FLORIDA SOLAR ENERGY CENTER®

Solar Water and Pool Heating Manual

Design and Installation & Repair and Maintenance

FSEC-IN-24

January 2006

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A Research Institute of the University of Central Florida

Solar Water and Pool Heating Manual

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&
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Florida Solar Energy Center
Cocoa, Florida

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Prologue: A Brief History of Solar Water Heating

Solar water heating has been around for many years because it is the easiest way to use the sun to save energy and money. One of the earliest documented cases of solar energy use involved pioneers moving west after the Civil War. They left a black pot in the sun all day to have heated water in the evening.

The first solar water heater that resembles the concept still in use today was a metal tank that was painted black and placed on the roof where it was tilted toward the sun. The concept worked, but it usually took all day for the water to heat, then, as soon as the sun went down, it cooled off quickly because the tank was not insulated.

Clarence Kemp of Baltimore patented the first commercial solar water heater in 1891. It was called the Climax. The Climax had several cylindrical water tanks of galvanized iron that were painted black. Kemp insulated the tanks in felt paper and placed them in a glass-covered wooden box for better heat retention. This invention earned Kemp the “father of solar energy in the United States” title.

Solar water heating improved the lives of homeowners, especially during the summer, because it eliminated the need to heat water on the stove. Firing up the stove to heat water warmed the entire house. In the winter, the solar water heater was drained to protect it from freezing, and homeowners resumed heating water on the stove. Kemp claimed the Climax could be used from early April through late October in Maryland. In southern California, it could be used year-round. High-energy costs in California made using free solar energy even more logical. By 1900, 1,600 Climaxes were installed in southern California.

A design by William Bailey in 1909 revolutionized the industry with the first flat-plate collector. The most visible difference in his design was a separate collector and storage tank. The collector had a grid of copper pipes and was covered with glass. He added a metal absorber plate to transmit the solar heat in the box to the water in the pipes. The storage tank was insulated. Since these improvements kept the water warm morning and night, the solar hot water heater was called the Day and Night collector. The system could be connected to a backup gas heater, wood stove or coal furnace. An electric heater could be placed inside the storage tank to heat the water automatically if it dropped below a preset temperature.

Bailey’s business grew until a freak cold spell hit southern California in 1913. Copper pipes in the collectors froze and burst when the temperature dropped to 19 degrees Fahrenheit. He solved this problem by placing nonfreezing liquid in the collector pipes. This liquid traveled through a coil in the storage tank to heat the water. He sold more than 4,000 Day and Night heaters by the end of World War I. The peak year was 1920 when more than 1,000 were sold.

Solar hot water heater sales decreased when natural gas prices dropped and gas companies offered incentives, including free installation, to switch to gas. Bailey recognized the trend and used his experience to produce gas water heaters. His company made its last solar water heater in 1941.

California's gas discoveries nearly put an end to solar water heating there, but this was not the case in Florida where solar was the only way to heat water cheaply. The Solar Water Heater Company was established in Florida in 1923. By 1925, Miami's population had increased to more than 75,000. Business flourished until Miami's building boom subsided in early 1926 and a hurricane struck the area in September. The plant closed shortly thereafter.

In 1931, the plant reopened with an improved collector. Charles Ewald changed the wooden box to metal to last longer in Florida's humid environment. He also insulated the box and replaced the steel tubing with more durable and better conducting soft copper. He discovered that soft copper withstood temperatures as low as 10 degrees Fahrenheit. Ewald added more pipe and placed it strategically for optimum efficiency. His design produced hotter water in greater volume. He called it the Duplex.

He also developed a method of matching the needs of the homeowner with the appropriately sized collector and storage tank. This revived the industry in 1934. The following year, New Deal legislation boosted home building and, in turn, the solar heating business. Inexpensive FHA Home Improvement Loans stimulated the market. By 1941, nearly 60,000 hot water heaters had been sold in Florida. About 80 percent of Miami's new homes had solar hot water heaters, and more than 50 percent of the city used them. Solar water heaters were also used in north Florida, Louisiana and Georgia and in other parts of the world, including Japan.

No matter how robust, the solar hot water boom wouldn't last. At the start of World War II, the government put a freeze on nonmilitary use of copper, stalling out the solar hot water heating market. After the war, the rise in skilled labor and copper prices made the collectors less affordable. Electric prices dropped in the '50s, making electric water heaters more appealing. Installation and initial cost was also cheaper than solar hot water heaters. The tank was automatic too. Solar water heating was not the same bargain anymore in the United States, especially when oil import limits were allowed to surpass 50 percent. A similar scenario happened later in Japan when it began importing oil in the '60s. The peak year for Japan's solar hot water sales was 1966.

Throughout history, solar energy remained popular until abundant sources of fossil fuel became available. Interest in solar energy surged during oil embargoes in 1973-74 and 1979.

Federal and state tax incentives led to rising sales in the early '80s. Sales flourished, but the industry paid a high price for this brief period of prosperity. A lot of companies entered the solar field just to make money and didn't care about long-term relationships with their customers. This led to poor installations and gave the industry a bad reputation. After 1985, most of these fly-by-nighters left the solar field.

Equipment has improved since the '80s. Improvements were precipitated by both certification design review and experienced installers. There are more safeguards available now to ensure competent system design and installation, such as training programs and certification. Training is important. Like any mechanical device, all these systems have to be serviced periodically for optimum operation. The Florida Solar Energy Center now has both collector and system certification programs. The national Solar Rating & Certification Corporation provides collector and system certification, as well as ratings for collectors and systems.

Today, more than 1.2 million buildings have solar water heating systems in the United States. This doesn't include 250,000 solar-heated swimming pools. Japan has nearly 1.5 million buildings with solar water heating in Tokyo. In Israel, 30 percent of the buildings use solar-heated water. Greece and Australia are also leading users of solar energy.

There is still a lot of room for expansion in the solar energy industry. There are no geographical constraints. For colder climates, manufacturers have designed systems that protect components from freezing conditions. Wherever the sun shines, solar water heating systems can work. The designs may be different from the early solar pioneers, but the concept is the same.

Acknowledgements

Principal authors of this manual are Charlie Cromer, Bill Guiney and John Harrison.

This manual is the result of the combined efforts and resources of a number of individuals and organizations. It and previous Florida Solar Energy Center (FSEC) solar water heating manuals have evolved from the original one developed by FSEC in the late 1970s. The current manual also incorporates, into one concise manual, the material that was in the previous "Solar Water and Pool Heating Manual," the "Solar Water and Pool Heating Design and Installation" and the "Solar Domestic Hot Water Systems Repair and Maintenance" manuals. The individuals involved in writing, reviewing and developing these manuals include former and current FSEC staff members: Subrato Chandra, Charlie Cromer, John Harrison, Bruce Holbaugh, Colleen Kettles, Tim Merrigan, Douglas E. Root and Gerard Ventre. Shelli Keisling converted all of the illustrations into electronic format for the current manual. Melinda Millsap and Mark Thornbloom editorially reviewed the manual and Melinda wrote the brief solar history. Individuals from the Florida solar industry including Ben Bentley, David Bessette and Bob Zrallack were instrumental in critiquing the current manual during its formative stages. They, and other members of the solar industry have always been invaluable reference sources and partners in developing solar energy in Florida.

The Florida Solar Energy Center is extremely grateful to the Florida Energy Office for their contract assistance in developing this and previous manuals. Thanks are also accorded to members of the Florida Solar Energy Industries Association for their assistance in developing the electronic version of the illustrations in this current manual.

The current manual is comprised of various sections and modules within those sections. With this format, revisions can be made simply and quickly, as required. As is the case with every FSEC document, comments on how this manual can be improved are always welcome. Technical comments or inquiries should be addresses to the Florida Solar Energy Center.

Overview

Purpose and Scope

The intent of this manual is to equip the reader with the knowledge and skills needed to design, install, operate and maintain the most common types of solar water heating systems. The manual serves as the textbook for the solar thermal course sponsored and conducted by the Florida Solar Energy Center. It also functions as a study guide for those intending to take licensing or certification exams.

The manual presents an overview of solar thermal applications, provides basic information on the principles of solar energy, reviews solar thermal technologies, and provides detailed instruction on the safe, efficient installation of solar water heating and pool heating systems. The manual is divided into six sections, with each separated into individual modules.

Section 1: Solar Concepts provides a basic understanding of solar thermal concepts

- **Module: Solar Applications** outlines the various applications that can be served by the use of solar water heating systems

- **Module: Solar Basics** provides the reader with an understanding of the physical principles employed in solar thermal technologies.

Section 2: Solar Water Heating Systems focuses primarily on what are commonly called solar domestic hot water systems, which heat water.

- **Module: System Types** describes and illustrates the main types of solar systems, along with variations of each type as well as various freeze protection strategies and design.

- **Module: System Components** details the principal components of solar water heating systems and their function within the system.

Section 3: System Installation covers the steps involved in installing a solar water heating system.

- **Module: Collector Mounting** describes methods for properly placing and installing solar collectors.

- **Module: Component Installation** provides guidelines for the proper and safe placement and connection of the remainder of solar system components.

- **Module: System Installation Checkout and Start-Up**, presents start-up and checkout procedures for systems being installed.

Section 4: Troubleshooting presents structured methods to follow in diagnosing and correcting solar water heating system problems.

- **Module: Problem Assessment and System Checkout** provides guidelines for assessing installed system problems.

- **Module: Troubleshooting Checklist** provides a comprehensive checklist for determining probable causes and the appropriate corrective actions.

Section 5: Solar Swimming Pool Heating Systems is devoted to solar systems that provide heat for swimming pools.

- **Module: System Components, Installation and Operation** illustrates and describes the physical elements of solar pool heating systems and provides guidelines for component and system installation and operation.

Appendix

1. Crome Dome Collector Siting Aid is a tool for determining the best location for solar collectors. Its simplicity and ease of use in the field make it ideal for installation and service personnel.

2. FSEC Simplified Sizing Procedure for Solar Domestic Hot Water Systems is an invaluable guide in sizing solar water heating systems in Florida.

3. Electric Water Heater Circuitry describes the electrical connections in a standard hot water tank with two heating elements. An illustration shows where the high-limit protector is located in the electrical circuits and how two thermostats prevent operation of both heating elements simultaneously.

4. Volt-Ohmmeter (VOM) or Multimeter Operation provides basic information on volt-ohm-meter and multimeter operation and includes a standard temperature and thermistor resistance table for 3,000 and 10,000 Ohm thermistors.

5. Solar System Flow Rates describes two simple methods for checking solar system flow rates.

6. Tools for Service and Repair lists the tools and equipment that field personnel generally need to service a solar system.

Section 1: Solar Concepts provides a basic understanding of solar thermal concepts.

- **Module: Solar Applications** outlines the various applications that can be served by the use of solar water heating systems

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Section 1
Module: Solar Thermal Applications and Technologies

A wide variety of applications can benefit from the use of solar technologies. Currently, the principal use of solar thermal systems in the United States is for hot water heating and pool heating. This is the main subject area of this manual – domestic solar water heating systems. Nevertheless, the use of solar technologies to provide space heating is also available in colder regions. Internationally, solar technologies are used for a myriad of applications, including standard water and pool heating as well as space heating, crop drying, cooking, and water distillation, to name but a few.

This section provides a general overview of the various applications that can benefit from the use of these technologies.

Solar Thermal Applications

In the United States the use of solar thermal systems is most predominant in the residential market. This has a large impact on local and national energy usage and conservation. Traditionally, the primary use of solar in this sector has been for swimming pool and domestic water heating as well as space heating.

