Domestic Hot Water Systems

WORKSHOP IN

THE PRACTICAL ASPECTS OF

SOLAR SPACE AND DOMESTIC WATER HEATING SYSTEMS

FOR

RESIDENTIAL BUILDINGS

MODULE 6

DOMESTIC HOT WATER SYSTEMS

SOLAR ENERGY APPLICATIONS LABORATORY

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NOVEMBER, 1978

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The oldest and simplest domestic use of solar energy is for heating water. Solar hot water heaters were used in the United States at least 75 years ago, first in southern California and later in southern Florida. Although the use of solar water heaters in the United States declined during the last 40 years, use in Australia, Israel, and Japan has risen rapidly, particularly in the last 15 years. Since 1974 solar water heating is again drawing attention in the United States as a direct result of the general public interest in solar energy applications, the demonstration programs of public utility companies and the Solar Demonstration Program and the research and development activities supported by the Department of Energy.

OBJECTIVES

From the contents of this module the trainee should be able to:

1. Identify the types of domestic hot water systems available
2. Select a type of solar domestic hot water system that is appropriate for a particular location
3. Select a suitable collector type and size for a specific application
4. Install and put into operation a domestic hot water system.

TYPES AND CHARACTERISTICS OF SOLAR HOT WATER HEATERS

Most of the solar hot water heaters that have been experimentally and commercially used can be placed in two main groups:

1. Non-circulating types, involving the use of water containers that serve both as solar collectors and storage
2. Circulating types, involving the supply of solar heat to a fluid circulating through a collector and storage of hot water in a separate tank.

The circulating group may be divided into the following types and sub-types:

1. Direct heating, single-fluid types in which the water is heated directly in the collector, by:
   a. Thermosiphon circulation between collector and storage
   b. Pumped circulation between collector and storage
2. Indirect heating, dual-fluid types in which a non-freezing medium is circulated through the collector for subsequent heat exchanger with water, when:
   a. Heat transfer medium is a non-freezing liquid
   b. Heat transfer medium is air

NON-CIRCULATING TYPE

Although of little potential interest in Colorado, or elsewhere in the United States, a type of solar water heater extensively used in Japan involves heat collection and water storage in the same unit. The most common type comprises a set of black plastic tubes about six inches in diameter and several feet long in a box covered with glass or clear plastic. Usually mounted in a tilted position, the tubes are filled each morning with water and heated by solar energy throughout the day. The filling can be accomplished by a float-controlled valve and a small supply tank. Late in the day, heated water can be drained from the tubes for household use.

In typical Japanese installations, non-pressurized hot water service is thus provided.

DIRECT HEATING, THERMOSIPHON CIRCULATING TYPE

The most common type of solar water heater, appropriate for non-freezing climates, is shown in Figure 6-1. The collector, usually single glazed, may vary in size from about 30 square feet to 80 square feet, and the insulated storage tank is commonly in the range of 40 to 80 gallons capacity. The hot water requirements of a family of four persons can usually be met by a system in the middle of this size range, in a sunny climate. Operation at supply line pressure can be provided if the system is so designed. With a float valve in the storage tank or in an elevated head tank, unpressurized operation can be utilized if the system is not designed for pressure. In the latter case, gravity flow from the hot water tank to hot water faucets would have to be accepted, or an automatic pump would have to be provided in the hot water line to supply pressure service. Plumbing systems and fixtures in the United States normally require the pressurized system.

Location of the tank higher than the top of the collector permits circulation of water from the bottom of the tank through the collector and back to the top of the tank. The density difference between cold and hot water produces the circulating flow. Temperature stratification in the storage tank permits operation of the collector under most favorable conditions, water at the lowest available temperature being supplied to the collector and the highest available temperature being provided to service. Circulation occurs only when solar energy is being received, so the system is self-controlling. The higher the radiation level, the

