Solar Energy and Its Applications

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CHAPTER 15

SOALR ENERGY

The energy that the earth receives from the sun is electromagnetic radiation. Most of the energy is received in the visible and infrared portions and a small amount is received as ultraviolet radiation. Energy from the sun travels approximately 90 million miles in just over 8 minutes to reach earth. If 100 percent of the solar constant were to be collected on an area the size of the United States, we could absorb enough energy in 32 minutes to supply the energy needs of the entire world for a year.

SOLAR RADIATION SYSTEMS

Solar insolation is the amount of solar energy per unit area per unit of time that strikes the surface of the earth. If measurements were made of the solar energy available in outer space, a fixed amount could be determined. This fixed amount of energy is called the solar constant. The solar constant is as follows: 428 Btu/hr-ft^2 or 2,453 watt S/m^2 to 1,940 Langleys/min. Langleys (L) is the most common measurement used. At most, 70 to 80 percent of this amount strikes the surface of the earth; the remainder is absorbed or reflected by the atmosphere. Those solar rays that hit the earth's surface on a clear day are, for the most part, parallel to each other. When there is haze, cloud cover, smog, or dust in the air, the parallel pattern is broken and the rays are deflected in many different directions by these particles of water or dust in the atmosphere. This is the reason why light and heat appear to come at us from all directions; the term used for this is diffuse radiation.

With the right solar collector, *diffuse radiation* can be useful. Because of the filtering effect, the average solar intensity on the ground is about 1,400 Btu per square foot per day. This is equal in a square mile to the productivity of a large hydroelectric power plant.

COLLECTING SOLAR ENERGY

Collection of solar energy is based on the high absorption of radiant energy by dull black surfaces and on the "greenhouse effect." The latter refers to the ability of glass to transmit visible radiation and to prevent the loss of heat from the collector plate that radiates at longer wavelengths (infrared frequencies). Glass (or plastic) cover plates are generally used over flat-absorber plates to reduce heat loss (fig. 15-1). The heated absorber plate has tubes that allow fluid to circulate through the plate and receive heat. The heated fluid heats potable water, closed spaces, or drives an absorption air-conditioner.

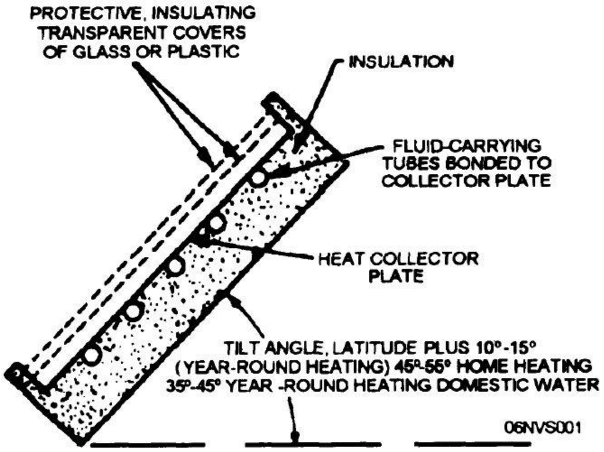


Figure 15-1 — Cross section of a typical solar heat collector with heavy back insulation and two cover sheets.

AIR	
ADVANTAGES	**DISADVANTAGES**
Moderate cost. No freezing problems. Minor leaks of little consequence. As air is used to heat the house, no temperature losses due to heat exchangers (devices which transfix heat from one fluid to another), when the system is used for space heat. No boiling or pressure problems.	Can only be used to heat homes; cannot presently be economically adapted to cooling. Large air ducts needed. Larger storage space needed for rocks. Heat exchanger needed if system is to be used to heat water.
WATER OR LIQUID	
ADVANTAGES	**DISADVANTAGES**
Holds and transfers heat well. Water can be used as storage. Can be used to heat and cool homes. Compact storage and small conduits.	Leaking, freezing, and corrosion can be problems. Corrosion inhibitors needed with water when using steel or aluminum. There are liquids which are noncorrosive and nonelectrolytic; however, they are toxic and some of them are flammable. A separate collector loop using a nonfreezing fluid and a heat exchanger or, alternatively, a draining water or inhibited water system is required to prevent freezing. In warm regions, where freezing is infrequent, electric warmers or recirculation can be used.

Table 15-1.—Advantages and Disadvantages of Air and Liquid Heating Systems

The amount of solar energy collected by a solar collector depends on its efficiency. The construction, configuration, and the choice of material determines the efficiency of a solar collector.

SOLAR COLLECTOR ORIENTATION

Although solar collectors can collect heat from the diffuse component of solar radiation, solar systems are designed to use radiation. Direct radiation is in the form of parallel rays coming straight from the sun. To capture this energy, tilt the solar collector, as shown in figure 15-1, so it is nearly perpendicular to the solar rays.

In addition to choosing the best collector tilt angle, take into consideration the direction that the collector faces. Normally, true south is the best and most frequent choice, however, 10 degrees west of south maybe preferable in some locations if early morning haze or fog is a regular occurrence.

Equally important as collector location is keeping the collectors out of the shade, especially between 0900 and 1500 hours, when most of the useful energy collection occurs. In summary although many buildings do not have a “perfect” solar orientation, there are still many places with good solar energy potential.

COLLECTORS

The collector is the most important and most expensive part of a solar-heating system. Collectors for space and water heating are of two basic types: liquid and air. Liquids may be water, an antifreeze mixture, or various hydrocarbon and silicone heat transfer oils. An air type of collector uses air as the collector medium. For the advantages and disadvantages of air-and liquidheating systems, see table 15-1. The absorber plate is that part of the collector that absorbs the solar energy and converts it to thermal energy. Some thermal energy is carried to the building or thermal storage unit by the medium that circulates through passages in the absorber plate. The absorber plates are made of metal, plastic, or rubber compounds. The metals commonly used in order of decreasing thermal conductivity are copper, aluminum, and steel. Plastic (polyolefin) and rubber (ethylene propylene compound) is inexpensive. However, because of their low thermal conductivity and their temperature limitations, they are suitable only for low-temperature applications, such as heating water in swimming pools or for use with watersource heat pumps. Figure 15-2 depicts typical cross sections of solar collectors.

Flat-plate collectors are most suitable for low-temperature applications, such as domestic water and space heating. They collect both direct and diffuse radiation. It is not required that they track the sun. Tubes should be 1/2 inch in diameter or greater for low-pressure drop and longer life. The better the attachment of tube-to-plate (such as by soldering), the better the heat transfers.

Liquid and air collectors each have some advantages. Liquid types are most suited to domestic hot water because the collector area is usually smaller.

The design procedures for air collectors differ however. Heat transfer oils used in liquid systems offer freeze protection and some corrosion protection, but they also require heat exchangers for heating domestic hot water, as do antifreeze-water mixtures.

Selective Surfaces

Collectors are black and gray in color and have a rough textured surface. The rough-surface absorbs solar rays better than a smooth surface. A smooth, shiny surface will reflect radiant energy away from the collector. Generally, surfaces are made of metal particles, rather than paint, because paint cracks and peels at high temperature.

Collector Covers (Glazes)

The transparent covers serve to admit solar radiation to the absorber while reducing convection and radiation heat losses from the collector. The covers also protect the absorber from dirt, rain, and other environmental contaminants.

The materials used as covers include glass or plastic sheets. Glass is most commonly used because of its superior optical properties and durability. Standard plate glass reflects about 8 percent and absorbs about 6 percent of normal incident solar radiation, resulting in a transmissivity of about 86 percent. Glass is subject to impact damage and is more expensive than plastic; however, it does not degrade in sunlight or at high collector temperatures and is more durable than plastic.