Residential applications




- Domestic hot water
- Swimming pool and spa heating
- Space heating
- Water purification/distillation
- Air Conditioning

Commercial applications




- Hotels
- Schools
- Apartment and condominium complexes
- Recreation areas and campgrounds
- Hospitals/Nursing homes
- Restaurants
- Laundries
- Car washes
- Beverage manufacturing
- Cane sugar refining
- Canning facilities
- Food processing
- Meat packing facilities
- Poultry farms
- Light commercial businesses
- Summer camps
- Recreation areas and campgrounds
- Industrial process heat

Agricultural applications

- Crop drying
- Green houses
- Dairy processing
- Meat processing
- Aqua-culture
- Food processing

Think of some other applications that are not listed above and list them below.

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Once again, this manual concentrates on domestic hot water and pool heating. Nevertheless, as indicated above, other solar thermal applications are quite numerous.

Section 1
Module: Solar Basics

Understanding solar thermal systems requires the knowledge of several energy terms and physical principles. This chapter presents important terms and principles and shows how they apply in solar thermal systems.

Terms and Principles

Insolation is the amount of the sun's electromagnetic energy that "falls" on any given object. Simply put, when we are talking about solar radiation, we are referring to insolation. In Florida (at about sea level), an object will receive a maximum of around 300 Btu/ft^{2}hr (about 90 watts/ft^2 or 950 watts/meter^2) at high noon on a horizontal surface under clear skies on June 21 (the day of the summer equinox).

Sun Path

On the surface of the earth, insolation varies over time because of the planet's daily rotation, tilted axis and elliptical orbit around the sun. Imagine the sky as a dome (sky dome) with the horizon as its edge. From this perspective, the sun's path describes an arc across the sky from dawn until dusk. This perceived path and its variations over time can be plotted as in Figure 1, which shows the annual sun path from the perspective of 28 degrees north latitude. This figure illustrates the seasonal changes in the sun's path for a given location. It shows that the winter the sun rises in the Southeast, sets in the Southwest, has a relatively short path and rises to a shallow 39 degree angle above the horizon at noon. In the summertime, the sun rises in the Northeast, sets in the Northwest, has a longer path and rises to a much higher angle above the horizon.

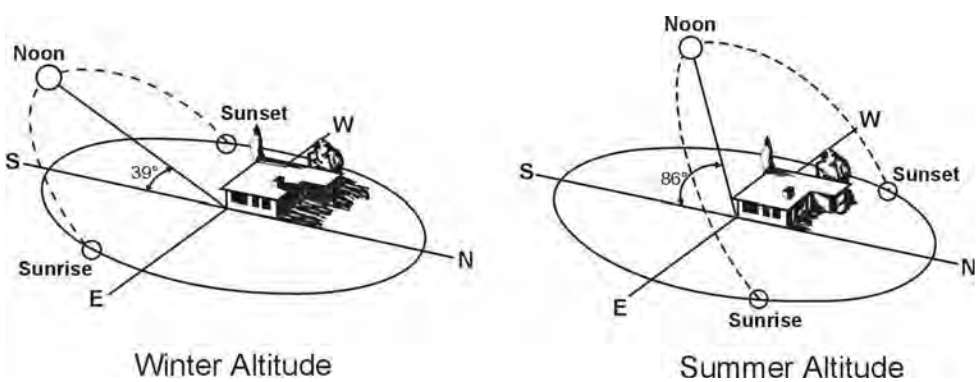


Figure 1. Annual Sun Path for 28º N Latitude (Orlando, Florida)

Atmosphere

The atmosphere absorbs certain wavelengths of light more than others. The exact spectral distribution of light reaching the earth's surface depends on how much atmosphere the light passes through, as well as the humidity of the atmosphere. In the morning and evening, the sun is low in the sky and light waves pass through more atmosphere than at noon. The winter sunlight also passes through more atmosphere versus summer. In addition, different latitudes on the earth have different average “thicknesses” of atmosphere that sunlight must penetrate. Figure 2 illustrates the atmospheric effects on solar energy reaching the earth. Clouds, smoke and dust reflect some solar insolation back up into the atmosphere, allowing less solar energy to fall on a terrestrial object. These conditions also diffuse or scatter the amount of solar energy that does pass through.

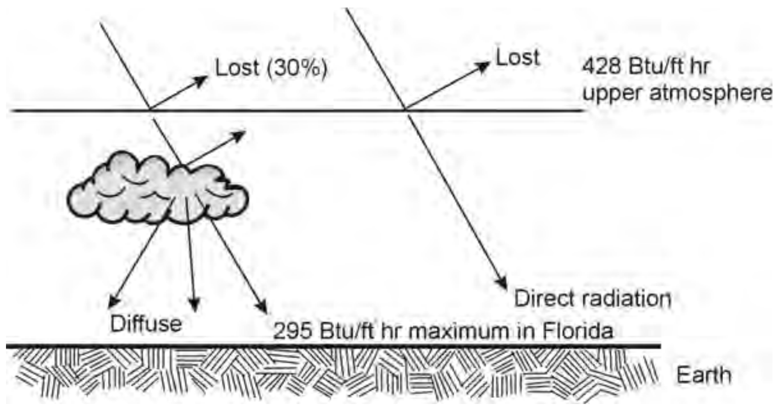


Figure 2. Atmospheric Effects on Solar Energy Reaching Earth

Angle of Incidence

The sun’s electromagnetic energy travels in a straight line. The angle at which these rays fall on an object is called the angle of incidence (See Figure 3). A flat surface receives more solar energy when the angle of incidence is closer to zero (normal, perpendicular) and therefore receives significantly less in early morning and late evening. Because the angle of incidence is so large in the morning and evening on earth, about six hours of “usable” solar energy is available daily. This is called the “solar window.”

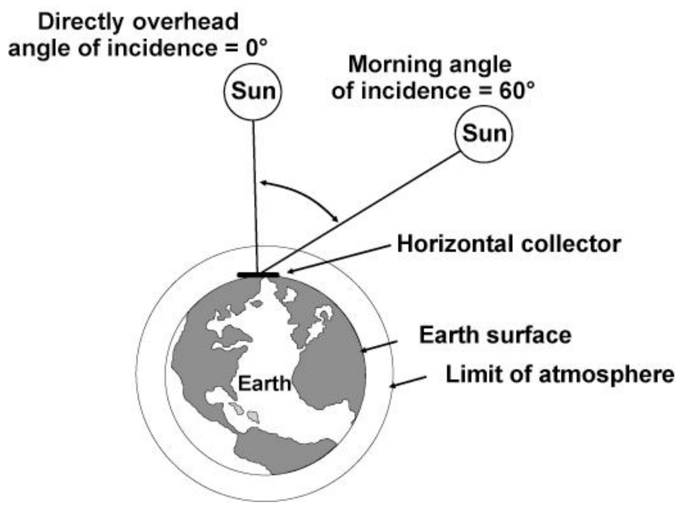


Figure 3. Angle of Incidence

Absorptance vs. Reflectance

Certain materials absorb more insolation than others. More absorptive materials are generally dark with a matte finish, while more-reflective materials are generally lighter colored with a smooth or shiny finish. A golf ball covered with black matte paint placed in sunlight will absorb more solar insolation than a plain white golf ball.

The materials used to absorb the sun's energy are selected for their ability to absorb a high percentage of energy and to reflect a minimum amount of energy. The solar collector's absorber and absorber coating efficiency are determined by the rate of absorption versus the rate of reflectance. This in turn, affects the absorber and absorber coating's ability to retain heat and minimize emissivity and reradiation. High absorptivity and low reflectivity improves the potential for collecting solar energy.

Heat Transfer

Because all natural systems seek a balance, heat always moves from warm (more energy) to cool (less energy). Heat moves by three methods: conduction, convection and radiation.

Conduction

Conduction occurs when a solid material is heated. Molecules exposed to a heat source become energized. These energetic molecules collide with neighboring, less-energetic molecules, transferring their energy. The greater the energy transfer ability of the solid’s molecules, the more energy they can transfer and the better the solid’s conductivity. Copper has high conductivity while glass has low conductivity. If you place a heat source at the bottom of a copper tube and a glass tube at the same time, the top of the copper tube will become hotter quicker than the top of the glass tube.

Convection
Like conduction, convection occurs by molecular motion but in a fluid (such as a gas or liquid), rather than in a solid. When a gas or liquid is heated, the energized molecules begin to flow. On earth, where gravity is a factor, the heated, less-dense fluid flows upward as cooler, more compact fluid moves down. This process of displacement continues as long as the heat source remains.

Radiation
Radiation occurs not by molecular action but rather by emission of electromagnetic waves, generally in the invisible, infrared spectrum. Because radiation does not rely on the presence of matter (molecules) for transport, it can occur in a vacuum. Just as the sun radiates to the earth, a warm object on earth will radiate infrared waves at night to objects in deep space. All objects with heat radiate to objects with less heat that are in a direct path.

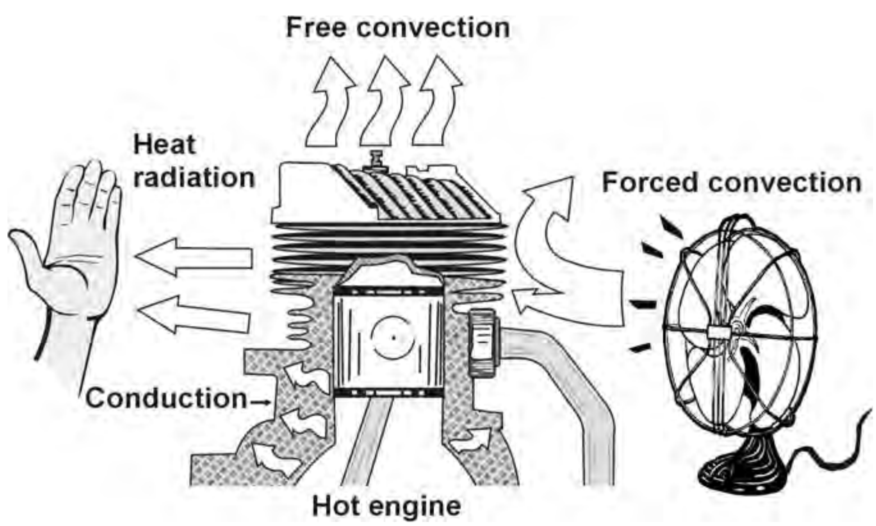


Figure 4. Illustration of Conduction, Convection and Radiation

Temperature Differential or Delta T

The greater the difference in temperature between two points of an object or between two objects, the greater the driving force to move heat from the warmer to the cooler point. This applies whether the heat transfer method is conduction, convection or radiation. Consider the following examples:

Conduction: Applying a 500^{o}F heat source to the bottom of a copper tube will make the top of the tube hotter and it will heat faster than if the heat source were at 250^{o}F.

Convection: A hot air balloon will rise faster if its air is 250° F rather than at 150° F.

Radiation: A camper sitting before a raging bonfire will feel much warmer than a camper sitting by the fire's glowing embers.

Thermal Mass

Thermal mass is the measure of a material's molecules ability to hold thermal energy. The higher the thermal mass, the material's energy capacity, the more efficiently the material can store sensible heat. Rock and masonry are two such materials that have high thermal mass and are solids. Water is a fluid with good energy capacity, making it a good thermal mass medium for energy storage.

Applying the Basics

The purpose of a solar heating system is to collect solar energy, convert it to heat, store the heat, and provide the stored heat for an intended purpose. The efficiency of the system depends on how well the solar basics are applied.

Collecting and Converting Solar Energy

Solar collectors capture the sun's electromagnetic energy and convert it to heat energy. The efficiency of a solar collector depends not only on its materials and design but also on its size, orientation and tilt.

Daily Variations

Available solar energy is at its maximum at noon, when the sun is at its highest point in its daily arc across the sky. The sun's daily motion across the sky has an impact on any solar collector's efficiency and performance in the following ways.

