Solar Energy Systems

Continuing Education from the
American Society of Plumbing Engineers

CEU 263

September 2018

ASPE.ORG/ReadLearnEarn

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The sun hits the Earth with enough energy every minute to meet the needs of the world's population for an entire year. Its energy output is 386 billion, billion megawatts per second, which translates to a power level of 1.4 kilowatts per square meter or 440 British thermal units (Btu) per square foot (see Figure 10-1). The Earth bathes in a variety of energy wavelengths and particles from the sun, but for the purposes of this chapter, solar energy is a renewable, environmentally friendly resource in the form of heat and light. Solar energy is available everywhere on Earth, at least part of the time, and this energy is provided free of charge. It just needs to be harvested to be used to provide heat, lighting, mechanical power, and electricity.

How much energy can be harvested from the sun? The sun delivers, on a clear day, about 1,000 watts per square meter. The average time that the sun delivers 1,000 watts per square meter in New York City is approximately four hours. Therefore, on average, approximately 4,000 watt-hours can be captured per day per square meter. (One 100-watt light bulb working continuously for 10 hours consumes 1,000 watt-hours.)

ADVANTAGES OF SOLAR ENERGY

A solar energy system can be used to help earn two LEED credits:

- SS Credit 7.1: Heat Island Effect—Non-Roof
- EA Credit 2: On-Site Renewable Energy

Solar energy also reduces reliance on natural gas or electricity for water heating and reduces pollution emissions.

Tax Credits

Tax credits are constantly changing and evolving. Be sure to check for the current local, state, and federal incentives. Many sources for this information are available, including:

- On-site Renewables Tax Incentives: energytaxincentives.org/business/renewables.php
- Database of State Incentives for Renewables and Efficiency: dsireusa.org
- Solar Energy Industries Association (SEIA): seia.org

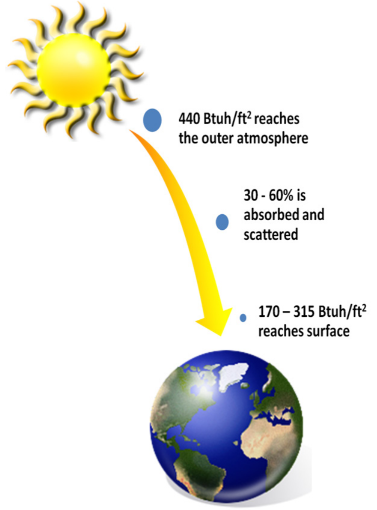

Figure 10-1 Amount of Sun's Energy that Reaches the Earth

ENERGY FROM THE SUN

Energy from the sun can be categorized as thermal energy (heat) or light energy (electricity).

Thermal Energy

Solar thermal technologies use the sun's heat energy to heat substances (such as transfer fluids or panels) for applications such as water heating and space heating. Many products are on the market that utilize thermal energy. Often the products used for this application are called solar thermal collectors and can be mounted on the roof of a building or in some other sunny location.

Research shows that an average household with an electric water heater spends about 25 percent of its home energy costs to heat water. Solar water heaters offer large potential savings—as much as 50 percent to 85 percent annually lower than the cost of electric water heating. A simple payback of four to eight years can be expected on a well-designed and properly installed solar water heater. (Simple payback is the length of time required to recover the investment through reduced or avoided energy costs.)

The United States spends more than $13 billion a year on energy for home water heating. That is equivalent to 11.4 barrels of oil per household—more than the amount of oil (in the form of gasoline) burned by a medium-size automobile driven 12,000 miles.

Solar water heaters do not pollute. Specifying a solar water heater system prevents carbon dioxide, nitrogen oxides, sulfur dioxide, and other air pollution. When a solar water heater replaces an electric water heater, the electricity displaced over 20 years represents more than 50 tons of avoided carbon dioxide emissions alone.

Consider a family of four with a hot water demand of 60 usages per day that installs a solar water heating system with two collectors and an 80-gallon storage tank that has an expected minimum system life of 20 years. The solar energy supplied is 11,010,000 Btu per year, so the energy supplied in 20 years is 220,200,000 Btu. The emissions reduction in 20 years is 16.5 tons of carbon dioxide, 3,330 pounds of nitrous oxides, and 1,950 pounds of carbon monoxide.

Light Energy

Light energy can be converted directly into electrical current through photovoltaic devices. Photovoltaics (PV) is a technology often confused with solar thermal and is, in fact, what many people mean when they refer to solar energy. Photovoltaics (photo = light, voltaics = electricity) is a semiconductor-based technology (similar to the microchip) that converts light energy directly into an electric current that can be used either immediately or stored, such as in a battery or capacitor, for later use. PV panels and modules are very versatile and can be mounted in a variety of sizes and applications (e.g., on a roof or awning of a building, on roadside emergency phones, or as very large arrays consisting of multiple panels and modules). They also can be integrated into building materials, such as PV roofing material, which replaces conventional roofing shingles.

Photovoltaic systems offer the following advantages:

- Reliability: PV modules can be used to provide power in situations where continuous operation is crucial.
- Durability: Many PV modules are capable of producing power for 25 years or longer with minimal degradation.
- Low maintenance cost: Most PV systems do not require much maintenance beyond periodic inspection and occasional service.
- Reduced sound pollution: PV systems operate with minimal sound and movement.
- Photovoltaic modularity: PV systems are typically modular, which allows for additional power to be added to a system as it is needed.
- Safety: PV systems are very safe when properly installed.
- High altitude performance: Photovoltaics power output is optimized at increased altitude due to the greater isolation.