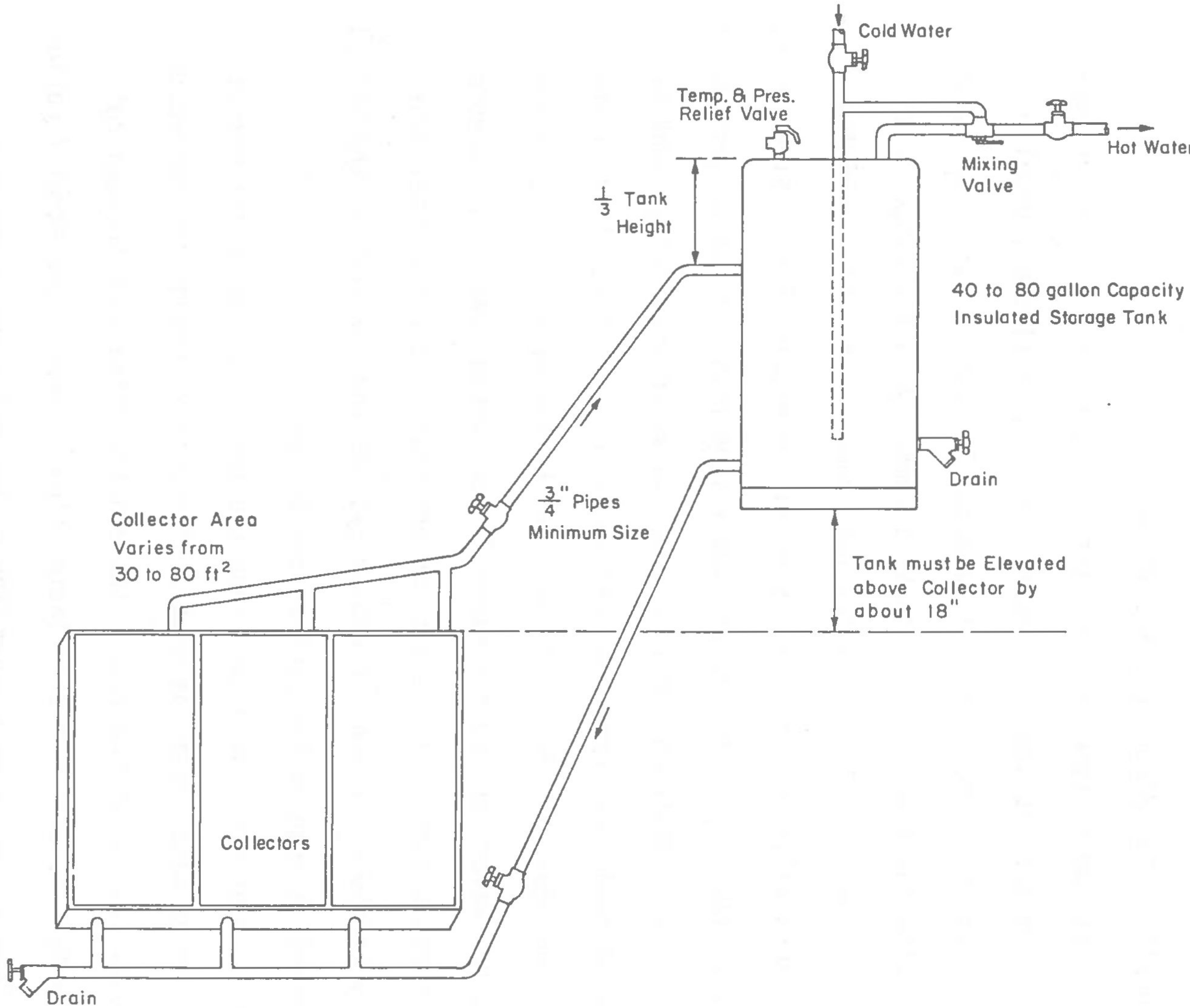

Figure 6-1. Direct Heating Thermosiphon Circulating Solar Water Heater

greater the heating and the more rapid the circulating rate will be. In a typical collector under a full sun, a temperature rise of 15°F to 20°F is commonly realized in a single pass through the collector.

To prevent reverse circulation and cooling of stored water when no solar energy is being received, the bottom of the tank should be located above the top header of the collector. If the collector is on a house roof, the tank may also be on the roof or in the attic space beneath a sloping roof.

Although seldom used in cold climates, the thermosiphon type of solar water heater can be protected from freezing by draining the collector. To avoid draining the storage tank also, thermostatically actuated valves in the lines between collector and storage tank must close when freezing threatens, a collector drain valve must open, and a collector vent valve must also be open. The collector will then drain and air will enter the collector tubes. Water in the storage tank, either inside the heated space or sufficiently well insulated to avoid freezing, does not enter the collector during the period when sub-freezing temperatures threaten. Resumption of operation requires closure of the drain and vent valves and opening of the valves in the circulating line. The possibility of control failure or valve malfunction makes this complex system unattractive in freezing climates.

DIRECT HEATING, PUMP CIRCULATION TYPES

If placement of the storage tank above the collector is inconvenient or impossible, the tank may be located below the collector and a small pump used for circulating water between the collector and storage tank. This arrangement is usually more practical than the thermosiphon type in

Colorado because the collector would often be located on the roof with a storage tank in the basement. Instead of thermosiphon circulation when the sun shines, a temperature sensor actuates a small pump which circulates water through the collector-storage loop. A schematic arrangement is shown in Figure 6-2. To obtain maximum utilization of solar energy, control is based on the difference in water temperature at collector outlet and bottom of storage tank. Whenever this difference exceeds a preset number of degrees, say 10°F, the pump motor is actuated. The sensor at the collector outlet must be located close enough to the collector so that it is affected by collector temperature even when the pump is not running. Similarly, the sensor in the storage tank should be located in or near the bottom outlet from which the collector is supplied. When the temperature difference falls below the preset value, the pump is shut off and circulation ceases. To prevent reverse thermosiphon circulation and consequent water cooling when no solar energy is being received, a check valve should be located in the circulation line.

If hot water use is not sufficient to maintain storage tank temperature at normal levels (as during several days of non-use), boiling may occur in the collector. If a check valve or pressure-reducing valve prohibits back flow from the storage tank into the main, a relief valve must be provided in the collector-storage loop. The relief valve will permit the escape of steam and prevent damage to the system.

DIRECT HEATING, PUMP CIRCULATION, DRAINABLE TYPES

If the solar water heater described above is used in a cold climate, it may be protected from freeze damage by draining the collector when sub-freezing temperatures are encountered. Several methods can be used.

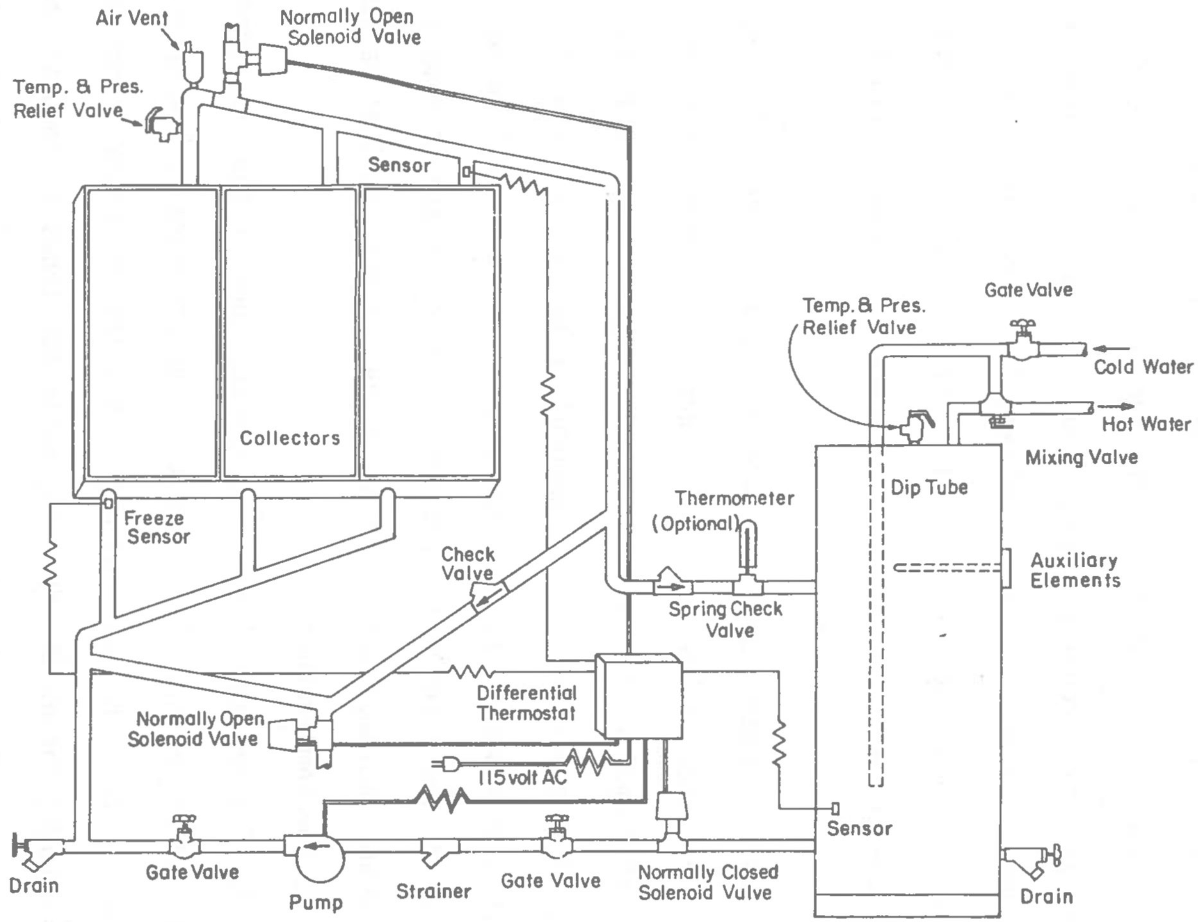

Figure 6-2. Direct Heating, Pump Circulation Solar Water Heater with Automatic Drain-Down (Applicable also to a Two-Tank System)

Their common requirement, however, is reliability, even when electric power may not be available. One arrangement is shown in Figure 6-2.