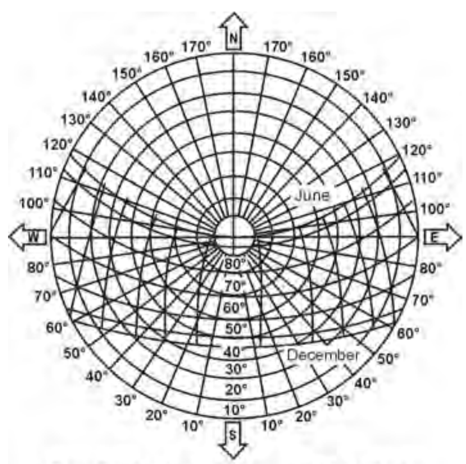
- Since the angle of incidence of the solar energy – measured from the normal (right angle) surface of the receiving surface – changes throughout the day, solar power is lower at dawn and dusk. In reality, there are only about 6 hours of maximum energy available daily.
- The total energy received by a fixed surface during a given period depends on its orientation and tilt and varies with weather conditions and time of day and season.

Aiming the solar device to track the sun's rays to strike it at right angles (normal) all day seems logical, but solar collectors are large and heavy and must be strong to withstand weather conditions. Tracking the sun requires considerably more hardware than does fixed mounting. Most practical designs accept the loss of energy suffered through fixed mounting and use an orientation close to that which collects the most solar energy possible.

Consequently, fixed solar collectors are best positioned to face true south in the northern hemisphere and true north in the southern hemisphere. If the collector will be unavoidably shaded in the morning when installed at its best solar location, it can be oriented slightly west in the northern hemisphere and slightly east in the southern hemisphere.

Seasonal Variations

The dome of the sky and the sun's path at various times of the year are shown in Figure 5 (note that 28˚ is about the latitude of Orlando, Florida). The top illustration shows the paths projected on a flat surface. In mid-June the days are long; the sun rises well north of due east and sets well north of due west. It also passes almost directly overhead (86˚) so that at solar noon on June 21 a horizontal plate will almost collect a maximum amount of solar energy (see Figure 6a). But in December, the sun rises later – south of due east – to a noon elevation of less than 40˚. It sets early on the west-southwest horizon. So, to get about the most solar power at noon in December, a fixed collector should face south and be tilted up at an angle of about 50˚ to the horizontal, as shown in Figure 6b.



Sun Paths in the sky at 28° latitude.

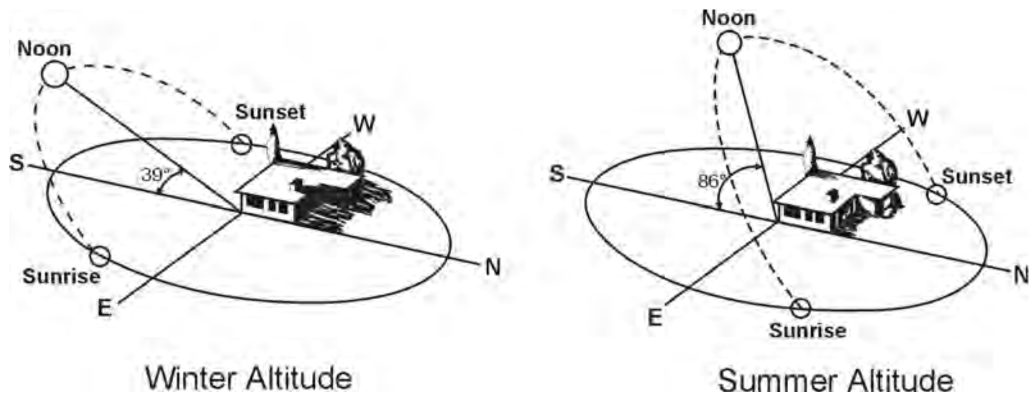


Figure 5. Sun Path Diagrams for 28º N. Latitude

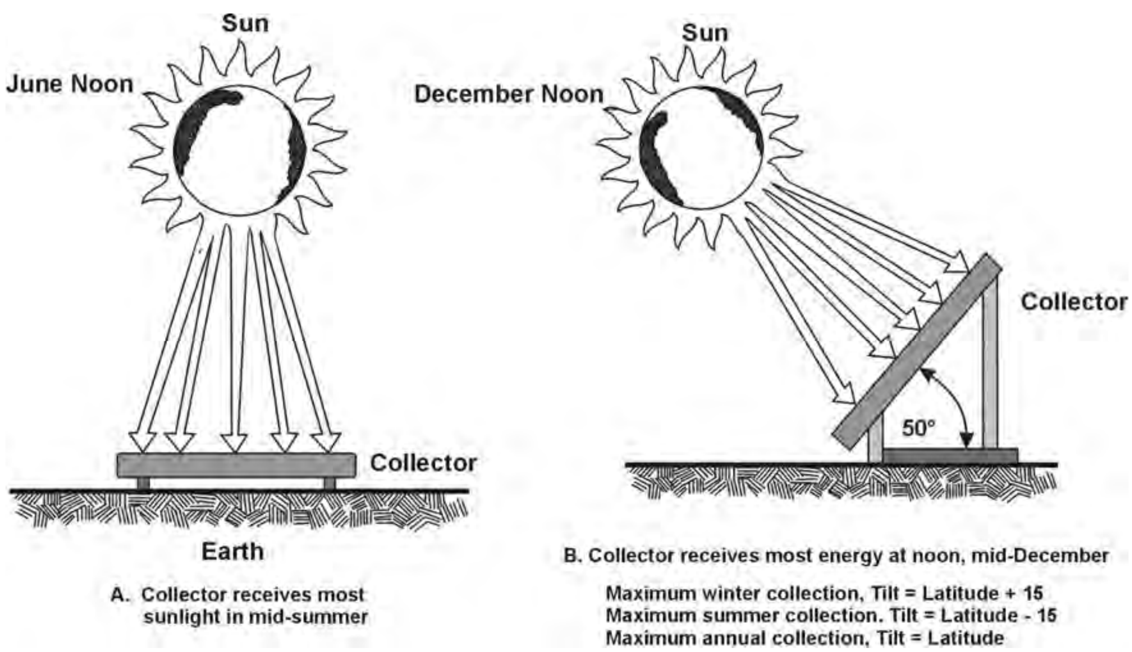


Figure 6a And 6b. Collected Energy Varies with Time of Year And Tilt

For many solar applications, we want maximum annual energy harvest. For others, maximum winter energy (or summer energy) collection is important. To orient the flat-plate collector properly, the application must be considered, since different angles will be "best" for each different application.

Collector Orientation

Collectors work best when facing due south. If roof lines or other factors dictate different orientations, a small penalty will be paid, as shown in Figure 7. As an example: for an orientation 20˚ east or west of due south, we must increase the collector area to 1.06 times the size needed with due south orientation (dashed line on Figure 7) to achieve the same energy output. The orientation angle away from due south is called the azimuth and, in the Northern Hemisphere, is plus if the collector faces toward the east and minus if toward the west. Correction factors may be used to properly size solar collectors which cannot face due south. Closer to the equator, this can change. The lower the tilt of the collector, the less the direction affects it. A collector at 5-10˚ tilt is almost flat to the sun. At 5˚ latitude and at a 5˚ tilt, the collector could be in any direction.

We have assumed that nothing shades the collector during any part of the day. If tall trees, for example, shade a collector until 10 a.m., an orientation west of south (so that the afternoon sun will provide the bulk of the energy collected each day) would enable maximum solar energy collection. Moving the collector or increasing its size will correct disruptions to solar insolation. To help the installer determine shading problems, solar pathfinders are available from several manufacturers, or use the Crome-Dome provided with this manual.

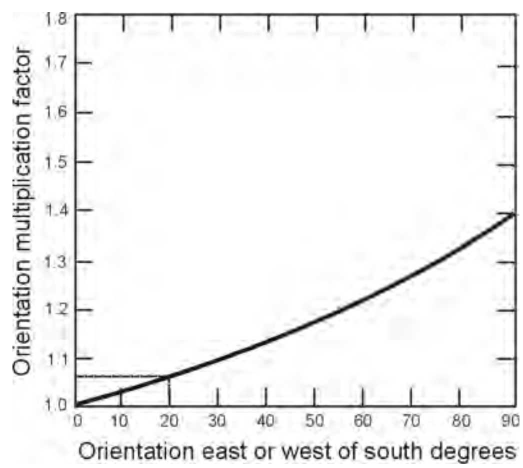


Figure 7. Glazed Collector Orientations

Tilt Angle

The best tilt angle will vary not only with the collector's geographical location but also with seasonal function. Solar water heating systems are designed to provide heat year-round.

Figure 8 below shows results for various collector tilt angles for Central Florida. For the slope angles shown in the figure, we observe these effects:

a) Mounting at an angle equal to the latitude works best for year-round energy use.

b) Latitude minus 15˚ mounting is best for summer energy collection.

c) Latitude plus 15˚ mounting is best for winter energy collection.

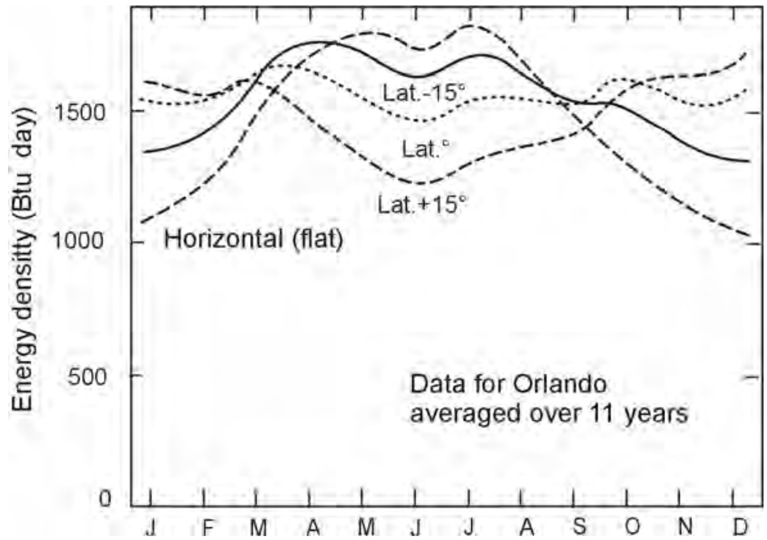


Figure 8. Various Collector Tilt Angles

Table 1 illustrates the effect of various tilt angles on a flat-plate solar collector installed in Miami, Florida.

Table 1. Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m^2/day average) in Miami, Florida (25.80˚ N. Latitude)

Tilt Angle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	3.5	4.2	5.2	6	6	5.6	5.8	5.6	4.9	4.4	3.7	3.3	4.8
Latitude -15	4.1	4.7	5.5	6.2	5.9	5.5	5.7	5.6	5.1	4.7	4.2	3.9	5.1
Latitude	4.7	5.2	5.7	6.1	5.6	5.1	5.4	5.5	5.1	5.1	4.7	4.5	5.2
Latitude +15	5.0	5.4	5.6	5.7	5.0	4.5	4.8	5	4.9	5.1	4.9	4.9	5.1
90	4.1	3.9	3.4	2.6	1.9	1.6	1.7	2.1	2.7	3.5	3.9	4.1	3

Methods exist to move a collector so the sun's rays strike it at a right angle all day and in all seasons. Use of such sun-tracking mechanisms increase the amount of energy a collector receives, but it also increases the system's cost, complexity and future maintenance requirements. Most practical designs accept the loss of energy suffered through fixed mounting and use an orientation and tilt to collect the most usable solar energy possible.

Therefore, for year-round use, a collector tilt of about 25˚ for south Florida or about 30˚ in North Florida works best. On a final note, installers must also keep in mind the aesthetics of the collector mounting on the plane of the roof.

