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AN INEXPENSIVE ECONOMICAL SOLAR HEATING SYSTEM FOR HOMES

Johnny W. Allred, Joseph M. Shinn, Jr., Cecil E. Kirby, and Sheridan R. Barringer

Langley Research Center
Hampton, Va. 23665

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SUMMARY

This report describes a low-cost solar home heating system to supplement the homeowner's present warm-air heating system. The report is written in three parts: (1) A brief background on solar heating, (2) Langley's experience with a demonstration system, and (3) information for the homeowner who wishes to construct such a system. Instructions are given to the homeowner for a solar heating installation in which he supplies all labor necessary to install off-the-shelf components estimated to cost $2000. These components, which include solar collector, heat exchanger, water pump, storage tank, piping, and controls to make the system completely automatic, are readily available at local lumber yards, hardware stores, and plumbing supply stores, and they are relatively simple to install. Manufacturers and prices of each component used and a rough cost analysis based on these prices are given for the homeowner's convenience. This report also gives performance data obtained from a demonstration system which has been built and tested at the Langley Research Center. Results of the tested demonstration system indicate that the homeowner can reduce his heating bill by approximately 40 percent for a 1500-foot^2 home insulated to 1974 FHA minimum standards. If fuel-oil costs are assumed to increase at 10 percent per year, this $2000 investment will be recovered in approximately 10 years.

INTRODUCTION

The cost of fuel oil for residential heating has more than doubled in the past several years. Further cost increases in the future are likely as the limited supplies are consumed and fuels become less available. This situation has forced a search for other sources for supplying our energy at reasonable costs. One of the most promising sources is solar energy.

Solar energy itself is free but not the equipment that collects, stores, and distributes it to the home. It is not possible at the present time to go to local heating contractors and select a solar heating system from stock. If the homeowner has to hire a contractor to order and install the required components, the system would probably not be cost effective at this time. However, if the homeowner is moderately skilled in the use of hand tools and can provide the time for ordering and installing the required components himself, a solar heating system might be considered. The cost, of course, is not the only consideration. A homeowner can contribute to the conservation of our limited supply of fossil fuels and at the same time reduce pollution.

These instructions are intended only for the mechanically inclined homeowner. Some knowledge of carpentry, plumbing, and electrical wiring is necessary. A homeowner contemplating construction of a solar heating system based on these instructions should carefully study this complete document to determine in advance if he has the necessary knowledge and spare time which will be required to complete such a demanding project.

The purpose of this report is to present results of performance tests on a demonstration low-cost solar heating system built and tested at the Langley Research Center and to provide information to the homeowner on how to install this system. The only available building at the Center suitable for simulating a home had a flat roof. The collectors, therefore, were mounted adjacent to the building on a wooden framework inclined at an angle typical for a home. (See fig. 1.) The solar heating system was connected to

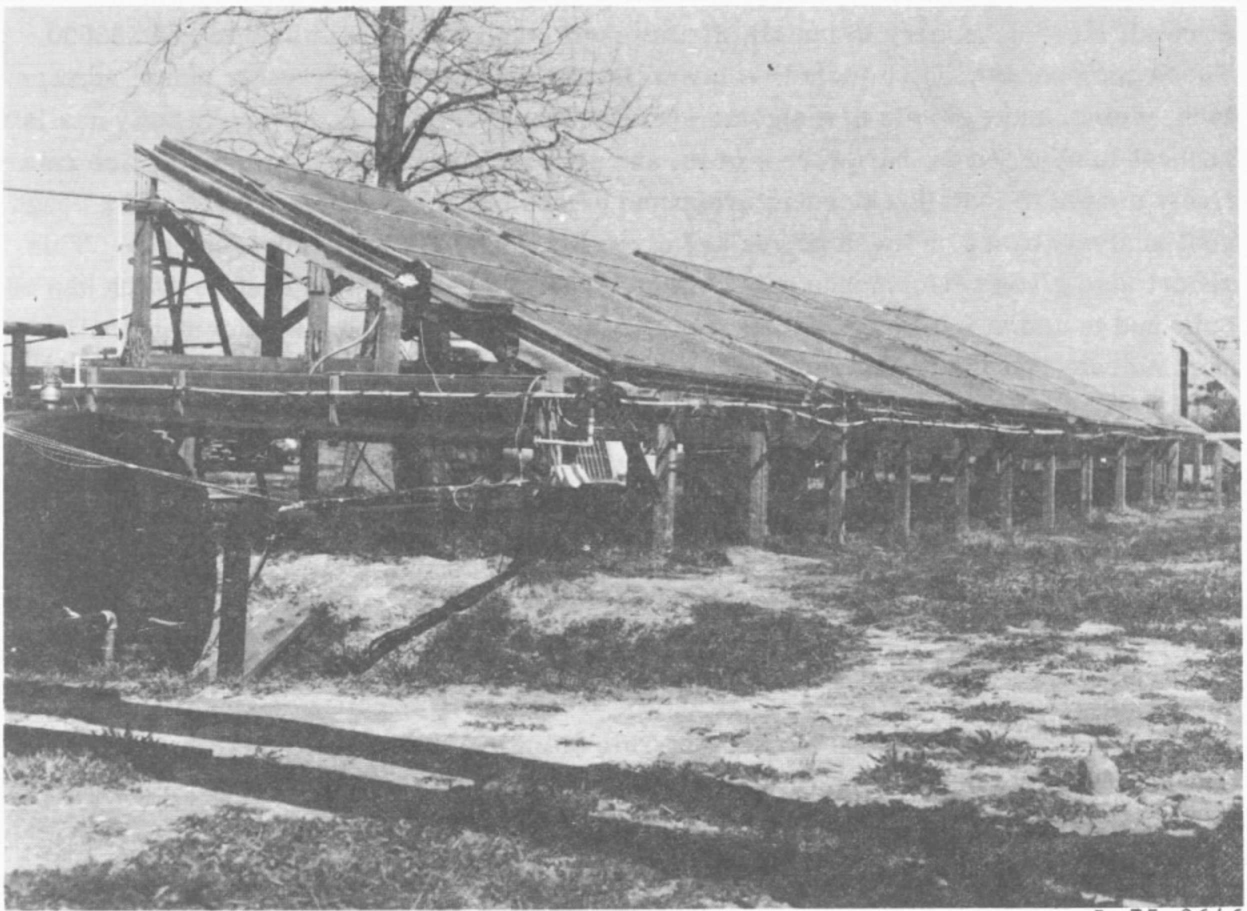

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Figure 1.- Photograph of solar collector array.

the forced-air heating system of the building and tested under actual operating conditions. Instrumentation was provided to measure the incoming heat from the Sun and to determine separately the amount of heat collected and used by the building or stored in the heat storage tank. Glass is normally used as a cover material on solar collectors; however, since plastic film is lower in cost than glass and is known to be usable on solar heated greenhouses, performance tests were carried out with two types of plastic film, polyvinyl fluoride and polyethylene. Test data verify that a substantial savings in the homeowner's annual fuel bill can be obtained with the system described. Currently, this system provides winter heating only. Some experimental systems exist which use solar energy to produce summertime cooling. Such systems are not currently cost effective; however, efforts are underway by many organizations in this country and abroad to develop reliable, low-cost cooling equipment using water from a low-cost conventional flat-plate type collector. When such equipment becomes available at reasonable prices, it can be added to this system. George C. Marshall Space Flight Center in Huntsville, Alabama, and Lewis Research Center in Cleveland, Ohio, are currently involved in programs to develop such equipment. (See refs. 1 and 2.) The economic analysis is applicable to a homeowner's system using the same type prefabricated solar panel as the demonstration system tested at Langley. All the required components can be purchased for approximately $2000. If fuel-oil costs are assumed to increase at 10 percent per year, this $2000 investment will be recovered in approximately 10 years.

The prefabricated solar panels are the most expensive part of the system. Therefore, additional instructions are provided for lower cost solar panels which can be fabricated by the homeowner. Fabrication of these panels requires more time and effort on the part of the homeowner but saves approximately $300. This results in a total cost of only $1700 and an investment recovery time of 8 years.

The assumed 15-year lifetime of the system is an engineering estimate for cost payback comparisons based on components and materials used. The plumbing items are all used in conventional heating systems and life expectancy of the items should be the same. Local conditions will influence the total lifetime costs. For example, in some areas the system water might have to be changed every year adding the cost of 750 gallons of water and the cost of rust inhibiting chemicals. Interest on the $2000 in materials cost has not been considered in this economic analysis.

Appendixes A to E have been added to the report to assist the homeowner. This is for the "do-it-yourself" handyman who may be interested in installing a solar heating system.

The following cautions should be noted:

1. Specification of the components and equipment used is directed toward other researchers and development engineers working in the solar field. It does not imply

endorsement by NASA of the items listed. They are simply the items chosen for this demonstration. A homeowner would have many options for the exact design and choice of materials for his specific installation (e.g., glass instead of plastic film cover and used or salvaged components instead of new).

2. The modifications made to existing equipment must meet the building codes in the homeowner's area and may require checking by licensed plumbers and electricians.

3. Solar energy systems will surely undergo many iterations before a perfected solar system will be produced.

4. Cost effectiveness of the installation will be affected by the cost of fuel and the amount of sunshine.

5. If you do this work for your own personal use, you will not violate any existing patents or copyrights. If you manufacture and sell this system or components of this system, you may violate existing patents or copyrights.

6. There are no accepted standards for solar heating systems by the Federal Housing Administration (FHA), the Veterans' Administration (VA), and financial institutions; therefore, loans may be impossible to obtain and existing mortgage restrictions may be violated.

7. The homeowner should be aware that this system has been time tested for only a little more than a year.

8. In some cases roof trusses and concrete floors may not be properly stressed to carry the added loads.

BACKGROUND

State of the Art

Solar heating systems have been in use for many years. Solar heat stored in iron was used in 1877 as reported by Daniels and Duffie (ref. 3). Air blowing over the heated iron was then used to heat a home. One of the first flat-plate type solar collectors was patented by Bailer in 1910 (ref. 3). Solar water heaters were in widespread use in Florida in the 1930's but many were replaced when low-cost natural gas became available in the 1940's. Several solar heated homes have been constructed and operated successfully over the past 40 years. In 1939, a solar house was built at the Massachusetts Institute of Technology (MIT). Since that time, three more houses have been built at MIT and research is still continuing. Table 1 (unpublished work of R. F. Greene of the Langley Research Center) lists these and some other homes for which data have been published; the references (refs. 4 to 8) are also included for those desiring further information. The list includes systems which use air as the working fluid as well as water. The technology

TABLE 1.- SUMMARY OF SOLAR HOUSE HEATING SYSTEMS

Date	Location	Designer	Type collector	Collector area, ft^2	House area, ft^2	Heating load, percent	Storage	Backup heat	Hot water	Cooling	Reference
1939	Massachusetts, MIT 1	Hottel	Water	400			Water, 2000 gal				4
1948	Massachusetts, MIT 3			400			Water, 1200 gal				4
1948	Massachusetts, Dover	Telkes					Heat of fusion				4
1956	Massachusetts, MIT 4	Engebretson	Water	640	1450	56	Water, 1500 gal	Oil	Yes		5
1950	Colorado, Boulder	Löf	Air	463	1000	25 to 50	Rock, 9 tons				4
1958	Colorado, Denver	Löf	Air	600	3200	26.5	Rock, 12 tons	Gas	Yes		4,5
1955	Arizona	Bliss	Air	315	672		Rock			Yes	4
1958	Arizona	Bliss	Water	1623	1400	64	Water, 4500 gal	Electric	No	Yes	4,5
1954	Capri, Italy	Lindström	Water	320	1940	50	Water, 80 gal	Electric	No		5
1959	Washington, D.C. 1	Thomason	Water	840	1500	95	Water + rocks, 1600 gal	Oil	Yes		6
1961	Washington, D.C. 2	Thomason	Water	560			Water + rocks, 1600 gal	Gas	Yes	Yes	6
1965	Washington, D.C. 3	Thomason	Water				Water + rocks, 1600 gal	Gas	Yes	Yes	6
1958	Tokyo, Japan	Yanagimachi	Water	1410	2460	70	Water, 9600 gal	Heat pump	Yes	Yes	5
1959	New Jersey, Princeton	Olgyay	Air	600	1200		Heat of fusion	None			5
1970	California, Skytherm	Hay	Pool water	Roof			Water on roof		No	Yes	7
1972	Delaware, Solar 1	Böer	Air	960	1500	50	Heat of fusion	Heat pump	Yes	Yes	8

involved in solar heating systems is, therefore, well understood (ref. 9). The components used are also simple and reliable in operation and relatively easy to install by the homeowner. In the past few years many manufacturers of these components have apparently recognized the trend toward do-it-yourself solar heating system installations. Popular Science Magazine (ref. 10) provides a list of solar heating component manufacturers with brief descriptions of the types of systems and components. Detailed information on solar radiation and how it varies at different hours during the day and different months of the year for various geographical locations may be found in references 11 and 12.

Types of Solar Collectors

There are two basic types of solar collectors, the focusing type and the flat-plate type. Focusing collectors use specially shaped mirrored surfaces to concentrate the solar rays. This type of collector can produce very high temperatures – up to several thousand degrees – but requires a tracking system to maintain its orientation relative to the incoming sunlight. Even with slightly overcast skies operation ceases completely.

The flat-plate collector, however, can collect some heat during thinly overcast days. An additional advantage of the flat-plate collector is its simplicity. It does not need a tracking system to keep it continuously pointed at the Sun as required by a focusing-type collector. In most areas of the United States, the flat-plate collector is better adapted to the present type of application than the focusing-type collector. Because of its simplicity, lower cost, and relatively high collection efficiency, the flat-plate type collector was chosen as the most suitable type for do-it-yourself installation by the homeowner in a heating application.

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General Description

Major components of a solar heating system are the solar collector, the hot-water distribution system, a hot-water storage tank, a circulating pump, flow controls, and a water-to-air heat exchanger mounted in the return air duct of the existing warm-air furnace. Since hot-water baseboard heating systems are designed to use 180° F water and the control system operates in a different manner, the flat-plate type solar collector is not readily compatible with such a system.

The solar collector on the roof of the home is heated by the Sun just as a greenhouse for wintertime gardening is heated. On sunny days, water circulating through the collector is used to absorb heat and carry it into the house or to a hot-water storage tank for later use. At night or on cloudy days, heated water from the storage tank is used. The pump circulates water from the storage tank to the collector and then to the heat exchanger in the return air duct of the warm-air furnace and then back to the storage tank as shown in figure 2. The hot water in going through the heat exchanger warms up the returning house air before it returns to the furnace for final reheating. In order to regulate the flow of water to the heat exchanger, another thermostat is added to the house and set a few degrees above the existing thermostat. In some cases the air is heated sufficiently by the solar heated water and the existing thermostat does not cut on the burner in the furnace to provide any additional heat. At night or in cloudy weather when hot water is available from the storage tank, the pumped water automatically bypasses the collectors and goes directly to the heat exchanger. Details of the valves and controls to accomplish this are given in appendixes A to E.

Guidelines

To provide 40 percent of the heating as was done by the demonstration system in the Langley Research Center environment, the area of this solar collector system should be equal to approximately one-third the floor area of a home insulated to 1974 FHA minimum standards. The home must have a south-facing roof adequate to mount this required area of collectors. It is not necessary for the roof to face directly south. Deviation from due south by 15° or 20° does not seriously affect overall performance. The demonstration system was mounted at a typical pitch of 5 inches vertical rise for each 12 inches in the horizontal direction, referred to as a 5/12 pitch. Roof pitches from 3/12 to almost vertical are acceptable.

The ideal pitch for winter operation is approximately equal to the local latitude plus 20° which in the Hampton, Virginia, area is approximately 57° (approximately 3/2 pitch). However, the improved performance achieved by mounting the collector at 57° does not save enough to pay for the structural system to support it. Such a structure must be professionally designed to meet local building codes and to withstand the wind forces which

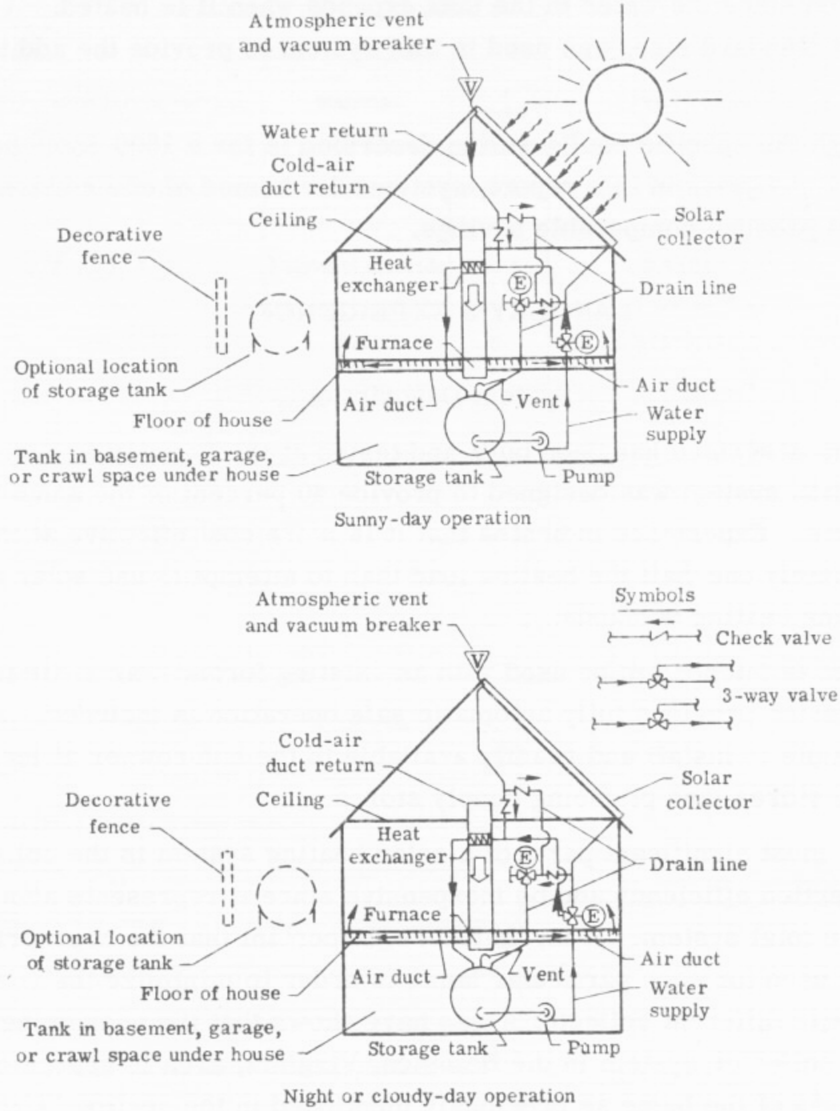


Figure 2.- Schematic flow diagram of solar heating system.

would result when high winds blow from the rear of a tilted solar collector and impinge on the underside of the collectors tending to lift them from the roof. Therefore, it is much simpler and structurally more sound to mount the collectors directly on the existing roof and leave the shingles in place.

The insulated hot-water storage tank, for storage of excess heated water for later use, can be located in the garage, in a tool shed, behind a decorative fence, or buried underground – whichever is most convenient. Plastic pipes carry the hot water to and from the tank. Plastic pipes are low in cost, easily installed, and provide sufficient insulation. To size the storage tank, approximately $1\frac{1}{2}$ gallons of water storage should be provided for each square foot of solar collector area plus approximately 1 gallon, for expansion, for each 50 gallons of water storage. This allowance must be included for thermal expansion since the water in the tank expands when it is heated. A 1000-gallon tank, the closest standard size, was used in this system to provide the additional required volume.

Even though the specific configuration described is for a 1500-foot^2 home, by following the guidelines given in this report, systems for homes of other sizes can be constructed and will produce comparable savings.

