incidentals required to complete all work under this section as shown on the plans and as specified.

The work shall include the application of caulk between the collectors, between the collectors and the Collector Socket and at locations directed by the Engineer in which it will be necessary to maintain a closed air circulation system or prevent heat loss because of the entry of ambient air.

Art. 2. CAULKING WORK: All caulking work shall be first class in every respect and any defective or careless work shall be removed and replaced by the Contractor. The caulk shall be applied smoothly and uniformly in a manner to weatherproof the collectors or prevent entry or exiting of air.

Art. 3. MATERIALS: All caulking used on this project must be fresh and originally in containers with the seals unbroken and the labels intact. All materials shall be of the best quality manufactured and approved by the Owner.

The caulking material shall be the following or equivalent.

General Electric
Silicone Rubber Caulk
G.E. 2567-012

EXPANDED METAL FILTER MATERIAL FOR THE SOLAR COLLECTORS

Art. 1. SCOPE OF WORK: The contractor shall furnish all labor, materials, services, equipment and incidentals required to complete all work under this section as shown on the plans and as specified.

This work shall include the purchase of the expanded metal filter material, the fabrication of the rack for the filter material, the insertion of the filter material in the rack and the placement of the "holds downs" which will keep or maintain the filter material in the racks.

Art. 2. FUNCTION OF THE MATERIAL: The expanded metal filter material is a material normally used as a washable, reusable air filter in larger commercial airconditioning systems. The material in the subject application will be painted black as specified in Section 8 and will form the heat absorber unit for the system. As the sun's flux is absorbed by the blackened filter material, the material will increase in temperature. The air will circulate in the system and because the material is expanded metal, the air will pass over, around and through the heated filter material. As the air passes through the filter material, the air will be heated. Note the rack for the filter material is at a slant with reference to the heat duct of the collector. The rack is near the insulation at the low end of the collector and near the glazing at the upper end of the collector.

Art. 3. WORKMANSHIP: The workmanship shall be of the very best. The filter material shall be placed in the rack free of snag or tear and shall be held in place with the fixtures as shown on the plans and as specified. Indivividual filter units will be butted end-to-end without a significant gap between units.

Art. 4. MATERIALS: The expanded metal filter material shall be composed of six sheets of an aluminum expanded metal. Three sheets will have a coarse cut, approximately 1/2-inch, before expansion and three sheets will have a fine cut approximately 1/4-inch, before expansion. The sheets shall be bound together in a continuous homogenious sheet approximately 1/2-inch in thickness and 2 1/2 X 5-feet in width and length. The expanded metal filter material shall be encased in an aluminum frame before insertion into the rack. Sizes other than the 2 1/2 X 5' X 1/2" may be accepted if approved by the Owner. An example source of the filter material is:

Triple A Filter Service
4402 Burnet Road
P.O. Box 4674
Austin, Texas 78765
(512-454-0358)

PAINTING FOR THE SOLAR COLLECTORS

Art. 1. SCOPE OF WORK: The contractor shall furnish and install all materials, accessories, labor, services, equipment and incidentals required for the work under this section as shown on the plans and as specified.

This work shall include the application of the paint to the surface of the expanded metal filter material which is used as the collector heat absorber plate.

Art. 2. MATERIALS: All paints used on this project must be fresh and originally in containers with the seals unbroken and the labels intact. All materials shall be of the best quality manufactured and approved by the Owner.

The following manufacturer's materials may be used on this project; any other manufacture's materials must have the written approval of the Owner before they can be used for this work:

Flat Black Color - Devoe Mirrolac Flat Black #7103 or
Sherwin-Williams High Heat Resistant #B68BA2.

Art. 3. WORKMANSHIP: The workmanship shall be of the very best. All materials shall be applied under adequate illumination, evenly spread and smoothly flowed on without runs or sags.

All surfaces, before being painted, shall be thoroughly cleaned of all dirt, oil, grease, dust, scale or other foreign matter. This cleaning and preparation shall be done by washing the filter materials with water or solvent.