Heat Storage

Most solar thermal systems employ a material with high energy capacity to store sensible heat until it is needed for a specific purpose. Water, masonry and even iron are all such thermally massive materials with high energy capacities. When the purpose of the solar thermal system is to provide heated water, the water itself is the thermal mass that stores the heat generated by the solar collector.

For these solar water heating systems, the water itself may be the fluid heated in the collector and then delivered directly to the tank. In areas where freezing temperatures are common during winter, the heat collecting fluid may be glycol or another heat transfer fluid with high energy capacity that can withstand freezing temperatures. Such systems employ heat exchangers at the storage tank to transfer the heat from the collector fluid to the potable water.

In solar water heating systems, the storage is sized with generous proportions to hold as much heated water as may be needed for a given purpose during times of low solar insolation. The tanks are also highly insulated to reduce heat losses.

Further from the equator, inlet water temperatures are colder, while in many cases, the insolation may be close to the same during some periods of the year. On a given day, if the amount of insolation is about the same, one might think solar systems in Toronto or Miami would perform about the same. The total heat energy collected and stored in the tank may be about the same, but the end-of-the-day tank temperatures will be different.

The Toronto storage tank will be colder than the Miami storage tank due to the difference in cold water supply temperatures. The cold water supply water temperature in Miami is approximately 75˚F, while the cold supply in Toronto is approximately 45˚F. More total solar energy is required to increase the Toronto system to the same end-of-the-day tank temperature.

To achieve the same end-of-the-day tank temperatures in Toronto you must increase the size of collector area to increase the energy gain of the system. Simply put, more collector is required in order to increase the total degrees of the water being heated.

Additional System Considerations

To meet its intended purpose, a solar thermal system must meet criteria beyond simply collecting and storing solar energy.

Safety

A solar thermal system must not contaminate the medium used to store or provide the system's energy output. For example, solar water heating systems must not contaminate water that may be used in food preparation or in human contact activities. For this reason, solar water heaters with heat exchangers frequently employ two walls to isolate the potentially dangerous heat collecting fluid from the water to be heated.

Mechanical safety must also be assured in designing and installing solar collectors. A 4-by-10-foot solar collector can act like an airplane wing in strong winds, so it must be structurally well connected and securely attached to its mounting surface.

Affordability

Affordability can be defined as performance balanced by price. A solar thermal system with collectors that track the sun's path will perform better than one with fixed collectors. However, the tracking mechanisms can double the cost of the system. In the same way, a solid gold absorber will perform better than a copper one, but the cost would be astronomical. To be affordable, a solar thermal system must balance performance and cost. Because solar thermal systems produce Btus. Btu per buck (Btu/$) is a good measure of affordability.

Materials Used

Materials for solar energy systems must be chosen carefully. The most important factors are safety, performance, durability and cost.

The materials must retain their shape and strength during repeated thermal expansion and contraction–all the while being exposed to the weather. Collector materials lead hard lives. The collector is exposed to wind, rain, hail, temperature extremes and ultraviolet radiation. Untreated plastics, woods and synthetic boards deteriorate rapidly under such conditions. Even steel must be protected by plating, galvanizing or painting. The collectors must be able to tolerate stagnation temperatures. This can be as high as 400°F for some solar collectors. Durability is important in all materials used in a solar system because the cost effectiveness varies directly with their life expectancy.

Section 2: Solar Water Heating Systems focuses primarily on the common solar system design types.

- **Module: System Types** describes and illustrates the main types of solar water heating systems, along with variations of each type, as well as various freeze protection strategies and designs.

- **Module: System Components** details the principal components of solar water heating systems and their individual function.

Section 2
Module: System Types

I. System Types

This module describes the most common types of solar water heating systems. Factors that influence the selection of a specific system type include the amount of water that needs to be heated, relative cost and efficiency, simplicity of operation, and climate conditions in which the system will be used.

Solar water heating systems fall into two general categories:

- active systems, which use a pump to control water flow, and
- passive systems, which use no pump.

Both active and passive systems can be either direct or indirect (Figure 1).

- In a direct system, the potable water circulates from the storage tank to the collector and back to the storage tank. Thus, the heat collecting fluid is the same potable water that is in the water heater.

- In an indirect system, the fluid that circulates through the collector may be water or it may be another heat transfer fluid. This heat-collecting fluid never comes in contact with the potable water in the storage tank. Instead, it transfers heat to the potable water through a heat exchanger.

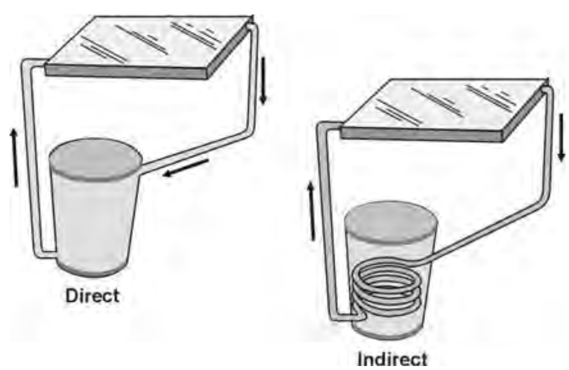


Figure 1 Direct and indirect solar water heating systems

Once again, there are two types of solar water heating systems – active and passive – and each has two categories – direct and indirect.

Active	Passive
Direct	Direct
Indirect	Indirect

The following pages will discuss the most common system types and their subcategories. Several design variations exist in each system type. The types and variations include:

1. Active Direct Systems
   - Active direct systems that use different types of controllers

2. Active Indirect Systems
   - Active indirect systems that use different types of controllers, heat collecting fluids, and heat exchange mechanisms

3. Passive Direct and Indirect Systems
   - Passive direct systems in which the collector and storage are one and the same
   - Passive systems that circulate water through thermosiphoning action and can be direct or indirect

1. Active Direct Systems

Active direct systems incorporate the following components:

- Water storage tank
- Solar collector
- Controller to regulate pump operation
- A pump or circulator to transfer water from the storage tank to the collector

Several additional components ensure proper system operation. Each of these components, listed below and in Figure 2, are discussed in detail in Section 2, Module: System Components.

1. Check valves prevent thermosiphoning action.
2. Isolation valves isolate subsystem components for service.
3. Pressure relief valves relieve high pressure.
4. Temperature and pressure relief valves relieve high temperatures and pressures.
5. Air vents release air that could cause air locks in the system.
6. Vacuum breakers allow proper collector loop drainage.
7. Drain valves drain the collector loop and tank or other subsystem components.
8. Freeze valves and sensors help to protect the collector from being damaged by freezing temperatures.
9. Optional temperature indicators and flow meters monitor components.

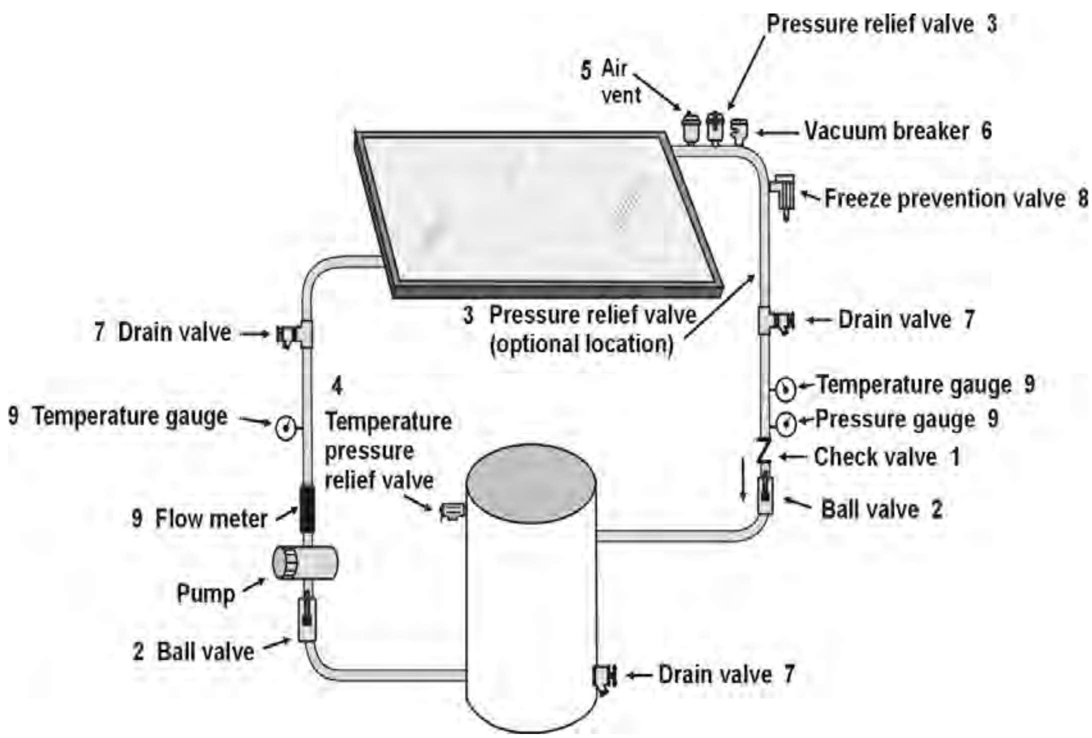


Figure 2 Additional system components

Active direct systems are principally differentiated by their pump control or freeze protection scheme. Following are descriptions and illustrations of four active direct systems based on their method of pump control.

Differential Controlled

In a differential controlled system (Figure 3), the circulating pump operates when sensors located at the top of the collector (hottest point) and bottom of the storage tank (coldest point) indicate a 5-20^{o} F temperature difference. Thereby, the water always gains heat from the collector when the pump operates. When the temperature difference drops to about 3-5^{o}F, the pump switches off. During the course of the day, the controller is constantly comparing the two sensor temperatures. In this way, water circulates through the collector only when sufficient solar energy is available to increase the water temperature.