LANGLEY'S EXPERIENCE

System Description

The system described has been built and tested at the Langley Research Center. This demonstration system was designed to provide 40 percent of the annual heating for a 1500-foot^2 home. Experience indicates that it is more cost effective at this time to supply approximately one-half the heating load than to attempt to use solar energy to meet the full home heating demands.

The system is intended to be used with an existing forced-warm-air furnace. A control system which provides fully automatic safe operation is included. All materials required are simple to install and readily available to the homeowner at local lumber yards, hardware stores, and plumbing supply stores.

One of the most significant parts of a solar heating system is the collector. It must have a high collection efficiency and be inexpensive since it represents about one-half the initial cost of the total system. It is, therefore, important that the appropriate collector type and size be used for each particular home in order to minimize the cost. Studies of various homes with different collector areas have shown that the economically optimum size for a solar collector system in the Hampton, Virginia, area is approximately one-third the floor area of the home as previously mentioned in the section "Guidelines." By increasing the collector area, the homeowner can save a higher percentage of his heating bill. However, as the cost of the solar system increases, the system becomes less cost effective.

Typical construction of a flat-plate solar collector panel is shown in table 2 and figure 3. The panel is similar in construction to the freezing compartment coil of a household refrigerator. A panel size of 3 by 8 feet was selected since this size is within the manufacturer's capability and since a homeowner can reach across the 3-foot width during handling and installation. Its upper surface is painted with a flat black paint to increase its absorption of solar rays. This panel is mounted in a wooden frame with an insulated bottom of 1.5-inch-thick fiberglass insulation. The frame is then covered with glass or special plastic to complete a collector. A typical cross-sectional view of a solar collector

TABLE 2.- TYPICAL PANELS INVESTIGATED

Configuration (cross section)	Material	Delivery, weeks (a)	Price comparison (a)
	Aluminum	6 to 10	b1 ($0.67/ft^2)
	Polyvinyl chloride	2 to 4	2.4 ($1.61/ft^2)
	Steel	6	7.5 to 9.7 ($5.00/ft^2 to $6.50/ft^2)

[a]Delivery time and price comparison were made in the spring of 1974. Prices are based on mass production of the panels.

[b]The aluminum panel was used as a basis to compare prices of other panels.

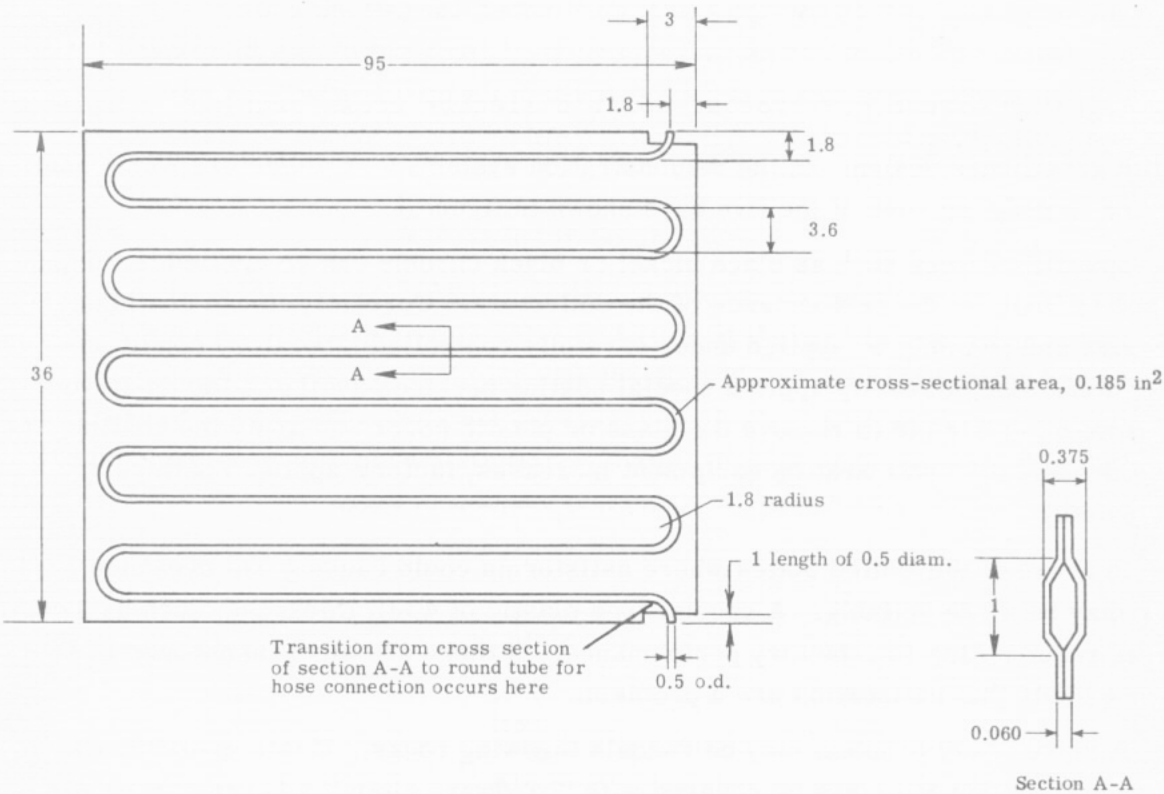


Figure 3.- Aluminum solar panel tested by Langley Research Center. Linear dimensions are in inches.

mounted on a roof is shown in figure 4. Most of the incoming solar rays can penetrate the glass or plastic cover without much energy loss. These solar rays are absorbed by the blackened surface; thus, the surface and the water flowing through the channels in the absorption panel are heated. The heat rays reemitted by the panel are of a longer wave length which cannot get back out through the glass or plastic cover and are thus trapped in the space between the glass or plastic cover and the panel. This is the same principle

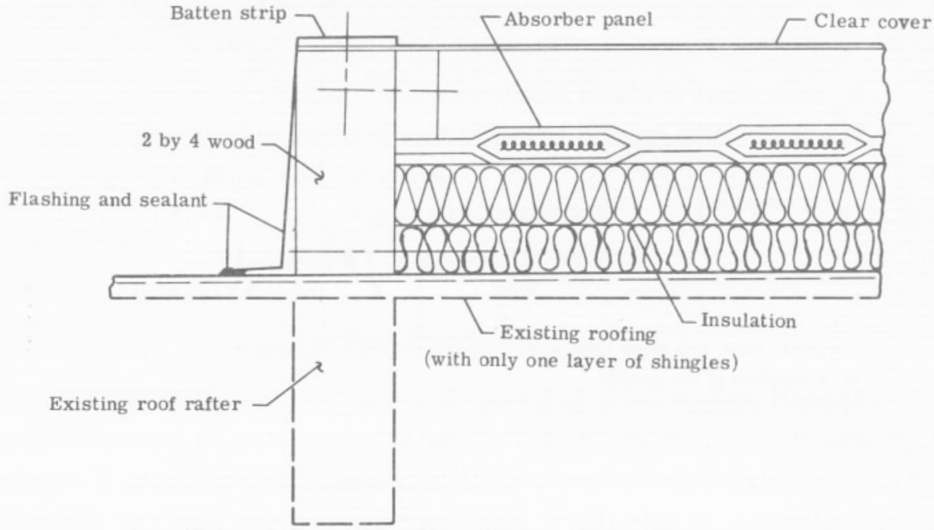


Figure 4.- Typical solar collector cross section.

used in greenhouse design. In the demonstration system, four collectors were manifolded together to make up each of the five bays shown in figure 1.

Special coatings such as black nickel or black chrome can be applied to the panel surface to improve the performance of the collectors. Currently, these coatings are expensive and can only be applied under carefully controlled laboratory conditions. If, at some future date, an easily applied special coating becomes available for do-it-yourself use, it would be simple to remove the glass or plastic cover and apply the coating. (Also, as the demand for solar heating equipment increases, factory-applied coatings are anticipated.)

In areas of the United States where hailstorms could cause glass breakage, a plastic cover may be more suitable. A special type plastic of 4 mil thickness, such as Tedlar film, is required for satisfactory performance. If there are any greenhouses in your city, it is not likely that hailstorms are a problem.

A more likely problem may be vandals throwing rocks. If this is a potential problem it is suggested that the glass be covered with "hardware cloth," a heavy screen wire material with a 1/4- to 1/2-inch mesh size. The hardware cloth will decrease the energy available by approximately 7 percent.

Equally important to efficient operation and minimum cost are the hot-water distribution system, the flow controller, and the hot-water storage tank. The hot-water distribution system is made predominately from chlorinated polyvinyl chloride (CPVC) plastic pipe and fittings. This type of pipe is not as expensive as steel or copper and is superior to the steel in corrosion resistance. Another advantage of the plastic pipe and plastic fittings is the ease with which they can be fabricated and assembled. No special tools are required to assemble the plastic piping other than a saw, some sandpaper, and the proper glue. The plastic pipe and fittings are glue welded together. Metal-to-plastic adapters are available and required for plastic pipe connections to the metallic components such as the solar panel, heat exchanger, and valves.

Flow control of the water in the solar heating system is accomplished with the differential temperature flow controller (DTFC) and two three-way resistance heater operated valves. The flow controller is of the differential temperature comparator type. Whenever the temperature in the solar collector is 10° F higher than the temperature of the water in the storage tank, the thermomechanically operated valves will be energized and the water flow will be directed through the solar collectors. When the temperature in the solar collectors is 5° F greater than the temperature of the water in the storage tank, the two three-way valves are deenergized and the water flow is diverted from the solar collectors and through the heat exchanger only. Because the water flow is through the solar collector when the two three-way valves are energized, the system is also fail-safe. If the power is lost to the solar heating system, the two three-way valves open and a vacuum breaker automatically opens to allow the solar collectors to drain by gravity. For a more detailed description of the differential temperature flow controller, see appendix E.

Variations in Solar Energy

In order to determine how a solar collector system will perform in a particular location, a knowledge of the available solar radiation at that specific place is required. This information is usually available through the U.S. Weather Bureau which has stations in most areas of the country. It is not necessary for a station to be in the same city but it should be close enough to have a similar climate. Typical data are shown in table 3.

TABLE 3.- MONTHLY AVERAGE SOLAR ENERGY

[37° N latitude, Hampton, Va.]

Month	Solar energy available, Btu/ft^2-mo (a)	Solar energy collectible, Btu/ft^2-mo (b)
January	53 500	5 307
February	57 000	6 139
March	71 500	14 054
April	71 000	14 314
May	70 000	17 115
June	70 000	18 635
July	72 000	21 468
August	71 200	18 231
September	66 500	16 971
October	62 000	12 595
November	51 000	8 823
December	47 200	6 012

[a]Maximum values at 35° collector tilt angle on a clear day.

[b]Average value where percentage of cloud cover, collector efficiency, and so forth are taken into consideration.

For approximate calculations, average values of solar radiation are often used. For example, on a clear day solar radiation reaehes the surface of the Earth in the Hampton, Virginia, area, which might be considered typical for cities in the Atlantic Central Region of the country, at an average rate of about 60 000 Btu per foot^2-month throughout the year. Unfortunately, the sky is not clear each day and clouds significantly reduce this value of available energy in many areas of the country. The monthly average values for each month of the year are given in table 3. The average value of collectible solar energy ranges from about 6000 Btu per foot^2-month in midwinter to about 18 000 Btu per foot^2-month in midsummer. These values are based on a collector efficiency of approximately 50 percent which is typical for a flat-plate solar collector operating at water inlet temperature of approximately 100° F on a clear day. A collector efficiency of 50 percent means that if the solar influx is 200 Btu per hour then 100 Btu per hour goes into the water.

These low values of actual collectible solar energy emphatically point out two effects: (1) bad weather drastically affects performance of a solar collector system and (2) more collectible energy is available in summer when it is not needed for house heating. Since no low-cost solar cooling system is currently available for domestic homes, all this energy is wasted. This is why extensive efforts are underway to develop an effective, low-cost air conditioning system utilizing hot water.

This discussion of the effects of weather on actual collectible energy is appropriate for most parts of the country. However, there are some areas of the country, such as Florida, parts of California and the desert regions of the southwestern United States, and certain mountainous areas such as Denver, Colorado, where clear skies are common. In such areas the performance of solar systems is excellent. The so-called high performance systems which claim to heat large homes with small collector areas may provide the claimed performance in these special regions, but homeowners in other regions should be very careful in considering them.

System Performance Analysis

The determination of the performance of the system installed at the Langley Research Center was one of the most important parts of this project. This prototype system was extensively instrumented to verify the actual performance of each component and the performance characteristics of the low-cost solar home heating system. Such extensive instrumentation is not required on a homeowner's system. Preliminary calculations were made to select the size of each component in the system. The measured data in table 4 list the maximum air temperature for each day T_{air}, range of wind velocity V_{wind}, clear sky solar radiation I_{max}, water flow rate through the solar collector w_{H_2O}, tank temperature each morning around 8:30 a.m. $T_{a.m.}$, tank temperature

TABLE 4.- TABULATION OF MEASURED DATA BASED ON CLEAR SUNNY DAYS

Date	T_{air}, °F	V_{wind}, mph	I_{max}, Btu/ft^2-hr	w_{H_2O}, gal/min	$T_{a.m.}$, °F	$T_{p.m.}$, °F	T_{H_2O}, °F	Q_c, Btu	Comments (a)
1-28-75	59	8	---	---	56	73	96	--------	H.E., only 2-hr operation
1-29-75	72	12 to 23	279	4.5	73	93	103	66×10^3	H.E., no cover – 27% eff.
1-30-75	48	12	283	4.6	82	86	96	95	H.E., no cover – 34% eff.
2-6-75	59	0 to 16	328	4.6	74	90	110	149	[b]H.E.
2-13-75	46	9 to 21	316	4.6	80	88	102	144	[b]H.E.
[c]2-22-75	54	5 to 9	---	4.8	72	103	128	281	[b]H.E.
2-25-75	59	17 to 24	357	6.6	93	130	140	232	[d]B.P.
[c]2-26-75	60	12 to 21	374	6.2	123	139	150	100	B.P.
3-18-75	55	9 to 16	276	4.6	85	95	118	129	H.E.
3-20-75	67	12 to 23	380	4.4	79	109	138	330	H.E.
[c]3-21-75	61	2 to 8	386	4.4	87	121	148	415	H.E.
3-24-75	81	0 to 35	311	6.5	133	146	154	82	B.P.
[c]3-25-75	69	12 to 21	384	6.5	131	159	172	175	B.P.
3-26-75	55	9 to 18	389	6.6	143	163	173	125	B.P.
3-27-75	45	0 to 7	289	6.1	88	109	124	132	B.P.
3-28-75	50	0 to 7	291	5.8	100	118	135	113	B.P.
3-31-75	53	4 to 9	397	6.0	97	139	156	263	B.P.
4-1-75	69	0 to 15	388	6.2	128	156	169	175	B.P.
4-2-75	73	0 to 13	384	6.2	131	165	178	213	B.P.
4-3-75	60	20 to 32	397	4.1	126	129	179	317	H.E.
4-4-75	55	21 to 29	407	5.5	88	135	152	294	B.P.
4-7-75	54	5 to 15	403	4.0	62	98	133	385	H.E.
4-8-75	63	5 to 12	403	4.2	66	117	150	576	H.E.
4-16-75	57	6 to 17	394	6.0	63	112	127	307	B.P.
4-17-75	63	3 to 10	394	6.3	103	144	158	257	B.P.
4-21-75	64	5 to 10	420	6.3	136	157	173	132	B.P.
4-22-75	59	10 to 14	374	6.0	136	150	163	88	B.P.
[c]4-23-75	79	7 to 16	351	5.8	95	136	150	257	B.P.
[c]4-24-75	78	14 to 25	381	5.6	84	107	120	144	B.P.
4-25-75	83	5 to 21	397	6.0	109	134	150	157	B.P.

[a]H.E. indicates that the system was operated with water flowing through the heat exchanger; B.P. indicates that the system was operated with water bypassing the heat exchanger and flowing directly to storage tank.

[b]Data taken with 60 percent of collector area covered with polyvinyl fluoride and the remaining area covered with polyethylene.

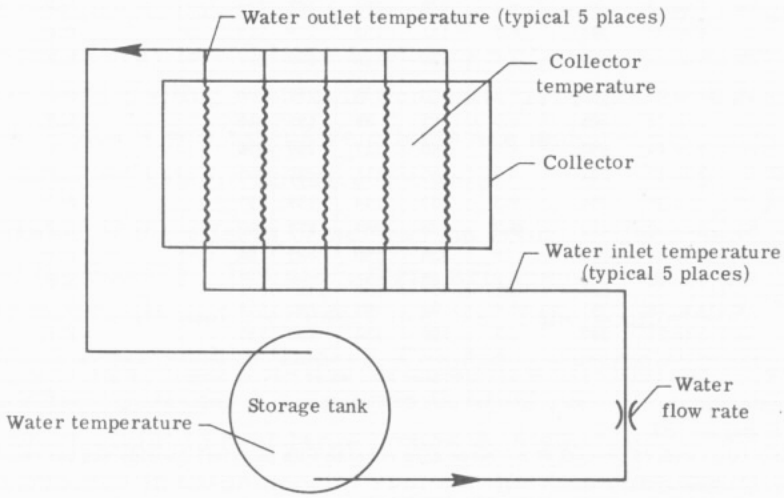
[c]Data for these days were used in the discussion.

[d]Installation of polyvinyl fluoride was complete before data were taken on February 25, 1975. All tests after February 25, 1975, were made with polyvinyl fluoride completely installed.

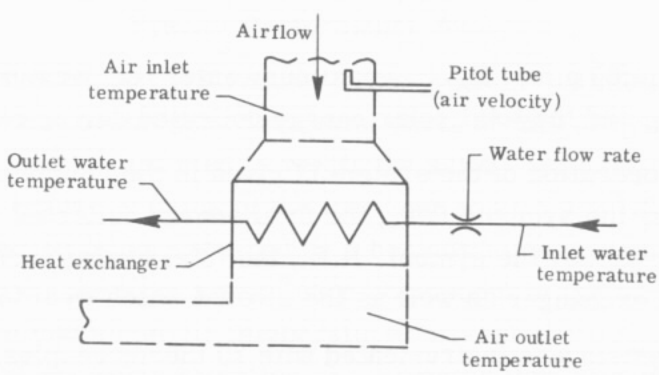
each afternoon around 4:00 p.m. $T_{p.m.}$, maximum water temperature at the outlet of the solar collector T_{H_2O}, and the total solar energy collected during each day Q_c. Detailed information about the operation of the system is given in the column labeled "Comments." Sometimes, as noted by the symbol B.P., the total energy collected went to the storage tank; other times, as noted by the symbol H.E., the total energy includes the amount which went to the heat exchanger as well as the amount which went to the storage tank.

The prototype system was instrumented with 20 thermocouples, 7 flowmeters, 1 pyranometer, and a pitot tube which was mounted in the cold-air return line of the furnace to measure air velocity. The pyranometer is an instrument to measure the sum of the direct solar radiation and the indirect radiation from the atmosphere. As shown in figure 5(a), the temperature measurements of the tank and collector were made to determine the exact performance of each component. Flowmeters were also placed in each line to measure the water flow through each water line; also, shutoff valves were installed in each line to control the flow of water through different panels. The water flow rate was approximately 6 gallons per minute when the water was not flowing through the water-to-air heat exchanger. When the water was directed through the heat exchanger causing more pressure drop in the system, the water flow rate dropped to 4 to 4.5 gallons per minute.

The instrumentation locations to check out the heat exchanger in the return air line of the furnace are shown in figure 5(b). The complete performance of the heat exchanger can be determined from the output of the four thermocouples, water flow rate, and pitot tube which measures the airflow through the heat exchanger. The water flow is measured by the previously mentioned flowmeters.



(a) Solar collector.



(b) Heat exchanger.

Figure 5.- Instrumentation.