All surfaces shall be clean and dry before painting. No painting shall be done in dusty, damp, windy locations. Ample time shall be given for each coat to thoroughly drv before applying the next coat. Both sides of the filter material shall receive two coats of the paint specified above.

Sufficient paint shall be applied by the spraying method such that all visible surfaces shall have a paint application. However, the paint shall not clog the air passage through the filter material.

GLAZING FOR THE SOLAR COLLECTORS

Art. 1. SCOPE OF WORK: The contractor shall furnish and install all materials, accessories, labor, services, equipment and incidentals required for work under this section as shown on the plans and as specified.

This work shall include the fabrication of the upper and lower sheets of glazing on each collector.

Art. 2. MATERIALS: All glazing used on this project shall be of the best quality manufactured and free of breaks, tears or other defects. The glazing material shall have the following minimum properties:

1. Solar Energy Transmission - 88% at 0^{o} incidence angle
   - 78% at 60^{o} incidence angle
2. Tensile Strength - 10,000 psi
3. Flexural Strength - 17,150 psi
4. Shear Strength - 12,800 psi
5. Specific Gravity - 1.324
6. Thickness - 0.060-inch

Example: Sun-Lite
Kalwall Corporation
88 Pine St.,
P.O. Box 237
Manchester, N.H. 03105

Art. 3. GLAZING WORK: All glazing work shall be first class in every respect. Any defective or careless work shall be removed and properly placed by the contractor. The glazing material for both the top and bottom shall be one piece for any individual collector unit. The material shall not be spliced or overlapped. The glazing material shall be stretched to a smooth flat surface and shall be attached to the sheet metal interior sheel and exterior pan in the manner shown on the plans. Sagging or buckling of the finished glazing will not be permitted.

TUBING INSULATION FOR THE SOLAR COLLECTORS

Art. 1. SCOPE OF WORK: The contractor shall furnish and install all materials, accessories, labor, services, equipment and incidentals required for work under this section as shown on the plans and as specified.

This work shall include the fabrication of the air tight divider which is fitted to the upper end of the collector and which forms a separation of the heated and return air circulating around the tank.

Art. 2. MATERIALS: The tubing insulation used on this project shall be of the best quality manufactured and free of tears or other defects. The tubing insulation shall:

1. be a flexible elastomeric thermal insulation.
2. withstand temperatures ranging from - 40°F to +220°F.
3. be resistant to moisture vapor and ozone.
4. have a smooth outer surface finish.

The tubing insulation shall have a 3/4-inch wall thickness and a one-inch inside diameter. Example source is:

Armstrong Standard Armaflex
3/4-inch wall thickness - Tubing #813

GENERAL DESCRIPTION OF WORK ON THE AIR DUCT

The contractor shall furnish all material, equipment, shipping and labor required to fabricate an air duct system as shown and described in the plans, specifications and special provisions included herein. The work to be accomplished will be the placement of 28 gage galvanized sheet metal in a circumferential manner around the asphalt storage tank but over the "standoffs" which are in place on the tank. The sheet metal shall be placed around the tank so as to form a continuous sheet or "skin" encapsulating the circumferential part of the tank with the exception of the Collector Socket portion of the system. The fabrication when complete will form a chamber or duct around the tank of which the sheet metal will be the exterior side of the duct and the tank shell will be the interior side of the duct. The air duct shall receive the air heated in the upper portion of the solar collectors and return the air to the lower portion of the solar collectors.

SHEET METAL WORK FOR THE AIR DUCT

Art.1. Scope of Work: The contractor shall furnish all labor, materials, services, equipment and incidentals required to complete all work under this section as shown on the plans and as specified.

This work shall include the placement of sheet metal over the standoffs which are in place on the tank. The sheet metal shall be attached to the Collector Socket and the sheet metal so placed as to form a continuous sheet around the tank.