The disadvantages of photovoltaic technology are:

- Initial cost: Each individual PV installation must be evaluated and sized to determine if it is economically feasible compared to existing alternatives.
- Variability of available solar radiation: Weather directly impacts the power output of any solar-based energy system. These variations in the amount of solar radiation must be accounted for in each individual design as they are site specific.
- Energy storage: To allow for backup power to be stored, it is necessary to incorporate batteries into the design, which further increases the cost of the system.
- Efficiency improvements: For the system to be cost-effective, it is typically important to use the energy with high-efficiency devices, which can require the replacement of inefficient devices or appliances.
- Education: PV systems can require additional training on using and maintaining the equipment if the owner is not familiar with the technology.

Consider a home in which a PV system is designed to supply one-third of the electrical needs. Assuming that the home uses 8,000 killowatt-hours (kWh) per year, the PV system would be required to produce 2,667 kWh per year. If the annual delivered energy at this location for a fixed tilt angle is 1,400 kWh per 1,000-watt solar panel, it would be necessary to utilize a 1,900-watt system. At a rate of $10 per watt of installed PV, this system would cost approximately $19,000. Based on the modular nature of the system, it could be possible to add another 900-watt system in the future.

COLLECTORS

The solar collector is the main component of the active solar irradiation collection subsystem. It is the device that absorbs the incoming solar energy, converts it to heat, and transfers this heat to a fluid (liquid or air) flowing through the solar collector (see Figure 10-2). To absorb or collect this energy, several different panel or collector styles are available, which can be classified into two general categories:

- Flat-plate solar collectors (see Figure 10-3): Non-concentrating collectors in which the absorbing surface is essentially planar and is approximately equal to the gross collector area
- Concentrating solar collectors: Collectors that use mirrors, lenses, reflectors, or other optical devices to concentrate the radiant solar energy passing through the collector's aperture onto an absorber that is smaller than the aperture area

See the definitions section at the end of this chapter for the different subtypes of these two general categories.

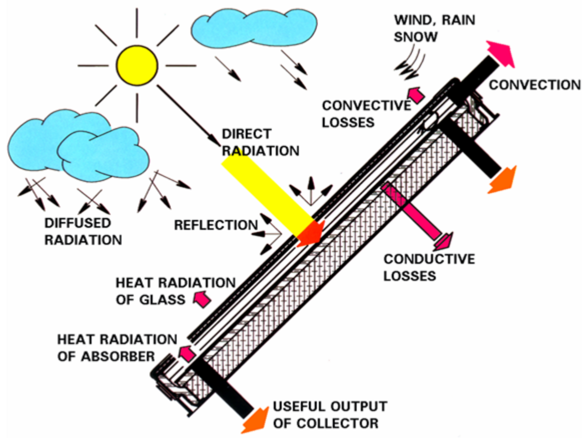

Figure 10-2 How Solar Energy Is Collected

Flat-Plate Solar Collectors

Flat-plate collectors can be designed for applications that require energy absorption at moderate temperatures (212°F above ambient temperature). The advantage of flat-plate collectors is that they use both beam and diffuse solar radiation. Additionally, they do not require orientation toward the sun and require minimal maintenance.

The primary usage of flat-plate collectors is in solar water heating systems, but they have the potential to be utilized in building heating and air-conditioning.

A typical flat-plate solar collector unit consists of the following basic elements:

- One or more collector covers (glazing), transparent to the incoming incident solar radiation and opaque to the infrared radiation from the absorber plate, are intended to protect the absorber plate from the environment and to act as a shield to reduce radiative and convective heat losses from the absorbing surface. Glass and plastic typically are the materials utilized for collector covers.
- An absorber plate (surface), usually incorporating channels (conduits) containing the heat transfer fluid, is used to absorb the sun's incident radiation and to transfer the energy (heat) to the fluid medium in the channels. Metals and plastics have been used in the construction of absorber plates, which are

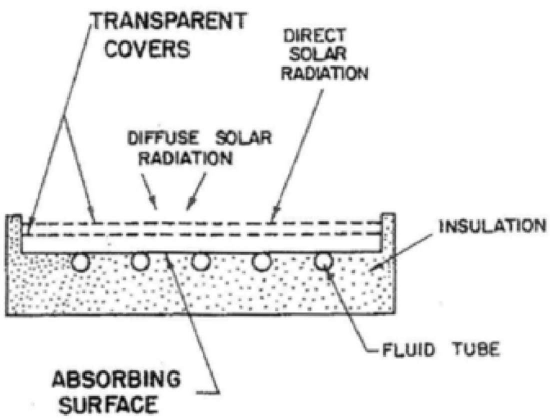

Figure 10-3 Flat-Plate Solar Collector

sometimes coated with a selective surface finish having high absorptivity and low emissivity factors. Extreme care should be exercised when selecting a metal for the construction of the absorber plates. Each material has its own characteristics, which may induce galvanic corrosion. Also, it should be noted that the thermal conductivities of plastics are less than those of metals. Therefore, plastic materials should be limited to low-temperature applications (e.g., swimming pool heating).

- Thermal insulation, placed behind the absorber plate and channel assembly and surrounding the perimeter of the solar collector module, is used to reduce heat losses and to increase radiation on the absorber plates and channel assembly.
- A backplate, which is placed behind the insulation and acts as a reflector surface, is used to reduce heat losses and increase radiation on the absorber plates and channel assembly. Aluminum and foil reflectors are the materials generally used in the construction of backplates.
- Headers (manifolds) are used to convey the absorbed energy. To ensure steady flow conditions, the headers should have a cross-sectional area larger than the area served by the channels. Metals and plastics are the materials commonly utilized in the construction of headers.
- A frame, including angle-fixing and mounting devices, etc., encloses the complete solar collector module.

