



Solar Energy

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Note: In determining your answers to the CE questions, use only the material presented in the corresponding continuing education article. Using information from other materials may result in a wrong answer.

OUR SUN

- Diameter: 864,000 miles (1,390,473 km)
- Mass: 438 trillion, trillion, billion pounds (1.99 trillion, trillion, billion kg)
- Surface temperature: 5,800°K (9,980°F)
- Core temperature: 15,600,000°K (28,079,540°F)
- Energy output: 386 billion, billion mega watts per second
- Distance from Earth: 93,000,000 miles (149,668,992 km)
- Power level at Earth: 1.4 kilowatts per square meter or 440 British thermal units (Btu) per square foot

The Sun hits Earth with enough energy every minute to meet the needs of the world's population for an entire year. Earth is populated with more than 6.5 billion people, and the population is growing at a rapid rate, even though the rate of increase actually has been declining since the 1980s. It is estimated that the global population will reach 9 billion people around 2045. Beyond the increase in the population itself are higher rates of increase in industry to support this population and the nations that are emerging into the industrial age. One of the downsides to this industrial growth is its insatiable appetite for energy. Fossil resources are finite, while appetites for consumption are not.

The biggest leap in energy consumption will come from emerging economies such as China and India, where populations are expected to grow by 25 percent over the next two decades and economic output and standards of living also will rise dramatically. Energy demand in China and India alone is expected to double by 2025, but the issue isn't limited to developing countries.

Canada is the No. 1 country for use of energy per capita. The United States is in second place per capita and uses a tremendous amount of energy. The United States is home to 4 percent of the world's population but consumes 25 percent of the world's energy. As the more developed countries continue to prosper, it is only natural that their energy needs will continue to grow accordingly.

A POSSIBLE SOLUTION

To reduce dependence on fossil fuels, the use of renewable energy sources must increase. Some progress is being made. For instance, solar panels are now compulsory on all new and renovated buildings in Spain as part of the country's efforts to update its building codes and to meet the growing demand for energy.

The sun bombards Earth with an enormous amount of energy continuously. If this energy source is tapped, it could provide "free" energy.

WHAT IS SOLAR ENERGY?

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 and used to provide heat, lighting, mechanical power, and electricity.

Various methods of harnessing the sun's abundant and clean energy are available. Energy from the sun, for these purposes, can be categorized in two ways:

- Thermal energy (heat)
- Light energy (photovoltaics)

Solar thermal technologies use the sun's heat energy to heat substances (such as transfer fluids or panels) for applications such as space heating, pool heating, and domestic water 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. The sun's heat also can be used to produce electricity on a large utility-scale by converting the sun's heat energy into mechanical 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). Currently they are being integrated into building materials, such as PV roofing material, which replaces conventional roofing shingles.

How much energy is needed to heat water?

- 1 kilowatt will raise 4.1 gallons of water 100 degrees in one hour (4.1 gph at 100°ΔT).
- 1 watt is approximately 3.41 Btuh.
- 1 kilowatt is 3,412 Btuh.
- 1,000 Btuh is approximately 293 watts.
- 1 Btu will heat 1 pound of water 1°F.

How Can Solar Help?

Research shows that an average household with an electric water heater spends about 25 percent of its home energy costs on heating water. Solar water heaters offer the largest potential savings, with solar water heater owners saving as much as 50 percent to 85 percent annually on their utility bills over 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 the equivalent of 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. See Figure 10-1 for a breakdown of how the use of solar energy compares to other energy sources.

Solar water heaters do not pollute. Specifying a solar water heater system prevents carbon dioxide, nitrogen oxides, sulfur dioxide, and the other air pollution and wastes created when the utility generates power or fuel is burned to heat the domestic water. 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.

Environmental Impact: What Is Being Saved?

Consider a family of four with a hot water demand of 60 usages per day. They install a solar collector system with two collectors and an 80-gallon storage tank and an expected minimum system lifetime 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
- 3330 lbs of nitrous oxides
- 1950 lbs of carbon monoxide

Does It Work for Commercial Applications?

Solar is being used by more businesses every day in applications ranging from heating water to providing a reliable and clean power source. A business can save 40 to 80 percent on electric or fuel bills by replacing a conventional water heater with a solar water-heating system. Solar energy also provides other benefits to business such as “power security,” enabling a business to continue operating even when outside utility power is disrupted.

Concentrating solar power plants generate electricity by using the heat from solar thermal collectors to heat a fluid that produces steam used to power the generator.

Why Use Solar?

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

- SS Credit 7.1: Heat Island, Non-roof, one credit
- E&A Credit 2: Renewable Resources, one to seven credits

Solar energy also reduces reliance on natural gas or electricity for water heating with a sustainable source of “free” energy 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
- Guide to Federal Tax Incentives for Solar Energy: seia.org (member login required)

DEFINITIONS

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

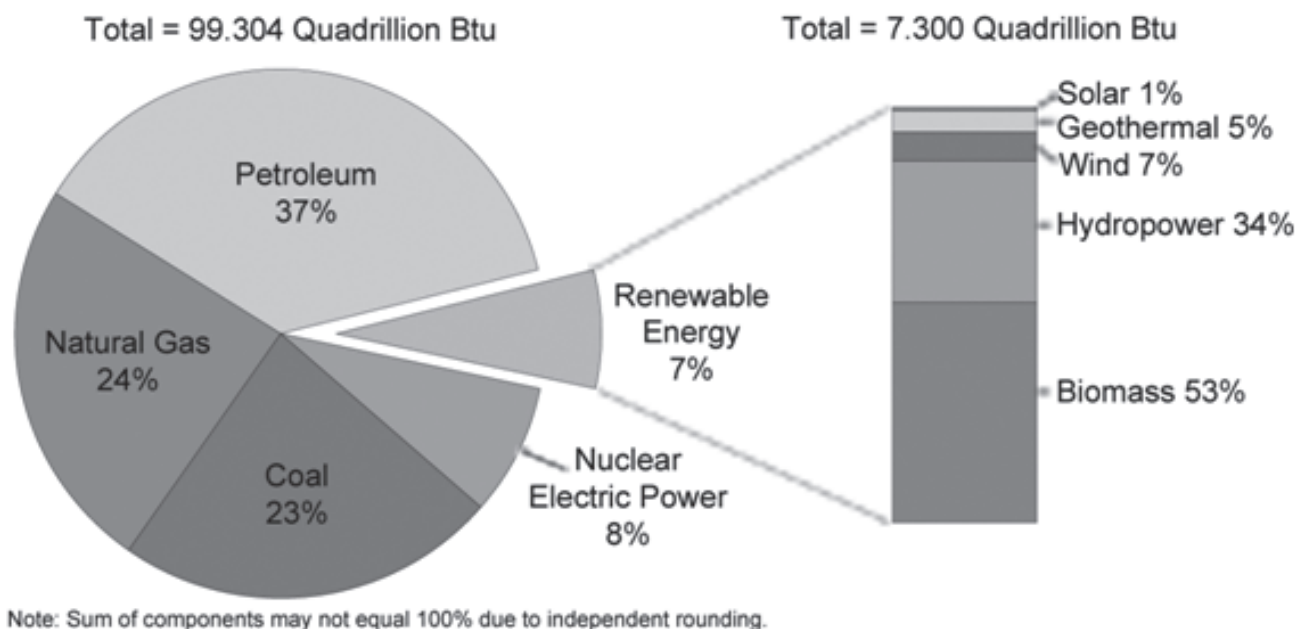


Figure 10-1 The Role of Renewable Energy in the U.S. Energy Supply

Source: U.S. Energy Information Administration

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

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

Area, aperture The maximum projected area of a solar collector through which un-concentrated 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 system

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 of which the surface area is smaller than the aperture area. Parabolic trough-shaped reflectors concentrate sunlight onto an absorber or receiver to provide hot water and steam, usually for industrial and commercial applications.