Although resistant to impact damage, plastic generally degrades in sunlight and is limited as to the temperatures they can sustain without undergoing serious deformation. In general, acrylic is the most ultraviolet-resistant, and polycarbonate offers good impact and high-temperature properties.

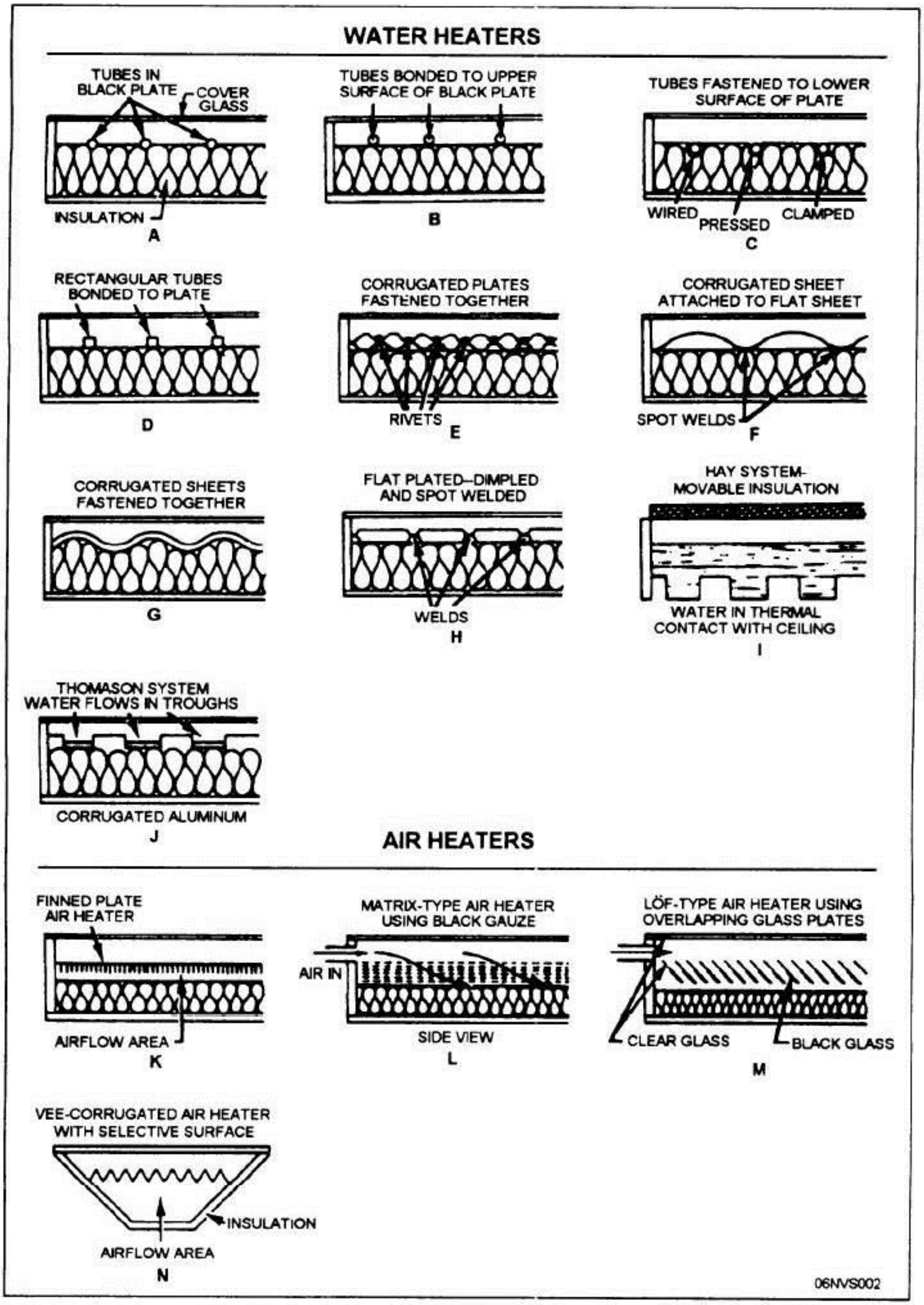


Figure 15-2 —Types of solar heat collectors

Collector Gaskets and Sealants

Gaskets and sealants must be carefully selected if a collector is to have a long life. Generally, the housing and the glazing have different rates of thermal expansion. Gaskets and sealants form a flexible interface between the two components and seal out moisture and other contaminants. If they fail, moisture fogs the glazing and may damage the absorber coating and the insulation. These problems can drastically reduce the thermal performance of the collector.

Two suitable sealing methods are shown in figure 15-3. The gaskets provide flexible support and the primary weather sealant ensures against moisture leakage. Desiccants are sometimes placed between the two glazings to absorb any moisture that may remain after cover installation.

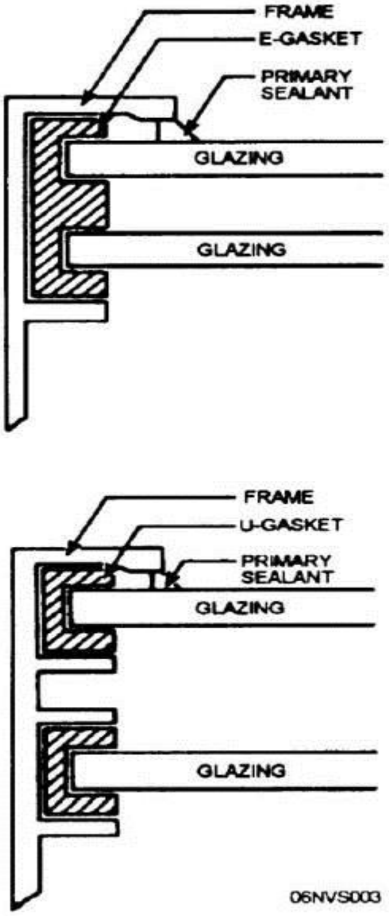


Figure 15-3 — Typical sealing methods for single or double glazing.

When you are selecting collector gaskets and sealants, certain material requirements must be kept in mind. The gaskets and seals must do the following:

1. Withstand significant expansion and contraction without destruction
2. Adhere effectively to all surfaces
3. Resist ultraviolet degradation
4. Resist outdoor weathering
5. Not harden or become brittle
6. Withstand temperature cycling from -30°F to 400°F

Silicone sealants have been found adequate for use as gasket material. Silicone sealants have exceptional weathering resistance and have received widespread use for many years.

Collector Fluid—Corrosion and Freeze Protection

The choice of collector fluid is important because this is the lifeblood of the system. The cheapest, most readily obtainable, and thermally efficient fluid to use is ordinary water. However, water suffers from two serious drawbacks: freezing and corrosion. Therefore, the choice of collector fluid depends on the type of solar system the choice of components, future maintenance, and several other factors.

Implicit in this discussion is the use of fluid in the collector. As explained in table 15-1, an air solar system does not suffer from corrosion or freezing. The low density and heat capacity of an air solar system requires the use of fans, large ducts, large storage volumes, and it is not suitable for domestic water heating.