Drainage of the collector in freezing weather can be accomplished by automatic valves which provide water outflow to a drain (sewer) and the inflow of air to the collector. The control system can be arranged so that whenever the circulating pump is not in operation, these two valves are open. To assure maximum reliability, the valves should be mechanically driven to the drain position (by springs or other means), rather than electrically, so that in the event of a power failure, the collector can automatically drain.

The drainage system shown in Figure 6-2 is actuated by the temperature sensor, at the bottom of the collector. When the sensor indicates a possibility of freezing, it can open the drainage and vent valves, thereby providing protection. The temperature sensor can be of the vapor pressure type, with capillary tube connections to mechanical valve actuators, or of the electrical type where the valves are held open by electrical means, automatically closing either when electrical failure occurs, or at low temperatures.

Start-up of a vented collector system must permit the displacement of air from the collector. In either the line-pressure system or the unpressurized system, the entry of water into the collector (from the shut-off valve or pump) forces air from the collector tubes as long as the vent remains open. The vent valve design can be of a type which automatically passes air but shuts off when water reaches it.

CIRCULATING TYPE, INDIRECT HEATING

The needs and means for collector drainage of direct heating systems in freezing climates involve costs and there is still some risk of freezing with those systems. The drainage requirement can be eliminated by the use of a non-freezing heat transfer medium in the solar collector, and a heat exchanger for transfer of heat from the solar-heated collecting medium to the service water. The collector never needs to be drained, and there is no risk of freezing and damage. Corrosion rate in the wet collector tubes is also decreased because there is no free oxygen in the heat transfer medium.

Liquid Transfer Media

A method for solar water heating with a liquid heat transfer medium in the solar collector is illustrated in Figure 6-3. The most commonly used liquid is a solution of ethylene glycol (automobile radiator antifreeze) in water. A pump circulates this unpressurized solution, as in the direct water heating system, and delivers the liquid to and through a liquid-to-liquid double-wall heat exchanger. Simultaneously, another pump circulates domestic water from the storage tank through the exchanger, back to storage. The control system is essentially the same as that in Figure 6-2. If the heat exchanger is located below the bottom of the storage tank, and if the pipe sizes and heat exchanger design are adequate, thermosiphon circulation of water through the heat exchanger can be used and the pump can be eliminated from the pipe loop. A small expansion tank needs to be provided in the collector loop, preferably near the high point of the system, with a vent to the atmosphere.

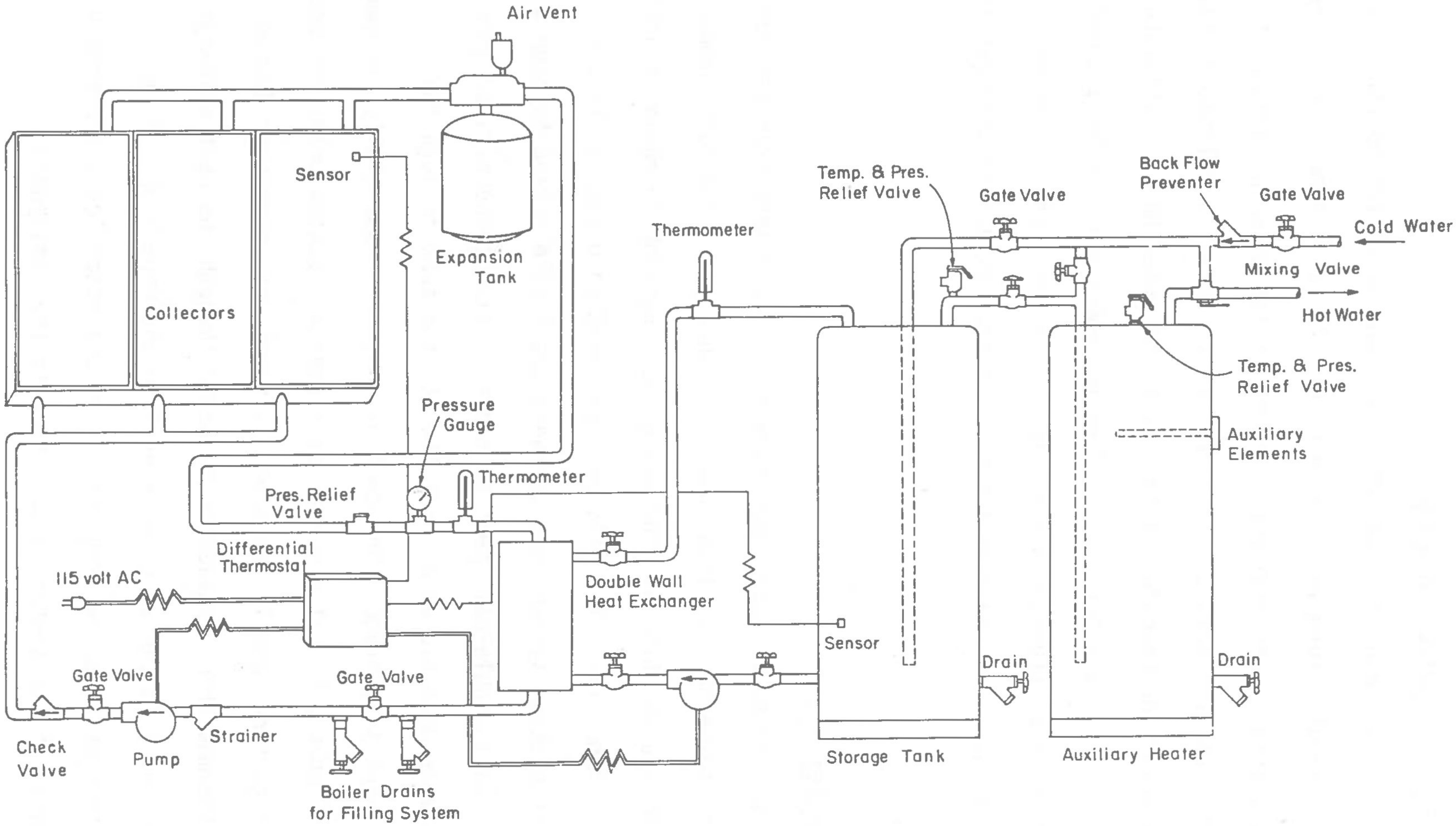

Figure 6-3. Indirect Heating, Pump Circulation Solar Water Heater with Liquid Heat Transfer Media

To meet most code requirements, the heat exchanger must be of a design such that rupture or corrosion failure will not permit flow from the collector loop into the domestic water, even if pressure on the water side of the exchanger drops below that on the antifreeze side. A conventional tube-and-shell exchanger would therefore not usually be acceptable. Similarly, a coil inside the storage tank, through which the collector fluid is circulated, would not be satisfactory. Parallel tubes with metal bonds between them, so that perforation of one tube could not result in liquid entry into the other tube, would be a suitable design. A finned tube air-to-liquid heat exchanger could also be used by circulating the two liquids through alternate rows of tubes, heat transfer being by conduction through the fins.