Many configurations of flat-plate solar collectors are available. For example, the absorber plate/channel assembly could be of a fin-shaped design or in corrugated sheets, with channels above, channels below, or channels as integral parts with the absorber plate. Also, flat-plate modules used in swimming pool heating applications (low temperature/high water volume) do not normally require a cover, backplate, or insulation by design. The absorber plate, channel assembly, and headers are the only elements necessary.

The amount of incident solar energy (radiation) collected is governed by the following criteria:

- Transmittance of the collectors covers, which should exceed 90 percent of the solar spectrum
- Absorptivity factor of the absorber plate to the incident solar radiation, which should exceed 95 percent
- Emissivity factor of the absorber plate in the infrared spectrum
- Thermal resistance between the absorber plate and the heat transfer medium
- Reduction of the conductive, convective, and radiative heat (thermal) losses from the panel, which depends on the operating temperature of the panel, usually ranging from 90–210°F or higher

The most widely used measure of the performance of flat-plate collectors is thermal efficiency (q), which is defined as the ratio of delivered heat to the incident solar radiation. However, it should be noted that the thermal efficiency of a flat-plate solar collector is not a sufficiently descriptive index to select a unit module. The most important properties of a flat-plate solar collector are the collector's operating temperature, the type of collector surface, and the type and number of collector covers.

The steps to determine the thermal efficiency of a flat-plate solar collector, including the necessary data, are:

1. To calculate the incident beam component of insolation normal to the collector ($I_{b,coll}$) and the diffuse component of insolation ($I_{h,d}$), obtain the insolation on a horizontal surface (I_h), cloud cover (CC), solar altitude angle (a), collector tilt angle (E), and latitude (L).
2. To calculate the absorbed radiation (I_{coll}), obtain the number of collector covers (n).
3. To calculate the delivered energy to the working fluid (qa), obtain the wind speed (v) in knots (m/s), collector temperature (T_{coll}) in degrees Rankin, and the collector's physical properties.

In-depth calculations can be performed using the book *Solar Engineering of Thermal Processes* by Duffie and Beckman. The following equation can be used in estimating the thermal efficiency:

Equation 10-1

$$\eta = \frac{Q_{useful}}{A_a I_a}$$

where

η = Thermal efficiency
Q_{useful} = Rate of useful energy output, W
A_a = Aperture area of the collector, m^2
I_a = Solar irradiance falling on the collector aperture, W/m^2

The definition of collector efficiency depends on the type of collector. In the case of thermal collectors, the rate of useful energy output is the heat added to the transfer fluid, which is defined by Equation 10-2:

Equation 10-2

$$Q_{useful} = mc_p (T_{out} - T_{in})$$

where

Q_{useful} = Rate of useful energy output, W
m = Mass flow rate of the heat transfer fluid, J/kg°K
T_{out} = Temperature of the heat transfer fluid leaving the absorber, °K
T_{in} = Temperature of the heat transfer fluid entering the absorber, °K

Concentrating Collectors

The advantages of using concentrating collectors in solar energy systems have long been recognized. Several thermal processes require much higher temperatures than those that can be reached by flat-plate solar collectors; therefore, concentrators must be employed. However, although many concentrating solar systems have successfully operated over the years, economics have played a very important role. Flat-plate solar collectors that do not require sun-tracking devices have taken predominance because of their lower manufacturing and installation costs.

The temperature of the receiver will increase until the convection and heat loss from the receiver are equal to the total absorbed solar energy. This temperature is called the collector stagnation temperature. Heat is removed prior to reaching the collector stagnation temperature and is utilized as useful energy.

To optimize the available energy, the amount of heat loss must be minimized. This can be accomplished by operating the collectors at a temperature near the ambient temperature or by reducing the heat loss at elevated temperatures. Since heat loss is directly proportional to the area of the surface, the most common way of the reducing the heat loss is by reducing the hot surface. In concentrating collectors, the area is reduced by reflecting or refracting the light from the collector's aperture onto an absorber with a small area. The geometry of the reflecting surfaces is primarily dominated by parabolic shapes (parabola, parabolic cylinder, or paraboloid), although spherical optics are available that allow for fixed aperture concentrators that do not require tracking due to the symmetry with respect to rotations about its center.

Some of the advantages of concentrating collectors over flat-plate collectors are as follows:

- The reflecting surfaces require less material and are structurally simpler, which reduces cost.
- The absorber area is significantly smaller, so the radiation intensity is much greater.
- The working fluid can attain higher temperatures.
- Little or no antifreeze solution is required.

Some of the disadvantages are:

- The concentrating collector only collects on the direct component of the radiation, which requires the addition of a tracking system to follow the sun's movement across the sky.
- Maintenance and operating costs are higher.
- Reflecting surfaces may deteriorate.
- The diffuse component of radiation plays a very small role in the heating of the fluid.

Compound Parabolic Concentrator

The CPC is a non-tracking solar collector consisting of two sections of a parabola of second degree, symmetrically located about the mid-plane of a collector. The two sections form a single curvature solar concentrator with an angular acceptance of 2 (θ_{max}).