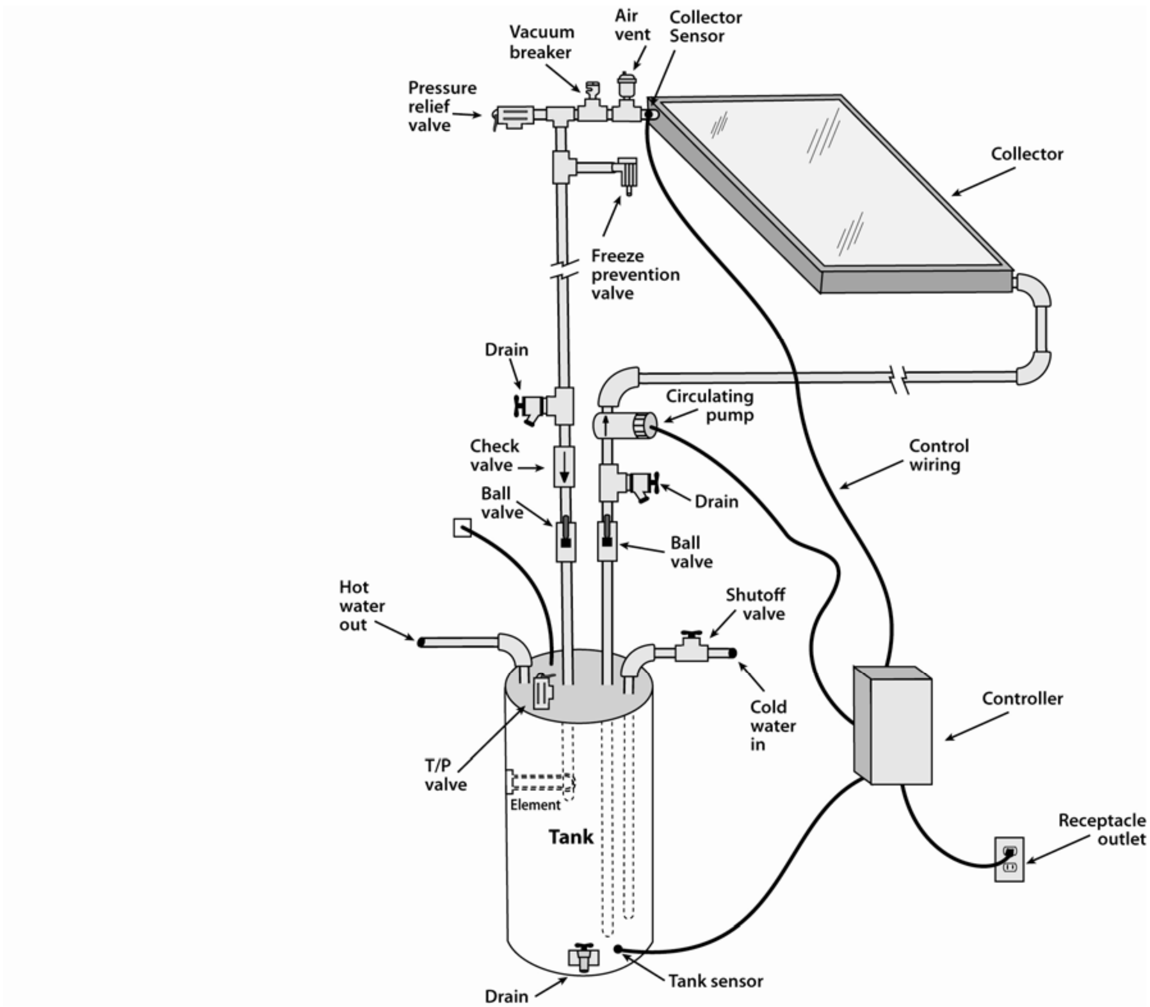


Figure 3 Active direct system with differential controller

Photovoltaic Controlled

Whereas the differential controlled active system uses a differential controller and sensors to regulate pump operation and heat collection, the photovoltaic (PV) controlled system (Figure 4) uses a PV module to perform these functions. Photovoltaics modules are semiconductor materials that convert sunlight directly to direct current (DC) electricity. In a photovoltaic controlled-system, a photovoltaic module generates power for a DC pump that circulates water through the collector and back into the storage tank. In a direct-coupled system, the module and pump are sized and properly matched to ensure that the pump will begin operating when sufficient solar energy for heating water is available and will stop operating when solar energy diminishes.

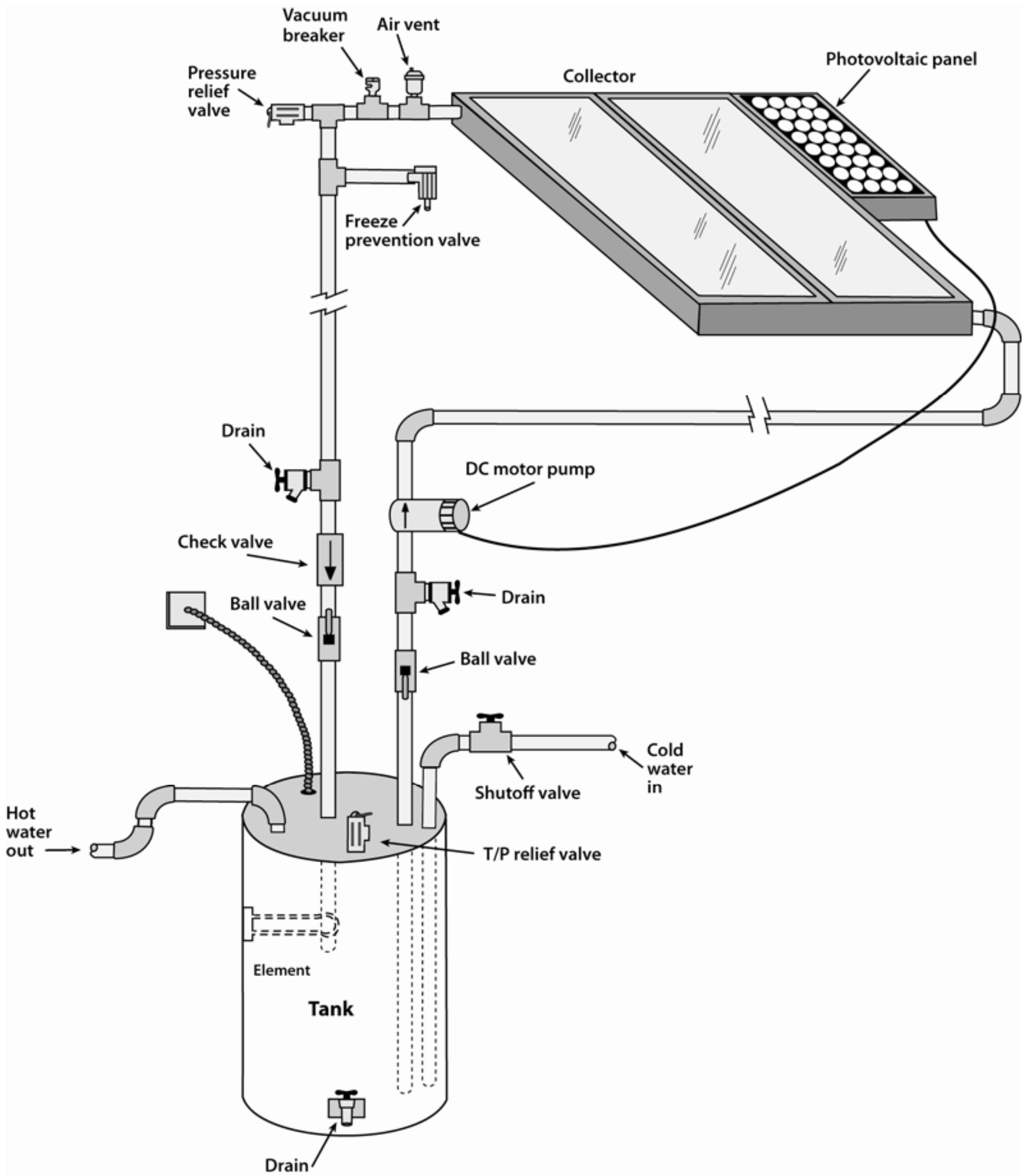


Figure 4 Active direct system with photovoltaic control

Timer Controlled

This control method is used in tropical climates where temperatures are mild year-round and significant amounts of solar energy are available almost every day. In a timer controlled system (Figure 5), a timer turns on a pump in mid morning and switches it off in late afternoon. To ensure that the heated water stratifies at the top of the storage tank, the system uses a very small (1/100-1/250 h.p.) pump. The collector feed and return lines are both connected through the use of a special valve at the bottom of the storage tank so only the coldest water from the tank flows through the solar collector.

Timer controlled systems could conceivably operate during rain or overcast conditions, so care must be taken to ensure the supply and return lines to the collector are located near the bottom of the storage tank. Therefore, if the pump operates during a cloudy day, only a small amount of the water at the very bottom of the tank will be circulated through the collector. This prevents potential major tank heat loss.

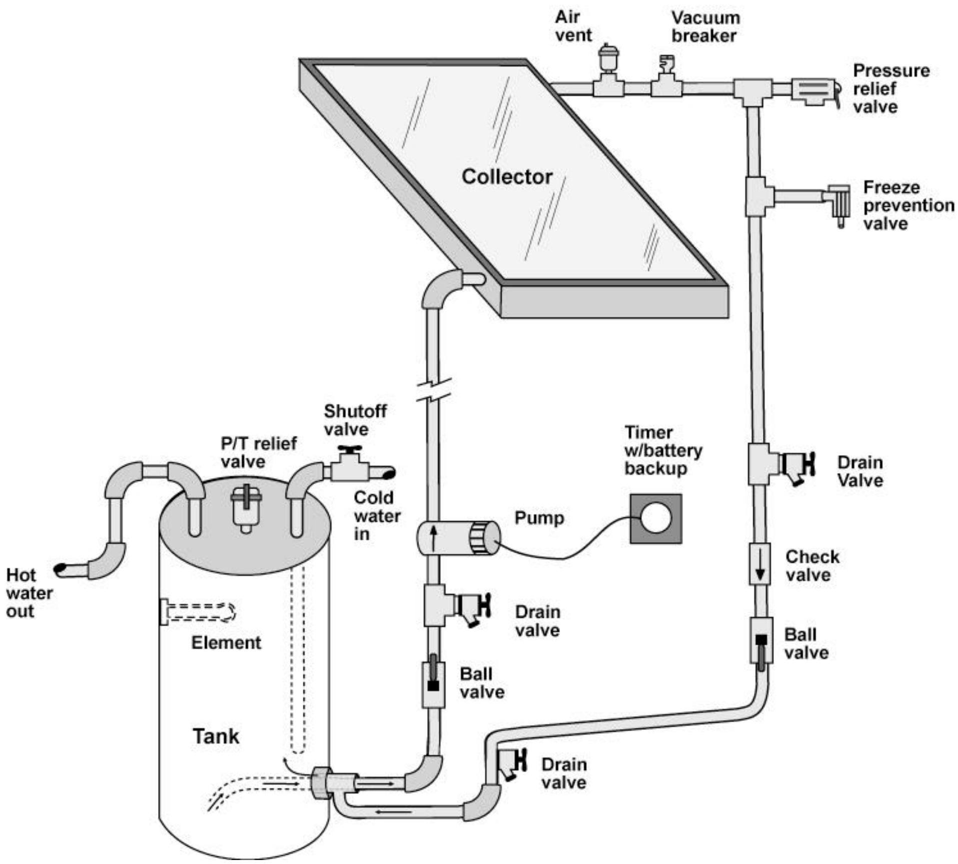


Figure 5 Active direct system with timer control

2. Active Indirect Systems

Indirect systems are typically used in areas of freezing temperatures or areas that have water that is very high in mineral content. The combination of high dissolved minerals and high temperatures produced by the solar system can accelerate scale buildup in system piping, fittings, and valves.

Like direct systems, active indirect systems employ a solar collector, a circulating pump, a potable water storage tank and a variety of ancillary valves. Unlike direct systems, indirect systems also incorporate a heat exchange mechanism that transfers heat from the freeze-proof heat-collecting fluid to the potable water in the storage tank. Active indirect systems are differentiated principally by the type of heat exchanger, controller, and heat collection fluid used.

Indirect Pressurized System

In an indirect pressurized system (Figure 6), the heat transfer fluid provides freeze protection at low temperatures. A differential or PV controller activates the circulator to move the fluid through the collector. A heat exchanger transfers the heat from the heat transfer medium to the potable water. The heat exchanger may be external to the storage tank, coiled around the outside lower half of the tank, or immersed inside the tank. A double wall heat exchanger is always used in systems that use toxic heat transfer fluids. For systems using non-toxic heat transfer fluids, a single wall heat exchanger is acceptable. An expansion tank on the solar loop compensates for the heat transfer fluid’s expansion and contraction. In addition, these systems require fill and drain valves for adding and servicing heat transfer fluids.