The effects of weather conditions can be shown by comparing different days of operation. The additional heat stored in the tanks at different outside air temperatures can be seen by comparing the total solar energy collected on February 26, 1975, and March 25, 1975. The temperature difference in the outside air for these two days is 9° F. An additional 75 000 Btu was collected on March 25, 1975, with all other conditions being approximately the same. The effect of the wind velocity over the collector can be seen by comparing energy collected on April 23, 1975, and April 24, 1975. All conditions were approximately the same except the wind velocity and the amount of heat collected. Approximately 78 percent more heat was collected on the day with the low wind velocity.

The values listed in table 4 are the maximum values measured on the indicated days. It is almost impossible to give an exact value for each hour for all the days which data were taken. A selected number of cases are discussed to determine the effect of weather conditions and operating conditions. The data for March 21, 1975, are discussed in detail as to what happens on a typical clear day of operation. For example, by comparing figure 6 with table 4, $T_{a.m.}$ was 87° F at 9:15 and $T_{p.m.}$ was 121° F at 3:15.

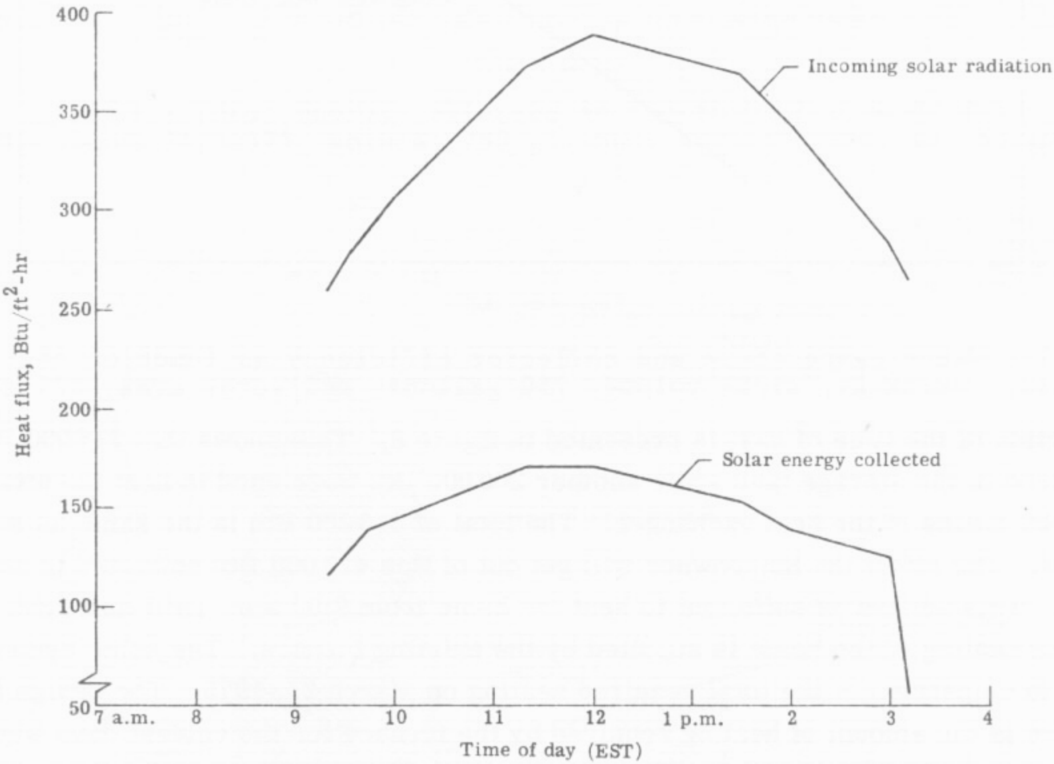


Figure 6.- Heat flux as function of time of day. March 21, 1975.

Also, the solar radiation I_{max}, listed in table 4 for March 21, 1975, is 386 Btu per foot^2-hour which is the maximum value shown in figure 6 at 12:00. The collector outlet water and tank temperatures measured on March 21, 1975, with solar energy from the collector being used in the heat exchanger at the same time energy was being stored in the tank, are shown in figure 7. The amount of energy collected during March 21, 1975,

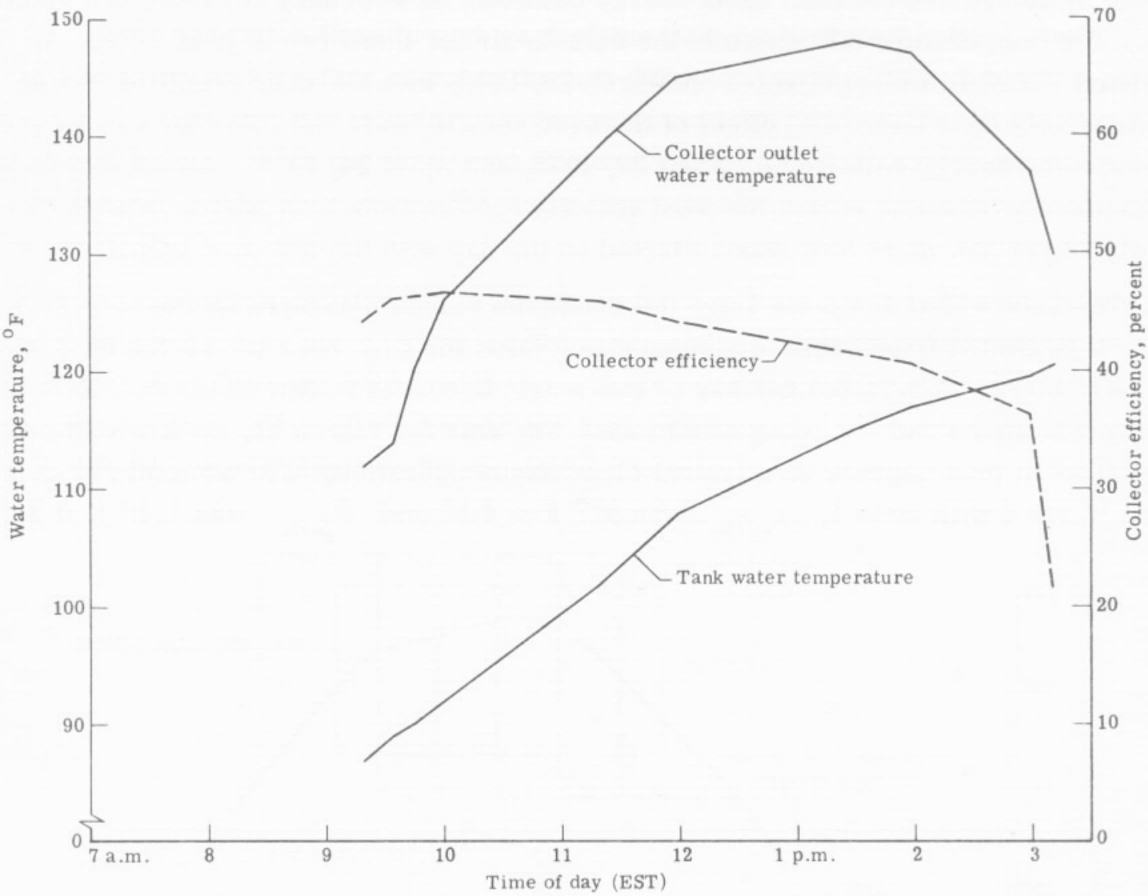


Figure 7.- Water temperature and collector efficiency as function of time of day. March 21, 1975; volume, 750 gallons; collector area, 475 $feet^2$.

as a function of the time of day, is presented in figure 8. This shows that 215 000 Btu were stored in the storage tank while another 200 000 Btu were used to heat the attached building by means of the heat exchanger. The total of 415 000 Btu is the same as shown in table 4. The effect the homeowner will get out of this 415 000 Btu collected is shown in figure 9. This amount is sufficient to heat the home from 9:00 a.m. until midnight. The remaining heating of the home is supplied by the existing furnace. The solar system supplied 60 to 65 percent of the total required heating on March 21, 1975. The design heat load curve is the amount of heating required by the furnace for the coldest days when the outside air temperature is 15° F. Fortunately, this condition exists only a very few days each year. For March 21, 1975, the outside air temperature was 45° F at midnight and approximately 60° F at 4:30 p.m. The curve, based on 70° F internal house temperature, in figure 9 reflects this change in temperature where the heating load is larger at night than during the day when the outside temperature is approximately 60° F. The energy

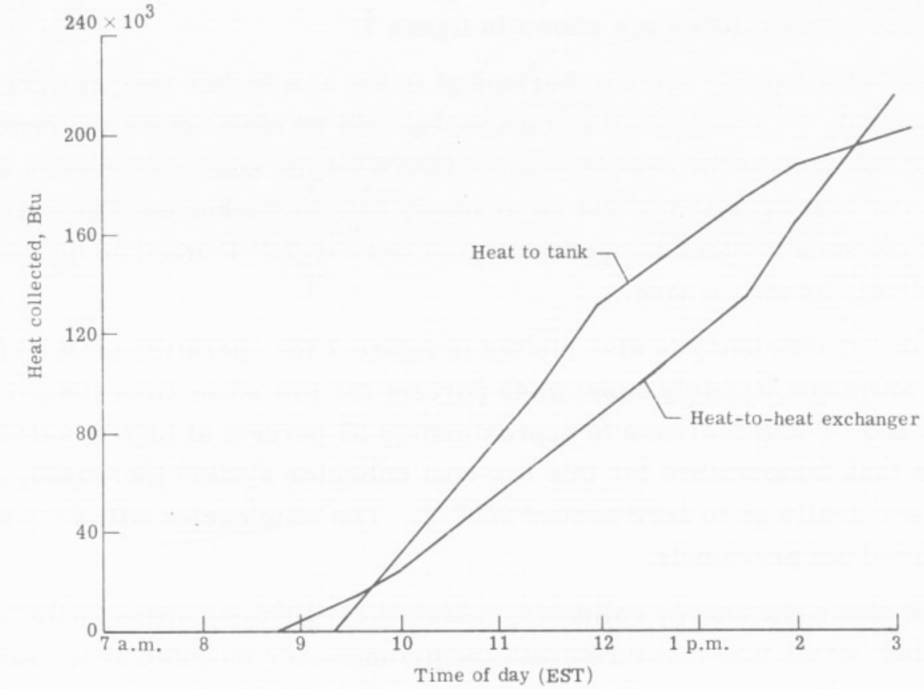


Figure 8.- Total energy collected as function of time of day. March 21, 1975; volume, 750 gallons; surface area, 475 feet^2.

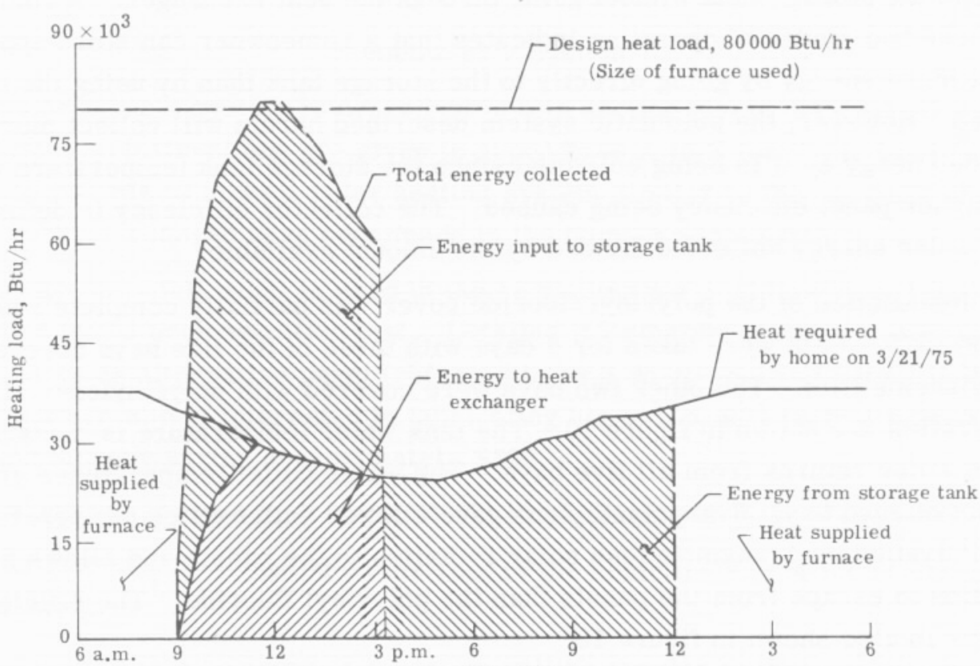


Figure 9.- Measured data applied to typical 1500-foot^2 home.

collected curve drops off very fast at 3:00 p.m. since the solar insolation is decreasing as the temperature in the storage water tank approaches the collector outlet water temperature. These temperatures are shown in figure 7.

When the solar heating system thermostat is set at a higher temperature than the existing thermostat, the energy in the storage tank will be used before the furnace comes on the line. If the demand for heat is greater than what the solar system can supply, the forced-warm-air heating will also cut on to supply heat to the home. The solar system pump will cut off when the tank temperature gets down to 75° F and then the heating will be done completely by the furnace.

The collector efficiency is also plotted in figure 7 for operation on March 21, 1975. These values are approximately equal to 45 percent for low water inlet temperatures around 90° to 100° F and decrease to approximately 35 percent at higher water temperatures. As the tank temperature for this low-cost collector system increases, the efficiency would eventually go to zero around 200° F. The efficiencies will vary with wind speeds as pointed out previously.

Figure 6 shows the energy collected on March 21, 1975, compared with the solar energy available, which was measured with the pyranometer mounted at the same angle as the collectors. The average efficiency for operation on this day was approximately 44 percent. The goal for future low-cost systems is to increase this efficiency. This will decrease the payback period determined by the cost analysis.

The other mode of operation used with this system was to collect energy and store it directly in the storage tank without going through the heat exchanger. A comparison between these two modes of operation indicates that a homeowner can store approximately 30 percent more energy by going directly to the storage tank than by using the heat as it is collected. However, the automatic system described herein will collect more energy by using the energy as it is being collected since the storage tank temperature will be lower, a higher panel efficiency being caused. The collector efficiency is defined as the amount of solar energy collected divided by the amount available.

The installation of the polyvinyl fluoride cover was partially complete before January 29, 1975. Data were taken for 3 days with three of the five bays covered with polyvinyl fluoride film. The other two bays were covered with polyethylene. The results of this operation are shown in figure 10. The tank water temperature is measured on the tank where water returns from all five bays. The water outlet temperatures are measured at the outlet of each bay. The polyethylene gave a lower outlet water temperature during the day. Polyethylene transmits less solar radiation to the panels and allows more thermal radiation to escape from the panels than the polyvinyl fluoride. The efficiency of the polyethylene is also shown in figure 10.

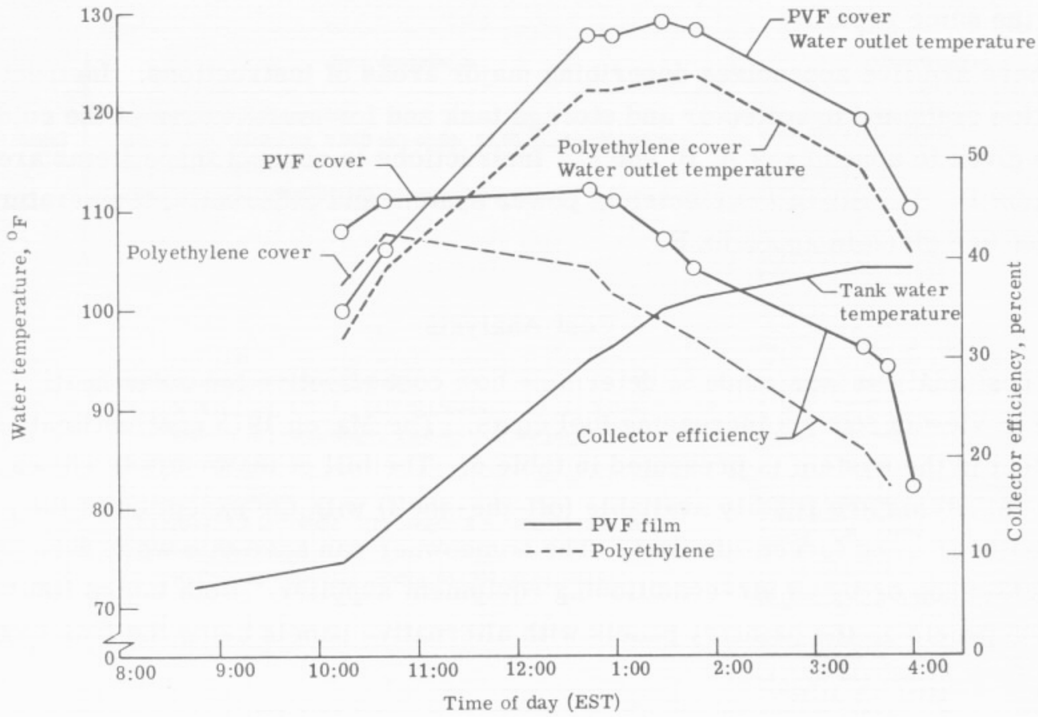


Figure 10.- Water temperatures and panel efficiency as function of time of day. Data taken on February 22, 1975, with 60 percent polyvinyl fluoride (PVF) film and 40 percent polyethylene on collector areas.

HOMEOWNER'S APPLICATION

Homeowner's System

The homeowner's system is described in this section giving detailed information about the system. Instructions are given in appendixes A to E for the homeowner to assemble components to make a solar heating system similar to the one built and tested at Langley. Three changes have been made in the homeowner's system:

(1) An off-the-shelf panel is used in the remaining parts of this report instead of the panel used in the demonstration test. Detailed information is given in section "Cost Analysis." Also an alternative panel (referred to as a do-it-yourself panel) is discussed for the homeowner who is interested in fabricating his own panels from a tube-double fin extrusion and thereby saving approximately $300.

(2) A concrete storage tank (septic tank) is used instead of the steel tank.

(3) The collector is mounted on the roof of the home instead of the backyard as in the tested system.

The characteristics of a homeowner's system will be similar to those of the demonstration system if the same components are used. Component substitution may modify operation and performance. It may be possible to obtain lower cost components and achieve the same result.

There are five appendixes describing major areas of instructions. Instructions for installation of the solar collector and storage tank and for modification of the cold-air duct are given in appendixes A, B, and C. Instructions to connect these items are given in appendix D. Details of the electrical power system and differential temperature flow controller are given in appendix E.

Cost Analysis

A cost analysis was made to determine how cost effective the solar heating system could be in view of today's increasing fuel costs. The March 1975 cost estimate of each major item in the system is presented in table 5. The bill of materials is shown in table 6. All items are readily available (off-the-shelf) with the exception of the modification to the existing forced-air duct. The homeowner can have this work done by a local sheet metal shop or by an air-conditioning equipment supplier. Both tables list the demonstration panels as the primary panels with alternative panels being the less expensive ones.