The acceptance depends on the ratio of aperture area (W_c) to the absorber area (W_a) and is expressed by the following relation:

Equation 10-3

$$\theta_{max} = \sin^{-1} \left(\frac{W_a}{W_c} \right)$$

where

θ_{max} = Maximum acceptance
W_a = Absorber area, ft^2
W_c = Aperture area, ft^2

The concentration ratio (CR) of the CPC system can be determined by the following expression:

Equation 10-4

$$CR = \frac{W_e}{W_a}$$

This collector system should be oriented in an east-west direction and tilted toward the south at an angle (E) from the horizontal plane. When the angle (y) is less than A_{max}, the CPC collector accepts both direct and diffuse components of sunlight. When the angle is greater than A_{max}, the CPC collector accepts only diffuse sunlight over the portion of the aperture area equal to the absorber area. Beam insolation incident on a CPC collector outside the acceptance angle does not reach the absorber area, but is reflected from the side walls back through the aperture.

The theoretical depth of the CPC collector (d_{coll}) depends on the concentration ratio and is defined by the following expression:

Equation 10-5

$$d_{coll} = W_a\left[\frac{(CR+1)}{2} \right] [(CR-1)^{1/2}]$$

In actual practice, it has been found advantageous to use a value of d_{coll} that is one-third smaller than that calculated from Equation 10-5.

HEAT TRANSFER FLUIDS

The heat transfer fluid carries the thermal energy through the solar collectors and a heat exchanger to the storage tank. The fluid used should be selected using the following criteria:

- Stability (thermal and oxidative) for the operating temperatures, including stagnation, liquid range (freezing to boiling), decomposition temperature, and vapor pressure
- Thermal properties (specific heat and thermal conductivity)
- Flash and fire points
- Specific gravity and viscosity at operating temperatures
- Compatibility with the system's components
- Toxicity ratings
- Cost, availability, and service life estimate

Table 10-1 Properties of Heat Transfer Fluids

Fluid	Freezing Point, °F (°C)	Boiling Point, °F (°C)	Stability	Flash Point, °F (°C)	Specific Heat, Btu/lb-°F	Thermal Conductivity, Btuh/ft²-°F	Viscosity, csk
Water	32 (0)	212 (100)	Requires pH or inhibitor monitoring	None	1	0.363	0.9
Ethylene glycol	-33 (-36)	230 (110)		None	0.8	0.23	3.4
Propylene glycol	-28 (-33)	225 (107)		None	0.85	0.225	5
Silicone	-58 (-50)	None	Good	450–600 (232–316)	0.34–0.48	0.083	20–50
Paraffinic oil	15 (-9)	700 (371)	Good to fair	300–455 (149–235)	0.43–0.63	0.07	1–60
Glycerol	-31 (-35)	230 (110)	Good	None	0.8	0.27	7

For example, in a cold climate, a fluid with a low freezing point should be selected, and vice versa, a fluid with a high boiling point should be selected in hot climates. Viscosity and thermal capacity determine the amount of pumping energy required. A fluid with low viscosity and high specific heat is easier to pump because it is less resistant to flow and transfers more heat.

The properties of various heat transfer fluids commonly used in solar-assisted service water heating systems are shown in Table 10-1.

HEAT EXCHANGERS

The use of a heat exchanger in a solar energy system makes it possible to store and deliver the energy (heat) absorbed by the solar collectors for subsequent utilization. A heat exchanger is simply a device designed to transfer heat between two physically separated media.

Three types of heat exchangers may be used to transfer this energy: air to air, liquid to liquid, and liquid to air. In air-to-air heat exchangers, the cooler air is heated by circulating it through, or around, a tank containing the warmer air. In liquid-to-liquid heat exchangers, the cooler fluid is heated by circulating it through, or around, coils containing the warmer fluid. In liquid-to-air heat exchangers, the cool air is heated by circulating it over coils containing the warmer liquid.

Regardless of the type of heat exchanger used, the transfer of the energy (heat) can only occur if a temperature differential exists between the two physically separated fluids or media. This heat transfer will continue until the two fluids reach the same temperature (thermal equilibrium). Heat transfer fluids are circulated through the heat exchanger, where the energy is transferred to the thermal storage medium, and the cooler fluid is pumped back to the solar collectors to absorb more heat. The rate of heat transfer between the two media depends on the type of heat exchanger used, the temperature difference between the two media, and the flow rate.

In many solar energy system designs, two heat exchangers are employed. One is used to transfer the absorbed energy from the solar collector loop to the thermal storage medium, and the other is used to transfer the stored energy from the thermal storage medium to the distribution subsystem.

During the heat-exchange process, the building's potable water supply could be contaminated by a nonpotable heat transfer fluid due to a failure of the heat exchanger. In addition to providing the necessary interface between the potable water and the heat transfer fluid, the heat exchanger protects the potable water from contamination by the heat transfer fluid, and its thermal performance greatly determines the overall efficiency of the system.

STORAGE TANKS

Solar energy can be stored, in the form of heat, for subsequent delivery and use on demand. The thermal storage system consists of a well-insulated tank (to minimize heat loss) containing the heat-storage medium and the related piping, controls, and other components used to safely and effectively add, store, and remove the thermal energy when necessary.

Thermal storage tanks used in solar energy systems should be constructed of a durable material, be water-tight, and not be subject to excessive corrosion. In addition, storage tanks should be designed to withstand all anticipated loads during normal in-service conditions. The controls and other components attached to or within the tank should be accessible for repair or replacement, and the tank should meet the requirements set forth in the applicable local codes and ordinances.