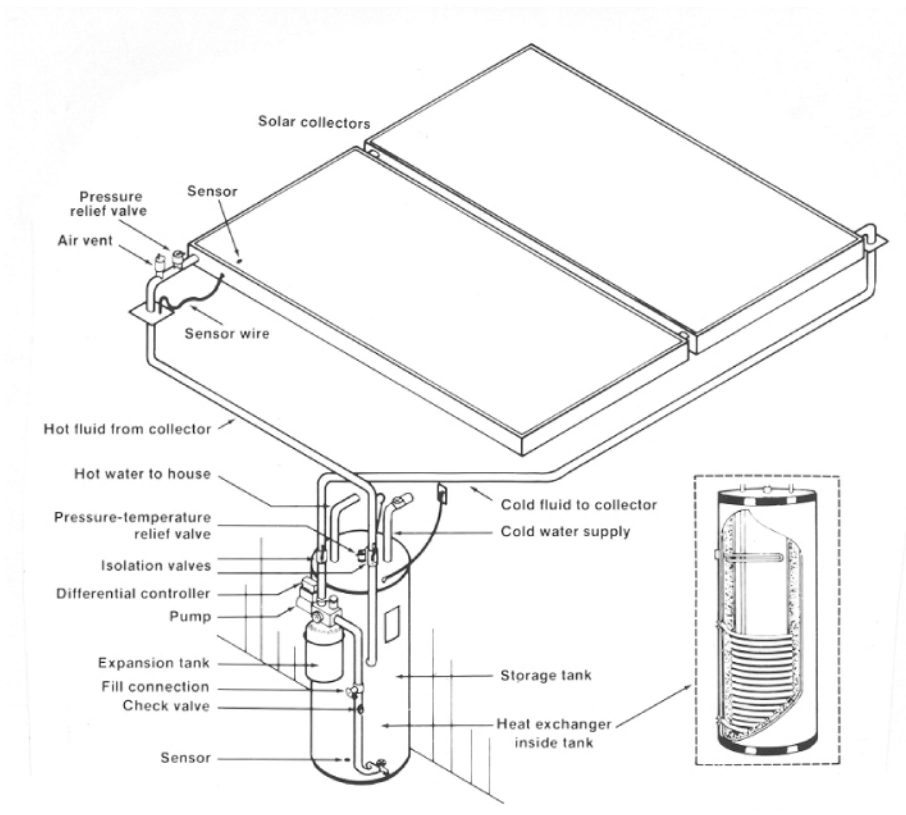


Figure 6 Active indirect system with tank internal heat exchanger

Drainback System

Drainback systems offer freeze protection and high-limit protection because the collectors empty by gravity when the system pump is not operating. Since these differentially controlled systems often use distilled water as the heat collection fluid, they offer improved heat transfer to the potable water. (This is because water has better heat transfer capabilities than other heat transfer fluids such as glycols or hydrocarbons.) When installed correctly, these system also provide a fail-safe method for protecting the collectors and piping from freeze damage. Each time the differentially controlled pump shuts off, all fluid in the slightly tilted collector and pipes drains into an insulated reservoir tank located in the building's interior. In some systems, the heat exchanger is incorporated in the drainback reservoir; in others, the heat exchanger may be external or inside the storage tank. This system does not require air vents or vacuum breakers; instead, the piping contains air that should not be added or released.

Drainback systems have a measured amount of air and a measured amount of water in the system. The air is transferred to the reservoir when the pump is running and the water fills the collector. The pump is never without water since water is returning from the collector loop. When the pump shuts off, the air in the reservoir is forced up and into the top of the collector by the water draining back into the reservoir from the bottom of the collector.

Several other special characteristics of drainback systems include:

- Pumps must be sized correctly to overcome gravity and friction losses
- Since the system is not pressurized, expansion tanks, check valves or fill and drain valves are not required
- Collectors and pipe drains must be installed to allow proper and unimpeded drainage back to the drainback reservoir

3. Passive Direct and Indirect Systems

Passive systems use no pumps or controllers. Instead, they rely on convection either to move water between the collector and storage tank in a thermosiphon system or to stratify heated water within an integral collector system. Most passive systems are direct; that is, the potable water directly collects the sun's heat in the collector. However, a few passive systems employ a heat exchanger. Following are descriptions of the most common types of passive systems.

Thermosiphon System, Direct or Indirect

In a thermosiphon system (Figure 7) the water storage tank is located above the collector. Cold water from the bottom of the thermosiphon system's tank flows through a pipe to the bottom of the solar collector. As the sun shines on the collector, the heated water expands slightly and becomes lighter than the cold water. Heavier, denser cold water from the tank flows into the collector inlet, which pushes the lighter, heated water through the collector outlet and up into the top half of the storage tank. This process of displacement provides a tank full of hot water at the end of the day. The solar heated water is drawn from the elevated tank either directly to the hot water service or to an interior auxiliary tank. Some thermosiphon systems (Figure 8) include a heat exchanger in or around the tank and an antifreeze solution to avoid freeze problems.

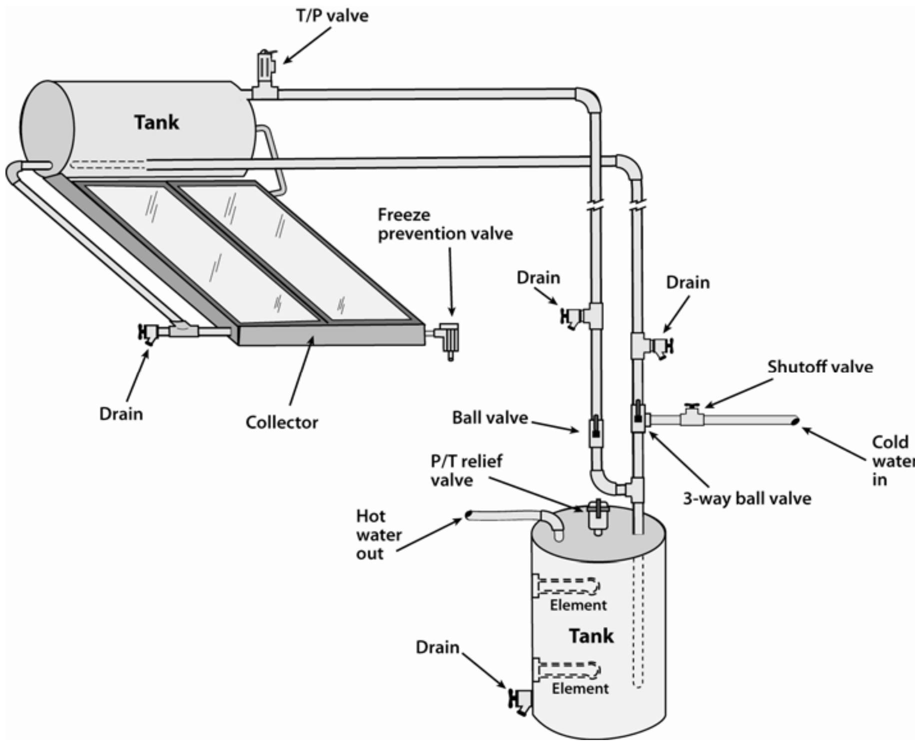


Figure 7 Direct thermosiphon system

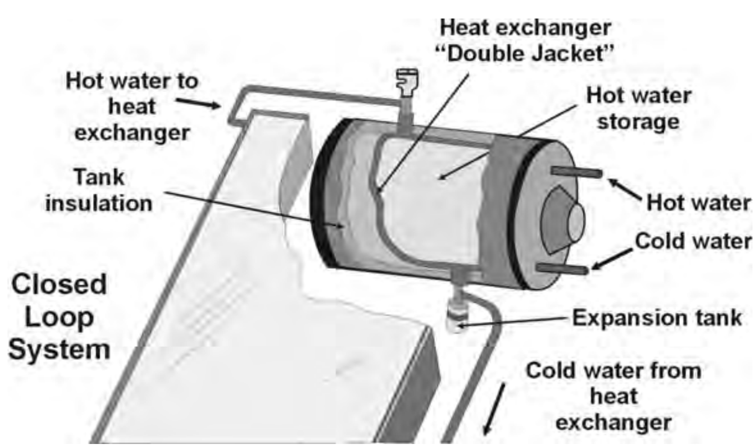


Figure 8 Indirect thermosiphon system

Integral Collector Storage (ICS) System

In other solar water heating systems the collector and storage tank are separate components. In an integral collector storage system, (Figure 9 and 10) both collection and solar storage are combined within a single unit. Most ICS systems store potable water inside several tanks within the collector unit. The entire unit is exposed to solar energy throughout the day. The resulting water is drawn off either directly to the service location or as replacement hot water to an auxiliary storage tank as water is drawn for use.

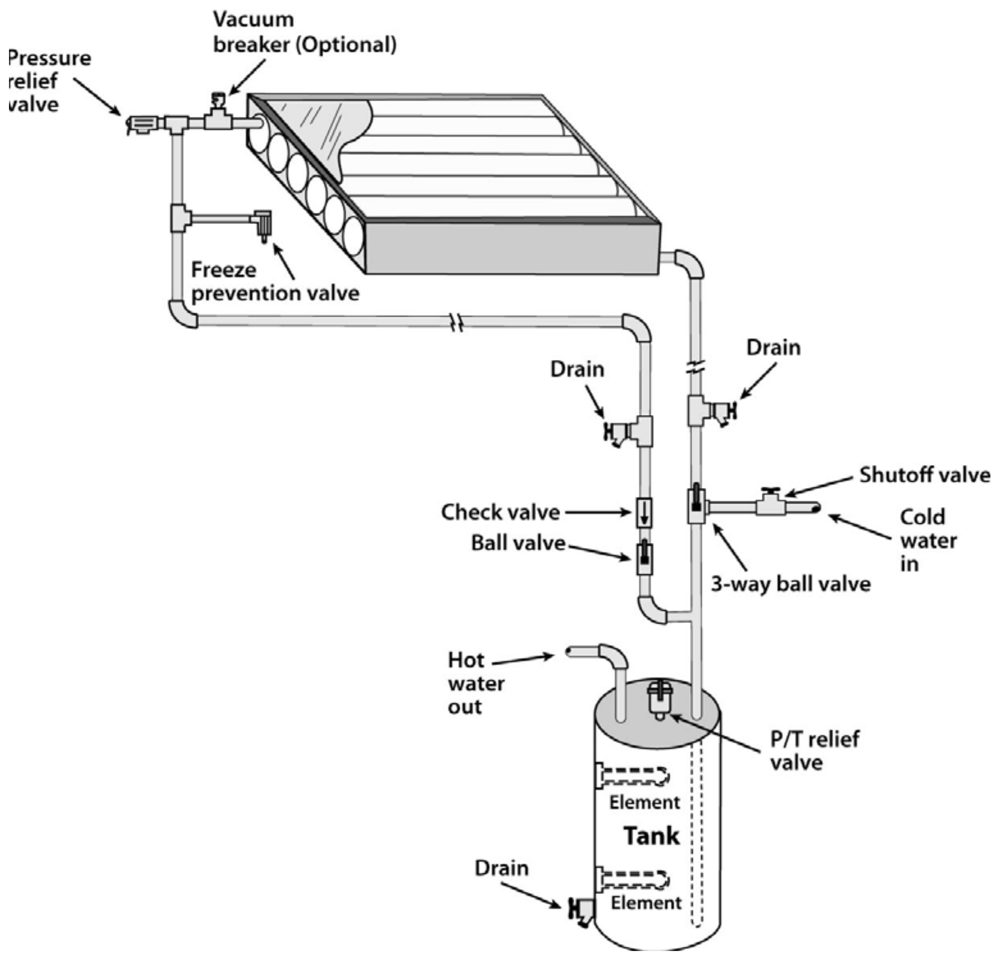


Figure 9 Integral collector storage (ICS) system

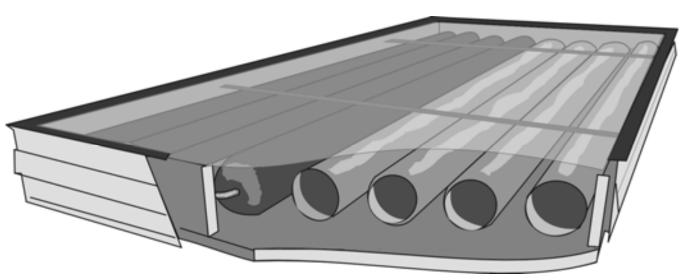


Figure 10 Cutaway of an ICS system

Batch System

The simplest of all solar water heating systems is a batch system (Figure 11). It is simply one or several storage tanks coated with a black, solar-absorbing material in an enclosure with glazing across the top and insulation around the other sides. It is the simplest solar system to make and is quite popular with do-it-yourselfers. When exposed to direct sun during the day, the tank transfers the heat it absorbs to the water it holds. The heated water can be drawn for service directly from the tank or it can replace hot water that is drawn from an interior tank inside the residence.