TABLE 5.- MATERIAL COST ESTIMATE

[March 1975]

	Cost
Collector:	
Heat-transfer panels, 480 ft^2	$ 700.00
Polyvinyl fluoride (PVF) film cover	100.00
Fiberglass insulation	50.00
Flat black paint	30.00
Flashing and sealing	30.00
Wood	100.00
Hose, screws, paint, and others	90.00
Subtotal	$1100.00
Equipment:	
Heat exchanger	$ 175.00
Pump	100.00
Storage tank	180.00
Heat-exchanger adapter	75.00
Piping	100.00
Controls	260.00
Tank insulation	50.00
Subtotal	$ 940.00
Total	$2040.00

TABLE 6.- BILL OF MATERIALS FOR SOLAR HEATING SYSTEM

Item	Item description	Manufacturer (a)
Panel (demonstration)	Aluminum roll bond panels: Alloy 1100; thickness, 0.060 in.; width, 33.75 in.; length, 96 in.; 20 panels required (Olin Brass Article FS-7767 or equivalent)	*Olin Corp., Olin Brass East Alton, IL 62024 Tranter, Inc. 705 E. Hazel St. Lansing, MI 48909 Dean Products, Inc., Panel Coil 1025 Dean St. Brooklyn, NY 11238 Fafco, Inc. 5860 Spring St. Redwood City, CA 94063
Panel (alternative)	Extruded aluminum tube with fins: Outside diameter, 1/2 in.; wall thickness, 0.035 in.; 2 fins; total width, 3 in.; total length, 2000 ft; total weight, approximately 250 lb	Brazeway, Inc. 2711 E. Maumee P.O. Box 546 Adrian, MI 49221
Collector insulation	Fiberglass insulation: Thickness, 1.5 in.; width, 3 ft; length, 8 ft; density, 3 lb/ft^3; 20 pieces required (Owens-Corning Fiberglas catalog no. 703 or equivalent)	*Owens-Corning Fiberglas Corp. Fiberglas Tower Toledo, OH 43659 Johns-Manville Corp. 22 E. 40th St. New York, NY 10016 PPG Industries Fiber Glass Div. One Gateway Center Pittsburg, PA 15222
Cover	Polyvinyl fluoride film: Thickness, 0.004 in.; total width (including overhang), 3.5 ft; total length (including overhang), 170 ft; total area, 595 ft^2 (Du Pont Tedlar PVF film 400BG2OTR or equivalent)	*E.I. Du Pont de Nemours & Co., Inc. Film Department 1007 Market St. Wilmington, DE 19898 General Electric Co. Space Products Div. Valley Forge Space Center P.O. Box 8555 Philadelphia, PA 19101 Filon Div. Vistron Corp. 12333 S. Van Ness at El Segundo Blvd. Hawthorne, CA 90250 ASG Industries, Inc. P.O. Box 929 Kingsport, TN 37662
Water pump	Rotary vane, positive displacement type pump: Capable of pumping 240 gal/hr of water, internal relief valve must be set at 50 psig; 1/3-hp, 120-V; 60-cycle motor (Procon Model No. C02057HFEP or equivalent)	*Procon-Colerain Products Affiliate of United Service Equipment Co. Division of Standex 910 Ridgely Rd. Murfreesboro, TN 37130 Bell & Gossett ITT 8234 Austin Ave. Morton Grove, IL 60053 Aurora Pump Div. General Signal Corp. 800 Airport Rd. North Aurora, IL 60542 Thrush Products, Inc. W. 8th at N. Jefferson P.O. Box 228 Peru, IN 46970

[a]Asterisk indicates manufacturer of items used in demonstration system.

TABLE 6.- BILL OF MATERIALS FOR SOLAR HEATING SYSTEM – Continued

Item	Item description	Manufacturer (a)
Water storage tank	Concrete water storage tank: Size, 1000 gal; width, 5 ft; length, 9 ft; depth, 6 ft or Steel water storage tank: Size, 1000 gal; diameter, 4 ft; length, 10 ft 8 in.	Local concrete (septic) tank suppliers Local tank suppliers
Insulation for storage tank	Standard tank insulation (equivalent to 6 in. of fiberglass insulation): Thickness, 6 in.; width, 23 in.; length, 48 in.; 24 pieces required	Same as for collector insulation
Heat exchanger	Water-to-air heat exchanger: One-row coil; type T; finned width, 18 in.; finned length, 22 in.; without turbulators	*Trane Co. 3600 Pammel Creek Rd. La Crosse, WI 54601 General Electric Co. Air Conditioning and Heating Appliance Park Louisville, KY 40225 American Air Filter Co., Inc. 200 Central Ave. Louisville, KY 40208 Young Radiator Co. Dept. T-72 2825 Four Mile Rd. Racine, WI 53404
Wood	Redwood or treated pine: 2 by 4 in.: total length, 320 ft 1/4 by 2 in.: total length, 320 ft	Local lumber company
Plastic tubing	Chlorinated polyvinyl chloride (CPVC) tubing: 3/4 in. nominal diameter, length as required 1/2 in. nominal diameter, length as required Tees and ells, number and size as required	Local plumbing supply stores
Pipe strainer	Pipe strainer for suction side of pump, 1-in.-diam. pipe size, with 100-mesh-size stainless-steel screen	Local plumbing supply stores
Three-way valves	Three-way fan coil valves: 3/4 in.: 125 psi; operating temperature, 40° F to 240° F; bronze body; 0.9-A rating; 24 Vac; 60 cycles, 1 required (Taco Product No. 561-3 or equivalent) 1 in.: same information as for 3/4-in. valve; 1 required (Taco Product No. 562-3 or equivalent)	*Taco, Inc. 1160 Cranston St. Cranston, RI 02920 Automatic Switch Co. 56-A Hanover Rd. Florham Park, NJ 07932 Skinner Electric Valve Div. Skinner Precision Industries, Inc. 100 Edgewood Ave. New Britain, CT 06050 Bell & Gossett ITT 8234 Austin Ave. Morton Grove, IL 60053
Check valve	Bronze swing check valve: 3/4 in.; 125 psi; screwed ends; 3 required (Jenkins No. 92-A or equivalent)	*Jenkins Bros. 100 Park Ave. New York, NY 10017 Taco, Inc. 1160 Cranston St. Cranston, RI 02920 Automatic Switch 56-A Hanover Rd. Florham Park, NJ 07932 Bell & Gossett ITT 8234 Austin Ave. Morton Grove, IL 60053

[a]Asterisk indicates manufacturer of items used in demonstration system.

Item	Item description	Manufacturer (a)
Vacuum breaker (antisiphon kit)	Vacuum breaker for 3/4-in. pipe	*Whirlpool Corp. Administrative Center Benton Harbor, MI 49022 The Johnson Corp. 809 Wood St. Three Rivers, MI 49093 Beacon Valve Co. P.O. Box 478 2 Jackson St. Waltham, MA 02154
Black paint	Enamel flat black paint: 2 gal needed for required two coats on aluminum (Sherwin-Williams catalog no. F62B50 or equivalent)	*Sherwin-Williams Co. 101 Prospect Ave., N.W. Cleveland, OH 44101 PPG Industries, Inc. 10800 S. 13th St. Oak Creek, WI 53154 3M Co. 3M Center St. Paul, MN 55101
Primer	Zinc chromate primer: 1 gal needed for required 1 coat (PPG catalog no. 6-204 or equivalent)	*PPG Industries, Inc. 10800 S. 13th St. Oak Creek, WI 53154 Sherwin-Williams Co. 101 Prospect Ave., N.W. Cleveland, OH 44101 3M Co. 3M Center St. Paul, MN 55101 Rust-Oleum Corp. 2301 Oakton St. Evanston, IL 60204

[a]Asterisk indicates manufacturer of items used in demonstration system.

The demonstration panel is not an off-the-shelf item from the supplier. A special unnecessary setup charge must be paid by the homeowner in order to have the supplier make this panel. However, a standard designed panel has become available since the purchase of the panel shown in figure 3. The off-the-shelf panel (fig. 11) has a similar water passage cross section. The off-the-shelf panel has a parallel water flow configuration, whereas the demonstration panel has a serpentine water flow configuration. This difference will not affect the performance of the collector since it is important to have approximately 1/2 gallon of water per hour flow rate per foot^2 of collector area. However, the homeowner can reduce the cost of the panel by fabricating the alternative panel listed in table 6. The instructions to make the panels are given in appendix A. This panel, as well as the demonstration panel, has a good heat flow path from the fin to the tube.

The tube-double fin extrusion type shown in figure 12, supplied in rolls, should perform as well as the tested panels since the material, water flow area, and tube spacing are approximately the same. The homeowner will have to remove a small section of the fins to bend the tube in the water flow pattern shown in figure 11. This configuration is lower in cost than the tested panels but requires additional work by the homeowner.

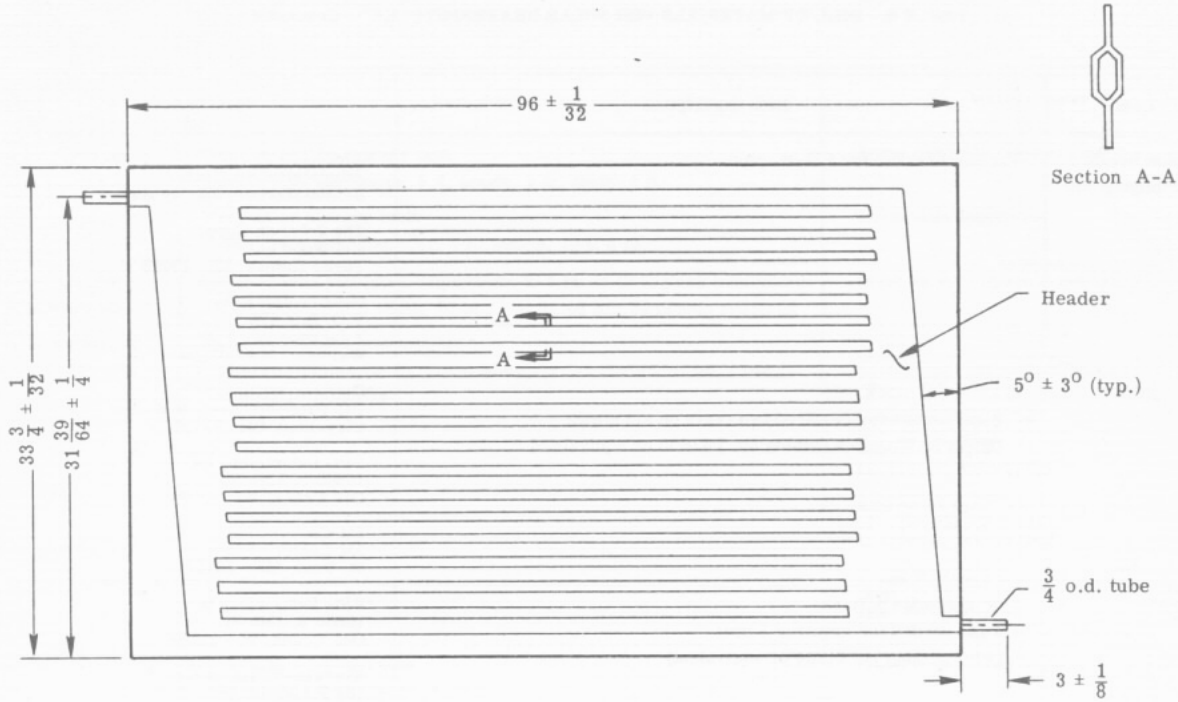


Figure 11.- Off-the-shelf standard solar panel. Dimensions are in inches.

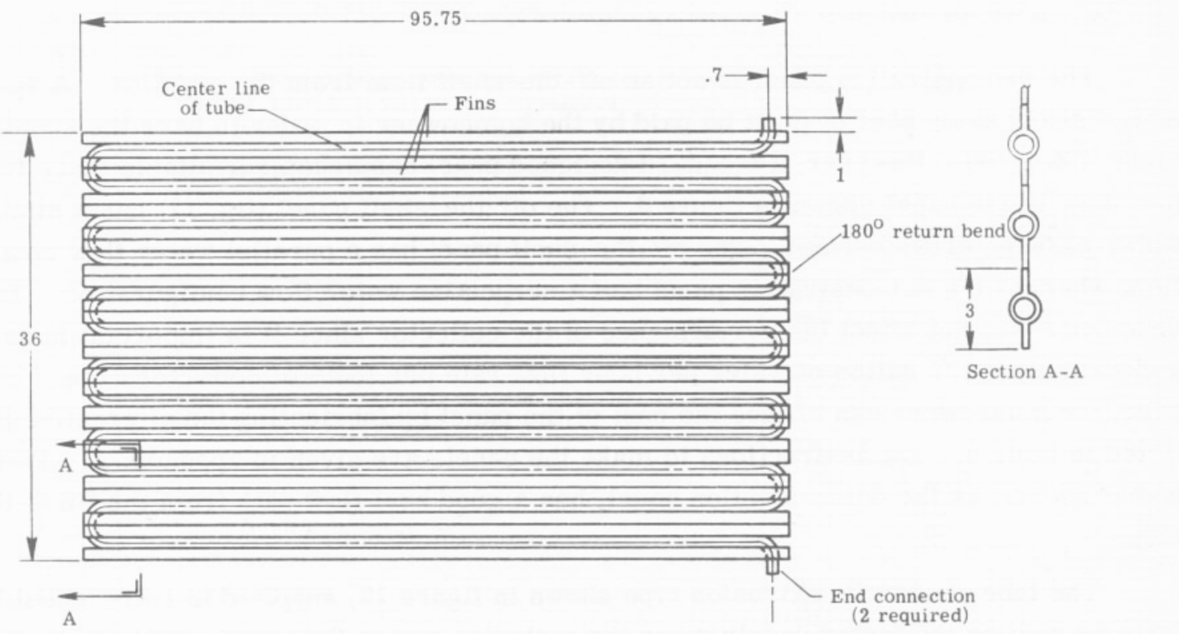


Figure 12.- Homeowner's fabricated tube-fin extrusion type panel. Linear dimensions are in inches. (See figs. A1 to A3 for additional details.)

Other manufacturers of comparable items which may replace items used in the demonstration system are given in table 6. The manufacturers of the items used in the demonstration system are indicated by an asterisk. The total cost of the homeowner's system should be estimated before the first item is purchased. The cost estimate listed in table 5 could vary depending on many factors. The cost figures do not include transportation or labor except for the modification of the cold-air duct. The assumption was made that the homeowner will supply all the labor.

To determine the number of years that it would take for the homeowner to get a return on his investment, local oil suppliers were contacted to determine the average amount of oil consumed by a homeowner with a living space floor area of 1500 feet^2. The average of the estimates given by several companies contacted was 1200 gallons per heating season. The savings based on this oil consumption is shown in figure 13, where total cost is plotted against payback time in years. Based on the March 1975 price of oil, 36.9 cents per gallon, and a reduction in the homeowner's heating bill of 40 percent, the payback time will be 18.5 years. The annual savings in dollars is \$177 (1200 gallons per year $\times$ \$0.369 $\times$ 40 percent of heating load = \$177). The payback time for a 10-percent increase in oil prices per year is shown to be approximately 10 years.

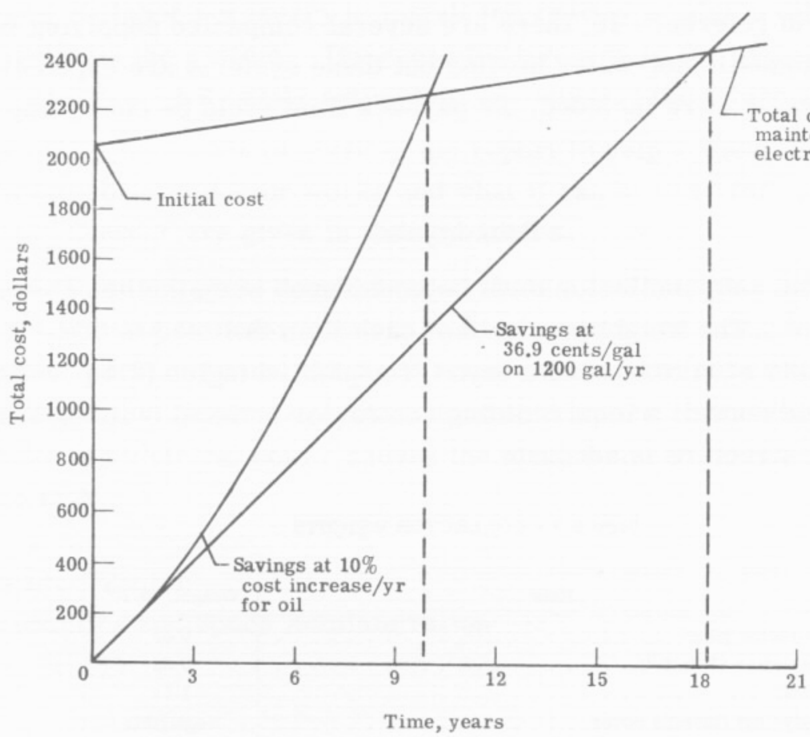


Figure 13.- Payback cost analysis based on solar system providing 40 percent of heating requirements.

The previous analysis is obviously an overly simplified approach, and each homeowner must assess his specific economic situation at the time he is considering the installation of a solar heating system. Factors which should be considered include cost of borrowing money, interest from investing the $2000, possible local and federal tax benefits, and changes in the assessed value of the home for real estate taxes. The total-cost curve includes the initial cost, maintenance, and electricity to run the pump. The only maintenance cost included is for replacement of the polyvinyl fluoride cover every 5 years which is the recommendation of the supplier. Maintenance of other components is expected to be minimal since they are standard well-proven ones with demonstrated reliability.

As mentioned, this cost analysis was based on an oil-fired system. Since the cost of electricity per Btu is higher than the price of oil per Btu, the savings curves for electrical forced-air heating will be to the left of the savings curves in figure 13. Therefore, the payback time occurs earlier for an electrical heating system. Since gas heating costs less than oil heating as of March 1975, the savings curves will be to the right of the oil savings curves, that is, a longer payback time. If the annual saving is $177, the payback time will be 18.5 years regardless of what percentage of the annual bill the $177 represents.

As pointed out in reference 10, there are several companies supplying solar collector systems for domestic hot-water heating but these systems are expensive. If heating of domestic hot water were included, the payback time could be cut by approximately one-half.

Roof Load

The weight of the solar collector must be considered when the homeowner installs the system on his roof. The weight per foot^2 of each item is listed in table 7. This weight is approximately equal to that of a layer of asphalt shingles (2.4 pounds per foot^2). The homeowner should consult a local building contractor or local building inspector to determine if the roof structure is adequate.

TABLE 7.- COLLECTOR WEIGHTS

Item	Weight, lb/ft^2
Collector panel	0.83
Insulation (3 lb/ft^3)	0.38
Wood	1.14
Polyvinyl fluoride cover	Negligible
Flashing and sealant	Negligible
Water	0.27
Total	2.62

Water Treatment

The homeowner should use a corrosion inhibitor in the solar heating system water. A water treatment company in the homeowner's area should be contacted to get recommendations as to type, concentration, and frequency of treatment to be used for that area. It is very important to specify the types of metals in the system. The metals used in the design described in this report are aluminum, copper, and steel. For the demonstration system, a water treatment company recommended that sodium dichromate be used with a concentration of 250 parts per million. However, a word of caution: Sodium dichromate is toxic and cannot be connected to the hot- or cold-water system of the house. The concentration should be periodically checked, especially after additional water is added to the storage tank. This treatment at a small cost of $5 to $10 is very important to the lifetime of the system. It will extend the life of the aluminum panels from approximately 3 months to many years of operation.

CONCLUDING REMARKS

This report describes the design, construction, testing, and economic analysis of a low-cost solar heating system. The minimum cost design approach requires the homeowner to supply all labor necessary to install the readily available off-the-shelf components which make up the system. The cost effectiveness of the system is influenced by many factors which are not easily estimated, particularly the future cost of fuel oil.

Background information is given in the report to help a specially skilled homeowner understand how a solar collector works and what it can be used for. Assembly instructions for the homeowner are given in the appendixes.

The results of the tested demonstration system indicate that the homeowner can supplement his existing forced-warm-air heating system and reduce his heating bill by approximately 40 percent for a 1500-foot^2 house insulated to 1974 FHA minimum standards. The completely automatic system does not require antifreeze protection and is fail-safe. Loss of electrical power causes the system to automatically drain itself back to the storage tank.

Langley Research Center
National Aeronautics and Space Administration
Hampton, Va. 23665
June 8, 1976

APPENDIX A

SOLAR COLLECTOR ASSEMBLY AND INSTALLATION ON ROOF

Collector Layout

The instructions to assemble the solar collectors and install them on a typical roof are given in this appendix. The procedure given is an acceptable way to install them but may not be optimum in all cases.