Liquid-type thermal storage tanks should also be designed with a means for draining the system when required (i.e., for maintenance). Generally, pressurized systems are designed to withstand a pressure equivalent to 150 percent of the design operating pressure. Relief devices (overpressure, over temperature, or combination) should be specified as required by design and local codes.

Thermal storage tanks used in solar energy systems should have a minimum insulation thickness, based on the insulation material having a k-value equal to 0.29, as shown in Table 10-2. The temperature differential is the difference between the typical in-service operating temperature of the thermal storage tank and the typical temperature of the surrounding air (or soil, if the storage tank is underground) during the operating season. If such data is not available, the local jurisdiction should be consulted for acceptable assumptions and

Table 10-2 Minimum Insulation Thickness for Thermal Storage Tanks, k = 0.29

Temperature Differential, °F (°C)	Minimum Thickness, in. (mm)
50 (28)	1½ (38)
100 (56)	3 (76)
150 (83)	4½ (114)
200 (111)	6 (152)
250 (139)	7½ (191)

values. For thermal insulation materials having k-values other than 0.29, the material manufacturer should be consulted for the minimum insulation thickness needed for the corresponding temperature difference.

Ideally, to reduce heat losses to the surrounding area as much as possible, the thermal storage tank should be located as close as possible to the solar collectors. However, this is not possible in many designs because the collectors are usually mounted on the building's roof, and the structure would not be capable of supporting the tank and its contents. Therefore, the second best location for the thermal storage tank is usually the building's basement or another heated area, with protection against moisture and cold, as close as possible to any existing service water heating components and the point of ultimate use. Thermal storage tanks should not be located in areas where flammable materials are stored.

CONTROLS FOR ENERGY COLLECTION

The controls of a solar energy system regulate its operation and allow maximum utilization of the system's capabilities. These devices control the quantity of solar energy collection and the heat delivery in direct response to the building's heating demand.

Collection Loop

The controls are set to turn the pump on or off at specified temperature differentials between the solar collectors and the thermal storage tank: the temperature differential required to activate the pump (ΔT_{on}) and the temperature differential needed to turn off the pump (ΔT_{off}).

As the sun rises, the temperature in the solar collector array will increase above the temperature in the storage tank. When ΔT_{on} is reached, the controls will turn on the pump to circulate the heat transfer medium through the solar collectors and absorb the heat. This heat is then extracted from the heat transfer medium in the system's heat exchanger and transferred to the storage tank. The circulation process of the heat transfer medium will continue until the temperature differential between the solar collectors and the thermal storage tank reaches ΔT_{off} or approaches another specified temperature setting. When it reaches that temperature, the controls will turn off the pump and stop the circulation process, thus preventing heat losses to the environment through the solar collectors.

The temperature differential settings depend on factory adjustments of the controls. One setting is referred to as the threshold setting, the temperature differential between the pump turn-on and the pump turn-off condition, and the other setting is called the hysteresis setting, the time-delay circuit that prevents the pump from being cycled on and off immediately after a pump turn-on or a pump turn-off condition. These features prevent unnecessary wear of the pump and the controls.

The differential thermostat measures the temperature differential between the solar collector array and the service water in the storage tank and issues the appropriate command to the pump. Most differential thermostats are electronically operated, using thermistors to sense the temperatures and microprocessors to compare the data and issue the appropriate instructions to the pump.

Many other secondary features can be installed in the control system, including a high temperature limit switch, a relay for drain valves (in draindown systems) to open in the event of freezing conditions, and a proportional speed controller.

To operate the solar system at a higher efficiency, a greater degree of control sophistication is required. This condition can be achieved by operating the pump at a faster or slower speed, depending on the temperature differential between the solar collectors and the service water in the storage tank. When this temperature difference is small, 3–5°F (1.7–2.8°C), the circulating pump should be operated at slower speeds. However, when the temperature difference is 12–15°F (6.7–8.4°C), then the pumps should be run at higher speeds. Variable pump speeds are necessary to maximize solar energy collection.

The solar control system should include safety provisions for high temperature protection. The solar energy collection process should be discontinued when the service water in the storage tank reaches the highest desired temperature, usually in the 160–165°F (71–74°C) range.

Distribution Loop

The energy delivery system of a building requires two sensing controls. When a temperature change is needed, a thermostat calls for either cool or warm air. In response to this demand, the distribution loop's control system must turn on the appropriate source of energy to satisfy this need. Consequently, since the energy can be provided from various sources, a second control system is included to select the proper source and should be programmed to turn on the less costly energy source at the time of the demand.

The sensor for the second control system should be located at the top of the solar storage tank. It sets up the appropriate energy delivery system depending on the temperature of the solar storage water. A thermistor is the recommended system. The device senses the temperature of the solar storage and activates the microprocessor.

Since heat delivery systems vary depending on the capabilities desired, the controls are usually designed and installed for each particular site. The thermostat is a standard mechanical device, and the control components are also standard equipment.

APPLICATIONS

Swimming pool water heating and service water heating are common, cost-effective applications of solar energy systems.