Collector, flat plate A non-concentrating collector in which the absorbing surface is essentially planar and usually with approximately the same area as the aperture. Small tubes run through the box and carry fluid—either water or another fluid such as an antifreeze solution. The tubes attach to a black absorber plate. As heat builds up in the collector, the fluid passing through the tubes is heated. The hot transfer liquid goes to a storage tank, and water is heated as it passes through a tube inside the storage tank full of hot fluid. This is the most common type of collector for solar water heating.

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 liquid flowing through the absorber. These collectors are manufactured with a vacuum between the tubes, which helps them achieve extremely high temperatures (170–350°F). Their high efficiency makes them a good choice for commercial uses.

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. They have been used for preheating ventilation air and crop drying. They are inexpensive to make, and commercially have achieved efficiencies of more than 70 percent.

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 system used for absorbing incident solar radiation, converting it to thermal energy and transferring this thermal 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 a 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 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

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 Radiation with wavelengths greater than 70 millionths centimeter (7,000 Angstrom units) but less than radio waves, about 5.5 centimeters

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

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

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 a high absorptance and a 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 value of the solar constant is equal to 428.8 Btuh per square foot ($1,353 \text{ W/m}^2$).

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

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

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

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

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

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

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

Storage device (thermal) The containers, including all contents of such containers, 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, separable, and functional assembly or portion of a system

Thermosyphon 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 180 to 400 μm (Angstrom units)

Watt An energy per second unit (1 watt = 1 joule per second)

SOME QUICK ESTIMATING CALCULATIONS

Following are some estimates that can be used in calculations:

- One direct hour of sunlight = 1 kilowatt-hour per square meter
- 1 kilowatt-hour = 3,412 Btu
- 1 gallon of #2 fuel oil = 150,000 Btu
- 1 square meter = 10.6 square feet
- One 4x8 collector (approximately) = 3 square meters
- One 4x8 collector (approximately) = 12–15 kilowatt-hours per day

QUICK COST COMPARISONS

Tables 10-1 and 10-2 illustrate two simple spreadsheets used to estimate costs for different solar systems. Many variables and other project-specific items are not taken into account within these calculations, so the actual cost of a system will be higher. This is only to provide a general idea of the magnitude of the differences among the systems.

A plethora of information is available via the Internet, books, and magazines to assist in the design of solar systems. Some of this information can be found within this chapter; however, a more complete understanding will come only through further research.

SYSTEM SIZING RULES OF THUMB

Approximately 440 Btuh per square foot of energy generated by the sun could potentially reach the Earth (see Figure 10-2). Of that potential energy, 30 to 60 percent is lost in the journey through the atmosphere, and 170 to 315 Btuh per square foot eventually reaches the surface.

For example, Chicago receives 1,260 to 1,575 Btu per square foot per day of energy from the sun. For optimum output, panels should be installed at a 45-degree angle and face south. The optimum output from a panel is roughly 220 Btuh per square foot. The amount of energy disbursed by the sun fluctuates with sunspot activity and solar storms, but the maximum available energy from a collector is generally considered to be 220 Btuh per square foot.

SOLAR IRRADIATION COLLECTION METHODS

The solar collector is the main component of the active solar irradiation collection subsystem (see Figure 10-3). 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. To absorb or collect this energy, several different panel or collector styles are available, which can be classified into three general categories:

- Flat-plate solar collectors: 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

Table 10-1 Solar Cost Comparison, Method A

Solar Collector (Flat Plate)			Cost	Total Cost
Total kilowatts	Watts per square foot	Square feet	Cost per watt	
200	63	3,200	1	\$200,000
PV Panel			Cost	Total Cost
Total kilowatts	Watts per square foot	Square feet	Cost per watt	
200	16	12,500	10	\$2,000,000
PV Roof Material			Cost	Total Cost
Total kilowatts	Watts per square foot	Square feet	Cost per watt	
200	4	50,000	10	\$2,000,000

Table 10-2 Solar Cost Comparison, Method B

Solar Collector (Flat Plate)			Cost	Total Cost
Square feet	Watts per square foot	Total kilowatts	Cost per watt	
3,200	63	200	1	\$200,000
PV Panel			Cost	Total Cost
Square feet	Watts per square foot	Total kilowatts	Cost per watt	
12,500	16	200	10	\$2,000,000
PV Roof Material			Cost	Total Cost
Square feet	Watts per square foot	Total kilowatts	Cost per watt	
50,000	4	200	10	\$2,000,000

concentrate the radiant solar energy passing through the collector's aperture onto an absorber of which the absorber area is smaller than the aperture area

- Vacuum tube solar collectors: Collectors that use sealed vacuum tubes, which operate via a self-contained vapor reaction to heat a condenser at the end of the tube and transmit heat through a small, integral heat exchanger through a manifold through which the fluid (water and/or glycol) circulates

Flat-plate Solar Collectors

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. These 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, 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 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, used to reduce heat losses and increase radiation on the absorber plates and channel assembly
- A backplate, which is placed behind the insulation and acts as a reflector surface, 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), which 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 the headers.
- A frame, including angle-fixing and mounting devices, etc., enclosing the complete solar collector module

Many configurations of flat-plate solar collectors are available. For example, the absorber plate/channel assembly could be of fin design or 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 covers, 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 (32.2–98.8°C) or higher

The most widely used measure of the performance of flat-plate collectors is thermal efficiency (η), 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 proper-

ties of a flat-plate solar collector are the collector operating temperature, type of collector surface, and type and number of collector covers.

The steps for determining the thermal efficiency of a flat-plate solar collector, including the necessary data, are as follows:

- 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).
- To calculate the absorbed radiation (I_{coll}), obtain the number of collector covers (n).
- To calculate the delivered energy to working fluid (q_a), obtain the wind speed (v) in knots (m/s), collector temperature (T_{coll}) in °R, and collector physical properties.