Although aqueous solutions of ethylene glycol and propylene glycol appear to be most practical for solar energy collection, organic liquid such as Dowtherm J and Therminol 55 may be employed. Price and viscosity are drawbacks, but chemical stability and assurance against boiling are advantages over the antifreeze mixtures.

Air Transfer Media

An air heating collector can be used to heat domestic water with an air-to-water heat exchanger is illustrated in Figure 6-4. A solar air heater is supplied with air from a blower, the air is heated by passage through the collector, and the hot air is then cooled in the heat exchanger through which domestic water from a storage tank is either pumped or circulated by thermosiphon action. Air from the heat exchanger is recirculated to the collector. Differential temperature control (between collector and storage) is employed as in the other systems described.

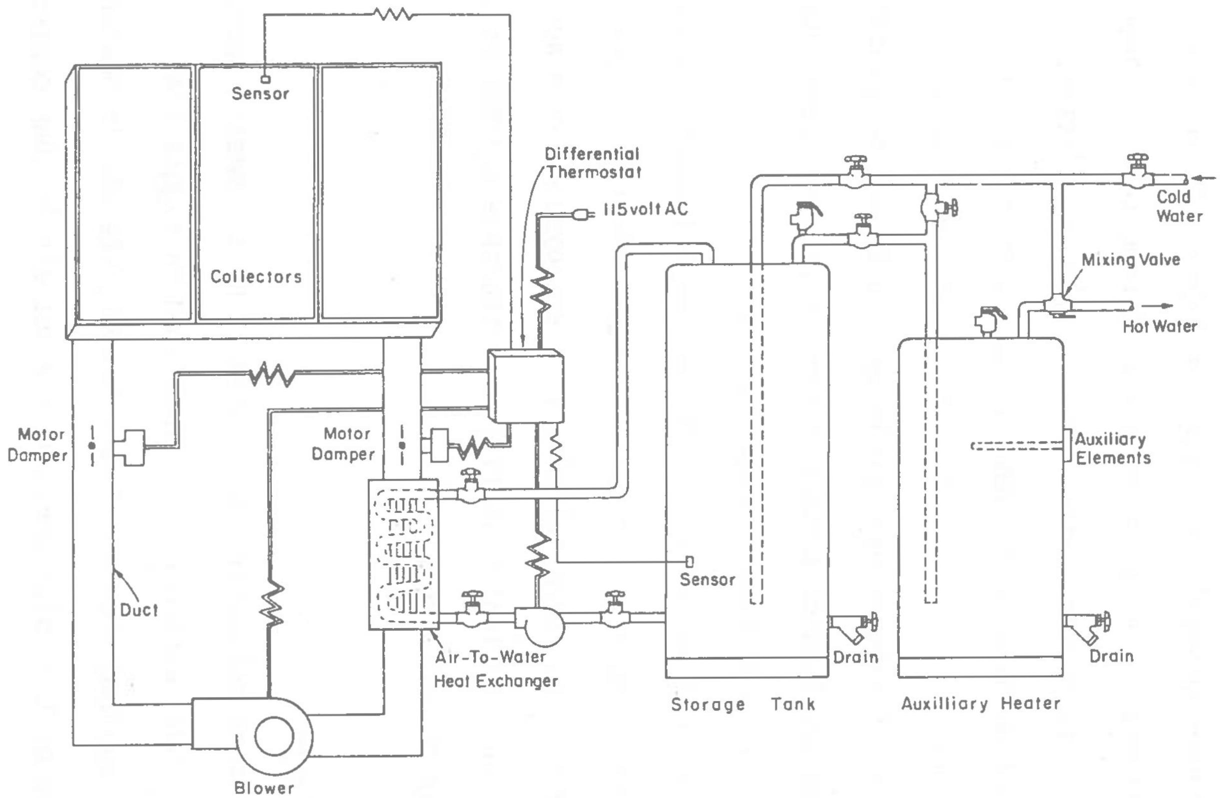

Figure 6-4. Solar Water Heater with Air Collectors

Advantages of the air heat transfer medium are the absence of corrosion in the collector loop, freedom from liquid leakage, and freedom from boiling and loss of collector fluid. Disadvantages are the larger conduit between collector and heat exchanger, high power consumption for circulation, and slightly larger collector surface requirements compared to liquid-heating collectors.

AUXILIARY HEAT

A dependable supply of hot water requires the availability of auxiliary heat for supplementing the solar source. The numerous methods of providing auxiliary heat vary in cost and effectiveness. A general principle for maximizing solar supply and minimizing auxiliary use is to avoid direct or indirect auxiliary heat input to the fluid entering the solar collector. If auxiliary heat is added to the solar hot water storage tank, so that the temperature of the liquid supplied to the collector is increased above that which only the solar system would provide, efficiency is reduced because of higher heat losses from the collector. Thus, auxiliary heat should be added at a point beyond (downstream from) the solar collector-storage system. A conventional electric hot water heater is shown in Figures 6-3 and 6-4 supplied with hot water from the solar tank (whenever a hot water tap is opened). Any deficiency in temperature is made up by electricity in the thermostatted conventional heater. It is evident that auxiliary heat supply in these designs cannot adversely affect the operation of the solar system.

A one-tank system with the electric resistance heaters in the upper portion of the solar storage tank, as shown in Figure 6-2, may not reduce solar collection efficiency significantly. Temperature stratification in the tank, accomplished by bringing cold water from the main into the bottom and by circulating through the collector from the bottom of the tank to the upper portion of the tank, prevents auxiliary heat from increasing the temperature of the water supplied to the collector. Water returning from the collector may be brought into the tank below the level of the resistance heater so that the hot supply is always available at the thermostatted temperature. In effect, the two tanks shown in Figures 6-3 and 6-4 are combined into one, with temperature stratification providing a separation. The total amount of storage is, of course, reduced unless the one tank is increased in size. If relatively high temperature water is desired, there may be an undersirable influence of auxiliary supply on collector efficiency because of some mixing in the tank.