A layout drawing of the solar collectors mounted on the homeowner's roof should be made before this project is undertaken. The roof on which the collector is to be mounted must face a southern direction, be large enough for the required collector area, and be exposed to the Sun during the middle of the day. Measurements of the available roof area will be required before selecting the location to mount the collectors. Sufficient working space around and between each bay should be provided for the collector installation and for the water supply and water return pipes. Measurements should be made in the attic as well as on the roof. Four collectors in each bay were used in the demonstration system since this configuration will fit most homes. This configuration can be changed to suit the roof but the water flow through each bay must be the same for best performance. All bays must have the same number of collectors per bay to obtain the same water flow through each bay. More than five collectors per bay are not recommended because a larger pump will be required.

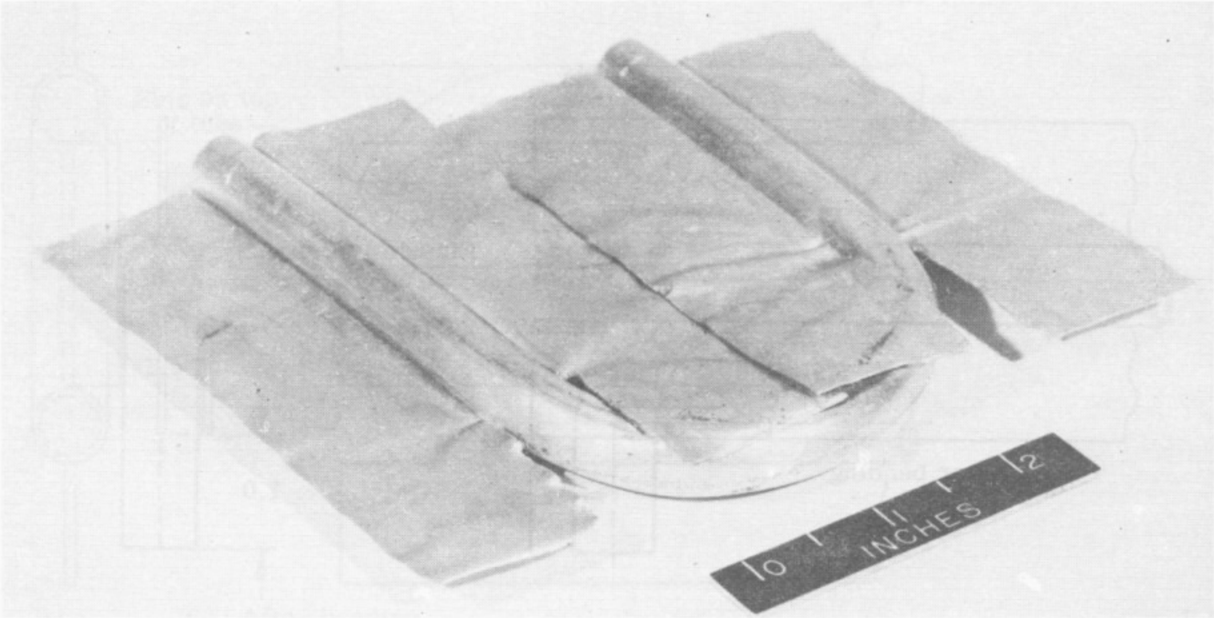
Collector Panel

The panel recommended for the homeowner is shown in figure 11. This off-the-shelf panel is almost identical to the demonstration panels. The different water flow path of the panel in figure 11 allows for complete draining of all water from the panel to prevent freezing problems. Hose connections from one panel to the next are described in the section, "Installation on Roof."

Alternative Collector Panel

The instructions to assemble the alternative collector panel are also given in this section. This do-it-yourself panel requires the homeowner to make many bends in the extruded aluminum tube. A photograph of one 180° turn is shown in figure A1. Start by cutting the fins away from the tube to make the panel water inlet as shown in figure A2. After the water inlet bend is made, unroll another 8 feet of the extrusion section to make the first 180° return bend as shown in figure A3. After making each turn, unwind another 8-foot length to the next turn. This operation should be done on a flat surface in order to bend the turns all in the same plane. A total of 11 turns will be required for each panel plus the two 90° end turns. The panel will be flexible as the last turns are made so it is advisable to attach it to a 3- by 8-foot piece of plywood which can be rotated with the panel to aid in making the turns. The outline of the panel should be drawn on the plywood and small nails should be used at each turn to hold the tubing in the proper location after the bends have been made. The water must drain out of the panels to prevent freezing during cold weather. This drainage can be accomplished by making the tubes and fins between bends parallel during panel assembly and installing the panels level on the roof. A check should be made when the first panel is made to see if the water will drain out. The final panel will look like the panel shown in figure 12. Twenty panels will be required for a total of 480 feet^2.

It is very important to prevent the tube from collapsing while being bent. Wood blocks which minimize the distortion of the tube and fins are made of a hard wood such as maple or birch. (See fig. A4.) Details of the groove are also given. Slots and cutouts are to allow room for the fins. A block with a groove is used to minimize the distortion while cutting the fins. The thin aluminum fins can be easily cut with any type of sharp tool. Be careful not to damage the tube. The assembly of these wood blocks is shown in figure A5; this is very similar to a standard tube bender which would damage the fins. The difference between the standard tube bender and this one is that the finned tube bender has slots for the fins. Practice making several bends before starting a 3- by 8-foot panel. Buy extra material when ordering the tube fin extrusion. If 2000 linear feet of material were ordered, this would include 80 extra feet.



L-76-1453

Figure A1.- Low-cost panel.

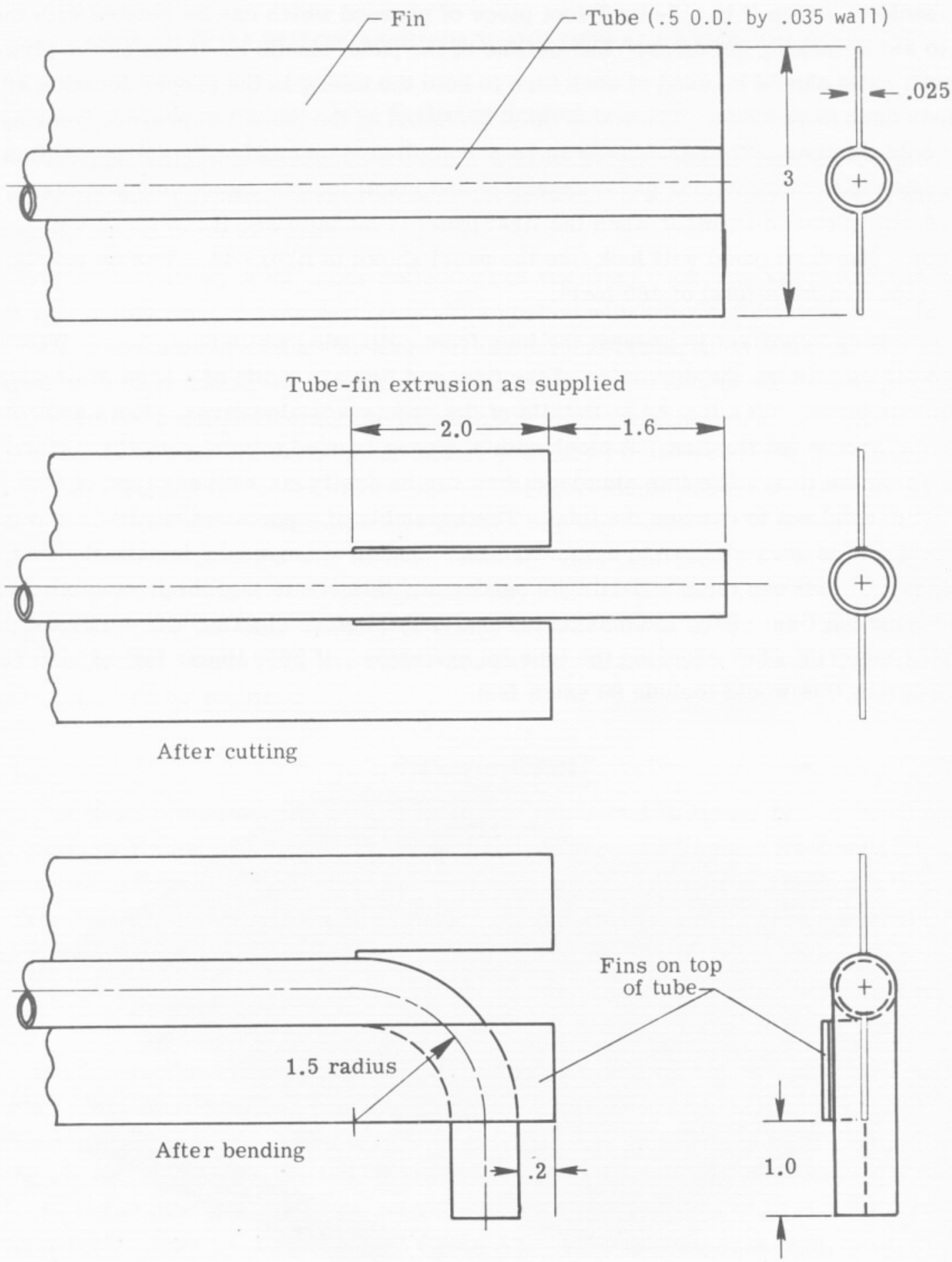


Figure A2.- Typical end connection of panel. Linear dimensions are in inches.

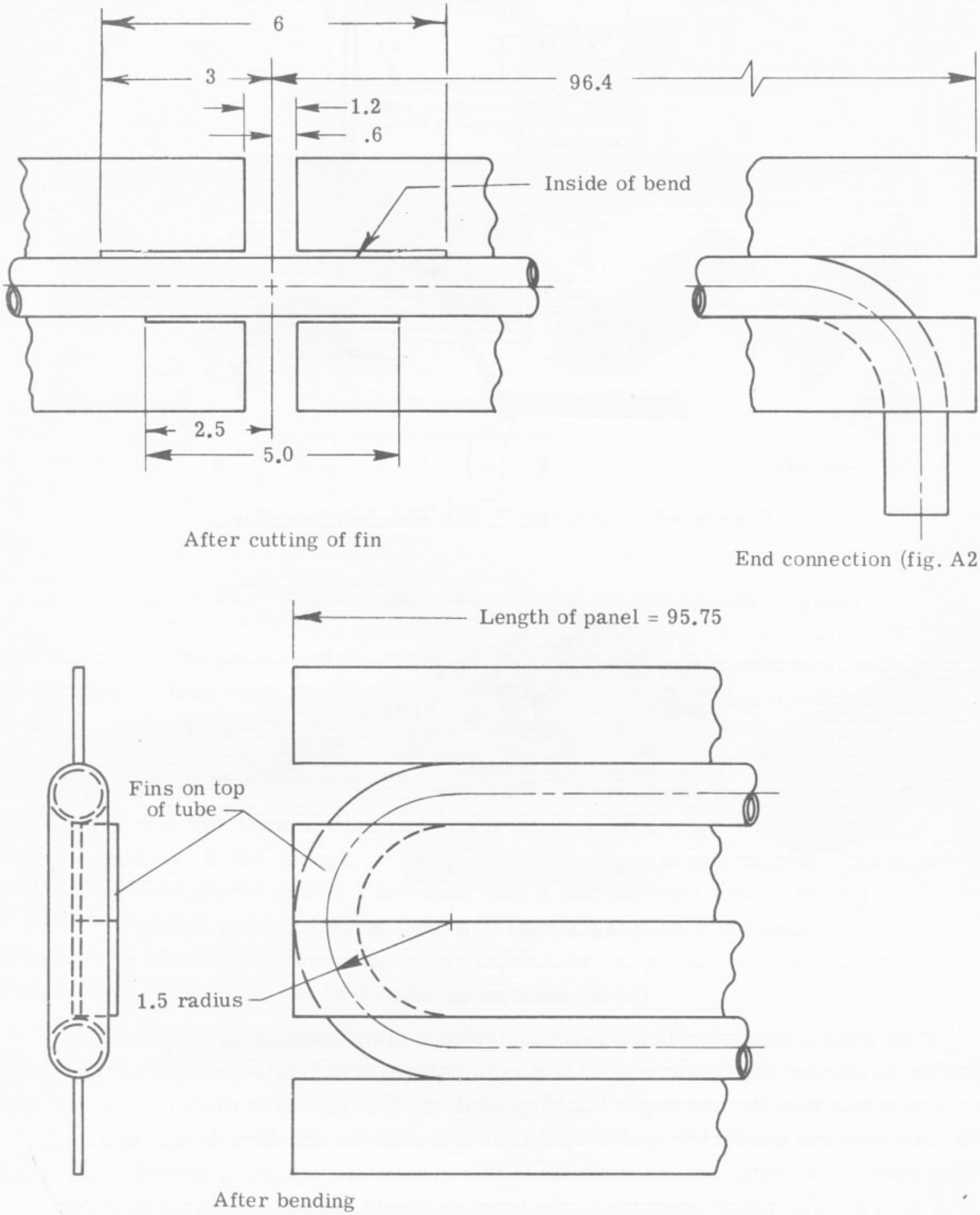
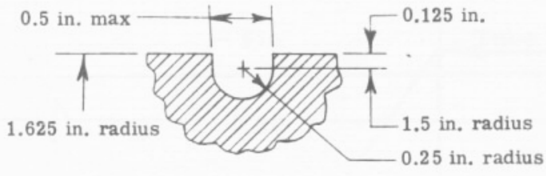
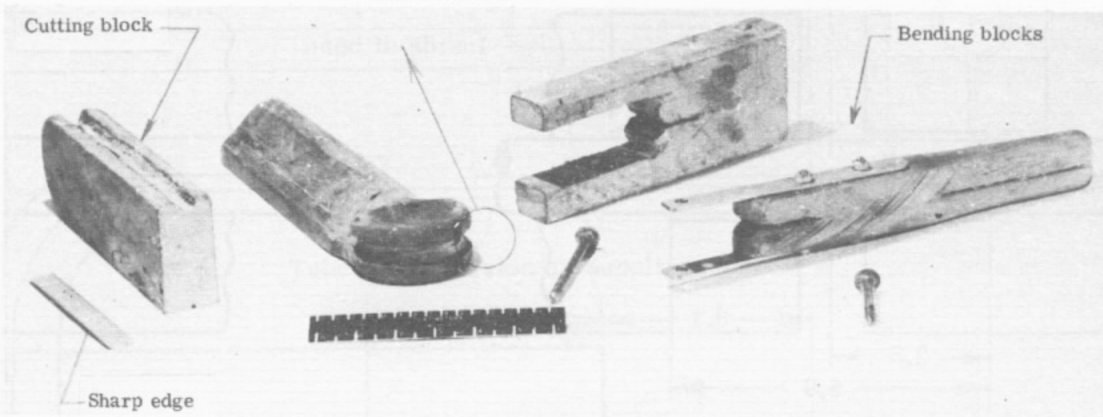


Figure A3.- Typical 180° return bend. Linear dimensions are in inches.

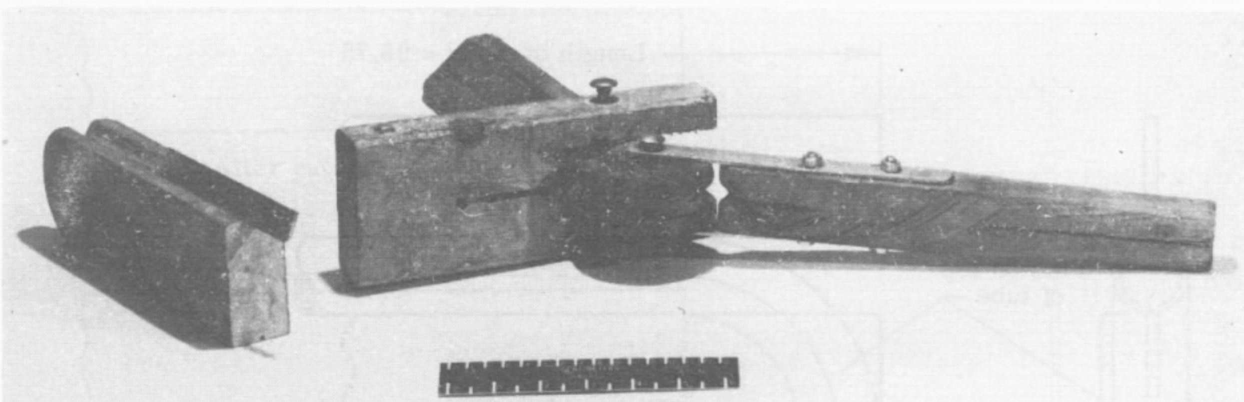
APPENDIX A



Groove details



L-75-7221.1
Figure A4.- Cutting block and bending tool.



L-75-7222
Figure A5.- Cutting block and assembled bending tool.

Installation on Roof

The system described is the one Langley used in its demonstration; however, because an off-the-shelf solar collector panel of standard design – only recently available at a lower cost than the one used – is suggested, the description of the installation of collector frames and panel receptacles was written around the standard design solar collector panel. The solar collector panels in this system are housed in frames made from pine 2 by 4's. The inside openings in the framing should not be less than 3 by 8 feet as shown in figure A6. Notches and holes for inlet and outlet tubes on panels should be laid out and fabricated on an individual basis because of the tolerances used by the manufacturer

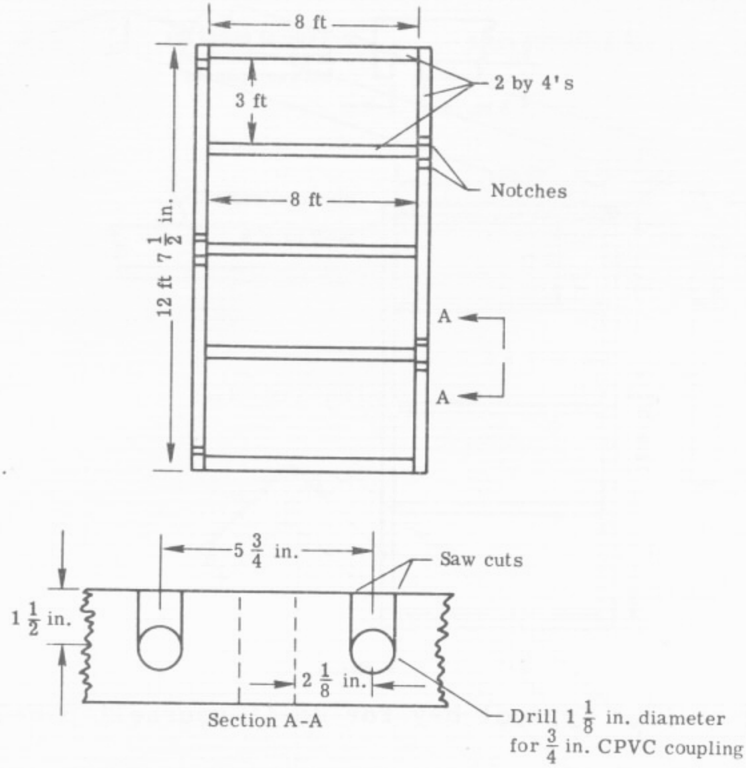


Figure A6.- Typical bay for off-the-shelf standard panel.

of the panels. The panels and the openings in the frame should be numbered with matching numbers. Each panel should be measured and the corresponding opening in the collector frame laid out for drilling and notching as shown in figure A6. The holes for the inlet and outlet tubes may be drilled at this time, but the notches should not be cut until the frame has been installed on the roof. The openings in the framing for the demonstration and the tube fin extrusion type panels are shown in figure A7. The solar heating collector is made up of five groups, or bays. Each bay contains four panels. The bays should be spaced approximately 2 feet apart and 2 feet from the edge of the house roof to provide accessibility to each bay during installation and later when maintenance is required. A homeowner, depending on his experience, may want to consult a book on general carpentry, which can be found in any public library.

The frames should be made up on a flat surface such as a patio or garage floor. The framing for the solar collector should be nailed together by using sixteen-penny nails. A typical plan view of a completed frame for one bay of the solar collector is shown in figure A6. For durability and to meet some local building codes, the 2 by 4's should be salt-treated pine.