If there is no danger of freezing and the collector loop consists of all copper flow passages, then ordinary water should be the choice for collector fluid. When encountering freezing

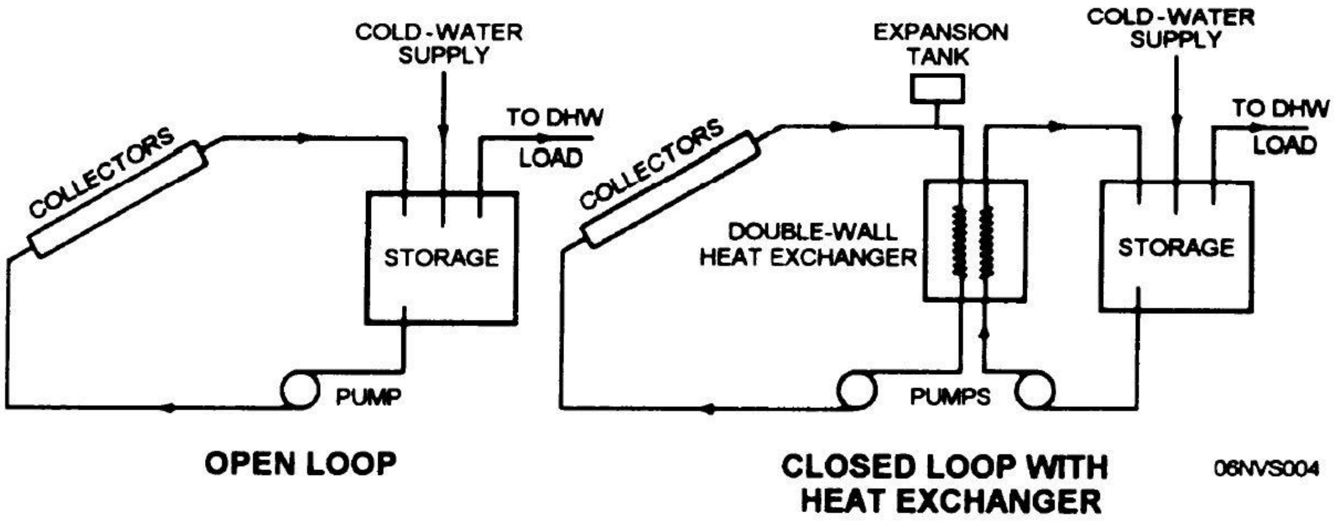


Figure 15-4 — Typical configuration for solar water-heating systems.

conditions, there are several designs to consider before deciding to use a heat transfer oil or antifreeze mixture. For the purposes of this discussion, these freeze protection schemes are summarized using figure 15-4 to explain the basic open-loop type of collector circuit.

DRAIN-DOWN METHOD — When the water in the collector approaches freezing, the water drains into the storage tank. This scheme requires automatic valves to dump the water and purge the air from the system. Often a large pump is required to overcome the system head and reprime the collectors. A way to avoid automatic (solenoid) valves is to drain the collectors whenever the pump shuts off. This still requires a larger pump. You may require heat exchangers to separate potable water from nonpotable water.

HEAT TAPES — Electrical-resistant heat tapes are thermostatically started to heat the water. This scheme requires extra energy and is not completely reliable. Inserting heat tapes into preconstructed collectors may be difficult.

RECIRCULATING METHOD — The control system shown in figure 15-4 merely turns on the pump when it approaches freezing. In this way, warm water from storage circulates through the collectors until the freezing condition is over. The only extra component needed is a freeze sensor on the collector, which is a minimum cost item. However, by circulating heated water, the capacity of storage decreases and less is available the following day.

HEAT TRANSFER FLUID

When the preceding methods are not acceptable or the choice of water is unacceptable because of concern about corrosion, you should use a heat transfer fluid. Use a heat transfer fluid with a heat exchanger in a “closed-loop” configuration.

There are two categories of heat transfer fluids nonaqueous and aqueous. Silicones and hydrocarbon oils make up the nonaqueous group, while the aqueous heat transfer fluids include untreated potable (tap) water, or inhibited distilled water, and an inhibited glycol/water mixture. The potable tap water and inhibited distilled water do not offer freeze protection.

Silicone Fluids

Silicone heat transfer fluids have many favorable properties that make them prime candidates for collector fluids. They do not freeze, boil, degrade, or corrode common metals, including aluminum. They have excellent stability in solar systems stagnating under 400°F. Silicone fluids are also virtually nontoxic and have high flash and fire points. Current evidence suggests that silicone fluids should last the life of a closed-loop collector system with stagnation temperatures below 350°F to 400°F. The flash point is high, 450°F, but since HUD standards say that heat transfer fluids must not be used in systems whose maximum stagnation temperature is less than 100°F lower than the flash point of the fluid, this limits most silicone oils to systems with a maximum temperature of 350°F or less. Also, silicones do not form sludge or scale, so system performance does not decrease with time.

The main drawback of silicone fluids is their cost. The cost of the 20 to 30 gallons of collector fluid required for a typical 500 ft2 collector system becomes considerable. As with hydrocarbon oils, the lower heat capacity and higher viscosity of silicone fluid requires larger diameter and more expensive piping. Because of the higher viscosity, larger pumps are required and subsequently, higher pumping costs. One other problem with silicone fluids is the seepage of fluid at pipe joints. This problem can be prevented by proper piping installation and by pressurizing the system with air to test for leaks. There have also been reports of seepage past the mechanical seals of circulating pumps.

Silicones have the advantage of lasting the life of the system with little maintenance. The high initial cost of silicone heat transfer fluid may be less than the savings that result from minimum maintenance and no replacement of collector fluid. The use of silicone fluid allows aluminum absorbers to be used without fear of corrosion. Hydrocarbon oils, like silicones, also have a long service life, but cost less. They are relatively noncorrosive, nonvolatile, environmentally safe, and most are nontoxic. They are designed for use in systems with lower operating temperatures, since some brands break down at higher temperature to form sludge and corrosive organic acids.

Distilled Water

Distilled water has been suggested for use in solar collectors, since it avoids some of the problems of untreated potable water. However, distilled water is still subject to freezing and boiling. Therefore, an antifieeze/antiboil agent, such as ethylene glycol, should be added.

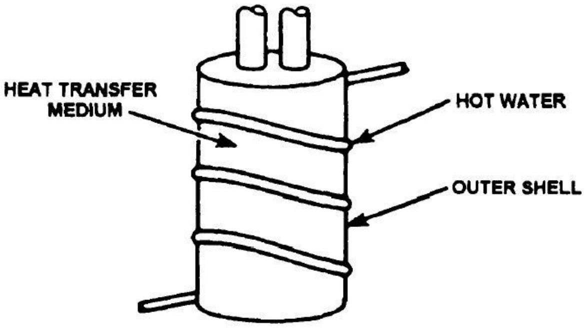
Water/Antifreeze

Nonfreezing liquids can also be used to provide freeze protection. These fluids are circulated in a closed loop with a double-wall heat exchanger between the collector loop and the storage tank (fig. 15-5.)

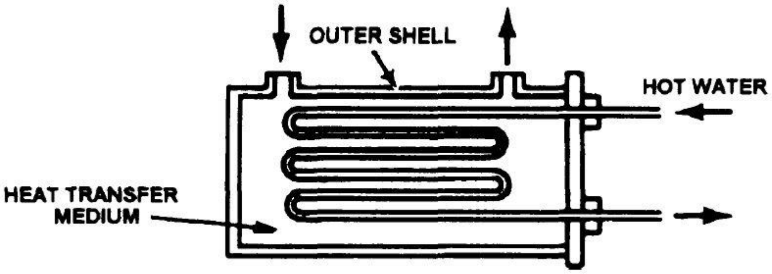
Water/antifreeze solutions are most commonly used. Ethylene glycol and propylene glycol are the two most commonly used antifreezes. A 50-50 water/glycol solution provides freeze protection down to about -30°F and also raises the boiling point to about 230°F.