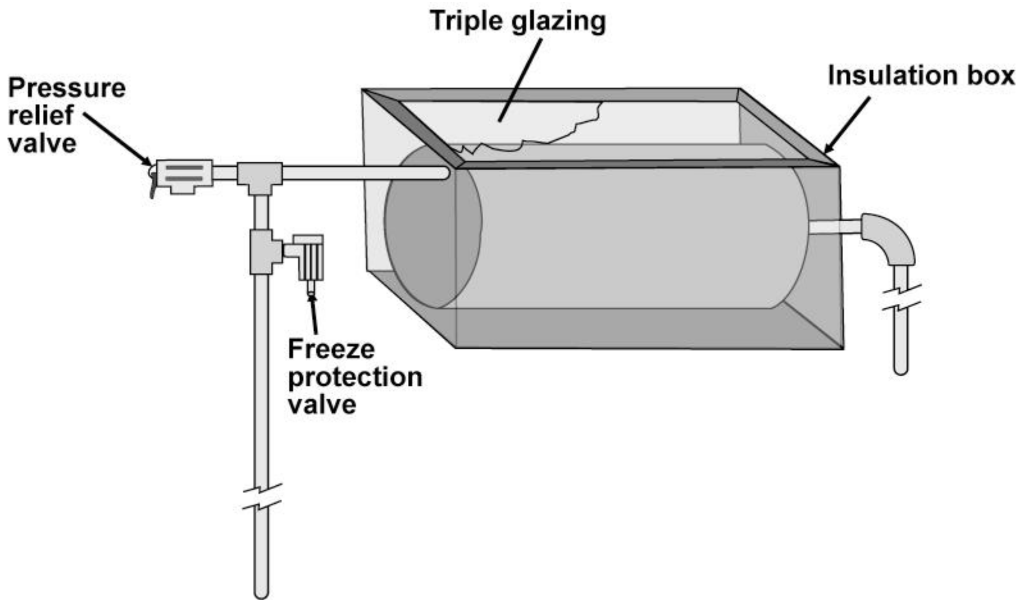


Figure 11 Batch solar water heater

II. FREEZE PROTECTION

Freeze protection mechanisms prevent freeze damage to system components. There are five basic methods used to prevent freezing. These include:

1. Indirect Antifreeze Fluid Circulation
2. Draining
3. Water Flow
4. Thermal Mass
5. Auxiliary heater

Except for solar systems in the tropics, all systems require some type of freeze protection method. The following examples are some of the more common methods used to prevent freezing. Systems may employ one or more of the following methods of freeze protection.

1. Indirect antifreeze fluid circulation

Indirect heat exchange systems, which are frequently used in cold climates, use a heat-transfer fluid that provides freeze protection in very low temperatures. The antifreeze solution circulates in a closed loop through the collector and heat exchanger. This provides protection to the collector and exterior piping during freezing temperatures.

2. Draining

Direct systems can be protected from freezing by removing all the water from the collector and the exposed piping. This can be done manually or automatically by one of two methods: drain down or drain back.

a. Automatic Drain-down

In a drain down system (Figure 12), sensors and a controller activate one or more automatic valves that isolate the collector loop from the tank. The automatic valve should be installed to allow collector loop drainage when power to the electrically operated valve is interrupted. The collectors and piping for these systems must be installed so that no gravity traps or low spots occur so that the collector loop fluid will drain totally by gravity.

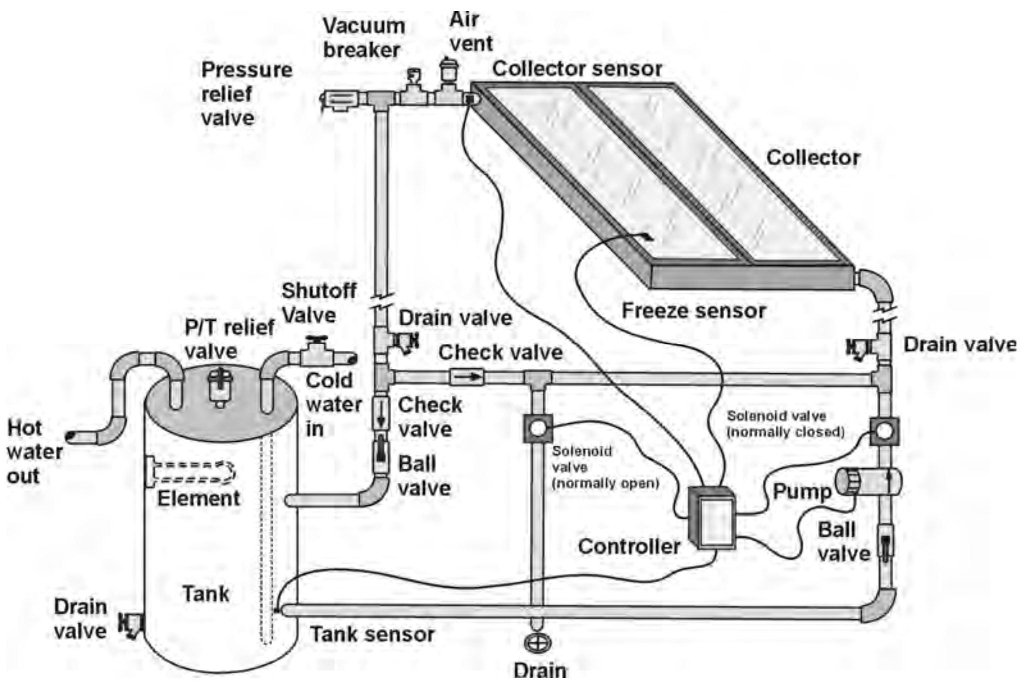


Figure 12 Drain-down system configuration

b. Manual Drain-down

Systems can also be designed to be manually drained. The system must have isolation valves between the collector and the storage tank and drain valves on the supply and return lines. The manual draining operation must include shut off of any system controller and circulating pump. It is best to keep the drain valves open when the collectors are drained. A leak or failure of the isolation valve can provide a path for water to flow back to the solar collector and result in freeze damage.

Complete draining requires both properly sloped piping and a means for air to enter the system. The use of a vacuum breaker will ensure that the collector loop drains properly. In turn, refilling after draining requires a method to allow air to escape at the high point of the system. A properly installed air vent will provide a means of allowing air to be purged automatically from the system.

c. Drain-back

In drain-back systems (Figure 13), a reservoir collects the heat-transfer fluid (usually distilled water) that drains from the collector loop each time the pump turns off. When the pump turns on, it recirculates this same fluid. Generally, a drain back system uses a heat exchanger to transfer heat from the collector fluid to the potable water.

The pump used in these drain-back systems must be capable of overcoming fairly large static heads, since the collector may be mounted several stories above the pump. The pump must be installed in such a way that it is below the low-water mark when liquid is not circulating. As in drain down systems, the collectors and piping for drain back systems must be installed in a way that allows no gravity traps or low spots to prevent the drain back of the heat-transfer fluid.

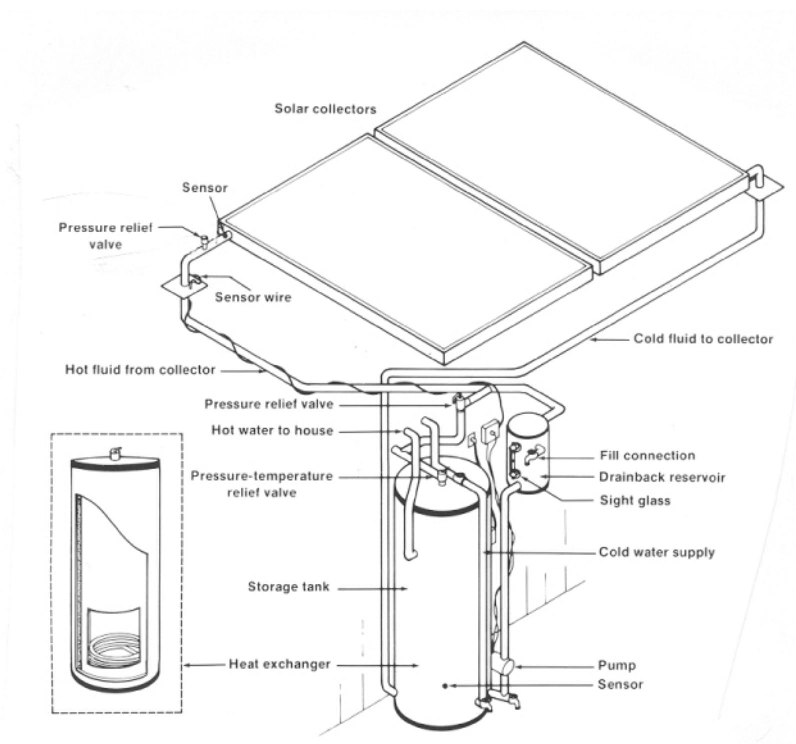


Figure 13 Drain-back system with internal tank heat exchanger

3. Water flow

Freeze prevention may be provided by moving warm water from the bottom of the tank through the collector. This movement can be accomplished by recirculation or use of freeze-protection valves.

a. Recirculation

In direct systems, recirculation may be used where the threat of freeze damage is infrequent. For recirculation, a freeze sensor is connected to the controller to turn on the pump whenever the collector temperature approaches freezing. For systems that use a separate freeze sensor, the freeze sensor should be placed on the collector plate at the middle or bottom of the collector (away from the collector inlet) so that it will sense the coldest temperature of the collector. Another option is to turn the pump on manually during freeze conditions.

Because the pump requires electric power, this method will fail when a power outage and freeze occur simultaneously. At such a time, the collector must be drained manually.

b. Freeze protection valves

A freeze protection valve (Figure 14), set to open before freezing temperatures, is installed on the collector return plumbing line just beyond where the line penetrates the roof. When the valve registers a set temperature, it opens and warm water bleeds through the collector and out the valve to protect the collector and collector loop piping from freezing. Once the valve registers warmer temperatures (from the tank water being circulated through the valve), it closes. This action is repeated throughout the freezing conditions. The valve may be controlled by a spring-loaded thermostat or a bimetallic switch. Figure 15 shows where a freeze-protection valve is typically located on a solar DHW system.

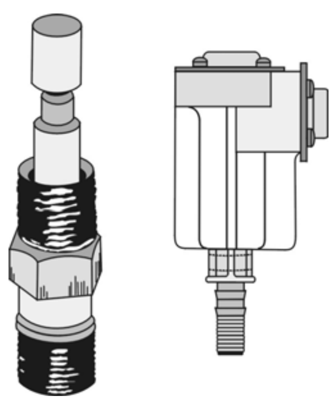


Figure 14 Freeze protection valves

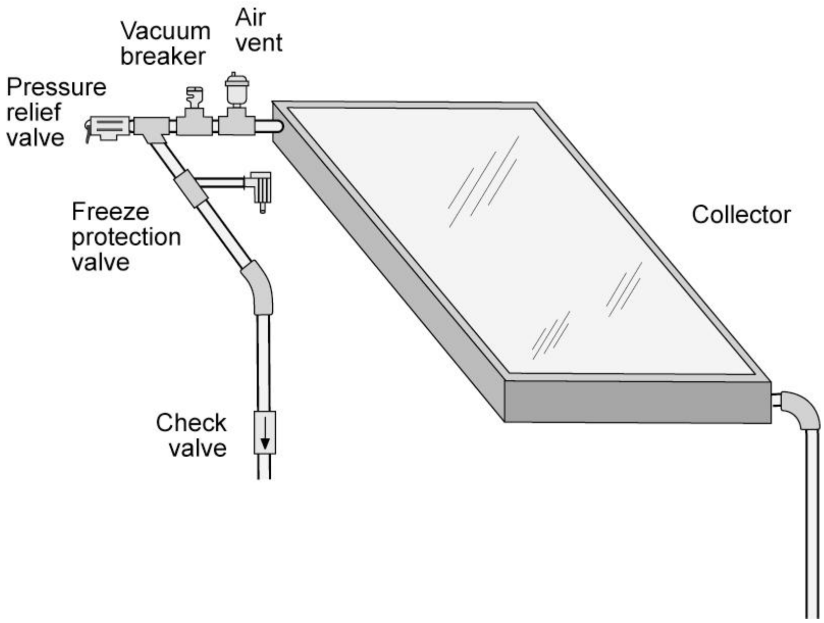


Figure 15 Location for freeze protection valve

Freeze-protection valves require water pressure to force water through the valve (and in turn through the collector and associated piping) when activated. If these valves are installed on well water or cistern systems, low-pressure relief valves should also be installed on the system. The valve will open and drain the collector and collector loop when power outages create low pressures.