Art.2. Sheet Metal Work: All workmanship shall be strictly first class in every respect and any defective or careless work shall be removed and properly replaced by the Contractor. The sheet metal shall be supplied in continuous strips or rolls of lengths greater than 35-feet and at least four-feet in width. The sheet metal shall be placed in a concentric manner around the tank. One of the (four-feet) ends of the sheet metal shall be attached to the upper edge of the Collector Socket which is composed of 2" X 2" X 3/16" angle and the other end of the sheet metal shall be attached to the lower edge of the Collector Socket which is also made of 2" X 2" X 3/16" angle. The concentric placement of sheet metal strips should begin at one end of the tank and proceed to the opposite end. As the sheet metal strips are placed circumferentially around the tank, they shall be lapped a dimension of at least two inches. The strips shall be attached with sheet metal screws spaced at one-foot center in the lap area.

During placement, one end of the four-foot wide sheet metal strip shall be attached to the upper edge of the Collector Socket and the strip placed around the standoffs with a smooth and snug fit. Pressure or tension may be applied to the strip to achieve the smooth and snug fit. The opposite end of the strip may then be attached to the lower edge of the Collector Socket as shown on the plans.

The tank has several appendages protruding or attached. Where applicable, the sheet metal shall be cut and fitted around the appendages in such a manner that only small voids shall be found between the cut metal and the appendage.

SPECIAL SPECIFICATION
FOR
POLYURETHANE FOAM
SOLAR-HEATED ASPHALT STORAGE TANK

I. Work

Furnish all supervision, labor, materials, tools, and equipment required to place (4) inches of insulation in an acceptable manner on a solar heated asphalt storage tank located in the Midland Maintenance Yard, Midland, Texas. The insulation material shall be polyurethane foam. The storage tank is approximately 12,000 gallon capacity, 10' in diameter and 20' in length, mounted with the axis in the horizontal manner. The bottom of the tank is approximately 11' above the ground level. The above dimensions are to be verified by the bidder.

II. General Application (Present Condition)

The asphalt tank to be solar heated is presently in place including standoffs and sheet metal duct work. The tank is ready to receive insulation except for taping work. The taping is to be done just prior to the application of foam as indicated on the plans and in the Protection of Air Duct Passage From Intrusion of Foam section found later in these specifications. The Contractor shall prepare the surface in an acceptable manner to assure the bonding of the 4-inches of polyurethane foam to be applied. In general, all surfaces to receive polyurethane foam shall be free of all oil, grease, frost, dirt, dust, or other such foreign matters, and shall be dry.

III. Equipment and Materials

Spray equipment shall be that of a recognized manufacturer, and shall be kept in well-maintained condition conducive to quality application. The compressed air equipment shall provide sufficient pressure and quantity to maintain the spray equipment with an even coat of material and apply the finished foam at the required density.

The contractor shall provide all scaffolding, bridging material, tarps and or sheeting needed to complete the job in an efficient manner. Tarps or other protective covering shall be used to cover the solar collectors. Particular emphasis shall be given to the protection of the glazing of the collectors to prevent foam from adhering to the glazing surface. The polyurethane material (nominal 2 pcf density ± 0.5 pcf) shall be a two-component mix, normally mixed in a 1.0 to 1.0 ratio. The completed material shall display less than 5 percent distortion in a temperature range from 0 degrees F to 150 degrees F. The initial K factor desired in terms of Btu/Sq.Ft., hr., degrees F, in., is 0.12. The tensile strength shall not be less than 40 psi. The closed cell content shall be at least 95 percent. The compressive strength as measured by D-1621-59T shall not be less than 25 psi. The service temperature shall be from -300 degrees F to 250 degrees F.

IV. Insulation Application.

The finished foam before weatherproofing shall be a minimum of four inches in thickness. The foam shall be applied in a manner to result in as smooth and workmanlike an exterior as possible. The density of the foamed material after application and drying shall not be less than two pounds per cubic foot nor greater than two and one-half pounds per cubic foot. Where the tank is supported on metal cradles, the insulation shall be sprayed full depth for a distance not less than four times the insulation thickness in a direction that radiates from the tank, or to the concrete foundation whichever is shorter. All metal, such as support lugs, eyes or manholes, which are an integral part of the tank, shall be fully insulated or may be insulated to a smaller extent as directed by the engineer.