The following equations should be used in calculating the thermal efficiency:

Equation 10-1

$$I_{b, coll} = I_{h, b} (\cos i) / \sin a$$

Equation 10-2

$$I_{h, d} = 0.78 + (1.07) a + (6.17) CC$$

Equation 10-3

$$I_{coll} = I_{b, coll} (1 - P_{bn}) \alpha_{s, b} + I_{h, d} (1 - P_d) \alpha_{s, d}$$

Equation 10-4

$$q_a = I_{coll} - L_t$$

Equation 10-5

$$\eta = q / (I_{b, coll} + I_{h, d})$$

where:

$I_{b, coll}$ = Incident beam component of insolation normal to the collector surface, Btuh per square foot (W/m^2)

$I_{h, b}$ = Horizontal beam component of insolation, Btuh per square foot (W/m^2)

i = Angle of incidence, degrees

a = Solar altitude angle, degrees

$I_{h, d}$ = Diffuse component of insolation, Btuh per square foot (W/m^2)

CC = Cloud cover, tenths (1/10) of sky covered

I_{coll} = Absorbed radiation, Btuh per square foot (W/m^2)

P_{bn} = Reflectance from several covered sources

$\alpha_{s, b}$ = Absorptance (beam)

P_d = Diffuse reflectance

$\alpha_{s, d}$ = Absorptance (diffuse)

q_a = Energy delivered to working fluid, Btuh per square foot (W/m^2)

L_t = Thermal losses of collectors, Btuh per square foot (W/m^2)

η = Thermal efficiency, percent

Concentrating Collectors

The advantages of using concentrating collectors in solar 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, the

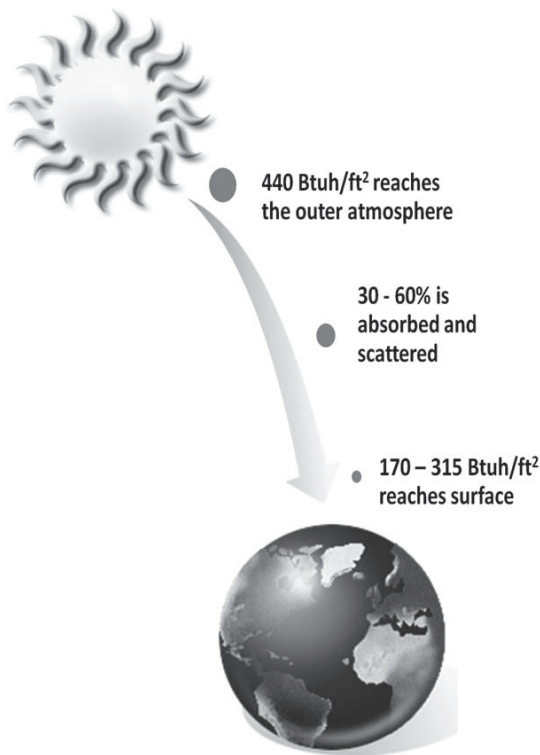


Figure 10-2 Amount of Sun's Energy that Reaches the Earth

economics have played a very important role. The flat-plate solar collectors that do not require sun-tracking devices have taken predominance because of their lower manufacturing and installation costs.

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

- The reflecting surfaces require less material and are structurally simpler than flat-plate units.
- The absorber area is significantly smaller than that of a flat-plate unit. Therefore, 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 collectors only collect on the direct component of the radiation.
- 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.

Among the concentrating collector systems, particular notice should be paid to the following.

Stationary Reflector Tracking Absorber

The stationary reflector tracking absorber (SRTA) system was developed by W. Gene Steward (Environmental Consulting Services in Boulder, Colorado) and J. L. Russel (General Atomics in San Diego, California). The Steward SRTA is a compound curvature collector, whereas the Russel SRTA is a single curvature collector. Both SRTA systems are for electric power generation (photovoltaic application). This collector system is based on optical principles showing that, regardless of the position of the sun, a fixed mirror can focus

most of the incoming solar radiation on a line parallel to the rays of the sun.

The size of the SRTA absorber is based on the width of the solar image and the maximum absorber length necessary to capture all reflected rays.

A theoretical average geometric concentration factor (F_c) is defined as the ratio of the projected surface area of a concentrator (A_p) to the area of the sun's image (A_i) on the collecting surface. The temporal average for a day is obtained from the following relation:

Equation 10-6

$$\bar{F}_c = \frac{A_p}{A_i} = \frac{I}{\theta_i} \int_0^{\theta_i} \bar{F}_c di$$

where:

θ = Incidence angle i at mirror sunrise

The value of the concentration factor obtained from Equation 10-6 does not take into account surface irregularities in the reflecting mirror. In actual practice, the absorber may be five or six times greater than the theoretical value to compensate for surface irregularities in the reflecting mirror and to absorb some diffuse radiation on cloudy or hazy days.

When comparing a flat-plate collector system and a SRTA system, it is imperative that a complete system analysis be performed. One does not pay for the surface area, but rather for the amount of heat or useful energy delivered per unit surface area. A cost comparison between a flat-plate collector and a SRTA system can be made on the following:

Equation 10-7

$$\left(\frac{A_{fp}}{\eta_{fp}} \right) \text{ (cost per ft}^2 \text{ of flat-plate collector)}$$

Equation 10-8

$$\frac{\pi d_a^2}{\eta_{SRTA}} \times \frac{\text{cost per ft}^2 \text{ of mirror surface}}{\text{frontal area per mirror area}}$$

where:

A_{fp} = Surface area of flat-plate collector, square feet (m^2)

η_{fp} = Diameter of flat-plate collector, percent

d_a = Diameter of aperture area of SRTA collector, feet (m)

η_{SRTA} = Efficiency of stationary reflector tracking absorber collector, percent

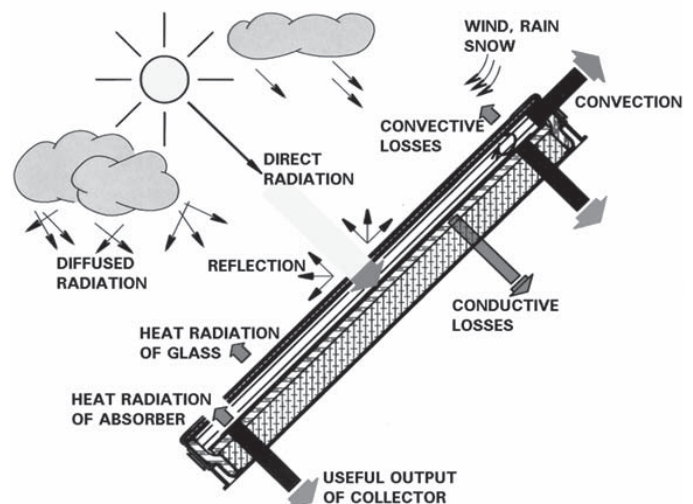


Figure 10-3 How Solar Energy Is Collected

The cost of the SRTA absorber is prorated on a mirror surface area basis. For complete cost comparisons, the cost of the entire solar system for each design should be considered.