OTHER TYPES OF SOLAR COLLECTORS

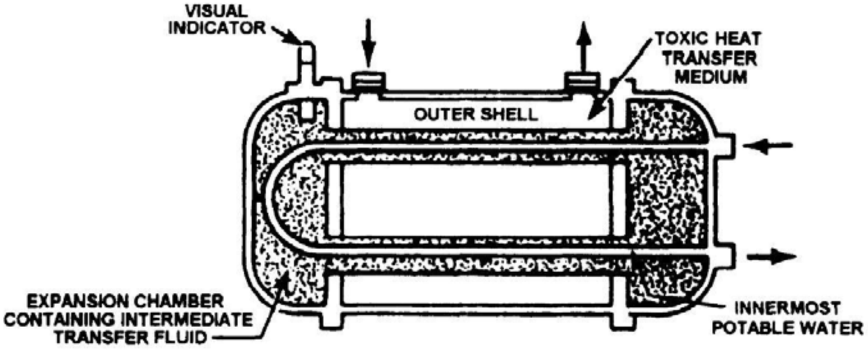
The three most common types of solar collectors are flat-plate collectors, evacuated tube collectors, and concentrating collectors. Because of certain cost and performance advantages, flat-plate collectors have been used extensively for domestic water heating and space heating. Evacuated tube and concentrating collectors are used mostly in solar applications requiring high temperatures. A brief description follows.



DOUBLE WALL. ANOTHER METHOD OF PROVIDING A DOUBLE SEPARATION BETWEEN THE TRANSFER MEDIUM AND THE POTABLE WATER SUPPLY CONSISTS OF TUBING OR A PLATE COIL WRAPPED AROUND AND BONDED TO A TANK. THE POTABLE WATER IS HEATED AS IT CIRCULATES TROUGH THE COIL OR TROUGH THE TANK. WHEN THIS METHOD IS USED, THE TUBING COIL MUST BE ADEQUATELY INSULATED TO REDUCE HEAT LOSSES



SHELL AND TUBE. THIS TYPE OF HEAT EXCHANGER IS USED TO TRANSFER HEAT FROM A CIRCULATING TRANSFER MEDIUM TO ANOTHER MEDIUM USED IN STORAGE OR IN DISTRIBUTION. SHELL AND TUBE HEAT EXCHANGERS CONSIST OF AN OUTER CASING OR SHELL SURROUNDING A BUNDLE OF TUBES. THE WATER TO BE HEATED IS NORMALLY CIRCULATED IN THE TUBES, AND THE HOT LIQUID IS CIRCULATED IN THE SHELL. TUBES ARE USUALLY METAL, SUCH AS STEEL, COPPER, OR STAINLESS STEEL. A SINGLE SHELL AND TUBE HEAT EXCHANGER CANNOT BE USED FOR HEAT TRANSFER FROM A TOXIC LIQUID TO POTABLE WATER BECAUSE DOUBLE SEPARATION IS NOT PROVIDED AND THE TOXIC LIQUID MAY ENTER THE POTABLE WATER SUPPLY IN A CASE OF TUBE FAILURE.



SHELL AND DOUBLE TUBE. THIS TYPE OF HEAT EXCHANGER IS SIMILAR TO THE PREVIOUS ONE EXCEPT THAT A SECONDARY CHAMBER IS LOCATED WITHIN THE SHELL TO SURROUND THE POTABLE WATER TUBE. THE HEATED TOXIC LIQUID THEN CIRCULATES INSIDE THE SHELL BUT AROUND THIS SECOND TUBE. AN INTERMEDIARY NONTOXIC HEAT TRANSFER MEDIUM CIRCULATES THROUGH THE SHELL, THE INTERMEDIARY LIQUID IS HEATED, WHICH, IN TURN, HEATS THE POTABLE WATER SUPPLY CIRCULATING THROUGH THE INNERMOST TUBE. THIS HEAT EXCHANGE CAN BE EQUIPPED WITH A SIGHT GLASS TO DETECT LEAKS BY A CHANGE IN COLOR (TOXIC LIQUID OFTEN CONTAINS A DYE) OR BY A CHANGE IN THE LIQUID LEVEL IN THE INTERMEDIARY CHAMBER, WHICH COULD INDICATE A FAILURE IN EITHER THE OUTER SHELL OR INTERMEDIARY TUBE LINING.

Figure 15-5 — Heat exchangers for solar water-heating systems.

Flat-Plate Collectors

The flat-plate collectors are much simpler than the concentrating collectors. They do not need to face directly at the sun; they can absorb diffused light and almost anyone can make one. We know that dark surfaces absorb radiation, and lighter surfaces reflect it. A flat-plate collector is a black sheet of metal with fluid channels or conduits running over, under, or even through it.

A flat-plate collector works much like a greenhouse. Rays come through the glass, reflect off the walls and the floor of the greenhouse, but cannot escape back into the atmosphere. When rays of short wavelength hit the absorber plate, some of their energy is reradiated back toward the source, but their intensity is weakened—thus increasing the length of the waves. Because they cannot pass back through the glazing, they hit the absorber repeatedly, giving the plate several chances to absorb them.

Evacuated Tube Collectors

Figure 15-6 shows an evacuated tube collector. The vacuum tube collector has a vacuum between the absorber and the glass outer tube. This reduces convection and conduction heat losses.

Evacuated tube collectors operate essentially the same as flat-plate collectors. Solar radiation passes through the outer glass tube and the coated absorber receives the heat. The heat energy is transferred to the fluid flowing through the absorber. Most evacuated tube designs collect both direct and diffused radiation efficiently, but certain types are designed for more efficient collection of direct radiation. Although evacuated tube collectors are considerably more expensive than typical flat-plate collectors, they are much more efficient when high collection temperatures are needed for operating absorption chillers of for industrial processing.

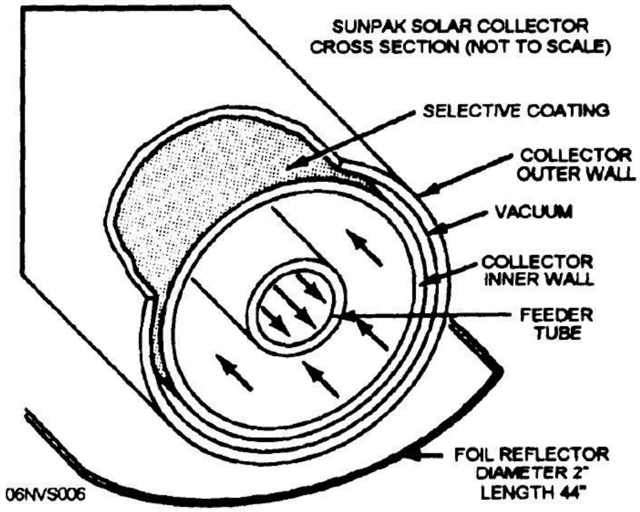


Figure 15-6 — Evacuated tube solar heat collector

They may not be as efficient as flat-plate collectors at low temperatures, such as domestic water heating and space heating.

Concentrating Collectors

Concentrating, or focusing, collectors intercept direct radiation over a large area and focus it onto a small absorber area. These collectors can provide high temperatures more efficiently than flat-plate collectors, since the absorbtion surface area is much smaller. However, diffused sky radiation cannot be focused onto the absorber. Most concentrating collectors require mechanical equipment that constantly orients the collectors toward the sun and keeps the absorber at the point of focus.