Spraying shall cease, in the event of excessive wind velocities, when directed by the engineer. Generally, velocities greater than 15 miles per hour will be deemed excessive; however, other conditions may dictate excessiveness at lower velocities. Wind breaks may be used where air currents cause problems in obtaining a reasonably smooth laydown pattern. Nearby items which may be damaged by flying foam particles such as automobiles and buildings will be covered at the contractor's expense by tarps or sheeting as directed by the engineer.

Normally up to a one-inch thickness will be permitted in one pass (forward and backward or up and down). Then another nearby area should be sprayed until the initial sprayed area becomes tack-free. Generally, this requires only a few seconds, then the initial area may be resprayed for additional build-up of thickness. The insulation shall be allowed to cure thoroughly before being subjected to even minor mechanical or physical loads.

Application of foam will not be permitted in air temperatures below 50 degrees F. unless temperatures of the surface is 70 degrees or higher. Application will not be permitted when surface temperatures are greater than 150 degrees F.

V. Weatherproof Coating.

The polyurethane foam shall be protected from untraviolet rays, erosion, and moisture by the application of a weather proof coating. The coating thickness shall not be be less than 0.020-inch. The weather-proof coating should be applied as soon as possible after foaming but allowing the time interval suggested by the coating supplier. The foam surface shall be clean and dry. Degraded polyurethane surfaces must be sanded and/or swept to insure proper coating adhesion. The coating shall not be applied in inclement weather or in temperatures less than 40 degrees F., greater than 100 degrees F. or when the relative humidity exceeds 95%. If applied in more than one coat, sufficient drying time will be required between coats.

The material for the weatherproof coating will normally be applied by spraying, but may be applied by brush or roller to (completely cover the foam). The coating material shall be of the type, that will leave a non-sticky surface when dry. The color of the material shall be white or as approved by the Engineer.

The materials for consideration as weatherproof coating are as follows:

1. Butyl rubber (white)
2. Elastro Bond 875
3. Urethane
4. Neoprene - hypolon
5. Silicone
6. Hypalon mastic
7. Chlorinated rubber

VI. Protection of Air Duct Passage From Intrusion Of Foam

As previously described, the tank has been fitted with an air duct passage which encapsulates the circumferential portion of the tank. The air duct passage is composed of standoffs and sheet metal skin bound to the standoffs with metal straps. The tank has several appendages protruding or attached, including the support legs. The sheet metal skin, particularly near the appendages, has voids and is not in close contact to the appendages. Protection of air duct passage from intrusion of foam shall be provided by using aluminum adhesive tape. In addition, this item will include the use of aluminum tape to provide a cover to the air duct passage at the tank ends. In this operation, the aluminum tape shall be attached to the sheet metal skin, draped over the end void and attached to the end of the tank to form a enclosure while spraying the foam insulation.

VII. Aluminum Tape.

The aluminum tape shall consist of aluminum foil at least 3.5 mills thick and an acrylic base adhesive on one side protected by a release paper backing. It shall be SMACNA approved for airconditioning duct sealing work. The tape shall be provided in rolls having a tape width of at least 2 1/2 inches.

VIII. Safety

The contractor shall provide for his personnel suitable safety devices or apparatus to prevent excessive inhalation of the polyurethane components. Also, protection shall be provided to prevent skin and eye contact. Fresh air supply masks should be worn by personnel in the immediate area and approved organic vapor respirators should be worn by personnel in the general area. Foam should be considered a flammable substance and extreme localized heating or open flame contact should be avoided.

Appendix D

Testing Equipment Information

Testing Equipment Sources

1. Digital Temperature Indicator

   Analog Devices
   Model 2040 - DPM
   -67 degrees F to +302 degrees F
   With fluid probe

2. Sensors

   AC 2626K Temperature Probes
   Stainless Steel Tubular
   With AD 590 IC Sensors

3. Low Velocity Anemometer

   Model 1620-12
   Measures Air Velocities from 0 - 10 feet/second
   Omni Directional - Constant Temperature
   TSI Incorporated
   500 Cardigan Road
   P.O Box 43394
   St. Paul Minnesota 55164

   612-483-0900