Compound Parabolic Concentrator

The compound parabolic concentrator (CPC) system was developed by Roland Winston (Argonne National Laboratories in Argonne, Illinois). 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 $2(\theta_{\max})$. The acceptance depends on the ratio of aperture area (W_c) to the absorber area (W_a) and is expressed by the relation:

Equation 10-9

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

where

$\theta_{\max}$ = Maximum acceptance

W_a = Absorber area, square feet (m^2)

W_c = Aperture area, square feet (m^2)

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

Equation 10-10

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

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 expression:

Equation 10-11

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

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 10-11.

SYSTEM SIZING AND CALCULATIONS

Several computer simulation design programs are currently available for sizing solar-assisted service water- and space-heating systems. In this chapter, the f-chart method developed by the University of Wisconsin is used for sizing such systems. The f , expressed in terms of percent, is the fraction of the heating load supplied by solar energy or the percentage of the total heating load furnished by the solar system. These design charts are calculated utilizing double-glazed, selective-surface collector panels. Other types of solar

collectors (e.g., single-glazed selective surface; double-glazed non-selective surface; single-glazed non-selective surface) could be used. However, the data for developing the charts must be varied accordingly.

The following data is required when employing the f-chart method in the sizing procedures: number of degree days, ambient temperature, building heat loss (if space heating is being considered), hot water demand, collector orientation, and design parameters of the system.

Solar-assisted Service Water Heating

Solar-assisted service water-heating systems generally provide maximum savings when the system is designed to deliver 45 to 70 percent of the load ($f = 45$ to 70 percent). 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

To meet the requirements set forth in the Federal Housing Administration's Minimum Property Standards, the hot water supply temperature must be 140°F (60°C) minimum. This also helps reduce waterborne pathogens such as Legionella. Depending on the season and geographical location, the cold water supply temperature may vary from 40°F to 70°F (4.4°C to 21.1°C), although it is possible to have lower or higher temperatures. This should always be considered when calculating water heating or cooling applications.

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.

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

Sizing Procedure for Service Water Heating

The following steps should be followed when sizing a solar-assisted service water-heating system.

1. Determine the daily hot water demand.
2. Determine the hot water supply temperature. Generally, this temperature can be taken as 140°F (60°C).
3. Determine the cold water supply temperature. This temperature typically ranges from 40°F to 70°F (4.4°C to 21.1°C), depending on the season and geographical location. In the absence of such data, assume this temperature to be 45°F (7.2°C) as a year-round average.
4. Determine the closest weather station location and prepare an f-chart. A sample f-chart is illustrated in Figure 10-4. Data on degree days and percent f at the collection point may be obtained from the ASHRAE Handbook of Fundamentals and the Solar Decision Handbook.

5. Determine the percent f to be delivered by the solar system.
6. Using the f -chart, determine the size of the collector array (in square feet [m^2]) required to provide the desired percent f . The following calculations will provide approximate values, as indicated.
 - To determine the flow rate of the heat-transfer fluid in the collector loop, multiply the collector area by 0.039 (0.027 in SI units).
 - To determine the maximum heat transfer to the heat exchanger, multiply the collector area by 225 (709.6 in SI units).
 - To determine the size of the preheater tank, multiply the collector area by 2 (81.4 in SI units).
7. Determine the pump head in the collector loop.
8. Determine the pump head in the storage loop.
9. Determine the volume of heat-transfer fluid required.
10. To determine the size of the expansion tank needed, multiply the volume of the heat-transfer fluid by 10 percent.

Figures 10-5 and 10-6 illustrate typical installations of solar-assisted service water-heating systems.

Example 10-1

- Location: Memphis, Tennessee
- Family of four, standard kitchen and bathroom

Step 1: Determine the daily hot water demand, approximated as 15 gallons per person per day (56.8 L per person per day). For four persons, the daily hot water demand would be 60 gallons (227.2 L).

Step 2: Determine the hot water supply temperature. To meet FHA requirements, this temperature should be 140°F (60°C).

Step 3: Determine the cold water supply temperature. This temperature can be assumed to be 45°F (7.2°C).

Step 4: Develop an f -chart. See Figure 10-7.

If 60 percent of the load is to be supplied by the solar system, approximately 35 square feet (3.3 m^2) of collector area is required. The flow rate of the heat-transfer fluid in the collector loop would be $35 \text{ ft}^2 \times 0.039 = 1.4 \text{ gpm}$ ($3.3 \text{ m}^2 \times 0.027 = 0.09 \text{ L/s}$). The maximum heat transfer to the heat exchanger would be $35 \text{ ft}^2 \times 225 = 7,875 \text{ Btuh}$ ($3.3 \text{ m}^2 \times 709.6 = 2,341.7 \text{ W}$).

Sizing Procedure for Service Water and Space Heating

The following steps should be followed when sizing a combined solar-assisted service water- and space-heating system.

1. Calculate the building heat loss. ASHRAE-recommended methods should be used.
2. Determine the building's design temperature. This temperature is the lowest outside air temperature, in °F (°C), at which the building must be heated to 65°F (18.3°C).
3. Calculate the building's design load. This load is the product of the building's heat loss and the building's design temperature.

4. Determine the daily hot water demand, hot water supply temperature, and cold water supply temperature. Follow steps 1, 2, and 3 given for service water-heating systems.
5. Determine the closest weather station and prepare an f -chart.
6. Determine the percent f to be delivered by the solar system.
7. Determine the size of the collector array, in square feet (m^2), required to provide the desired percent f using the chart.
8. Determine the flow rate of the heat-transfer fluid in the collector loop, maximum heat-transfer fluid in the collector loop, maximum heat transfer to the heat exchanger, and the size of the storage tank. Use step 6 of the service water-heating procedure.
9. Determine the pump head in the collector loop and storage loop.
10. Determine the pump head for the entire heat-delivery loop (preheater, to and from storage tank, etc.).
11. Determine the fan coil size. The output of the fan coil should be equal to or greater than the building's design load.
12. Select a heat pump with an output equal to or greater than the building's design load.
13. Select an auxiliary heater with an output equal to or greater than the building's design load.

Figure 10-8 provides illustrations of combined systems.

Keys to Sizing

- Building load: What is the daily water demand?
- Building occupancy: On average, how many days per week is the building occupied?
- Location
- Safety measures/devices

Example 10-2

An apartment building occupied at all times has 64 units using 30 gpd each (1,920 gpd total). If one 30-square-foot panel generates 30,000 Btu per day in the summer, how many panels are needed?

- $30,000 \text{ Btu} / 8.34 \text{ pounds per gallon} / (120^\circ\text{F} - 60^\circ\text{F}) = 60 \text{ gallons at a } 60^\circ\text{F rise per panel}$
- $1,920 \text{ gpd} / 60 = 32 \text{ solar panels}$

Example 10-3

For the same apartment building, how much storage is needed?