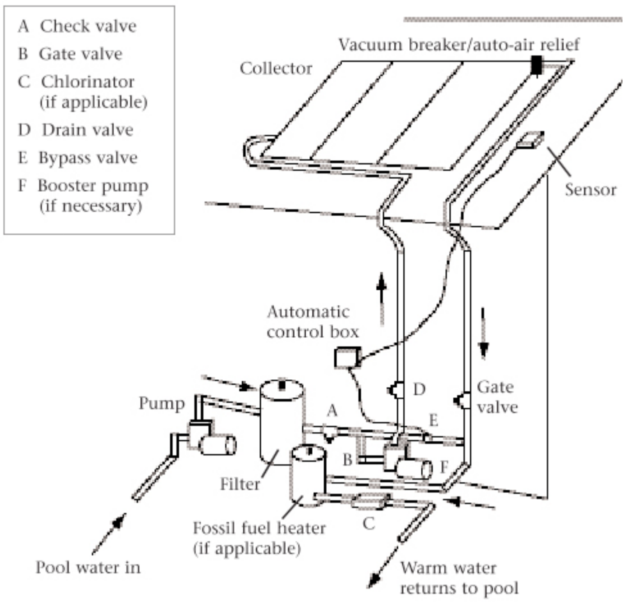

Figure 10-4 Solar Pool Heating System
Source: National Renewable Energy Laboratory, U.S. Department of Energy

Solar Swimming Pool Heating Systems

Swimming pool heating is a simple application of solar energy systems. The water in the swimming pool provides the required thermal storage, and the installation of the distribution system is relatively easy, including retrofits. Also, swimming pool heating is a low-temperature application of a solar energy system; therefore, low-cost solar collectors (i.e., unglazed, uninsulated plastic panel modules) can be employed. Figure 10-4 illustrates a typical solar swimming pool heating system.

Solar-Assisted Service Water Heating

In their simplest form, thermosiphon-type solar-assisted service water heating systems consist of a flat-plate solar collector module and a water storage tank. The storage tank must be installed at least 1 foot above the solar collector panel for this type of system to operate properly. No pumps are required in thermosiphon systems, and the flow of water is caused by natural convection (flow due to the density differential between the hot and cold water).

The potable water is heated in the solar collector array. As it is heated, the water expands, becomes less dense, and rises through the collector array into the top section of the storage tank. The cooler (more dense) water sinks to the bottom section of the storage tank and flows into the collector array to be heated. Figures 10-5 and 10-6 illustrate direct and indirect thermosiphon-type solar-assisted service water heating systems.

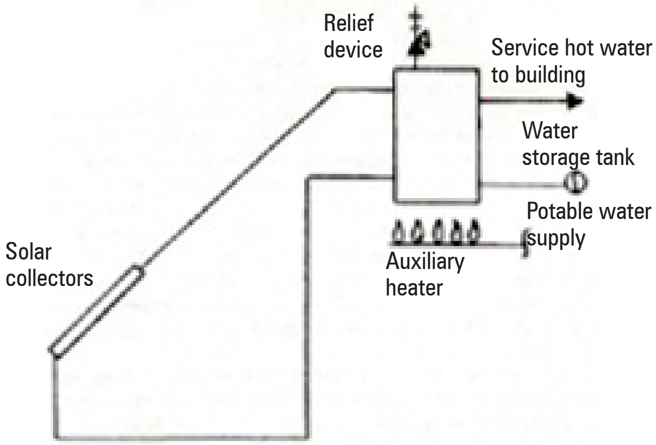

Figure 10-5 Direct Thermosiphon-Type Solar-Assisted Service Water Heating System

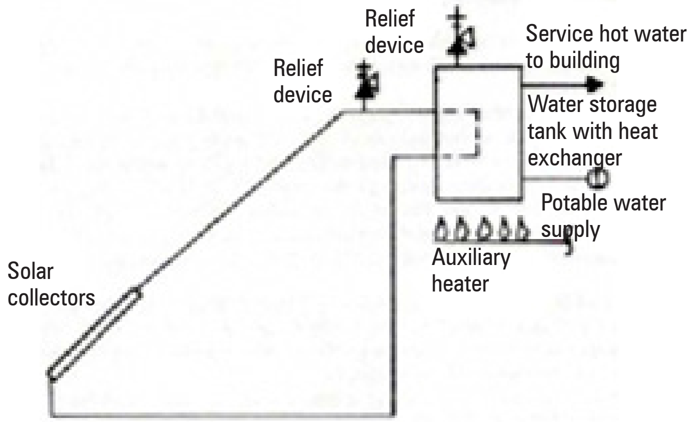

Figure 10-6 Indirect Thermosiphon-Type Solar-Assisted Service Water Heating System

Solar-assisted service water heating systems generally provide maximum savings when the system is designed to deliver 45 to 70 percent of the load. To determine the amount of energy required to heat the service water, the following information is needed:

- Hot water supply temperature
- Cold water supply temperature
- Daily hot water demand

Although many system types, applications, and design techniques may be considered for various service water heating requirements, a few basic guidelines should be followed in all cases:

- Design each system as simple as possible for each specific application.
- Match the system design to load patterns and magnitude, and avoid the misuse of design rules of thumb.
- Consider system efficiency, as well as collector efficiency.
- Examine all phases of a system's control cycle for potential operational and energy waste problems.
- Plan for component expansion, movement, and service during system design.

DEFINITIONS

The following terms are frequently employed in solar energy technology and related applications.

Absorber area The total heat transfer area from which the absorbed solar radiation heats the transfer fluid or the absorber media if both transfer fluid and solid surfaces jointly perform the absorbing function, in square feet (m^2).

Absorber (plate) The part of the solar collector that receives the incident solar radiation energy and transforms it into thermal energy. In some cases, the heat transfer fluid itself could be the absorber.

Absorptance The ratio of the absorbed flux to the total incident flux, measured in terms of percent.