Although the description of the above system refers to direct circulation of water through the collector, the same factors apply to the systems involving heat exchange with antifreeze solutions or air circulating through the collector. In all cases, auxiliary heat should be supplied downstream from the solar storage tank, regardless of whether the water itself is circulated through the collector or whether heat is exchanged between the domestic water and a solar heat transfer fluid.

TEMPERATURE STRATIFICATION IN SOLAR HOT WATER TANK

As in a conventional hot water heater, the temperature in the upper part of a solar hot water tank will normally be considerably higher than at the bottom. The lower density of hot water permits this stratification , provided that turbulence at inlet and outlet connections is not excessive. The supply of relatively cold water from the bottom of the tank to the collector permits the collector to operate at its highest possible efficiency under the prevailing ambient conditions. With a circulation rate such that a temperature rise through the collector of 15°F to 20°F occurs, the lower part of the storage tank is furnished to the collector for maximum effectiveness. If little hot water is withdrawn from the tank during a sunny day, the late afternoon temperature at the bottom of an 80 gallon tank connected to a 40- to 50-square foot collector may be well above 100°F -- even approaching the temperature at the top of the tank. Collection efficiency thus varies throughout the day, depending not only on solar availability but also on the temperature of water supplied to the collector from the tank bottom. Some data presented at the end of this module will illustrate the range of temperatures achievable in solar water heaters.

TEMPERATURE CONTROL LIMIT

In addition to the differential temperature control desirable in most solar water heating systems (which sense temperature differences between collectors and storage), protection against excessive water temperature may be necessary. Several possible methods can be used. In nearly all types of systems, whether direct heating of the potable water or indirect heating through a heat exchanger, a thermostatically controlled mixing valve can be used to provide constant temperature water for household use as shown in Figures 6-3 and 6-4. Cold water is admitted to the hot water line immediately downstream from the auxiliary heater in sufficient proportion to secure the desired preset temperature. The solar hot water tank is allowed to reach any temperature attainable, and the auxiliary heater furnishes additional energy only when the auxiliary tank temperature drops below the thermostat set point. Maximum solar heat delivery is thus achieved, and no solar heat needs to be discarded except that which might sometimes be delivered when the main storage (preheat) tank is at the boiling point. Any additional solar heat collected under that condition would be dumped through a pressure relief valve with steam escaping to the surroundings.

A steam vent from the solar hot water system involving a dual-liquid design, with heat exchanger, should normally be in the hot water loop rather than the collector loop. Loss of collector fluid by vaporization is thereby avoided. It is necessary, however, in this design, that the collector tubes and associated piping be capable of withstanding pressure at least as high as developed when the steam vent valve in the storage loop is actuated. If, for example, the blow-off valve in the storage circuit is set for 50 psi, and if the collector loop containing 50 percent ethylene glycol normally operates at a temperature 20°F above the storage tank temperature, pressure in the collector loop would also be about 50 psi when the storage tank vent is actuated. (There is approximate equality of pressure due to similarity between boiling point elevation and temperature difference in the heat exchanger.)

An alternative to the high pressure collector capability described above is available in the form of an organic heat transfer fluid having a high boiling point. Dowtherm J or Therminol 55 have boiling points above 300°F, so if one of these fluids is used, the development of pressure in the collector loop would not occur, even when the storage system is venting steam at 50 psi. This option appears considerably more practical than the pressurized collector required with aqueous fluids in the dual-liquid system.

Still another option for high-temperature protection is available if the collector is used as a heater for a high-boiling organic liquid or for air. To prevent the storage tank from reaching a temperature higher than desired, a limiting thermostat in that tank can be used simply to discontinue circulation of the heat transfer fluid (organic liquid or air) through the collector and heat exchanger. No additional heat is therefore dissipated in the form of collector heat loss. The collector temperature rises substantially, frequently above 300°F, but if properly designed, there should be no collector damage. With a reliable limit switch in the storage tank, there can be no dangerous pressure developing anywhere in the system. In addition, there is no loss of water (in the form of steam) even when there is no use of hot water for long periods.

If the hot water/cold water mixing valve downstream from the auxiliary heater is not used, a temperature limit control in the solar storage tank can be set at the maximum desired temperature of service hot water. Therefore, water cannot be delivered at any temperature higher than the set point in the solar storage tank or the set point in the auxiliary heater, whichever is higher. Less solar storage capability would be involved in this design because the solar storage tank is prevented from achieving higher temperatures, even when solar energy is available.

In a direct type of solar water heater operating at service pressure, with potable water circulating through the collector, a venting valve is provided near the top of the collector. It would have to be set for release at a pressure several pounds higher than the maximum in the service supply, so the collector storage system must withstand pressures usually above 50 psi. Occasional water loss through venting of steam would be expected.

LOCATION OF COLLECTORS

If the slope and orientation of a roof is suitable, the most economical location for a solar collector in a residential water heating system is on the south-facing portion of the roof. The cost of a structure to support the collector is thereby eliminated, and pipe or duct connections to the conventional hot water system are usually convenient. In new dwellings, most installations can be expected on the house roof. Even in retrofitting existing dwellings with solar water heaters, a suitable roof location can usually be provided.

If the mounting of collectors on the roof is impractical, for any of several reasons, a separate structure adjacent to the house may be used. A sloping platform supported on a suitable foundation can be the base for the collector. Pumps, storage tank, and heat exchanger, if used, can be located inside the dwelling. Effective insulation on ducts and piping must be provided, however, so that cold weather operation will not be handicapped by excessive heat losses. In cold climates, collectors in which water is directly heated must be located so that drainage of the collector and exterior piping can be dependably and effectively accomplished.

ORIENTATION AND TILT OF COLLECTORS

When roof orientation and slope are not ideally suited for collector mounting, i.e., roof does not face due south and is not tilted at latitude angle, variations may be tolerated without significant reduction in collection of heat. While collectors should be oriented to face due south whenever possible, variations as much as 15 degrees each or west of south will have small effect on system performance. If the collectors are subject to shading in the late afternoon (say after 2:30 pm), orienting the collectors 15 degrees to the east will be beneficial to total heat collection during the day. Similarly, if morning cloudiness prevails because of local climatic conditions, it may be beneficial to face the collectors a few degrees west of south.

For maximum annual heat collection, a south facing collector should be tilted at about latitude angle. However, variations of 10 degrees greater or less than latitude angle will generally reduce the amount of heat collected by about 5 percent.

PERFORMANCE OF TYPICAL SYSTEMS

GENERAL REQUIREMENTS

A typical family of four persons,in the United States, requires about 80 gallons of hot water per day. At a customary supply temperature of about 140°F, the amount of heat required if the cold inlet is at 60°F is about 50,000 Btu per day.