- $30,000 \text{ Btu} / 8.34 \text{ pounds per gallon} / (150^\circ\text{F} - 60^\circ\text{F}) = 40 \text{ gallons at a } 90^\circ\text{F rise per panel}$
- $40 \times 32 \text{ panels} = 1,280 \text{ gallons of storage}$

Keys to Performance

When laying out the panels, consider the following to ensure peak performance.

- What is the flow rate through a panel?
- How do off-peak loads affect temperature and control?
- What temperature does the sensor see?

- How big is the piping (heat loss, installation cost)?
- How efficient is the system?

PANEL LAYOUTS AND PIPING ARRANGEMENTS

Panels in Parallel/Arrays in Parallel

- 32 panels = Eight arrays (see Figure 10-9)
- 1–1.5 gpm per panel = 32–48 gpm total
- 2–2½-inch pipe
- Vents on cold water
- Sensor low at end
- 10°F band in summer; 2–4°F in lower months

Panels in Series/Arrays in Parallel

- 32 panels = Eight arrays (see Figure 10-10)
- 1–1.5 gpm per panel = 32–48 gpm total
- 2–2½-inch pipe
- One vent on hot water
- Sensor high at end
- 10°F band in summer; 2–4°F in lower months

Panels in Series/Arrays in Series

- 32 panels = Eight arrays (see Figure 10-11)
- 1–1.5 gpm per panel = 8–12 gpm total
- 1–1¼-inch pipe
- Vents at high points
- Sensor high at end
- 40°F band in summer; 10–20°F in lower months

Illustrations

Figures 10-12, 10-13, and 10-14 illustrate a dual water heater installation with one storage tank, a dual water heater installation with two storage tanks, and a detail of the solar panel array.

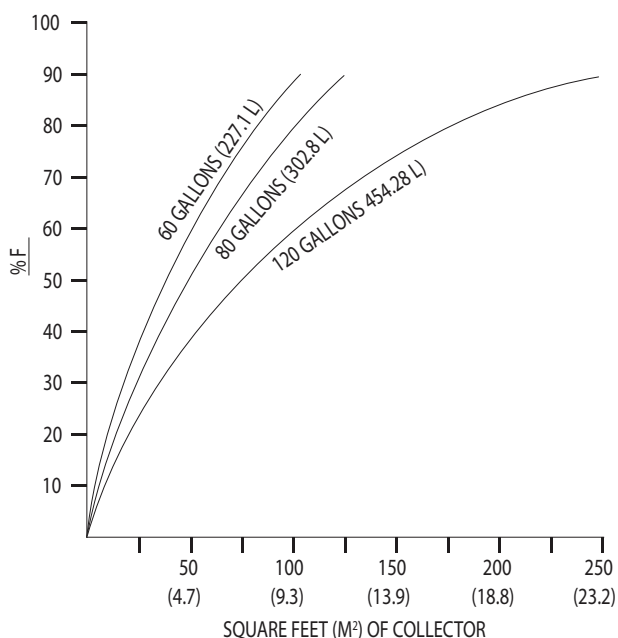


Figure 10-4 Sample f-chart, Service Water Heating Application

SPECIFICATIONS

The specifications are an important part of any system design. Several formats are used today. Always coordinate and verify the specification format that is to be used for a project.

In the current Construction Specifications Institute (CSI) format, plumbing is found in the 220000 sections. Some of the sections that may be included in a solar water heater system specification follow. Note that a system may require sections other than those listed. These are only listed as an example.

- 220500 Common Work Results for Plumbing
- 22053 General Duty Valves for Plumbing
- 220529 Hangers and Supports for Plumbing
- 220533 Freeze Protection for Plumbing Piping
- 220548 Vibration and Seismic Controls for Plumbing Piping and Equipment
- 220553 Identification for Plumbing Pipe and Equipment
- 230993.13 Controls Point List

Regardless of the format used, the basic objectives and requirements are the same. The following may serve as a guideline to writing specifications for a solar system.

Collectors

- Manufacturer and model number
- Number of covers
- Performance characteristics
- Testing agency and test method followed
- Stagnation conditions
- Recommended flow rate
- Operating temperatures
- Pressure drop at maximum flow rate
- Materials
- Glazing
- Gaskets
- Insulation
- Absorber plate
- Selective coating
- Recommended heat-transfer fluid
- Physical dimensions
- Module size
- Aperture area
- Weight
- Expected collector life
- Warranty

Heat Exchangers

- Manufacturer and model number
- Construction
- Recommended heat-transfer fluid
- Warranty
- Expected life
- Materials
- Physical dimensions
- Performance
- Testing agency and test method followed
- Operating conditions
- Flow rate

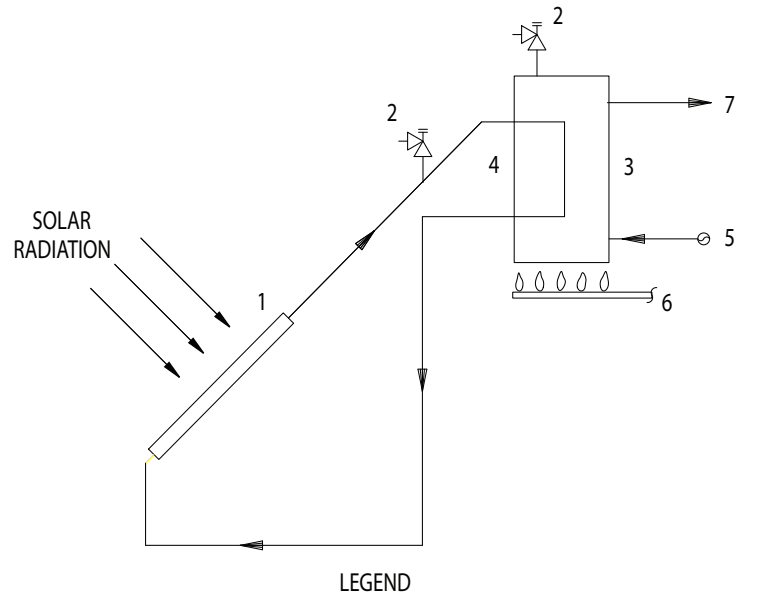
- Pressure drop
- Temperature
- Pressure
- Pumps
- Manufacturer and model number
- Motor coupling
- Mechanical seal
- Warranty
- Estimated life

Pump Body and Impeller Material

- Gasketing materials
- Motor voltage
- Amperage
- Operating conditions
- Flow rate
- Pressure drop
- Temperatures
- Pressure
- Pump curves
- Flange connections
- Preheater tanks
- Manufacturer and model number
- Storage capacity
- Body material
- Lining
- Insulation
- Plumbing connections
- Jacket
- Sacrificial anode
- Physical size
- Auxiliary heater
- Pressures
- Weight
- Warranty
- Estimated life
- Operating temperatures