AC loads Appliances, motors, and equipment powered by alternating current.

Angle of incidence The angle between the line of direct solar irradiation and the perpendicular to the aperture plane, in degrees.

Angle of reflection The angle between the reflected rays' propagation direction and the perpendicular to the surface at the point of reflection, in degrees.

Angle of refraction The angle between the refracted rays' propagation direction and the perpendicular to the interface at the point of refraction, in degrees.

Array One or more panels wired together at a specific voltage.

Area, aperture The maximum projected area of a solar collector through which unconcentrated solar radiant energy is admitted, in square feet (m^2).

Area, gross collector The maximum projected area of a solar collector module including any integral mounting devices, in square feet (m^2).

Auxiliary energy subsystem A configuration of equipment and components, utilizing conventional energy sources, to supplement the output of the solar energy system.

Battery storage A medium that stores direct current (DC) electrical energy.

Charge controller Equipment that regulates battery voltage.

Collector A device used to absorb the sun's energy.

Collector, concentrating A collector that uses reflectors, lenses, or other optical devices to concentrate the radiant solar energy passing through the aperture onto an absorber that is smaller than the aperture area. Parabolic trough-shaped reflectors concentrate sunlight onto the absorber or receiver.

Collector, flat plate A non-concentrating collector in which the absorbing surface is essentially planar and usually approximately the same area as the aperture.

Collector, evacuated tube (vacuum tube) A collector consisting of rows of parallel transparent glass tubes, each containing an absorber and covered with a selective coating. Sunlight enters the tube, strikes the absorber, and heats the contained liquid in the absorber, converting it into a vapor that rises to the heat pipe tip. These collectors are manufactured with a vacuum between the tubes, which helps them achieve extremely high temperatures (170–350°F).

Collector, transpired A south-facing exterior wall covered by a dark sheet-metal collector. The collector heats outside air, which is then drawn into the building's ventilation system through perforations in the collector.

Collector, trickle A flat-plate collector over which non-pressurized liquids flow.

Collector efficiency The ratio of the energy collected (or absorbed) to the total solar energy incident on the collector, expressed in percent.

Collector subsystem That portion or assembly of the solar energy system used for absorbing incident solar radiation, converting it to thermal energy, and transferring the energy to a heat transfer fluid. The collector subsystem includes the solar collectors, related piping or ducts, and regulating devices.

Collector tilt The angle above the horizontal plane at which a solar collector is mounted, in degrees.

Concentrating ratio The ratio of the aperture area to the absorber of a solar collector.

Concentrator A reflector, lens, or other optical device in concentration solar collectors used to focus the incident solar energy on the reduced absorber area.

Conduction A heat transfer process by which heat flows from a region of higher temperature to a region of lower temperature within a solid, liquid, or gaseous medium by molecular contact or between different media having direct physical contact.

Convection A heat transfer process in which heat is transferred from one region to another by motion of a fluid.

Convection, forced A convection transfer process caused by mechanical devices, such as fans and injectors.

Convection, free A convection transfer process caused by density differential within a fluid, without the involvement of any mechanical devices.

Cooling system The complete assembly of subsystems required to convert solar energy into other forms of energy for space cooling purposes.

Cover, collector The transparent material placed over the aperture or absorber area of a solar collector to provide protection from the environment and reduce thermal losses from radiation or convection.

Distribution subsystem The portion of a solar system from the storage subsystem to the point of ultimate use, including the related piping or ducts and regulating devices.

DC loads Appliances, motors, and equipment powered by direct current.

Emittance The fraction of heat radiated by the solar collector, measured in percent of the absorbed energy by the panel.

Emissivity The ratio of the radiation emitted by a surface to the radiation emitted by a black body at the same temperature.

Energy transport subsystem The portion of a solar system that contains the heat transfer media and transports the energy throughout the solar system, including related piping and regulating devices.

Heat exchanger A device designed for transferring heat between two physically separated fluids.

Heat pump A device designed to simultaneously or alternately use the heat extracted at a low temperature and the heat rejected at a high temperature for cooling and heating purposes.

Heat transfer medium A fluid used in the transport of thermal energy.

Heating and cooling system The complete assembly of subsystems required to convert solar energy into thermal energy and utilize this energy, in combination with auxiliary energy (if necessary), for combined heating and cooling purposes.

Heating system The complete assembly of subsystems required to convert solar energy into thermal energy and utilize this energy, in combination with auxiliary energy (if necessary), for heating purposes.

Hot water system The complete assembly of subsystems required to convert solar energy into thermal energy and utilize this energy, in combination with auxiliary energy (if necessary), for service water heating.

Infrared radiation Invisible radiation with wavelengths greater than 700 nanometers but less than microwaves (about 1 millimeter).

Irradiation (insolation), instantaneous The quantity of solar radiation incident on a unit surface area in a unit of time, in Btuh per square foot (W/m^2).

Insolation The solar radiation striking the surface of the Earth or another planet. Also the rate of delivery of solar radiation per unit of horizontal surface (see *irradiation*).

Inverter An electrical device that changes direct current to alternating current.

Module A configuration of PV cells laminated between a clear superstrate (glazing) and an encapsulating substrate.

Panel One or more modules (often used interchangeably with *module*).

Performance factor efficiency The ratio of the useful output capacity of a system to the input required to obtain it

Photovoltaic cell Thin squares, discs, or films of semiconductor material that generate voltage and current when exposed to sunlight.

Radiant emittance (exitance) The quotient of the radiant flux leaving an element of the surface containing the point by the area of that element.