There is a wide variation in the solar availability from region to region and from season to season in a particular location. There are also the short-term radiation fluctuations due to cloudiness and the day-night cycle.

Seasonal variations in solar availability result in a 200 to 400 percent difference in the solar heat supply to a hot water system. In the winter, for example, an average recovery of 40 percent of 1200 Btu/ft^2 of solar energy on sloping surface would require approximately 100 ft^2 of collector for an average daily requirement of 50,000 Btu. Such a design would provide essentially all of the hot water needs on an average winter day, but would fall short on days of less than average sunshine. By contrast, a 50 percent recovery of an average summer radiant supply of 2000 Btu/ft^2 would involve the need for only 50 ft^2 of collector for satisfying the average hot water requirements.

It is evident that if 50 ft^2 of collectors were installed, it could supply the major part, perhaps nearly all, of the summer hot water requirements, but it could supply less than half the winter needs. If, 100 ft^2 of collectors were used to better meet winter needs, the system would be oversized for summer operation and excess solar heat would have to be wasted. In such circumstances, if an aqueous collection medium were used, boiling of the system would occur and collector or storage venting of steam would have to be provided.

The more important disadvantage of the oversized collector (for summer operation) is the economic penalty associated with investment in a collector which is not fully utilized. Although the cost of the 100 ft^2 collector system would be approximately double that of the 50 ft^2 unit, the annual useful heat delivered would be considerably less than double. The larger system would, of course, deliver about twice as much heat in the winter season, when nearly all of it could be used, but in the other seasons, particularly in summer, heat overflow would occur. The net effect of these factors is a lower economic return per unit of investment for the larger system.

Stated another way, more Btu per dollar of investment (hence cheaper solar heat) can be delivered by the smaller system.

As a conclusion to the above example, practical design of solar water heaters should be based on desired hot water output in the sunniest months rather than at some other time of year. If based on average daily radiation in the sunniest months, the unit will be slightly oversized and a small amount of heat will be wasted on days of maximum solar input. And quite naturally, on partly cloudy days during the season, some auxiliary heat must be provided. In the month of lowest average solar energy delivery, typically one-half to one-third as much solar heated water can be supplied, or equivalently the same quantity of water is supplied but with a temperature increase above inlet only one-half to one-third as high. Thus, fuel requirements for increasing the temperature of solar-heated water to the desired (thermostatted) level could involve one-half to two-thirds of the total energy needed for hot water heating in a mid-winter month.

QUANTITATIVE PERFORMANCE

Although hundreds of thousands of solar water heaters have been used in the United States and abroad, quantitative performance data are extremely limited. In households where no auxiliary heat was used, the solar system probably supplied hot water most of the time, but failed during bad weather. If booster heat was used, hot water was always available, but the relative contributions of solar and auxiliary were seldom measured.

In a few research laboratories, particularly in Australia, some analytical studies of solar water heater performance, confirmed in part by experimental measurements, have been performed. More recently, analytical studies at the University of Wisconsin have been carried out. Table 6-1, based on an Australian study, shows the performance of a double-glazed, 45 ft^2 solar water heater in several regions of the country. Variable solar energy and ambient temperature throughout the year result in 1.4 to 2.5 times as much solar heat supply to water in summer than in winter. Climatic differences produced a solar heat percentage ranging from 60 percent to 81 percent of the annual total hot water requirements. Table 6-2 shows monthly performance of the same system in Melbourne, Australia, with average collection efficiency varying between 29 and 40 percent of incident radiation. Variation in inlet, outlet, and ambient temperature in a typical thermosiphon type of solar water heater is shown in Figure 6-5.

In a simulation study at the University of Wisconsin, hot water usage was programmed for a hypothetical residential user. The results show only slight variation in solar heat utilization at several use schedules and indicate only minor influence of storage temperature stratification on collector efficiency.

In summary, the normal output of well-designed solar water heating systems can be roughly estimated by assuming approximately 40 percent solar collection efficiency. Average monthly solar radiation multiplied by collector area and 40 percent delivery efficiency can provide a rough measure of daily or monthly Btu delivery. The total Btu requirements for the hot water supply, based on the volume used and the temperature increase set, then serves as the basis for computating the percentage contribution fromsolar and the portion required to be supplied by fuel or electricity.

Table 6-1. Daily Means for Twelve Consecutive Months of Operation of Solar Water Heaters at Various Localities

Location	Adelaide	Brisbane*	Canberra	Denili-quin	Geelong	Melbourne	Sydney
Hot water discharge**(gallons, US)	54.2	54.6	51.4	50.9	50.4	54.6	53.9
Electrical energy consumed (kWh)	3.5	2.5	3.4	2.5	3.8	4.6	4.4
Cold water temperature (°C)	17.7	21.6	12.7	16.8	15.9	16.1	16.6
Hot water temperature (°C)	58.9	56.4	58.4	60.3	58.7	57.4	57.7
Energy required to heat water (kWh)	9.8	8.4	10.3	9.7	9.5	9.9	9.8
Heat loss from storage tank (kWh)	2.2	1.9	2.5	2.5	2.2	1.9	1.9
Total energy consumed (kWh)	12.0	10.3	12.8	12.2	11.7	11.8	11.7
Solar energy contributed (kWh)	8.5	7.8	9.4	9.7	7.9	7.2	7.3
Solar energy contributed (percent)	71.0	76.0	73.0	81.0	67.0	61.0	62.0
Solar contribution best month (%)	99.0	94.0	98.0	100.0	92.0	95.0	70.0
Solar contribution worst month (%)	47.0	57.0	43.0	57.0	45.0	38.0	51.0
Ratio best to worst	2.1	1.6	2.3	1.8	2.0	2.5	1.4

* Hail screens suspended above the absorbers. No correction made for reduction of absorbing area.

** Water discharged at 6:00 a.m. daily. Double-glazed, flat-black, 45 ft^2 solar collector tilted toward equator at latitude angle plus 2.5 degrees. Storage 84 gallons (US). Thermosiphon circulation. Electric auxiliary heat.