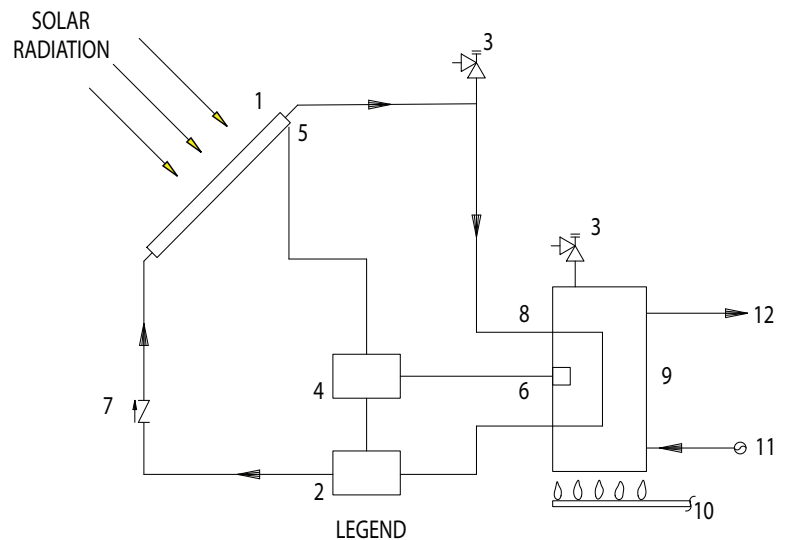
Storage Tanks

- Manufacturer and model number
- Capacity
- Operating temperatures
- Storage medium
- Freezing precautions
- Lining
- Working pressure
- Materials of construction
- Insulation
- Plumbing connections
- Jacket
- Physical dimensions
- Pressures
- Weight
- Drain valves
- Manhole
- Live and dead loads
- Warranty
- Estimated life



- | | |
|--------------------------------------|--------------------------|
| 1. SOLAR COLLECTORS | 5. WATER SUPPLY |
| 2. TEMPERATURE/PRESSURE RELIEF VALVE | 6. AUXILIARY HEAT SOURCE |
| 3. STORAGE TANK | 7. TO BUILDING |
| 4. HEAT EXCHANGER | |

Figure 10-5 Thermosyphon System, Service Water Heating Application, Indirect



- | | |
|--------------------------------------|---------------------------|
| 1. SOLAR COLLECTORS | 7. CHECK VALVE |
| 2. CIRCULATING PUMP | 8. HEAT EXCHANGER |
| 3. TEMPERATURE/PRESSURE RELIEF VALVE | 9. STORAGE TANK |
| 4. PUMP CONTROLLER | 10. AUXILIARY HEAT SOURCE |
| 5. SENSOR: COLLECTOR TEMPERATURE | 11. WATER SUPPLY |
| 6. SENSOR: TANK TEMPERATURE | 12. TO BUILDING |

Figure 10-6 Pump Circulating System, Service Water Heating Application, Direct

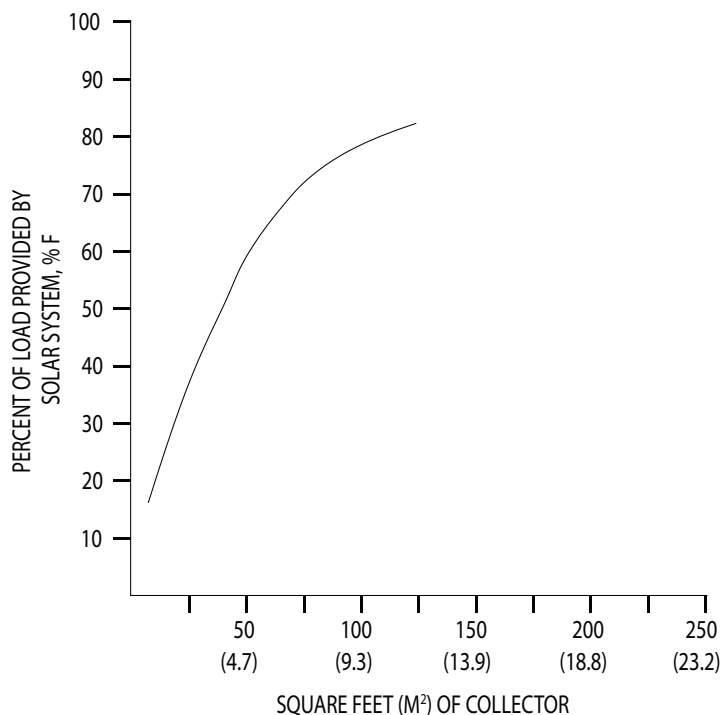


Figure 10-7 f-chart for Memphis, Tennessee

- Controls
- Manufacturer and model number
- Differential thermostat
- Sensor
- Available functions
- Power input
- Approvals and listings
- Ground provisions
- Warranty
- Estimated life

Heat Pumps

- Manufacturer and model number
- Pump type
- Rated heat and cooling output
- Rated heat and cooling coefficient of performance and energy-efficiency ratio
- Auxiliary heaters
- Filters
- Operating voltage and amperage
- Condenser coil operating range and flow rate
- Physical dimensions
- Weight
- Operating sequence
- Warranty
- Estimated life

Insulation

- Manufacturer and type (material)
- Heat transfer characteristics/thickness
- Flame spread and smoke-developed characteristics
- Vapor barrier/cover
- Method of application
- Warranty

ADDITIONAL READING AND OTHER RESOURCES

A bounty of information is available to assist in the design of solar systems. A more complete understanding will come through further research.

- *The Solar Hydrogen Civilization* by Roy McAlister
- Solar Energy Industries Association: seia.org
- Energy Star: energystar.gov
- Internal Revenue Service: irs.gov
- TIAP: energytaxincentives.org
- Solar Rating Certification Corporation (SRCC): solar-rating.org
- U.S. Department of Energy, Energy Efficiency and Renewable Energy: eere.energy.gov
- Solar and Sustainable Energy Society of Canada: sesci.ca
- Canadian Solar Industries Association: cansia.ca
- Kortright Centre for Conservation: kortright.org

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- ASHRAE Handbook — 1987 Systems and Applications, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.
- Solar Water Heater's: A Buyer's Guide* Natural Resources Canada, Ottawa: Minister of Supply and Services, 1987.