The panel size can be changed as long as all panels are the same size, but is not recommended because it will increase the cost of having the panels fabricated. Of course, the number of panels per bay can and should be changed to facilitate installation of the hot-

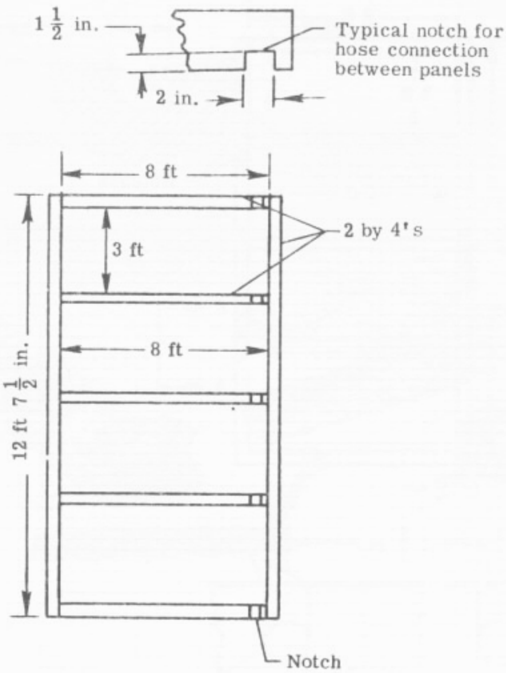


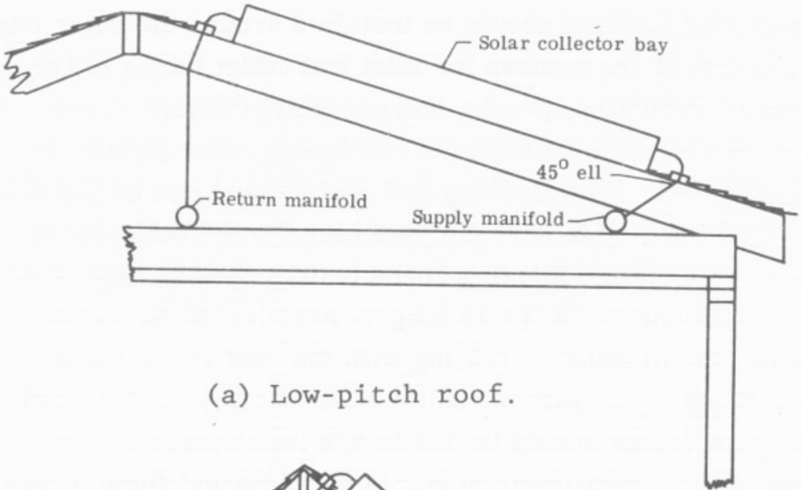
Figure A7.- Typical bay for do-it-yourself panel.

water distribution system described in appendix D. The bottom end of the bay should not come down too close to the intersection of the roof and the eaves. Enough space must be allowed to install the hot-water piping. (See fig. A8.) This space will be largely determined by the pitch and size of the roof as well as the style of the house.

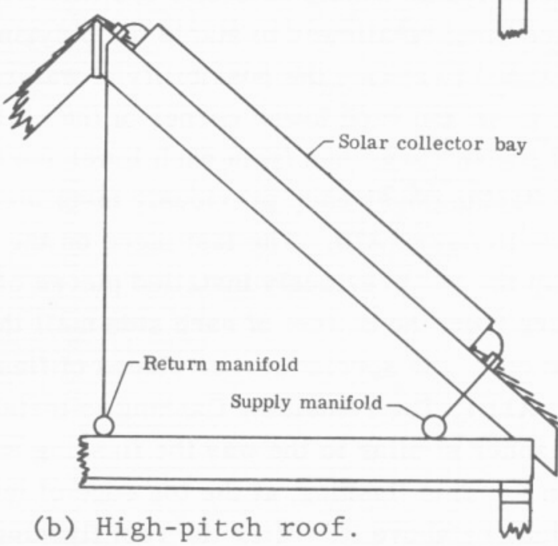
After the solar collector panel framing for each bay has been nailed together, the location on the roof should be properly laid out by measuring equal distances from the crown of the roof. As each bay frame is moved into position it should be secured in accordance with local building codes. The frame should be slant nailed on both the inside and outside periphery at intervals not greater than $1\frac{1}{2}$ feet with ten-penny nails as shown in figure A9.

Cut notches by making two saw cuts $1\frac{1}{2}$ inches deep at layout marks as shown in figure A6, and by tapping the 2 by 4 near the bottom of and between the saw cuts with a hammer. Usually, this procedure will cause the wood between the saw cuts to split away from the 2 by 4 neatly at the bottom of the two cuts; thus, a rectangular notch is formed. The blocks removed in forming the notches should be saved and given a number corresponding to each notch. The blocks are to be used for support of the battens that are installed later.

Prior to further installation, cut the insulation to fit inside the frame, paint the panels with one coat of zinc chromate primer and two coats of flat black enamel, and cut the polyvinyl fluoride cover for one bay.



(a) Low-pitch roof.



(b) High-pitch roof.

Figure A8.- Piping for roof.

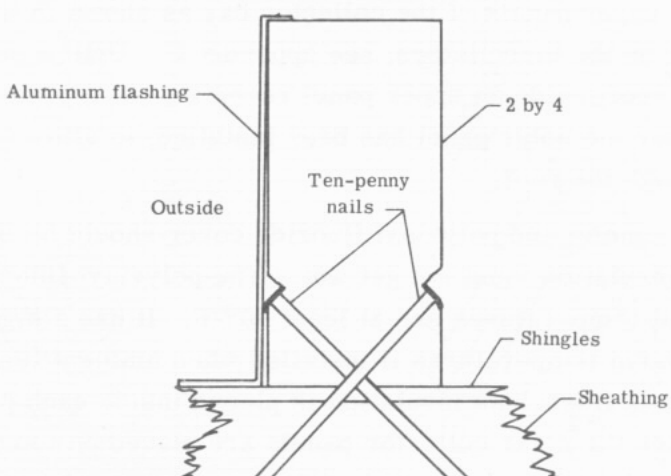


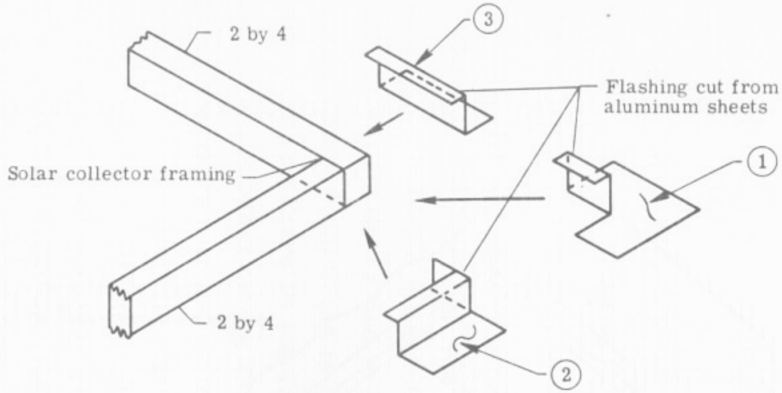
Figure A9.- Cross section of collector bay frame member.

APPENDIX A

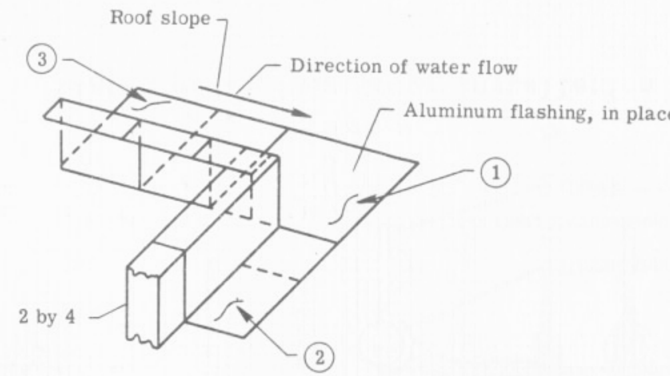
The aluminum roof flashing should be installed around the outer edge of the collector frame bay, except at the notches for inlet and outlet tubing of the solar panels, prior to installation of insulation, panels, and polyvinyl fluoride cover. The notches should not be covered with flashing until the insulation, solar panels, and polyvinyl fluoride covers have been installed. Roof flashing and roof cement can be purchased at any building supply store. The flashing to seal the joint between the collector frame bay and the roof shingles should be installed starting at the bottom outside edge of each collector frame bay. Cut the flashing in pieces as long as practicable for bending. This will minimize the number of joints requiring sealing with the roof cement and the number of places for water to leak through. The part of the flashing that covers the outer edge of the upper surface of the collector frame should be 1/2 to 5/8 inch wide, no more than 5/8 inch, because enough space must be allowed to staple the polyvinyl fluoride cover on. The flashing should be lapped to reduce the possibility of water getting inside the collector frame. From the bottom and each lower corner of the collector bay frame, work horizontally to the center of the bay; then from each lower corner, work up the sides of the bay overlapping the flashing over each previously installed piece. Special corner pieces of flashing are shown in figure A10. The last piece on the bottom edge of the collector frame should overlap the two previously installed pieces of flashing. On each side of the collector frame, work from the bottom of each side until the top edge of the frame is reached. At the top edge, the special corner pieces of flashing are installed before the top piece. (See fig. A11.) The remaining flashing is installed on the top edge of the collector frame in a manner similar to the way the flashing was installed on the bottom edge of the collector frame. This flashing, at the top edge of the collector frame, should be slipped under the shingles above it. After the roof flashing has been installed, all edges and lap joints should be covered with roofing cement which is spread with a putty knife.

The thermistor to monitor the temperature of the solar panels should be attached to the back of one of the upper panels of the collector bay as shown in figures A12 and A13. For additional details on the thermistors, see appendix E. Drill a small hole, 1/8 to 1/4 inch, through the roof inside an upper panel receptacle at a place close to where the thermistor will be after the solar panel has been installed, to allow the wires from the thermistor to go through the roof.

The insulation, panels, and polyvinyl fluoride cover should be installed in warm dry weather because the insulation must not get wet. The polyvinyl fluoride film should be installed when ambient temperatures are at least 70° F. It has a high thermal expansion rate and will sag in warm temperatures if installed when ambient temperatures are low. First, the 1.5-inch-thick fiberglass insulation is placed inside each panel receptacle on top of the shingles; then the solar collector panels are placed on top of the insulation, seating the inlet and outlet tubing in the cylindrical groove, as shown in figure A14 or A15, depending on the panel used. Lift the solar panel to which the thermistor is attached at the

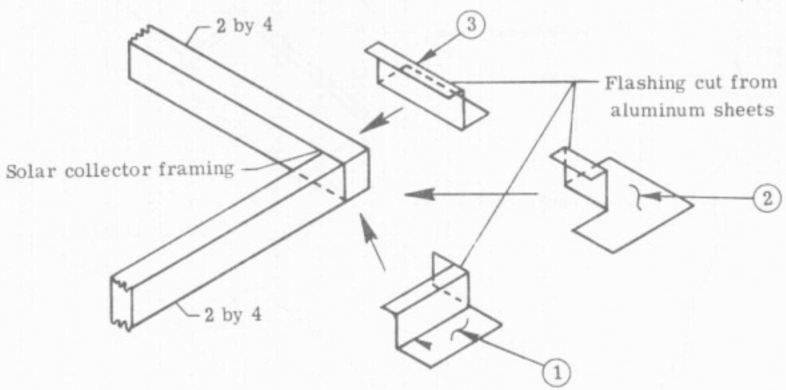


(a) Exploded view.

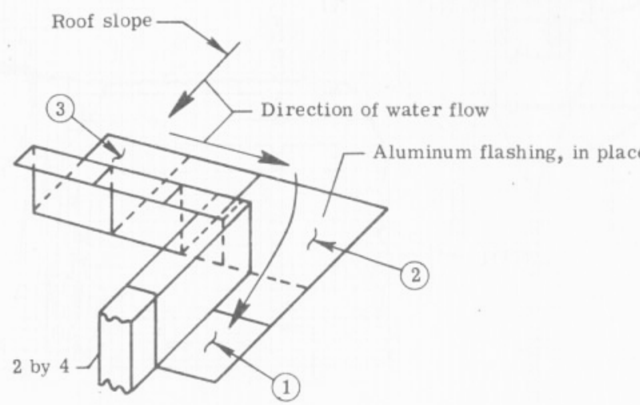


(b) Assembled view.

Figure A10.- Bottom corner of flashing. Install in order of numbers shown in circles.



(a) Exploded view.



(b) Assembled view.

Figure A11.- Top corner of flashing. Install in order of numbers shown in circles.

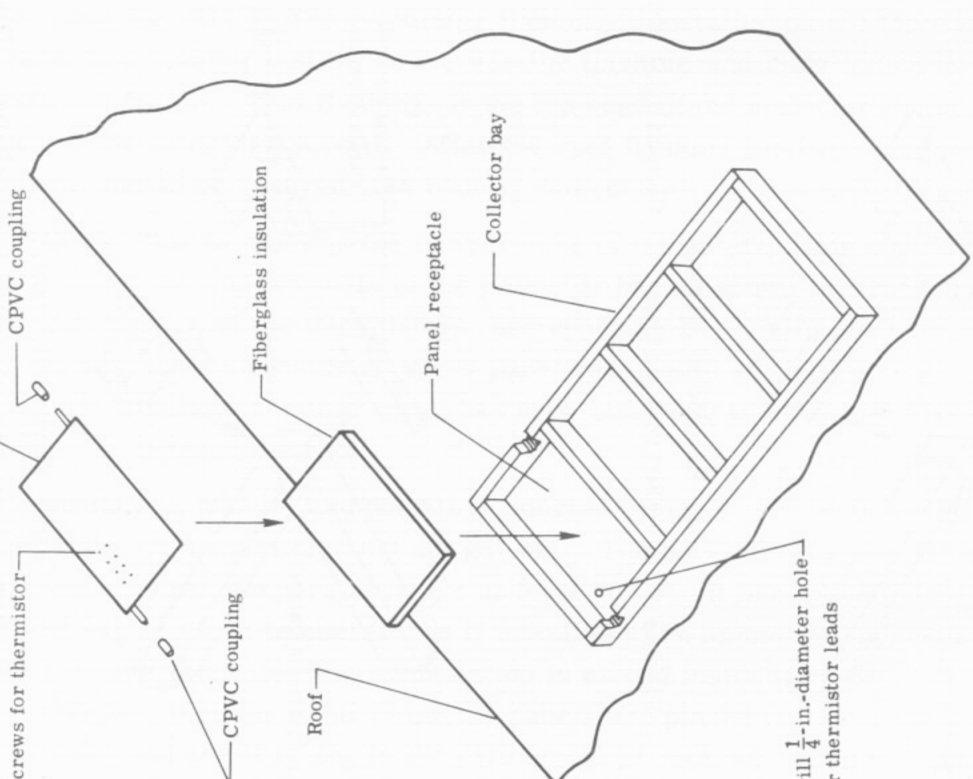


Figure A12. - Exploded view of solar collector bay.

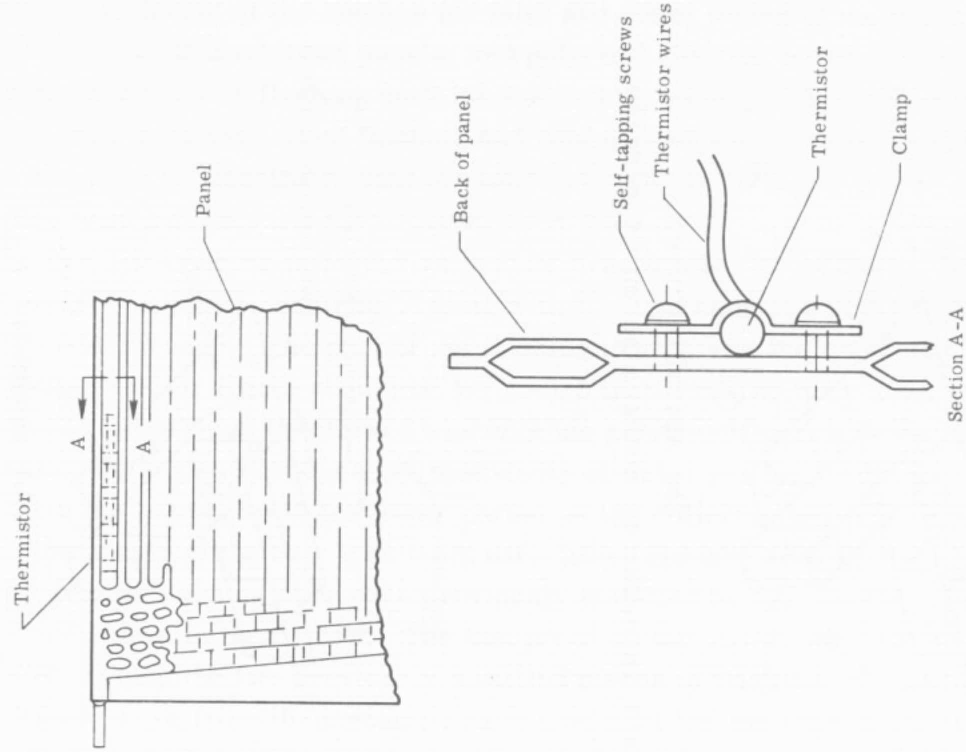


Figure A13. - Thermistor installation.

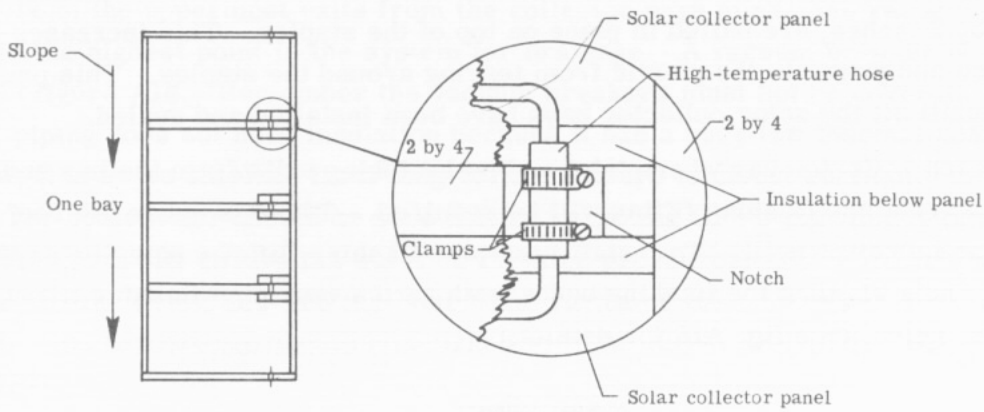


Figure A14.- Typical connection between do-it-yourself panels.