There are many types of concentrating collectors. The most popular types are the parabolic trough, the linear-trough fresnel lens, and the compound parabolic mirror. Figure 15-7, view (A), shows a linear concentrating or parabolic-trough collector. It collects energy by reflecting direct solar radiation off a large curved mirror and onto a small absorber tube that contains a flowing heat transfer liquid. The absorber tube is encased in a glass or metal tube that may be

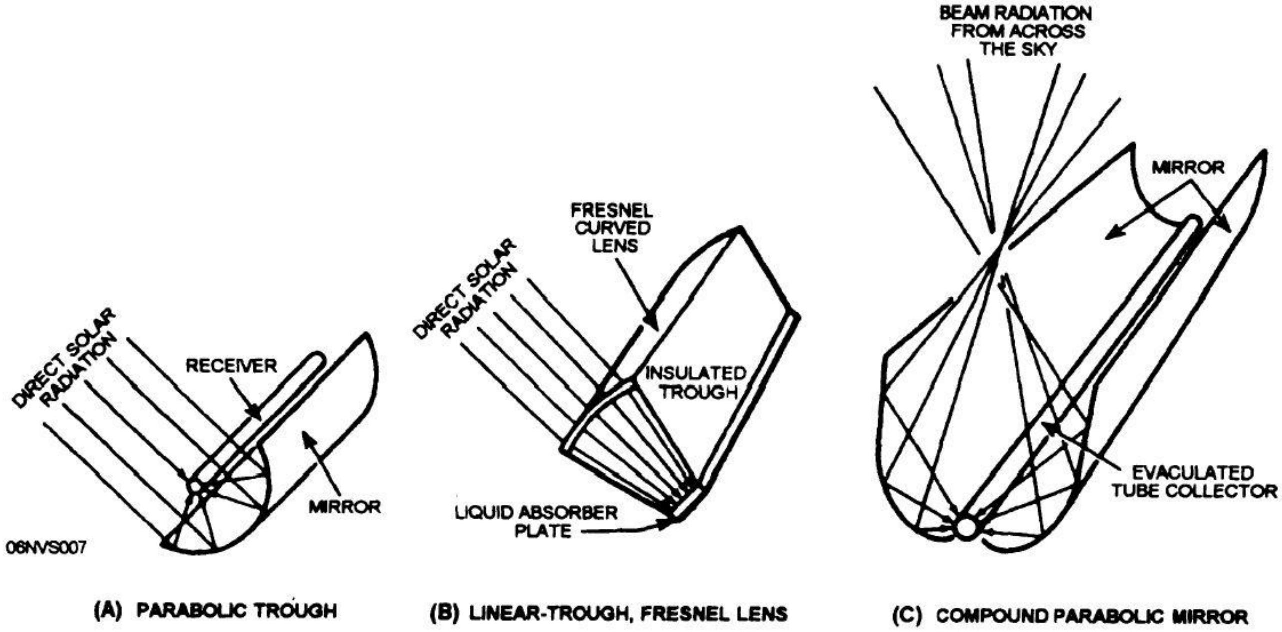


Figure 15-7 — Concentrating collectors for solar energy.

evacuated. This type of collector must track the sun and can collect only direct radiation.

Figure 15-7, view (B), shows a linear-trough, Fresnel lens collector. In this design, a curved lens is used to focus incoming rays onto a small absorber plate or tube through which the heat transfer liquid is circulated. This type of collector also requires a tracking mechanism and can collect only direct radiation.

Figure 15-7, view (C), shows a compound parabolic mirror collector. The design of the mirror allows the collector to collect and focus both direct and diffuse radiation without tracking the sun. Periodic changes in the tilt angle are the only adjustments necessary.

Direct radiation is intercepted by only a portion of the mirror at a time; thus, this collector does not collect as much solar energy as a focusing collector that tracks the sun. It is, however, less expensive to install and maintain. The absorber tube is encased within an evacuated tube to reduce heat losses.

Many other types of concentrating collectors produce high temperatures at good efficiencies However, the high cost of installing and maintaining tracking collectors restricts their use to solar cooling and industrial applications where extremely high fluid temperatures are required. In addition, concentrating collectors must be used only in those locations where clear-sky direct radiation is abundant.

ENERGY STORAGE AND AUXILIARY HEAT

Since effective sunshine occurs only about 5 to 6 hours per day (in temperate latitudes) and since heating and hot-water loads occur up to 24 hours a day, some type of energy storage system is needed when using solar energy.

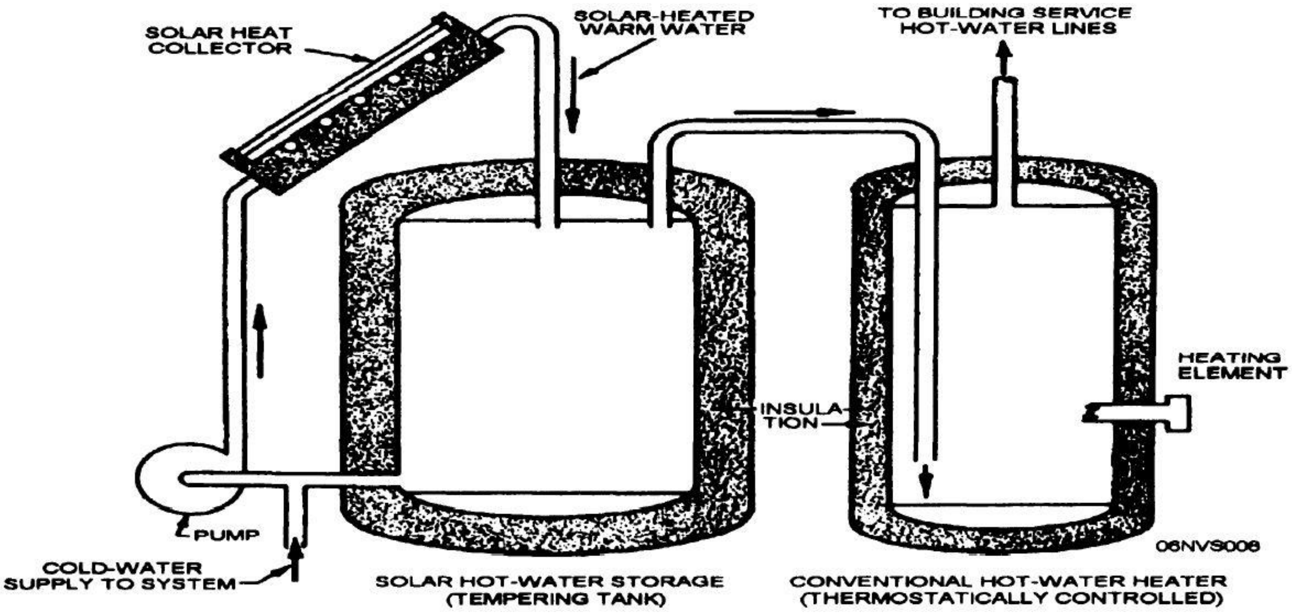


Figure 15-8. —Schematic of potable hot-water heating systems, using solar storage (tempering) tank ahead of the conventional fueled or electric service water heater.

Practical experience in the industry, as well as computer simulations and experiments, has resulted in rules of thumb for storage sizing. These guidelines provide storage sizes for which the performance and cost of active solar systems are optimized and relatively insensitive to changes within the range indicated.