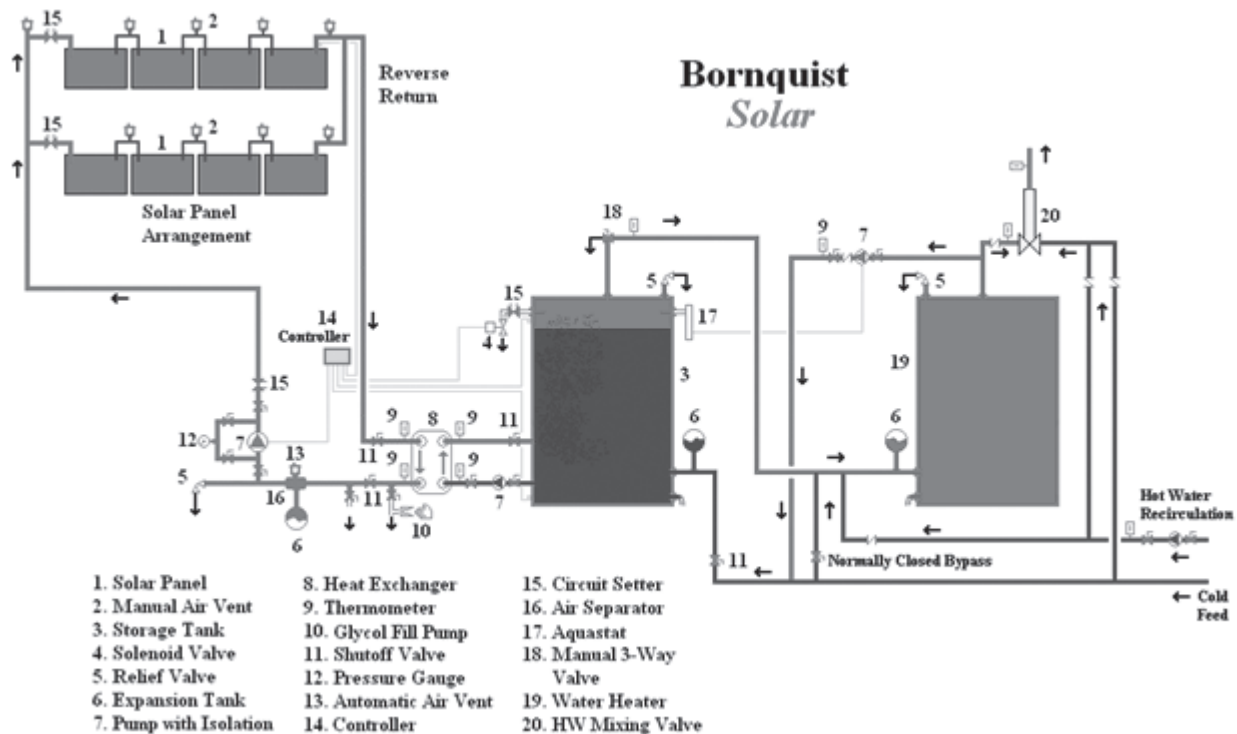
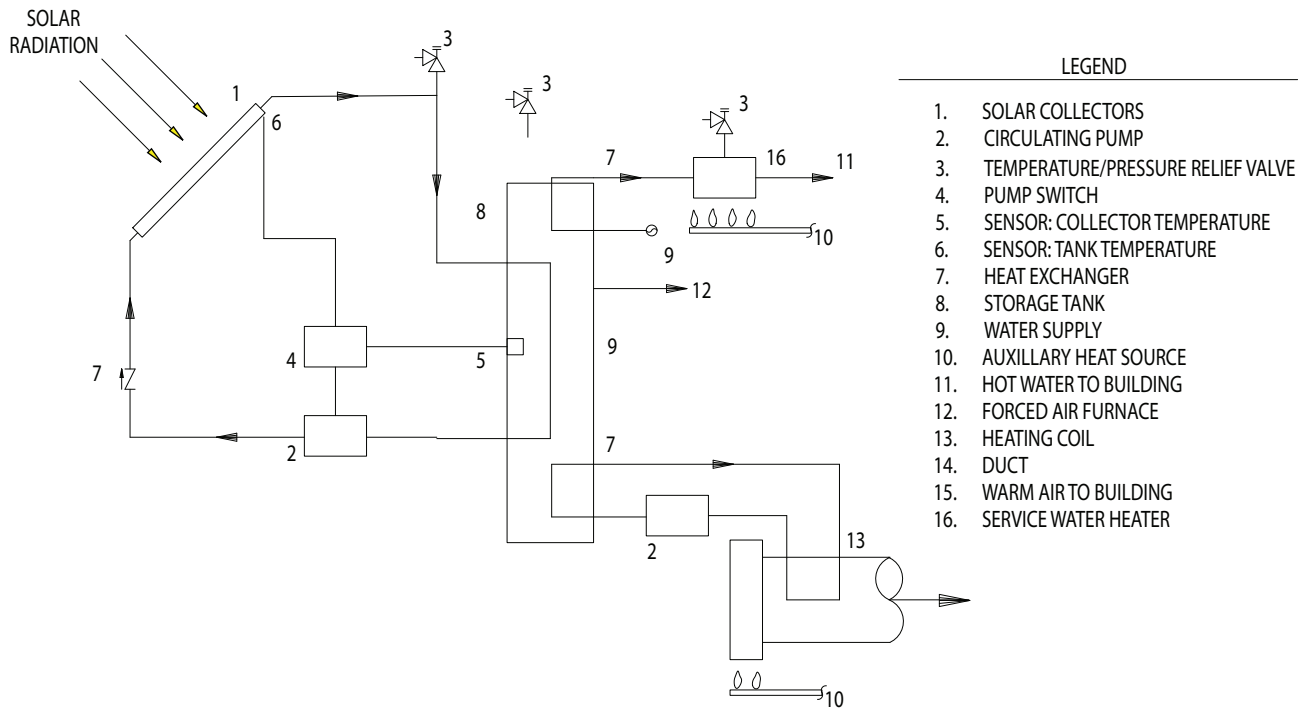


Figure 10-8 Pump Circulating System, Combined Space and Service Water Heating Applications