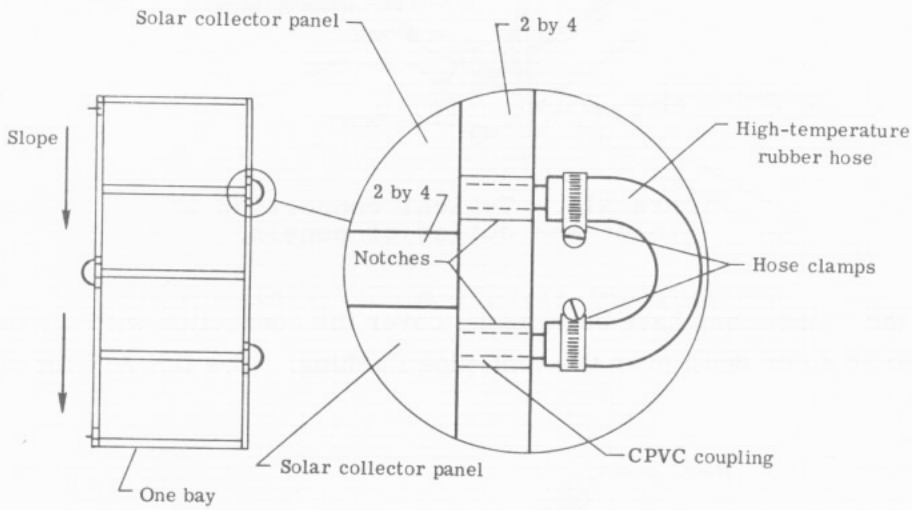


Figure A15.- Typical connection between off-the-shelf standard panels.

upper edge and thread the wires from the thermistor down through the fiberglass insulation, through the hole that was drilled in the roof. The wires from this thermistor will be connected later to the differential temperature flow controller. Use two of the CPVC plastic couplings described in appendix D as thermal insulation to keep the inlet and outlet panel tubing from being in direct contact with the collector bay frame. They will need to be reamed as there is a small shoulder inside in the middle of the coupling. Slip the coupling on the panel tubing as shown in figure A12. The blocks that were removed earlier to form the notches in the collector bay frames are now put back into place and sealed with duct seal. The remaining flashing where the inlet and outlet tubing pass through the collector bay is installed and sealed with roofing cement. The panels in each bay are then connected together in series as shown in figure A15 with high-temperature hose. After all panels in the bay have been installed, the polyvinyl fluoride cover is installed in place. The plastic film should be stretched taut and stapled in place. Then the batten strips, 1/4 inch by 2 inches, are nailed in place on top of the staples. This increases the holding surface and prevents the plastic from tearing around the staples. This process is repeated until all the solar collector bays have been installed and sealed.

At each collector bay where inlet and outlet tubing exits from the bay and enters the roof, a vent-pipe flashing fitting will be required. A hole is cut in the roof with a hole saw and electric drill. To install vent-pipe flashing, lift the shingles on the upward side of the hole slipping the flashing underneath as the vent-pipe flashing fitting is pushed through the hole. (See fig. A16 for details.)

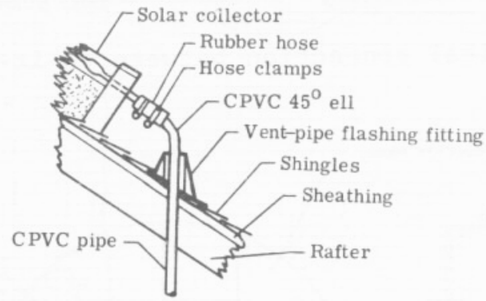


Figure A16.- Typical connection at inlet and outlet of panels.

After the connections have been made, cover the connection with a water-tight boot. This boot should come down over the vent-pipe flashing. (See fig. A17 for details.)

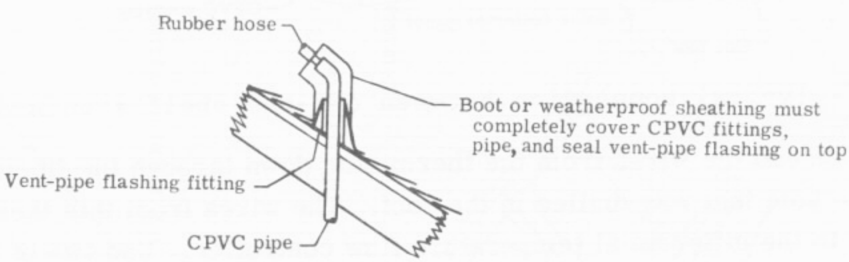


Figure A17.- Weather covering installation.

APPENDIX A

One or more of the uppermost exits from the collector bays must have vacuum breakers installed in the highest point in the system for drainage. A vacuum breaker is shown installed in figure A18. Remember the vacuum breakers must not be covered. Although the CPVC piping does not need insulation because it has a very low thermal conductivity coefficient, it must be shielded from long-term exposure to direct sunlight. A word of caution: The homeowner should be sure that he is getting CPVC pipe and fittings, not PVC. Only CPVC will endure hot water at elevated pressures. CPVC piping has an ASTM (American Society for Testing Materials) rating of 100 pounds per inch^2 at 180° F. The plastic pipe and fittings should be marked with the ASTM designation D2846 to be genuine CPVC.

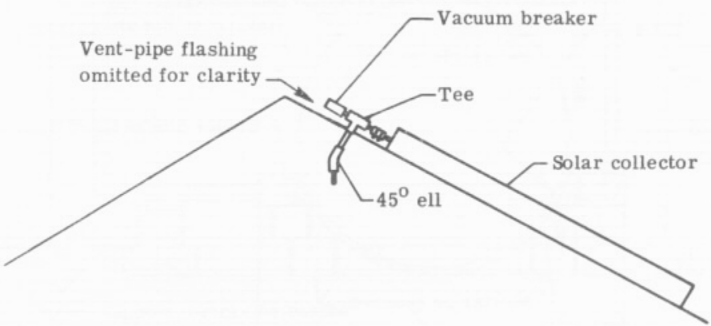


Figure A18.- Vacuum breaker installation.

APPENDIX B

STORAGE TANK AND FOUNDATION INSTALLATION

The storage tank may be installed either inside the garage or outside behind the house. The storage tank used in the demonstration system is shown in figure B1. The homeowner could use a foundation similar to the one shown if he elects to use a steel tank as used in the demonstration system. The steel tank used in this system was approximately 4 feet in diameter and 10 feet 8 inches long.

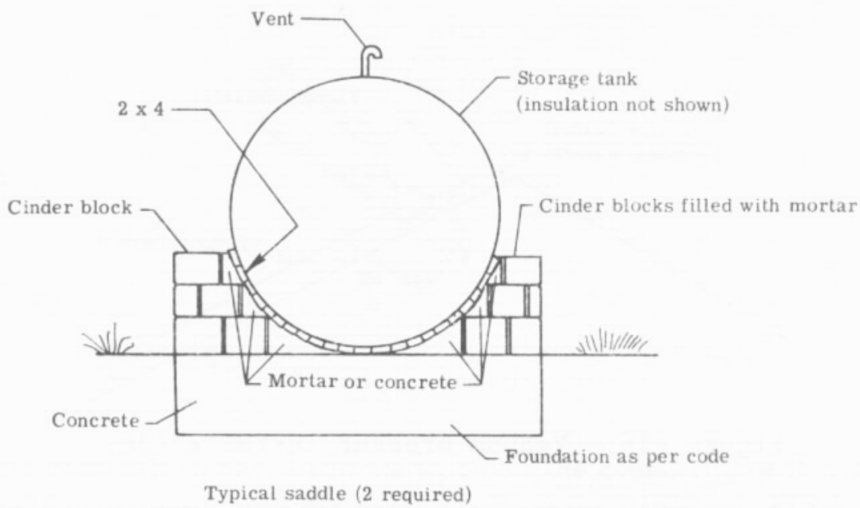


Figure B1.- Outside foundation used in demonstration system.

A concrete storage tank (septic tank) above ground is recommended instead of the steel tank since it is less expensive and simpler to install. The storage tank cost in table 5 is for a concrete tank, which can be placed in the backyard similar to oil and gas tanks above ground. The size of a 1000-gallon tank is approximately 9 feet long, 5 feet wide, and 6 feet high. Contact the local septic tank suppliers as to what can be supplied for a water storage tank to be mounted on the ground. Some tanks are not recommended for use above ground because the sidewalls do not have sufficient strength to support the water in the tanks. Contact the local building inspector as to where the tank can be located in the yard and how the tank can be installed. Build the tank supports similar to that shown in figure B2. Ask the tank supplier to place the tank on the supports when it is delivered. All other work can be done by the homeowner. The storage tank must be installed so that the inlet to the pump is a minimum of 2 feet below the surface of the water level in the tank. A decorative fence may be placed around the tank.

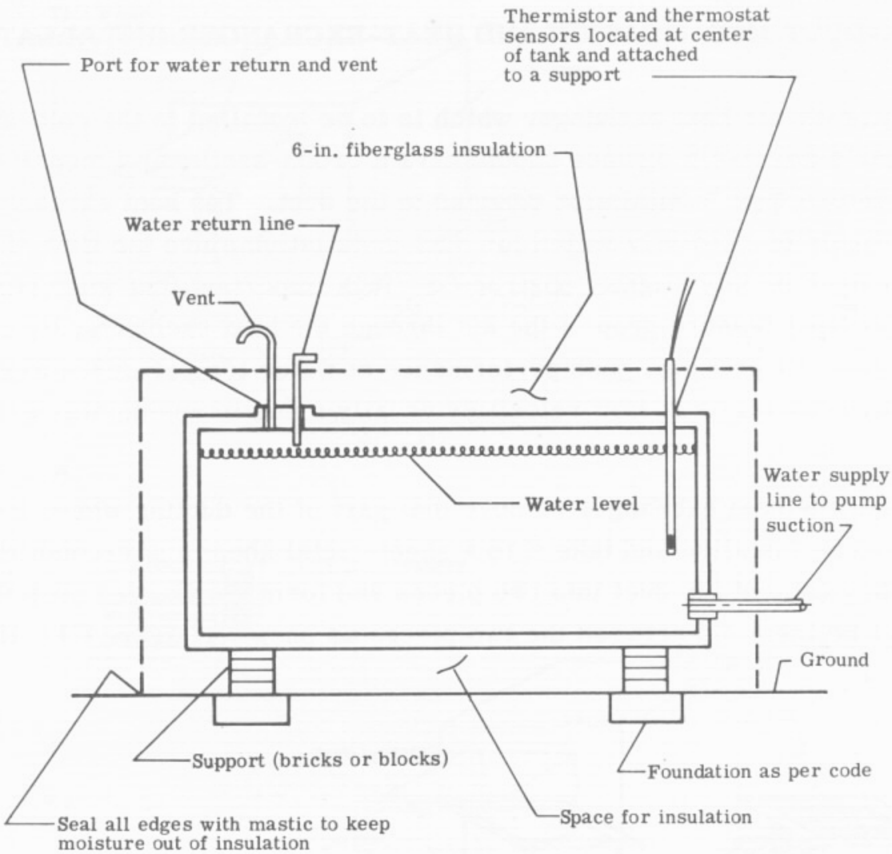


Figure B2.- Typical tank installation.

The homeowner should be cautioned that underground installation of concrete storage tanks will present the following difficulties:

(1) The thermal insulation will be more difficult to install and seal from moisture.

(2) The tank and pump installation will be more difficult. A hole must be dug for the tank, and the pump would have to be installed in a dry well.

(3) Maintenance or repairs would be more difficult.

Whether the storage tank is installed indoors or outside, it should be insulated with a low-thermal-conductivity type insulation, such as 6-inch-thick fiberglass. If the storage tank is installed outside, the insulation must be waterproofed with roofing cement or enclosed in a tool shed or other weatherproof shelter.

APPENDIX C

AIR-DUCT MODIFICATION AND HEAT-EXCHANGER INSTALLATION

The water-to-air heat exchanger which is to be installed in the cold-air return of the homeowner's warm-air furnace should have a cross-sectional dimension similar to the cold-air return duct to minimize changes to the duct. The heat exchanger in the bill of materials (table 6) is ideally suited for duct installation since the flow of air through the heat exchanger is only slightly obstructed. It is important that when purchasing the heat exchanger the pressure drop of the air through the heat exchanger be no more than 0.1 inch of water. It provides good performance at water temperatures available from solar collectors and air-duct flow velocities usually found in residential warm-air heating systems.

To install the heat exchanger remove that part of the ducting where the heat exchanger is to be installed and take it to a sheet-metal shop or air-conditioning service company. They can cut the duct into two pieces and form the flanges such that the heat exchanger can be installed between the two pieces as shown in figure C1. If the heat

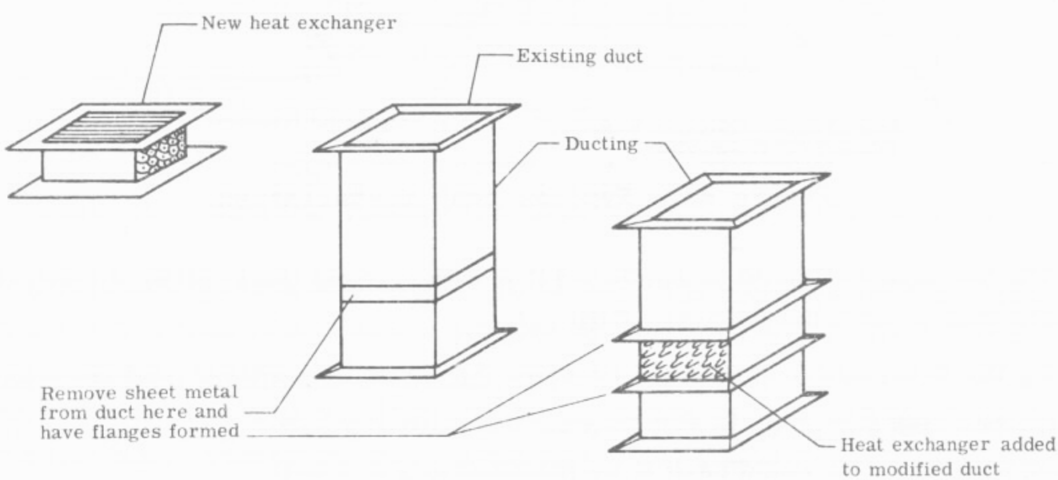
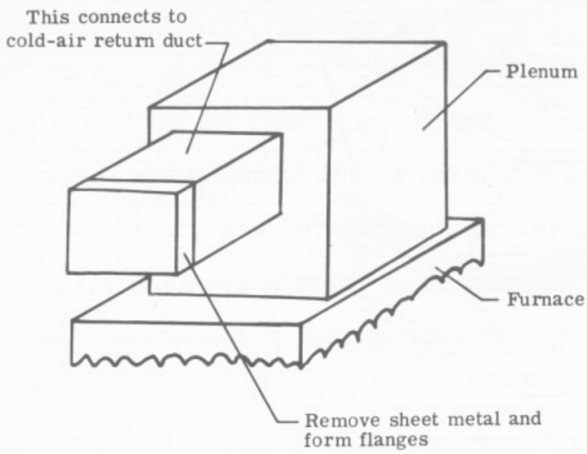


Figure C1.- Details of duct modification and heat exchanger installation.

exchanger can be located next to an existing flange joint in the cold-air return duct, then only the end of a piece of ducting will need to be shortened and flanged as shown in figure C2 to match the flanges of the heat exchanger. The homeowner should drill the holes in the duct flanges before reinstalling the duct. Drill holes in duct flanges to match existing holes in the heat exchanger. Using sheet metal duct flange gasket material, a soft rubber stripping, make up the flange or flanges of the ducting and install the screws. After the ducting has been reinstalled, the heat exchanger is ready to be installed. Place



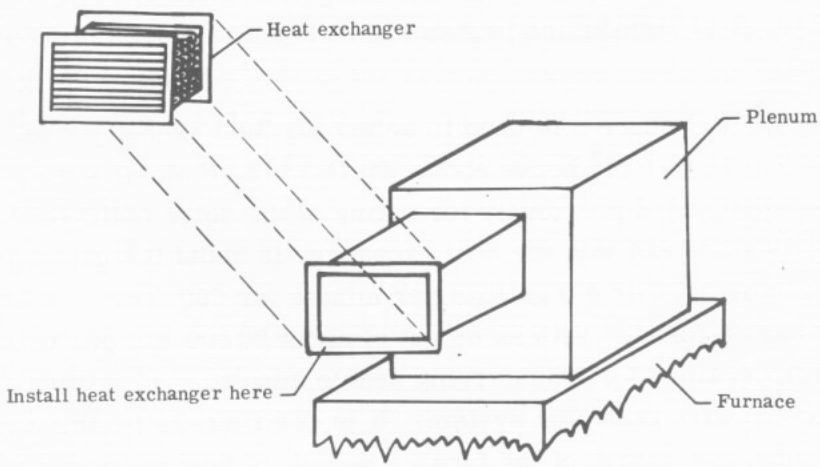


Figure C2.- Modification of cold-air plenum for installation of heat exchanger.

the heat exchanger into the opening in the cold-air return duct, matching up the screw holes in the flanges. Insert the rubber gasket materials and install the screws. Self-tapping screws are suitable for connecting duct flanges, but nuts and bolts may be required to connect the duct ends to the heat exchanger flange which is usually a thicker metal and predrilled.

If the heat exchanger cannot be installed adjacent to the cold-air plenum of the furnace, then that part of the duct adjacent to the plenum should be made as short as practicable, to prevent sagging of the duct. (See fig. C1.) This part of the ducting supports the weight of the heat exchanger.

If a heat exchanger cannot be obtained to fit the cross-sectional shape of the cold-air return duct, two transition pieces similar to those shown in figure C3 will be needed. These transition pieces can also be made by a sheet-metal shop. Installation of the heat

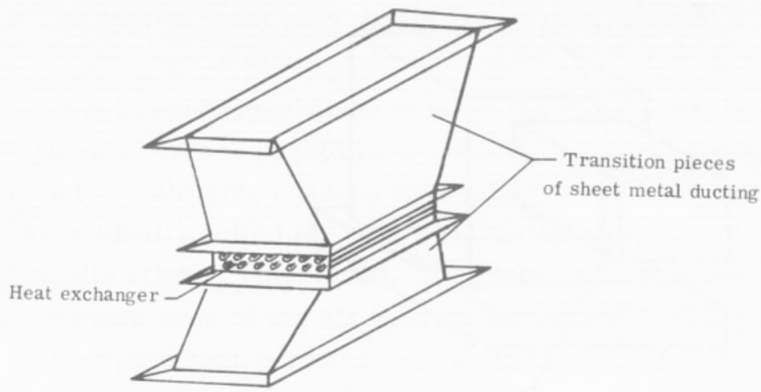


Figure C3.- Modification to duct where transition section is required.

exchanger by using transition pieces of ducting will be similar to the method just described. The cost of installation is going to be higher because of having to have transition pieces.

The following procedure was used to select the heat exchanger for the demonstration system. For a 1500-foot^2 house about 500 feet^2 of collector area is required as per the rule of thumb discussed previously for sizing of the solar collectors. The water flow rate from the collectors and into the heat exchanger is about 0.8 gallon per minute for each 100 feet^2 of collector area or 4.0 gallons per minute for 500 feet^2. A 1500-foot^2 house would typically have a furnace with an output of about 80 000 Btu per hour. The lowest reasonable water temperature for transferring usable quantities of heat to the air in the duct is about 105° F for any size collector system. It is desirable to be able to transfer at least 20 000 Btu per hour, one-fourth of the furnace output, of heat to the air which flows through the duct at about 900 feet^3 per minute. If the following information is given to an experienced heating and air-conditioning contractor, he can select a heat exchanger for you:

(1) Water flow rate of 4.0 gallons per minute

(2) Water inlet temperature of 105° F

(3) Air inlet temperature of 70° F

(4) Air outlet temperature of 90° F

(5) Heat to be transferred, 20 000 Btu per hour

(6) Air friction pressure drop across the heat exchanger to be no more than 0.1 inch of water

This information was used to size the heat exchanger for the demonstration system. A similar procedure can be used for other size systems. For example, a 2100-foot^2 home would require 700 feet^2 of collector area and would have a furnace output of about 110 000 Btu per hour. Again it is desirable to transfer at least one-fourth of the furnace output, 27 500 Btu per hour, to the air flowing through the duct at about 1330 $feet^3$ per minute. In this case, the information to give to the heat exchanger supplier would be

(1) Water flow rate of 5.6 gallons per minute ($0.8 \times 700/100$ ft^2)

(2) Water inlet temperature of 105° F (same for any size system)

(3) Air inlet temperature of 70° F (same for any size system)

(4) Air outlet temperature of 90° F (same for any size system)

(5) Heat to be transferred, 27 500 Btu per hour (one-fourth of 110 000 Btu per hour furnace output)

(6) Air friction pressure drop across the heat exchanger to be no more than 0.1 inch of water

The Btu output rating of the furnace is given on the metal nameplate attached to the furnace. The capability of the existing fan can also be found on the nameplate. This information should be given to the supplier of the heat exchanger since the heat exchanger will produce additional resistance to the airflow.