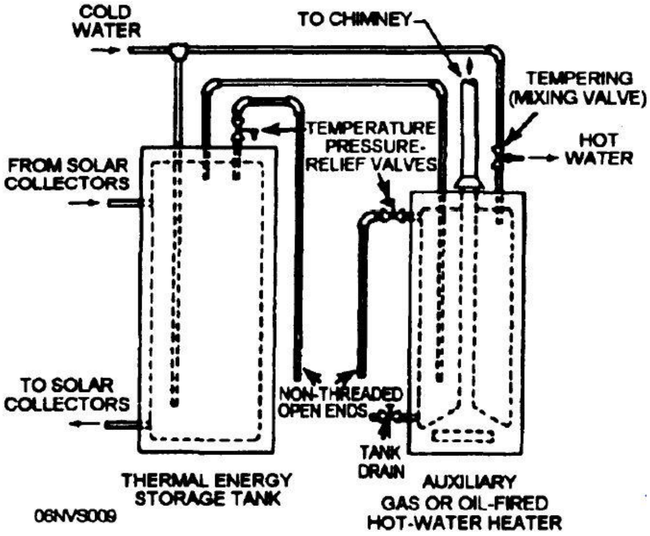


Figure 15-9 — Typical DHW installation.

Water Systems

Since water has a specific heat of 1 Btu/1b-°F, then 15 pounds of water storage is needed per square foot of collector or 1.8 gallons of storage is needed for each square foot of collector.

Air Systems

Since rock has a specific heat of 0.21 Btu/1b-°F and rock densities typically contain 20 to 40 percent voids, then the optimum storage size is 0.8 ft^3 per square foot of collector. Storage volumes in this range store the equivalent overnight of 1 full day of heating. A typical domestic hot-water system is shown in figure 15-8. The use of two tanks ensures that when hot water from the first (tempering) tank is available, the auxiliary heat does not come on; also, less total fuel is used to bring the smaller second tank up to temperature. Single-tank arrangements are not recommended because they frequently activate the heating element every time there is a draw of water, rather than wait for the solar collectors to provide additional heated water. The two-tank arrangement (fig. 15-9) avoids this control problem. Two-tank arrangements are suited to retrofits since the second tank (the water heater) is already there. A variation would be to use a heat exchanger (copper coil) (fig. 15-10) in the tempering tank collector loop for freeze protection. The tempering tank then becomes an inexpensive unpressurized tank.

Another method of heat storage in air systems is latent heat storage. Latent heat is stored in a material as it changes state from a solid to a liquid. Materials that have melting points near the temperatures supplied by solar collectors store heat as they melt and release it as they re-solidify. The two materials that have received the most attention are salt hydrates and paraffins.

Storage Tanks

Water may be stored in a variety of containers usually made of steel, concrete, plastic, fiber glass, or other suitable materials. Steel tanks are commercially available and have been used for water storage. They are available in many sizes and are easy to install. However, steel tanks are susceptible to corrosion and should be lined or galvanized. Dissimilar metal at pipe connections should be separated by high-temperature rubber connections or galvanic corrosion will occur. Steel tanks must be well insulated to reduce heat losses.

Fiber glass and plastic tanks are corrosion-resistant and installed easily. They are available in many shapes and sizes. Although many commonly fabricated tanks begin to soften at temperatures above 140°F, there are more expensive, specially fabricated tanks available that can withstand temperatures up to 150°F. The types of plastics needed to store large quantities of water at high temperatures can be more expensive than steel. Buried tanks must be protected from groundwater and resist buoyant forces. The tank must be reasonably accessible for repairs. In mild or warm climates, an outdoor location may be feasible.

Domestic Hot-Water Systems (DHW)

Domestic hot-water systems (without space heating) may use lined, insulated, or pressurized tanks similar to the conventional water heater. Appropriate temperature-and pressure-relief valves must be used. Since it is possible for solar collectors to reach hot temperatures, a tempering or mixing valve should be used. A typical two-tank installation with proper valves and connections is shown in figure 15-9.

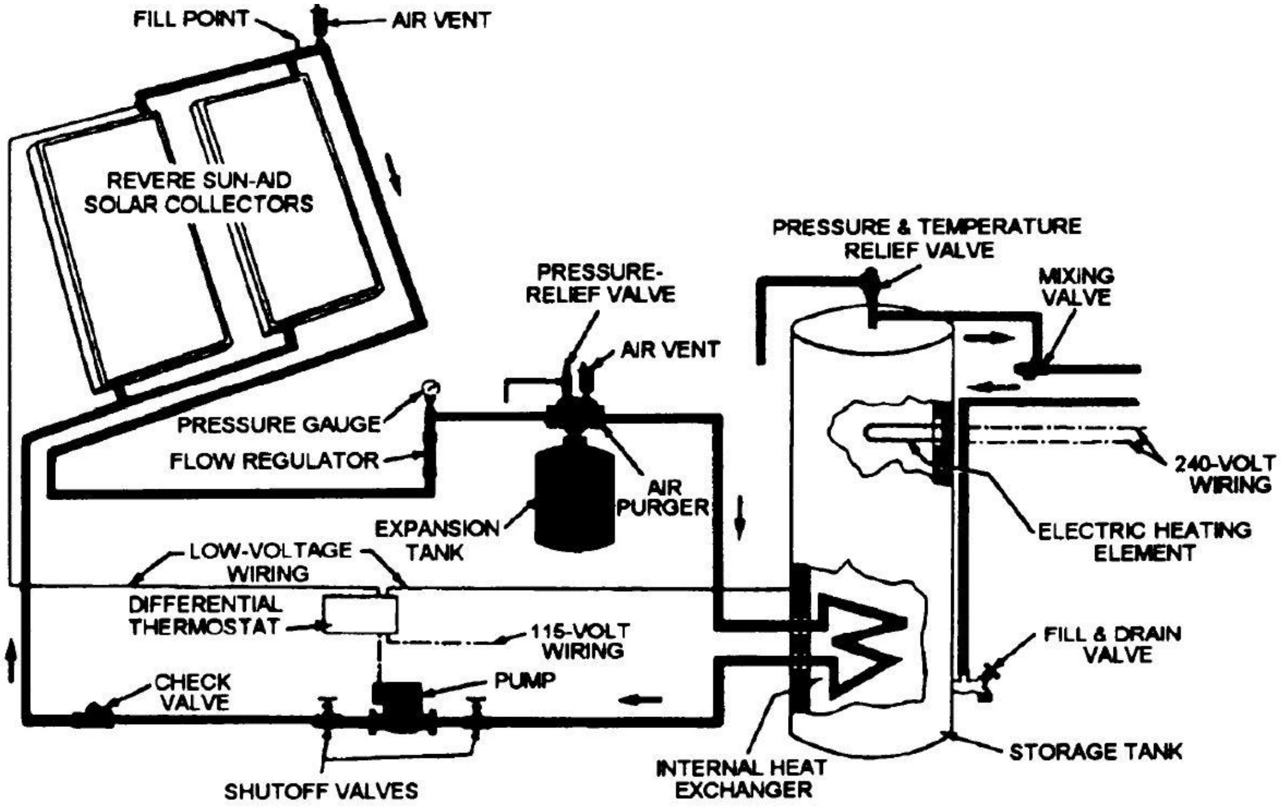
To size the collectors and storage tank, you must estimate the hot-water consumption of the facility or building. The hot water consumption rate for a typical family home is 20 gal/day/person. When the hot-water consumption rate is more than average, use 30 gal/day/person. So, 80 to 120 gal/day should serve a typical four-person family.