Radiant flux Power emitted, transferred, or received in the form of electromagnetic waves or photons.

Radiant intensity The quotient of the radiant flux emitted by a source (or by an element of a source in an infinitesimal cone containing the given direction) by the solid angle of the cone.

Radiation The heat transfer process by which heat flows from a body at a higher temperature to a body at a lower temperature, when the bodies are separated in space or when a vacuum exists between them (emission or transfer of energy in the form of electromagnetic waves or photons).

Selective surface A coating applied to a solar collector, or its absorber area, having high absorptance and low emittance.

Solar absorptance The fraction of the solar irradiance that is absorbed.

Solar constant The solar radiation intensity that is incident on a surface normal to the sun's rays, outside the Earth's atmosphere, at a distance from the sun equal to the mean distance between the Earth and the sun. The accepted valued of the solar constant is equal to 428.8 Btuh per square foot (1,353 W/m^2).

Solar degradation The process by which exposure to sunlight deteriorates the properties of materials.

Solar energy The photon (electromagnetic) energy originating from the sun.

Solar energy system Equipment and components arranged in a manner to collect, convey, store, and convert solar energy.

Solar energy system, active A solar energy system in which the incident solar radiation is absorbed by the solar collectors, transferred to an independent thermal storage unit, and distributed to the point of ultimate use by means of mechanical devices powered by conventional fuels (i.e., pumps and fans).

Solar energy system, air A solar energy system that uses air as the primary heat transfer fluid.

Solar energy system, closed A solar energy system that has a completely enclosed collector subsystem circulating the heat transfer fluid under pressure above atmospheric and is shut off from the atmosphere, except for an expansion tank.

Solar energy system, liquid A solar energy system that uses liquid as the primary heat transfer fluid.

Solar energy system, open A solar energy system that exchanges heat directly with the end-use application.

Solar energy system, passive A solar energy system in which solar energy utilization becomes the prime objective of engineering and architectural design. The flow of heat is achieved by natural convention, conduction, and radiation.

Solar energy system, thermosiphon A passive solar energy system in which fluids circulate due to their temperature differentials, rather than the influence of pumps or fans.

Storage device (thermal) The container, including all contents of the container, used for storing thermal energy. Heat transfer fluid, heat exchangers, flow control devices, valves, baffles, etc., that are integral with the thermal storage container are regarded as parts of the storage device.

Storage medium (thermal) The material in the thermal storage device, independent of the containing structure, in which the major portion of the energy is stored.

Storage subsystem The assembly of components necessary for storing energy so it can be used when required, including all related regulating devices used in connection thereof.

Subsystem A major, separate, and functional assembly or portion of a system.

Thermosiphon The natural circulation of a fluid caused by temperature differentials within the fluid system.

Transfer fluid, heat The medium that flows through a solar collector and carries the absorbed energy away from the collector.

Transmittance The ratio of flux transmitted through a material to the incident flux.

Ultraviolet radiation Radiation with wavelengths from 10 nanometers to 380 nanometers.

Watt A measure of energy expressed in unit of time (1 watt = 1 joule per second).

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CE Questions — "Solar Energy Systems" (CEU 263)

1. Which of the following is one of the most important properties of a flat-plate solar collector?
   a. collector's operating temperature
   b. type of collector surface
   c. type and number of collector covers
   d. all of the above

2. If the temperature differential is 100°F, what is the minimum insulation thickness of the thermal storage tank?
   a. 1½ in.
   b. 3 in.
   c. 4½ in.
   d. 6 in.

3. Which of the following is the angle between the line of direct solar irradiation and the perpendicular to the aperture plane?
   a. angle of incidence
   b. angle of reflection
   c. angle of refraction
   d. none of the above

4. ________ is an advantage of a photovoltaic system.
   a. variability of available solar radiation
   b. low initial cost
   c. low maintenance cost
   d. none of the above

5. Which of the following valves is part of a solar pool heating system?
   a. gate
   b. drain
   c. bypass
   d. all of the above

6. ________ is the heat transfer process by which heat flows from a body at a higher temperature to a body at a lower temperature.
   a. transmittance
   b. radiation
   c. convection
   d. radiant flux

7. What is the thermal conductivity of propylene glycol?
   a. 0.083 Btuh/ft^2-°F
   b. 0.23 Btuh/ft^2-°F
   c. 0.225 Btuh/ft^2-°F
   d. 0.27 Btuh/ft^2-°F

8. Which of the following is a disadvantage of a concentrating collector?
   a. high maintenance and operating costs
   b. antifreeze solution is required
   c. structurally simple reflecting surface
   d. small absorber area

9. A ________ collector uses reflectors, lenses, or other optical devices to concentrate the radiant solar energy passing through the aperture onto an absorber that is smaller than the aperture area.
   a. concentrating
   b. evacuated tube
   c. non-concentrating
   d. trickle

10. Which of the following materials is generally used in the construction of flat-plate solar collector backplates?
   a. PVC
   b. aluminum
   c. stainless steel
   d. galvanized steel

11. A heat-transfer fluid with ________ and ________ is easier to pump because it is less resistant to flow and transfers more heat.
   a. low viscosity; low specific heat
   b. high viscosity; high specific heat
   c. high viscosity; low specific heat
   d. low viscosity; high specific heat

12. Which of the following is needed to determine the amount of energy required to heat the service water in a solar-assisted service water heating system?
   a. hot water supply temperature
   b. cold water supply temperature
   c. daily hot water demand
   d. all of the above