APPENDIX D

INSTALLATION OF HOT-WATER DISTRIBUTION SYSTEM

Schematic of the Hot-Water Distribution System

The hot-water distribution system (fig. D1) consists of check valves, electrically operated three-way valves (actuated by a differential temperature flow controller and a thermostatic electric switch), CPVC pipe, tees, ells, and couplings, vacuum breaker, hot-water storage tank, hot-water pump, and heat exchanger. In figure D1, the cap shown on the three-way valve, used for a drain valve, in the hot-water distribution was necessary to provide an inexpensive drain valve that would be energized in the closed position when the other three-way valve was energized. The hot-water distribution system should be laid out as shown in figure D1, with a slope or gradient of not less than 0.25 inch per foot.

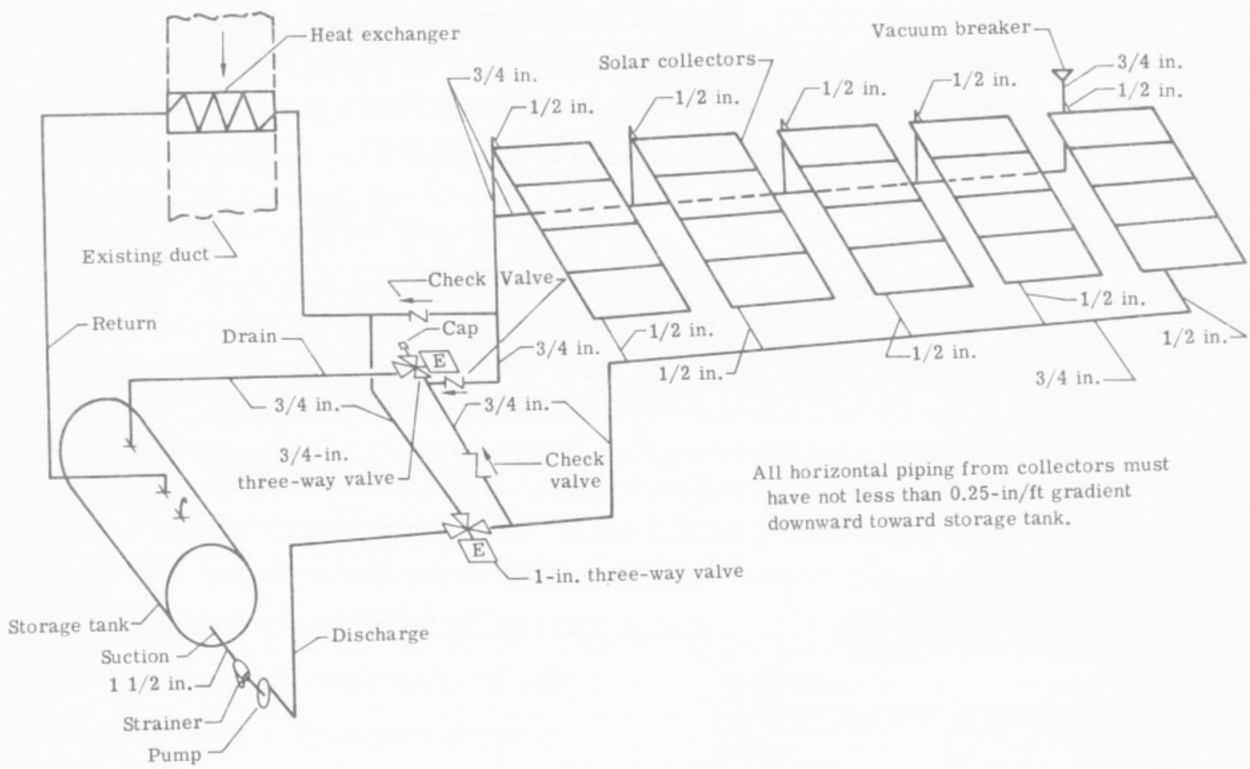
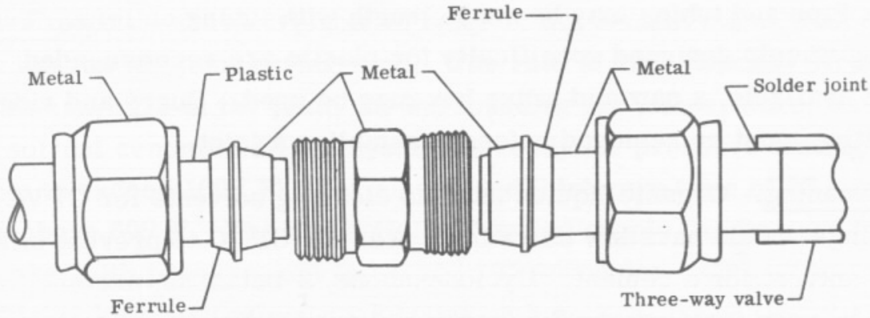


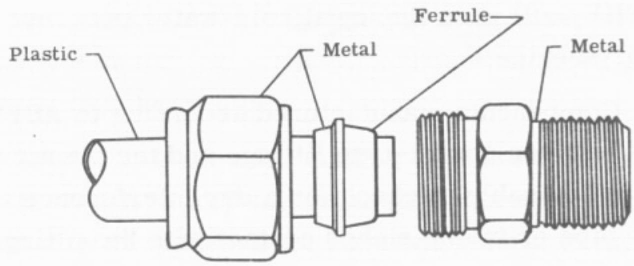
Figure D1.- Schematic of hot-water distribution system. All dimensions are nominal pipe sizes.

Horizontal piping must have a gradient so that the solar panels can automatically drain for freeze protection in case of a power failure. Plastic pipe to metal tube adapters are soldered to the two three-way valves (fig. D2(a)), which the homeowner can have done at any plumbing shop. The pump is a high-temperature positive displacement pump with an

APPENDIX D



(a) Plastic pipe to metal tube.



(b) Plastic pipe to metal pipe.

Figure D2.- Adapters.

internal relief valve which shall be set at 50 pound per inch^2 gage. This pump should be installed in the lowest elevation of the suction line as shown in figure D1. The heat exchanger will require two threaded ferrule-type transition fittings, as shown in figure D2(b), to make the connection from the copper tube of the heat exchanger to the CPVC piping. The pump suction strainer fitting shown in figure D1 should be fitted with a 100-mesh-size stainless-steel screen.

Assembly of CPVC Pipe and Fitting

Storage and handling.- CPVC pipe, tubing, and fittings should be stored indoors to avoid unnecessary dirt accummulation and long-term exposure to sunlight. Pipe and tubing should be stored flat on continuous supports in straight uncrossed bundles. Care should be taken in handling to insure that unnecessary abuse such as crushing or abrasion on concrete is avoided.

Thermal expansion.- CPVC pipe has a linear thermal expansion rate of approximately 1/2 inch per 100° F temperature change for each 10 feet of pipe. The pipe should not be clamped rigidly but rather supported by broad, smooth hangers which will allow the pipe to move. The hangers should be spaced not more than 3 feet apart.

Installation temperatures.- Solvent cementing should not be attempted at temperatures below 40° F, unless temporary heat can be supplied, nor at temperatures above 110° F.

Cutting.- Pipe and tubing may be cut to length with tubing cutters. Tubing cutters with thin cutting wheels designed specifically for plastic are recommended. When tubing cutters are not available, a saw and miter box may be used. Burrs and ridges caused by handling or cutting must be removed before assembling a joint.

Solvent cleaning.- Organic liquids used as cleaning solvents for CPVC pipe tees, ells, and couplings should have low solvation power for CPVC to prevent mistaken use of the cleaning solvent for a cement. Cyclohexanone, 2-butanone, acetone, or a CPVC cleaner should be used for cleaning the plastic pipe and fittings. THF (tetrahydrofuran) should not be used for cleaning CPVC piping and fittings. Uncemented joints made with a good solvent, such as THF, will pass the usual cold-water pressure check but are likely to fail later in hot-water service.

Interference fit.- Components manufactured according to ASTM D2846 (ref. 13) will provide interference fit between socket-type fittings and the plastic piping. Before making up a cemented joint, it is advisable to check for a dry interference fit. A good interference fit exists when the pipe or tubing makes contact with the fitting socket wall between one-third and two-thirds of the way into the socket.

Step-by-step assembly.- Correct assembly consists of the following steps:

(1) Cut the pipe square

(2) Remove burrs

(3) Check for interference fit

(4) Clean both pipe ends and fitting socket with a recommended CPVC cleaner or by light sanding, or both

(5) Apply a liberal coat of CPVC solvent cement to the pipe and apply a light coat of cement to the fitting socket

(6) Assemble immediately by bottoming the pipe in the socket and rotating a quarter of a turn as the joint is assembled

(7) Remove excess cement from the joint

If a joint has been properly made up, a small bead of cement will always appear at the juncture between the pipe or tubing and the fitting. Cement that becomes stringy or lumpy should not be used.

Plastic-to-metal transitions.- Union and compression type transition fittings are likely to include ferrules or O-rings or both which form an essential part of the assembly and should not be omitted. Plastic sockets to male threaded adapters should be installed with a recommended thread sealant, such as Teflon tape.

Pressure testing.- It is advisable to refer to the cement manufacturer's recommendation on the can for joint curing time. The rate of cure depends strongly on the cement formulation, size of the joint, the surrounding air temperature, and the humidity. Generally, a solvent cemented CPVC system is ready for pressure testing with cold potable water (not to exceed 100° F) after an elapsed joint cure time of 16 hours at ambient temperatures above 60° F. The domestic cold-water supply can be used to check the system for leaks, with pressure not to exceed 100 pound per inch^2. The system should be kept pressurized for approximately 8 hours with several inspections being made during the 8-hour period for joint leaks.

Repairs.- If a leak is discovered, that portion of the system should be drained and the joint and fittings should be cut out. The pipe should be dried and a new fitting installed using couplings and short lengths of pipe.

Soldering in the area.- The need for making up plastic-to-metal joints by soldering has been eliminated. However, if any soldering is performed on a metal joint, it should not be made any closer than 18 inches to an installed plastic to metal adapter in the same water line.

Safety Requirements for Handling of Solvents and Solvent Cements

Safety requirements for the handling of solvents and solvent cements are as follows:

(1) When joining the pipe and fittings with solvent cement in partially enclosed areas, adequate ventilation is required to minimize breathing of solvent vapors.

(2) In no case should any source of ignition be permitted where solvent or solvent cement is being used.

(3) Solvent and solvent cement should be dispensed only from approved safety containers. Containers for solvent and solvent cement should be tightly closed except when in use.

(4) Proper eye protection in the form of goggles or face shield is advisable when handling any liquid solvent.

(5) All rags impregnated with the solvent or solvent cement should be kept in a safety waste receptacle and disposed of daily.

(6) Proper gloves that are impervious to and unaffected by the solvents used should be worn when frequent contact is likely, whether in the form of cement or cleaner. Skin contact with chemical solvents should be avoided.

(7) Only solvent cement which meets the requirements of ASTM Specification D2846, paragraph 7 (ref. 13), should be used.

APPENDIX E

ELECTRICAL POWER SUPPLY AND DIFFERENTIAL TEMPERATURE FLOW CONTROLLER

The instructions to install the required electrical power components and the differential temperature flow controller (DTFC) are given in this appendix. The electrical power to operate the water pump and the furnace fan motor is controlled by the components listed in table E1. The DTFC turns the water pump on when solar energy can be collected and off when solar energy cannot be collected. The component locations indicated by the component symbols are shown on the electrical power schematic (fig. E1). The name and type of each component are listed in table E1 with the manufacturers of the components.

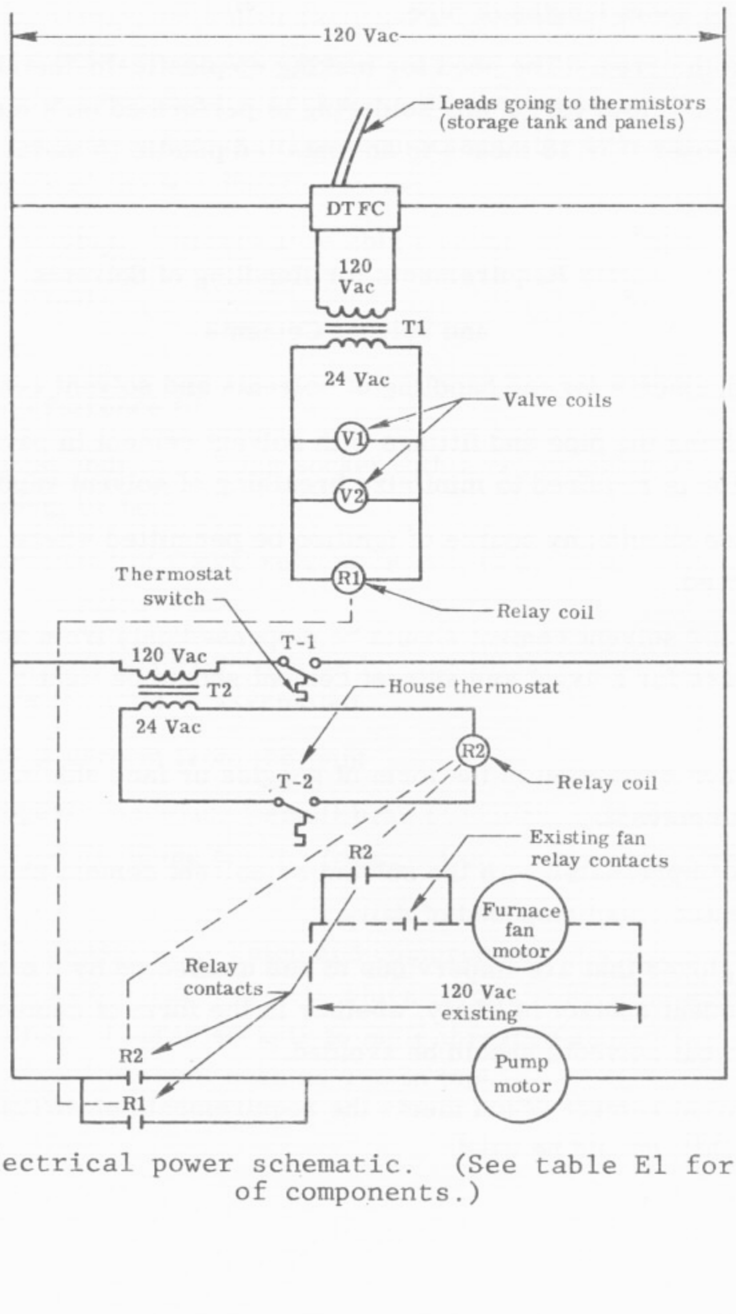


Figure E1.- Electrical power schematic. (See table E1 for description of components.)

APPENDIX E

TABLE E1.- BILL OF MATERIALS FOR ELECTRICAL SUPPLIES

Component		Component description	Manufacturer (a)
Name	Symbol		
Transformer	T1	120 to 24 Vac; 4 A (Type 6K8OVBR or equivalent)	*Allied Electronics Corp. 401 E. 8th St. Fort Worth, TX 76102 (1976 Engineering Manual and Purchasing Guide #760) Newark Electronics Corp. 500 N. Pulaski Rd. Chicago, IL 60624 Allen-Bradley Co. 1201 S. 2nd St. Milwaukee, WI 53204 Radio Shack Div. 2617 W. 7th St. Fort Worth, TX 76107
Transformer	T2	120 to 24 Vac; 1 A (Type 6K113HF or equivalent)	
Relay	R1	24 Vac; 10 A; double pole double throw (Type KA11AG or equivalent)	
Relay	R2	24 Vac; 10 A; double pole double throw (Type KA11AG or equivalent)	
Thermostat	T-2	(Chromalox WR-1E30 or equivalent)	Edwin L. Weigand Div. Emerson Electric Co. 7500 Thomas Blvd. Pittsburg, PA 15208 Honeywell, Inc. 2701 Fourth Ave. S. Minneapolis, MN 55408 General Electric Co. 1 River Rd. Schenectady, NY 12345 Robertshaw Controls Co. Control Systems Div. 1701 Byrd Ave. Richmond, VA 23230
Thermostat switch	T-1	Bimetallic operating temperature, 40° F to 200° F; single pole single throw; 115 Vac; 10-A rated; well included (Mercoid type FM437-3-3516 or equivalent)	*The Mercoid Corp. 4201 Belmont Ave. Chicago, IL 60641 PSG Industries, Inc. 910 Ridge Ave. Perkasie, PA 18944 United Electric Controls Co. 80 School St. Watertown, MA 02172 American Thermostat Corp. Box 60 South Cairo, NY 12482
Differential temperature flow controller	DTFC	120 Vac; 10° F turn-on differential; 5° F turn-off differential; two thermistors included; 300° F maximum sensor temperature (DEKO-LABS Model TC-3 or equivalent)	DEKO-LABS Box 12841 Gainsville, FL 32602 Rho Sigma 5108 Melvin Ave. Tarzana, CA 91356 Jack S. Scovel 4220 Berritt St. Fairfax, VA 22030

[a] Asterisk indicates manufacturer of items used in demonstration system.

APPENDIX E

The electrical circuit shown in figure E1 is designed to operate the water pump and furnace fan motor only when necessary and when certain temperature conditions are met. Electrical power will be supplied to only the water pump on sunny days when the home does not require heat. Electrical power will be supplied to the water pump and also to the furnace fan motor on sunny days when the house requires heat. The fan motor will cut off when the house is heated to the desired temperature. The water pump will continue to run as long as heat is being collected. The control valves (VI and V2 are the three-way valves listed in table 6) are energized on sunny days so that water is directed through the collector and then through the heat exchanger as the water returns to the storage tank. However, on cloudy days or at night, electrical power is supplied to the pump and fan motor only when the house thermostat T-2 calls for heat. The valves which are deenergized for this operation allow the water to flow directly to the heat exchanger without going to the collector.

The differential temperature flow controller enables the entire system to be completely automatic. The controller compares the temperature of the storage tank to the temperature of the solar panels to determine if the system is collecting energy or losing energy to the atmosphere. The controller deenergizes the pump motor when the panel temperature drops to 5° F above the storage tank temperature and automatically drains water out of the panels. The DTFC uses two thermistors as its primary sensing elements. One thermistor is attached to the underside of the panel at the water outlet of one of the bays and the other thermistor is located in the storage tank. The pump motor will start operating again when the panel temperature is 10° F above the storage tank temperature.

The electrical power schematic shows the two circuitry conditions under which electrical power is supplied to the water pump motor to circulate water to the solar panel on sunny days or to the heat exchanger at night or on cloudy days. The first circuit shown at the top part of figure E1 includes a transformer T1 which provides 24 volts to the three-way valves V1 and V2 and to a relay R1. The contacts of this relay will close the circuit to supply power to the water pump motor for circulating water through the solar panel. The signal for this operation is controlled by the differential temperature flow controller (DTFC, table E1) which is available from several suppliers.

The other circuit shown in the center of figure E1 includes a transformer T2 and two thermostat switches and a relay. Two conditions must be satisfied before power can be supplied to the water pump and fan motor. First, the storage tank temperature must be 75° F or higher to close the thermostat switch T-1. Second, the house solar thermostat T-2 must call for heat to be supplied to the house. If these two conditions are satisfied, relay R2 will close to supply electrical power to the water pump and fan motor. The water flows to the heat exchanger and then back to the storage tank as long as these two conditions are satisfied. The relay opens, when the conditions are not satisfied, to shut off electrical power to the water pump and fan motor. The solar thermostat should be set approximately 5^{o} F above the existing house thermostat so that the existing furnace does not cut on until the heat in the storage tank is used. When this heat is used, the house temperature will drop and be maintained by the existing furnace. Relay R2 is connected parallel to the existing relay on the furnace fan.

The connecting wiring between each component should be sized as required by the component manufacturer and by the local electrical inspector. Sketches which show components, distance between components, size of connecting wire, and method of installation will aid greatly in obtaining the electrical inspector's approval.

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