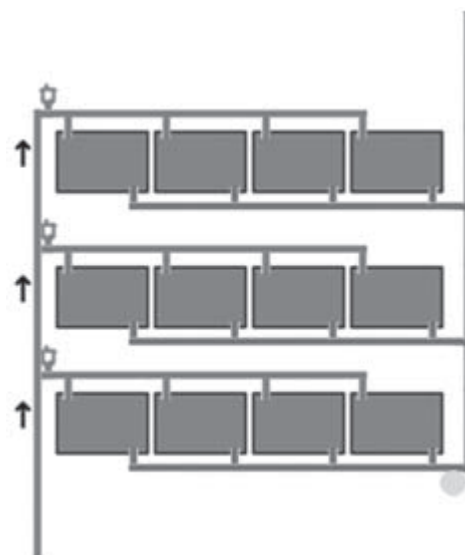


Figure 10-9 Panels in Parallel/Arrays in Parallel

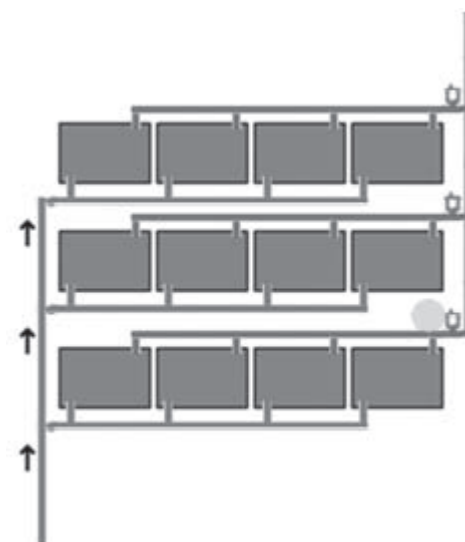


Figure 10-10 Panels in Series/Arrays in Series

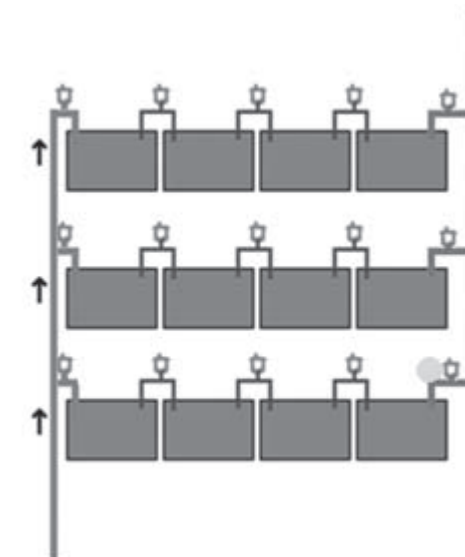


Figure 10-11 Panels in Series/Arrays in Series



Figure 10-12 Dual Water Heater with Solar Tank



Figure 10-13 Dual Water Heater with Dual Solar Tanks

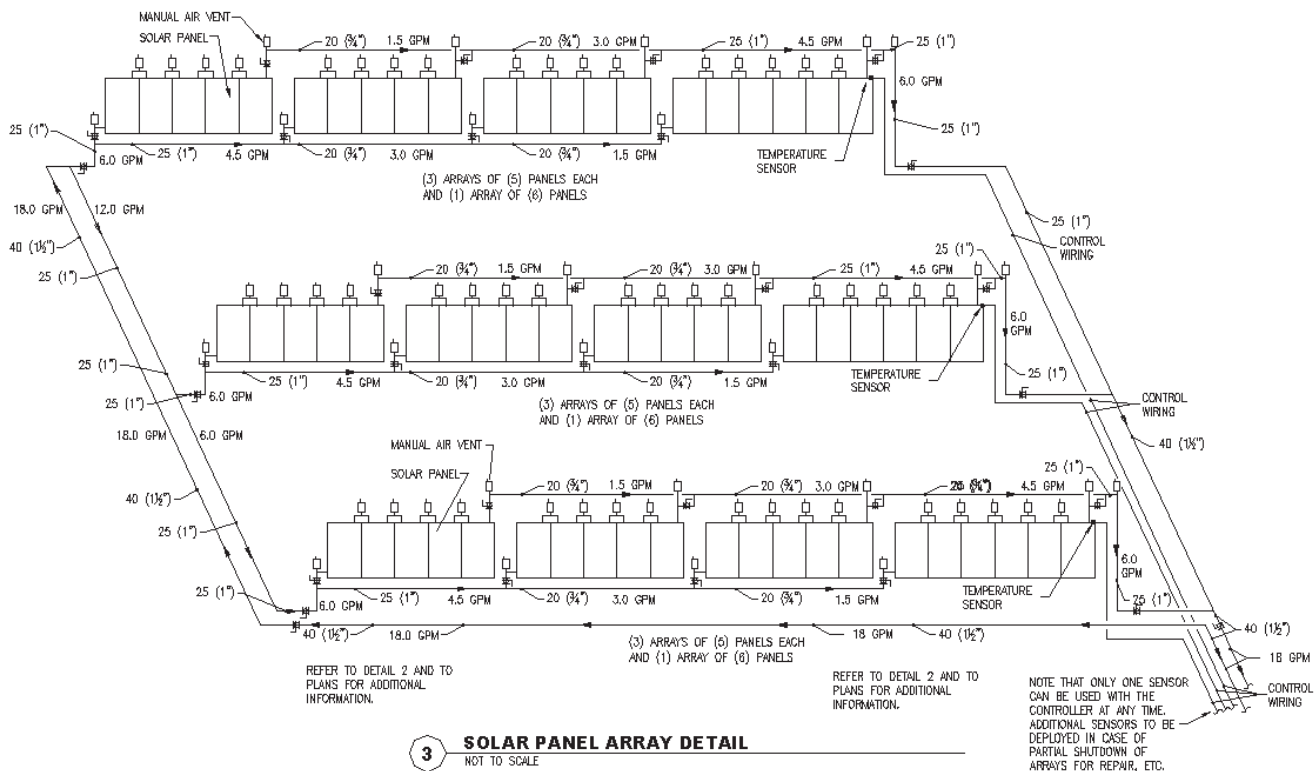


Figure 10-14 Solar Panel Array Installation

ASPE Continuing Education Application Form

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CE Questions — "Solar Energy" (CEU 191)

Circle the correct answers below.

- Energy from the sun can be categorized as _____.**
 - thermal energy
 - light energy
 - fossil fuel
 - both a and b
- Solar represents what percent of the total U.S. energy supply?**
 - 8
 - 7
 - 5
 - 1
- Which type of collector has achieved efficiencies of 70 percent or more commercially?**
 - flat plate
 - evacuated tube
 - transpired
 - concentrating
- _____ is power emitted, transferred, or received in the form of electromagnetic waves or photons.**
 - radiation
 - radiant flux
 - emittance
 - insolation
- Which of the following is an important property of a flat-plate solar collector?**
 - collector operating temperature
 - type of collector surface
 - type and number of collector covers
 - all of the above
- An advantage of the concentrating collector over the flat-plate collector is _____.**
 - lower maintenance costs
 - smaller absorber area
 - lower operating costs
 - none of the above
- Solar-assisted service water-heating systems generally provide maximum savings when $f =$ _____.**
 - 40 percent
 - 45–70 percent
 - 40–75 percent
 - 100 percent
- When sizing a solar-assisted service water-heating system, multiply the collector area by what to determine the size of the preheater tank?**
 - 2
 - 10
 - 15
 - 20
- A pump circulating system for a direct service water-heating application includes which of the following components?**
 - air vent
 - heating coil
 - heat exchanger
 - none of the above
- When sizing a combined solar-assisted service water- and space-heating system, the output of the fan coil should be equal to or greater than what?**
 - flow rate of heat transfer fluid
 - building design load
 - size of collector array
 - hot water demand
- A pump circulating system for combined space and service water-heating applications includes which of the following components?**
 - heat exchanger
 - temperature/pressure relief valve
 - storage tank
 - all of the above
- Which of the following should be included in the specification for the storage tanks?**
 - capacity
 - working pressure
 - operating sequence
 - both a and b