Table 6-2. Solar Water Heater Performance in Melbourne, Australia

Month	Mean Insolation on Absorber	Mean Daily Supplementary Energy	Mean Daily Solar Energy Contribution		System Efficiency
	$Btu/ft^2 \cdot day$	kWh	Percent	kWh	Percent
January	1630	2.9	75	8.9	40
February	2220	0.5	95	9.5	32
March	1690	2.6	74	7.4	33
April	1240	5.2	52	5.6	34
May	1290	6.2	47	5.5	32
June	1220	7.7	39	4.9	30
July	1290	8.1	38	5.0	29
August	1530	6.1	50	6.1	30
September	1600	4.9	59	7.1	33
October	1860	3.9	67	7.9	32
November	1880	3.7	68	7.9	32
December	1790	3.5	72	9.0	38
Year	1610	4.6	61	7.2	35

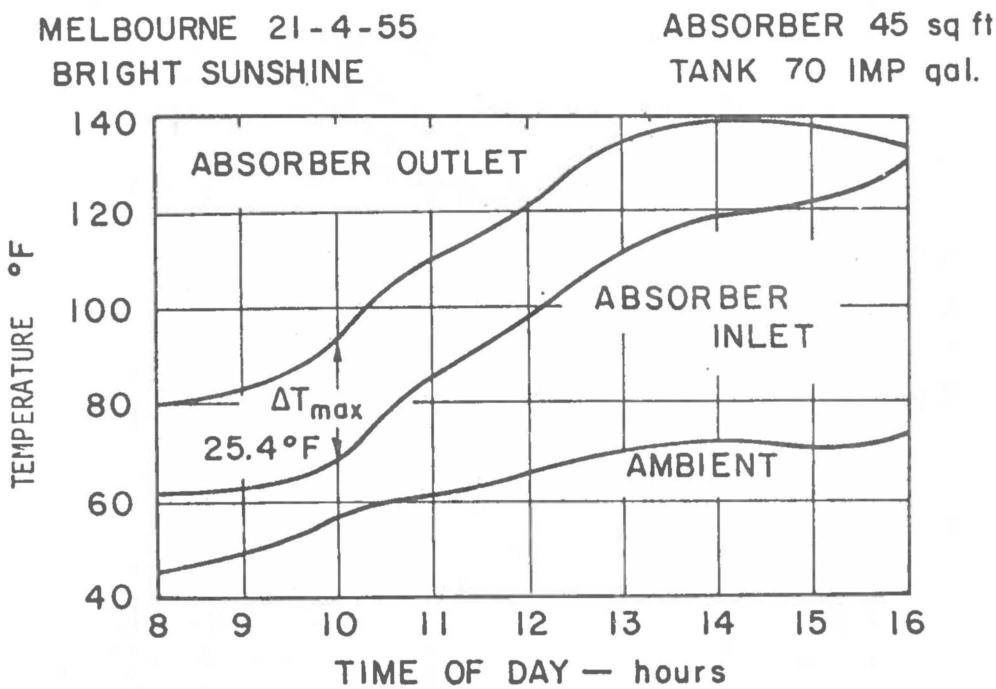

Figure 6-5. Absorber and Tank Temperatures for Thermosiphon Flow During a Typical Day

Sizing the Collectors

The curves shown in Figure 6-6 may be used to estimate the solar collector size required for hot water service in residential buildings having typical hot water systems. The system is assumed to be pumped liquid type, with a liquid-to-liquid heat exchanger, delivering hot water to scheduled residential uses from 6:00 a.m. until midnight. The shaded band represents results of computer calculations for eleven different locations in the United States. The cities included in the study are Boulder, Colorado; Albuquerque, New Mexico; Madison, Wisconsin; Boston, Massachusetts; Oak Ridge, Tennessee; Albany, New York; Manhattan, Kansas; Gainesville, Florida; Santa Maria, California; St. Cloud, Minnestoa; and Washington, D. C.

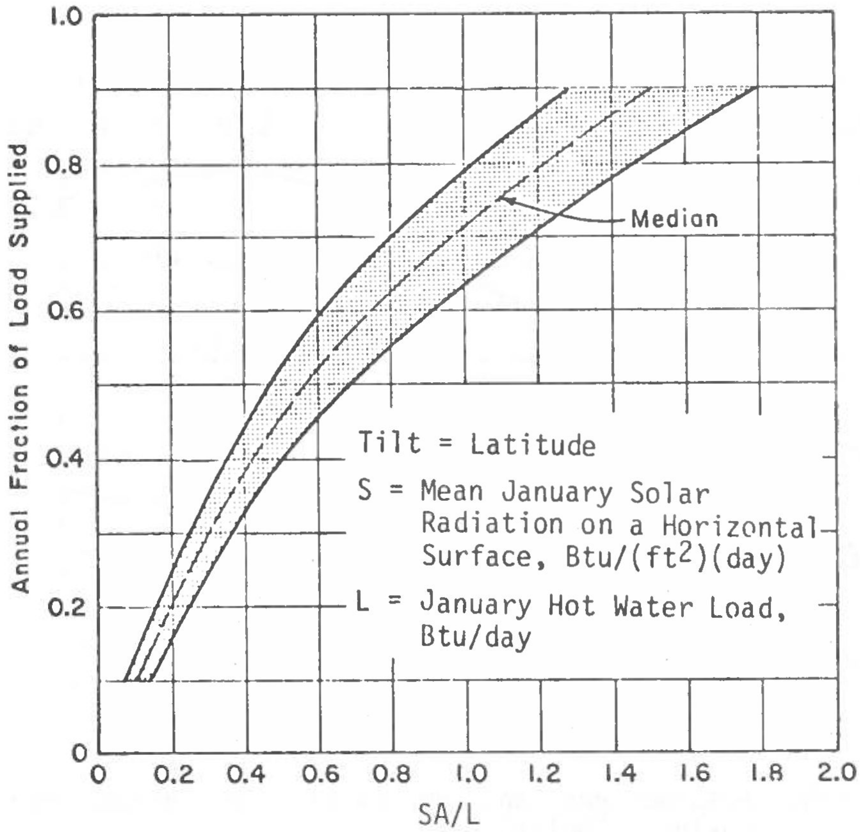

Figure 6-6. Fraction of Annual Load Supplied by Solar as a Function of January Conditions for Hot Water Heaters

The hot water loads used in the computations range from 50 gallons per day (gpd) to 2000 gpd. The sizing curves are approximate and should not be expected to yield results closer than 10 percent of actual value.

The vertical axis shows the fraction of the annual water heating load supplied by solar. The horizontal axis shows values of the parameter, S_J A/L, which involves the average daily January radiation on a horizontal surface, S_J; the required collector area, A, to supply a certain percentage of the daily hot water load, L. The January average daily total radiation at locations in the United States can be estimated from the radiation map in Figure 6-7. Values on the map are given in Btu/(ft^2•day). The curves are not applicable for values of f greater than 0.9.

It should be remembered that the service hot water load will be nearly constant throughout the year while the solar energy collected will vary from season to season. A system sized for January, with collectors tilted at the latitude angle, will deliver high temperature water and may even cause boiling in the summer. A system sized to meet the load in July will not provide all of the load in the winter months. Orientation of the collector can partially overcome month-to-month fluctuations in radiation and temperature.

Sizing Examples

Example 6-1. Determine the approximate size of collector needed to provide hot water for a family of four in a residential building in Kansas City, Missouri.