Thermosiphon Systems

A variation of the DHW system is the thermosiphon system. It uses the principle of natural convection of fluid between a collector and an elevated storage tank. The advantage is no pump or controller is needed. The bottom of the tank should be mounted about 2 feet higher than the highest point of the collector. This is the main disadvantage because structural requirements often prohibit the weight of a water tank on a high point of the structure. Also, since the thermosiphon system is connected directly to the potable water supply, it cannot be protected from freezing. A heat exchanger cannot be used effectively in this system.

Space Heating and DHW Systems

Space heating systems are a simple extension of the domestic hot-water (DHW) systems (fig. 15-10). The collectors and storage tank need to be resized to provide greater loads. A heat delivery system is added and the auxiliary heater (or existing heater) is connected into the system as



NOTES:

(1) **Piping insulation not shown.**

(2) **Some installations may require the use of nontoxic fluid or double wells between potable water and collector loop. This can be accomplished by the use of propylene glycol, silicone fluids, or the addition of a heat exchanger and pump between the collector loop and storage tank.**

Figure 15-10. —A DHW system with heat exchanger in hot-water storage tanks.

backup. The design of the space heating system, if a retrofit, depends on the existing system. Water-to-air heat exchangers may be placed in existing ductwork, in which case, an unpressurized, unlined tank may be used. This represents a minimum heating system, as shown in figures 15-11 and 15-12.

Domestic hot water could be added to the system shown in figure 10-33 by adding a preheat coil in the storage tank. Figure 10-31 has the potential to provide some cooling to the building by using the collector at night to radiate heat to the sky and store cool water for use during the day. A heat pump is another option that could be used to cool the building, reject the heat to the storage tank during the day, and then, as before, cool the tank at night through the solar collectors. Unglazed collectors are superior to glazed collectors for this application. There are many variations that can be used with the configurations shown.

Air types of space heating systems are receiving increased attention, and a typical system is shown in figure 15-14. (See table 15-1 for advantages of air versus liquid.) The heat storage tank is replaced by a rock bed (nominally 1 to 3 inches in diameter). Rock provides desirable temperature stratification. Designs should emphasize the minimum pressure drop through the rock bed. The rocks can be stored in a bin, which should be insulated, or beneath the building if this is feasible. Heat collected by the collectors is blown through the rock bed from top to bottom. Heat is delivered from storage to the building by circulating air in the reverse direction, bottom to top. Note that in contrast to water storage, heat cannot be added to and removed from the rocks at the same time.

During heat collection, the rocks at the top of the bin attain a temperature almost equal to that of the incoming solar-heated air, while the air leaving storage is delivered to the collectors at the minimum temperature of the rocks. The conduction between the rocks is small; thus, with no air circulation, the rock bed remains stratified with the top of the rock bed warmer than the bottom. Also, limited conduction and convection in the rock bed significantly reduce heat loss from the rock bed.

Heat is drawn from storage by circulating air from the building directly through the rock bed from bottom to top. The air is delivered to the building at a temperature near the maximum temperature of the collectors. If additional heat is required, supplementary heat is added downstream from the storage unit. This system allows the rock bed to deliver useful heat until all of the rocks are at room temperature.

A variation is a no-storage air heating system that circulates heated air when available. Performance is limited to daytime heating because of the lack of storage, but such systems are well suited to warehouses and factories with daytime operations. Domestic hot water is provided by pumping the water in the preheat tank through an air-to-water heat exchanger placed in the return air duct from the collectors. This is not efficient and is one of the disadvantages of the air system.

Heat Distribution for Liquid Types of Solar Systems

The temperature requirements of a hydronic heating system depend on the amount of heat exchanger surface. Most baseboard heaters have comparatively small surface areas, so they require higher temperatures, typically about 180°F. If larger heat transfer areas are available, as in older or modified hot-water systems, temperatures of 120°F maybe sufficient. Temperatures of 100°F to 120°F are adequate for the system that uses entire floors, walls, and ceilings as radiator surfaces.

During the winter, typical liquid types of solar systems are seldom operated at delivery temperatures above 150°F. Clearly the use of solar-heated water in standard baseboard heaters is impractical. Only modified baseboard heaters of adequate size or radiant panels are suitable for use in hydronic systems that use solar-heated water.

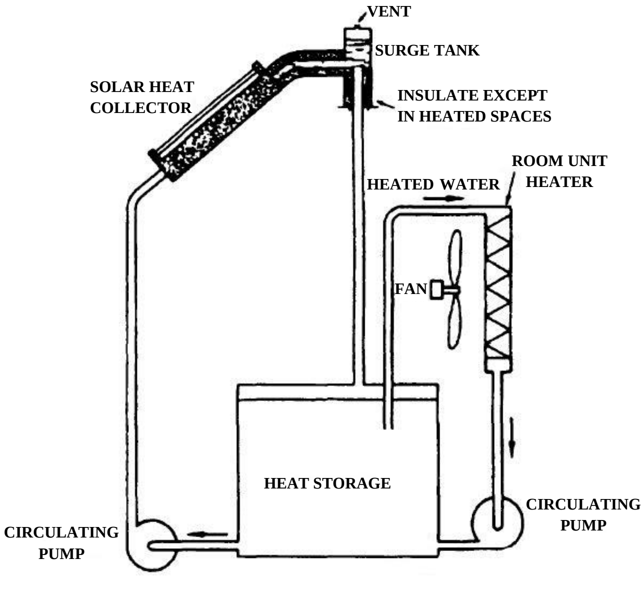


Figure 15-11 — Minimum heating system showing relationship of collector, storage, and room unit heater.

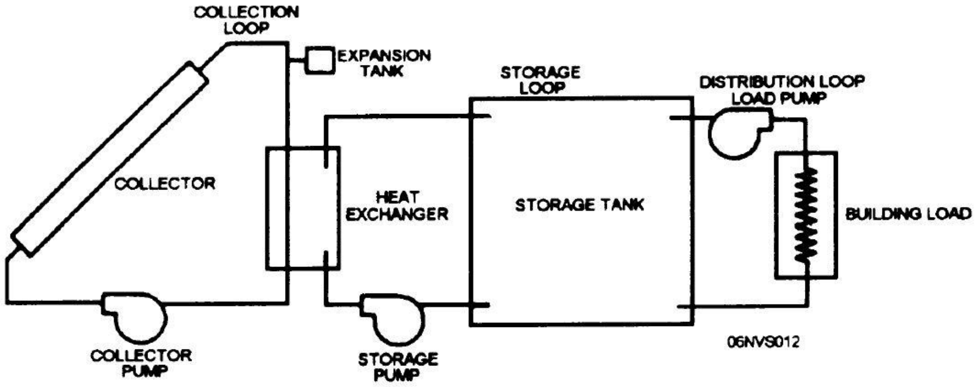
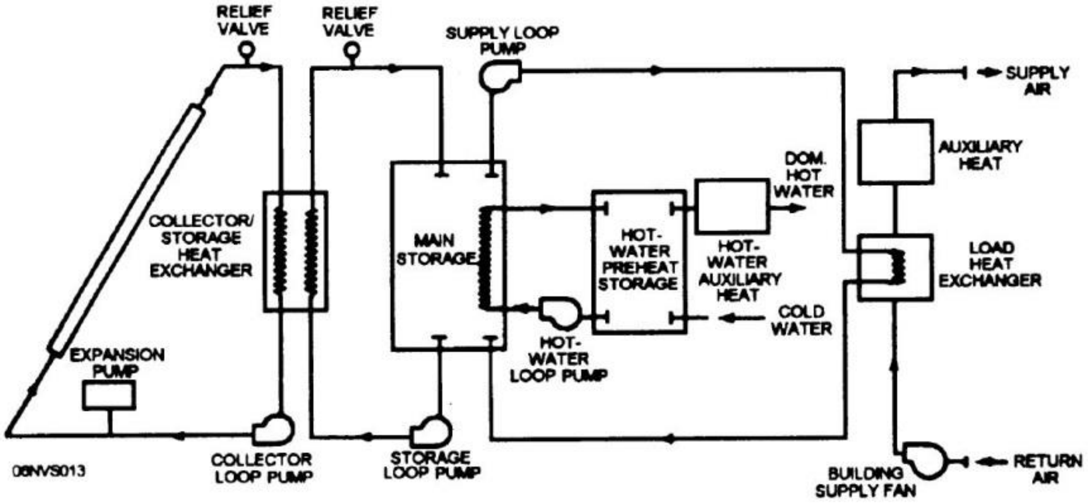