SOLUTION: The average daily service hot water load in January is:

$$L = 80 \text{ gallons/day} \times 8.34 \text{ pounds/gallon} \times 1 \text{ Btu/(lb)(°F)} \times (140°F - 50°F) = 60{,}048 \text{ Btu/day}$$

The desired service water temperature is 140°F and the temperature of the cold water from the main is 50°F. The monthly average daily solar radiation, S_J, available in January, from Figure 6-7, is 680 Btu/ft^2/day. For a water system to provide 60 percent of the annual load, from Figure 6-6, S_J A/L is about 0.8. Therefore:

$$A = 0.8 \times L/S_J = (0.8 \times 60048)/680 = 70.6 \text{ ft}^2.$$

If 3 by 8 foot collector modules are available, 2.9 units would be required. Three collector units should therefore be used.

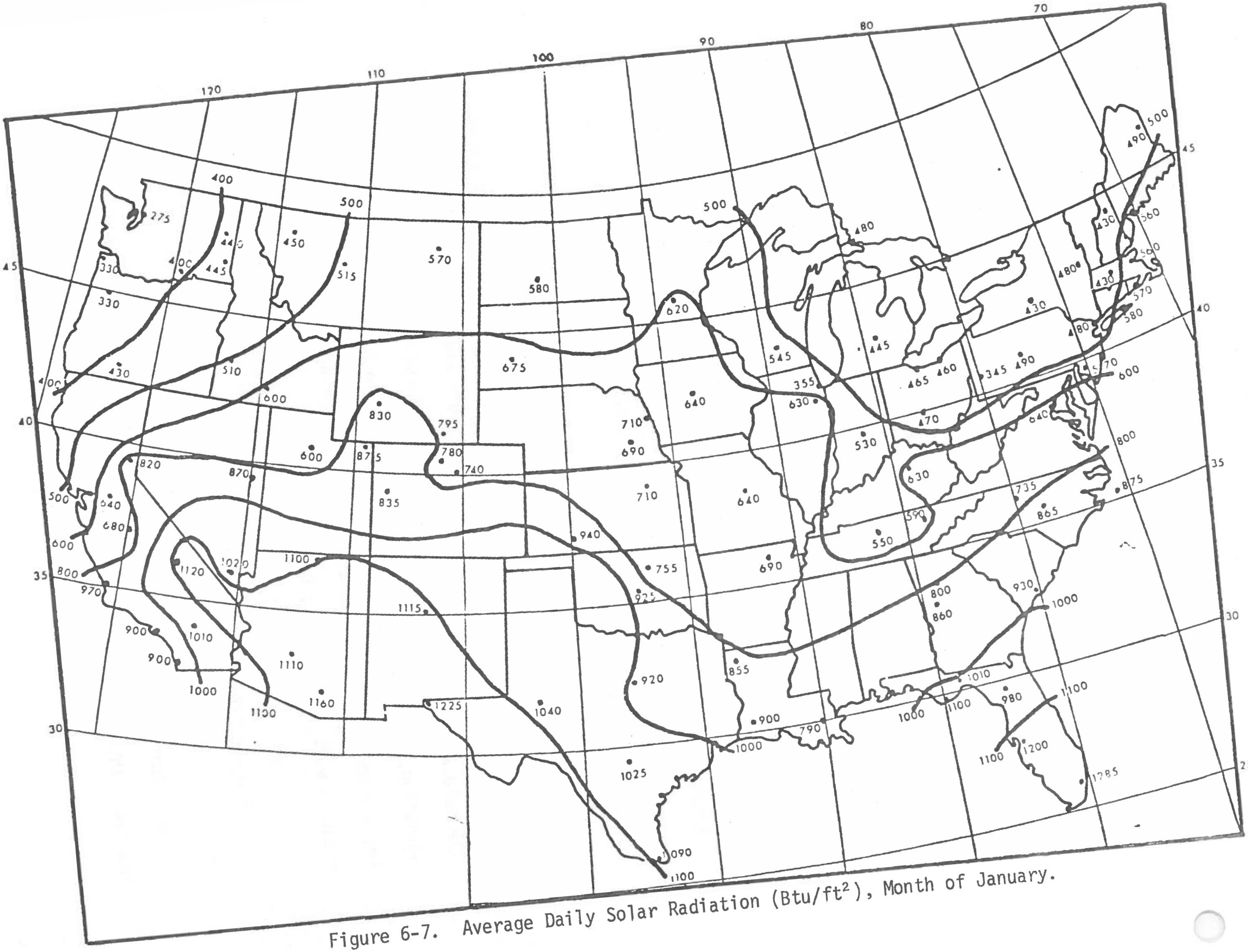

Figure 6-7. Average Daily Solar Radiation (Btu/ft²), Month of January.

Example 6-2. Determine the size of collector needed to provide hot water for a family of four in Albuquerque, New Mexico.

SOLUTION: The monthly load will be approximately the same as in Example 6-1:

$L=60{,}048$ Btu/day

From Figure 6-7, $S_J = 1151$ Btu/(ft^2·day). For a system to provide 60 percent of the annual load, Figure 6-6 shows that $S_J A/L$ is approximately 0.8. The collector area required is:

$$A = (0.8 \times 60048)/1151 = 41.8 \text{ ft}^2$$

Using 3 by 6 foot collector modules, 2.3 units would be required for this system, either two or three modules should be used. If two modules are used, the system would be expected to provide less than 60 percent of the annual load.

COSTS

The cost of installing a solar water heater (exclusive of the hardware) may range from about $500 for a system with a roof-mounted collector to over $1500 for a collector mounted on a stand adjacent to a house. In a recent procurement of several types of solar water heaters for ground mounting next to existing houses, an electric utility company spent $1500 to $2500 for each system, including hardware, and totally installed. Non-freezing collectors of about 50 ft^2, 80-gallon water tanks, pumps, fans, and controls were included.

As designs are standardized and manufacturing volume increases, it may be anticipated that the total installed cost of an average-sized residential solar water heating system will be about \$1500. Assuming a collector area of about 50 square feet and a reasonably sunny climate, this unit should be able to deliver at least 250,000 Btu/ft^2 of collector per year, for a total of 12.5 million Btu annually. With an average daily requirement for 50,000 Btu of heat for hot water, the 18 million Btu annually required could be two-thirds solar. If electric heat at five cents per kilowatt-hour (about \$14 per million Btu) is being replaced, an annual electric saving of about \$175 is achieved. A \$1500 solar water heater could thus pay for itself from electric savings in about eight years. Or, if coventionally financed at 8 percent interest, an annual cost of interest plus principal of, approximately 12 percent, or \$120 per year, would be less than the electric savings by \$50 per year. This favorable economic comparison for solar water heaters is applicable now in many parts of the country and should prevail very generally in the next few years.