Figure 15-12 — Space heating system with a closed-loop collector.

One economical means of auxiliary heat supply and heat distribution for liquid types of solar systems involves the use of a warm-air system. A typical system is shown in figure 15-15. In this system, the warm-air furnace is located downstream from a liquid-to-air heat exchanger supplied with solar-heated water. The furnace can then serve to boost air temperature when insufficient heat is available from the solar-heated water, or it can meet the full heat load when no heat is available in solar storage. Auxiliary heat can be supplied by a gas, oil, or electric furnace, or by the condenser of an air-to-air heat pump.

Another method of heat distribution is to use a water-to-air heat pump that draws heat from the solar storage tank and pumps it to a condenser coil placed in a central air duct. The advantage of this system is that it can effectively use heat from solar storage at temperatures down to 45°F; thus more of the stored heat is available. Also, average storage temperatures are lower, resulting in significantly increased collector efficiency. Some manufacturers are combining solar systems with heat pumps to reduce auxiliary energy costs. When a heat pump and solar system are combined in this manner, the system is usually called a solar-assisted or solar-augmented heat pump (SAHP) system.

Figure 15-13—Space heating and domestic hot-water systems.



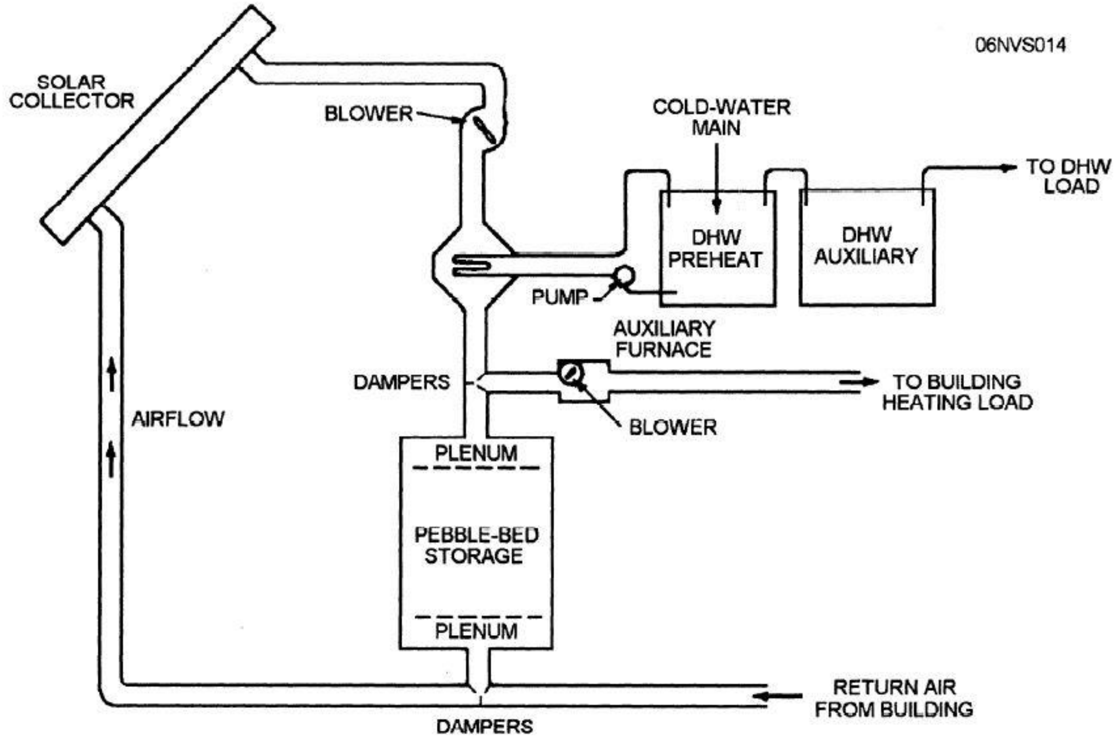


Figure 15-14 - Typical air types of space heating systems.

Solar-assisted heat pump systems are configured in many different ways. For example, the solar collectors can be either water or air types; the heat storage medium can be water or a solid material, such as rock or brick; and the heat pump can be of either the air-to-air design or the water-to-air design. But heat pumps have a characteristic that can limit their effectiveness: the efficiency and capacity of a heat pump decrease as the temperature of the heat source (usually outdoor air) decreases. This deficiency can be overcome, however, by using solar collectors to gather the energy of the sun to keep the heat source in the temperature range required for efficient heat pump operation.

Heat Distribution for Air Types of Solar Systems

The pipes and pumps of the liquid types of solar systems are replaced by air ducts and fans. The warm-air system is obviously the best heat distribution system for use with an air type of solar system. The ability to circulate air to the building directly through the collectors is one of the major

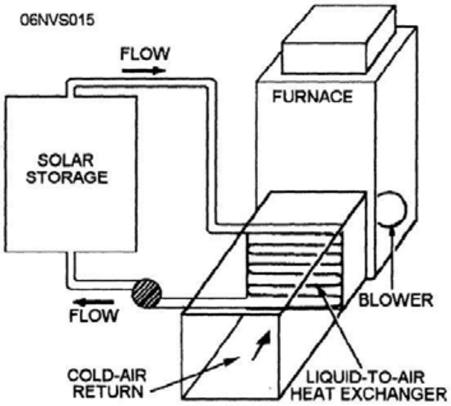


Figure 15-15 - A liquid-to-air heat delivery system.

advantages of this system. The rock-bed storage also works best with a warm-air system.

Although warm air as low as 100°F can be used to heat an occupied building, most existing warm-air systems are sized assuming warm-air temperatures of 120°F to 150°F. Typical midday collection temperatures usually range from 130°F to 170°F. Maximum storage temperatures are typically around 140°F at the end of the collection period. Thus, the heating load can be met by the temperature of the solar-heated air for a large portion of the day. When storage temperatures are insufficient to maintain the desired temperature of the building heat from an auxiliary source must be added to supplement the solar-heated air. The auxiliary furnace is located downstream from the rock bed, so the rock bed serves as a preheater for the furnace. This arrangement allows the rock bed to deliver useful heat until all of the rocks are at room temperature.

An air handler unit provides the dampers and blowers necessary to direct air circulation between the solar collectors, rock bed, and building. An air handler unit may be more expensive than the combined cost of individual dampers and blowers, but it is probably less expensive to install. It is also more compact.