A check valve must be used in all systems with freeze-protection valves. They are installed in the collector loop return line (See Figure 15). To protect the absorber plate, water must flow through all the pipes. The check valve prevents tank water from flowing straight from the tank to the freeze valve by way of the return line, thus bypassing flow through the collector.

4. Thermal mass

When used in milder climates, integral collector storage and batch type solar systems are protected from freezing by the large thermal mass in their collectors. Nevertheless, special care must be taken to protect exterior and attic collector loop piping. Any thermal mass protected system can eventually lose heat and freeze. The size of the collector tanks, the climatic and geographical location, local winter temperatures, and the length of the freeze all play a factor in determining how effective thermal mass will be as a freeze protection option.

5. Auxilliary heating

A less commonly used freeze-protection option is to use heat tape or electrical devices that are incorporated in the collector and collector loop piping. During freezing periods, these are activated to provide warmth to the collector and piping. As in recirculation, this relies on the continued availability of electric power during freezes.

Section 2
Module: System Components

INTRODUCTION

Solar water heating systems have components for heat collection, heat storage, heat delivery and freeze protection. Active systems need controls for pump operation and valves for safety and proper operation. Passive systems utilize many of the same components but in some cases for different reasons. This chapter describes the following system components.

- Collectors - collect and convert the sun's energy to heat.
- Tanks - store solar heated water and heat transfer fluids.
- Heat delivery components - include piping, heat-transfer fluids and heat exchangers.
- Freeze protection mechanisms - prevent collectors and pipes from freezing.
- Isolation, check, relief and safety valves are used to valve fluid flow.
- Gauges and meters are used for system monitoring

COLLECTORS

Solar collectors capture the sun's electromagnetic energy and convert it to heat energy. While most direct and indirect active systems use flat-plate collectors, some systems employ evacuated tube collectors, or use collectors that incorporate one or more storage tanks.

Flat-Plate Collector

Flat plate collectors are designed to heat water to medium temperatures (approximately 140º F. As shown in Figure 1, flat-plate collectors typically include the following components:

- Enclosure: A box or frame that holds all the components together. The material is chosen for its environmental durability as well as its structural characteristics.

- Glazing: A transparent cover over the enclosure that allows the sun's rays to pass through to the absorber. Most glazing is glass but some designs use clear plastic. In general, the sun's heat energy passes quite easily through the glazing as short waves. Heat energy that re-radiates from the collector absorber is in long waves. Glass glazing prevents long waves from passing back through the glazing.

  Glazing also blocks air motion across the absorber, thereby reducing heat loss through convection. The glazing also servers as a transparent insulation that can be single or multiple layers. The more the layers the greater the insulation value, but multiple layers also decrease the amount of light that is transmitted through the layers of glazing.

- Glazing frame: Attaches the glazing to the enclosure. Glazing gaskets prevent leakage around the glazing frame and allow for contraction and expansion.
- Insulation: Material between the absorber and the surfaces it touches that blocks heat loss by conduction thereby reducing the heat loss from the collector enclosure. The insulation must be able to withstand extremely high temperatures, so insulations like Styrofoam are not suitable.
- Absorber: A flat, usually metal surface inside the enclosure that, because of its physical properties, can absorb and transfer high levels of solar energy. The absorber material may be painted black with a semi-selective coating or it may be electroplated or chemically coated with a spectrally selective material (selective surface) that increases its solar absorption capacity by preventing heat from re-radiating from the absorber.
- Flow tubes: Highly conductive metal tubes across the absorber through which fluid flows, transferring heat from the absorber to the fluid. The heat transfer fluid tubes remove heat from the absorber. The collector may also incorporate headers, which are the fluid inlet and outlet tubes.

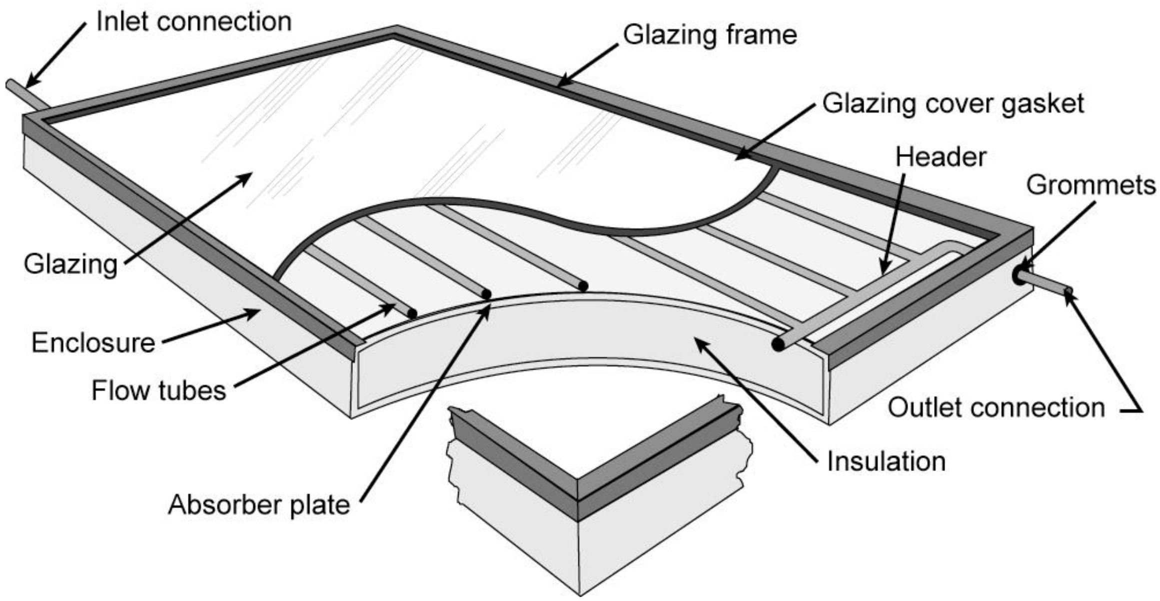


Figure 1 Flat plate collector

Evacuated-tube collectors

Evacuated-tube collectors generally have a smaller solar collecting surface because this surface must be encased by an evacuated glass tube. They are designed to deliver higher temperatures (approximately 300^{o}F). The tubes themselves comprise the following elements:

- Highly tempered glass vacuum tubes, which function as both glazing and insulation.
- An absorber surface inside the vacuum tube. The absorber is surrounded by a vacuum that greatly reduces heat losses.

In “flooded” evacuated-tube collectors (Figure 2) the absorber itself forms a tube through which the heat collection fluid is pumped. Flooded evacuated-tubes are typically used in passive thermosyphon systems.

In a “heat pipe” evacuated-tube collector (Figure 3), a flat absorber plate running the length of the tube covers a heat pipe filled with a fluid that evaporates at relatively low temperatures. As the fluid is heated, it evaporates and rises to the top of the tube. There it transfers the heat to water in a manifold. The condensed heat-collection fluid then returns by gravity to the bottom of the heat pipe. These systems can be active or passive.

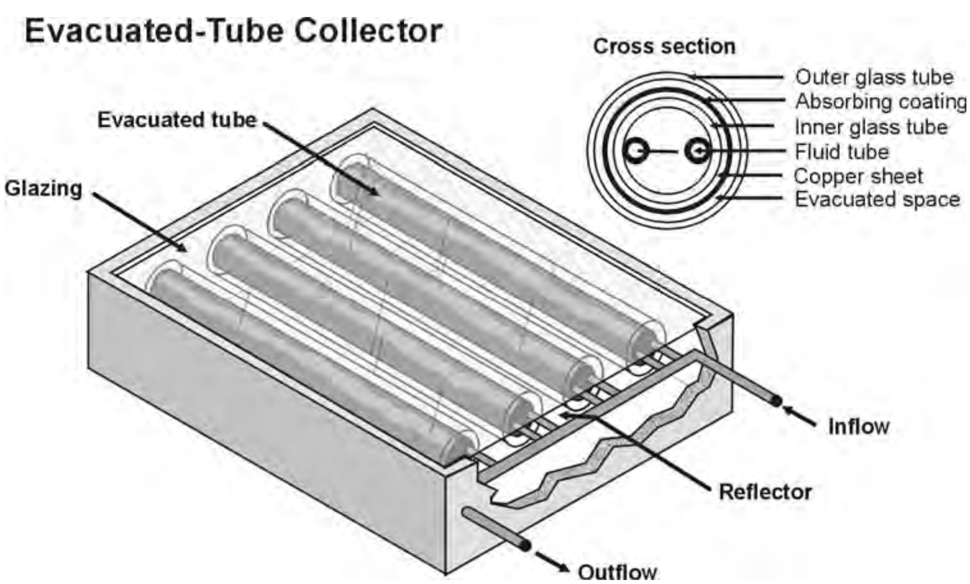


Figure 2 Flooded evacuated-tube collector

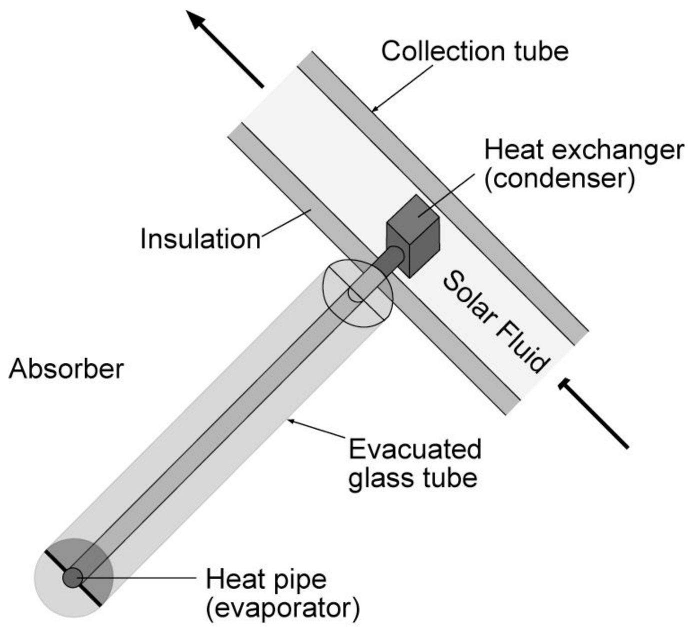


Figure 3 Heat pipe evacuated-tube collector

Integral Collectors

In integral collector storage (ICS) and batch solar water-heating systems, the collector functions as both solar absorber and water storage.

ICS collectors (Figure 4) generally incorporate 4" or larger diameter horizontal metal tanks connected in series by piping from a water inlet at the bottom of the tank to an outlet at the top. The tanks, which are coated with either a selective or moderately selective absorber finish, are enclosed in a highly insulated box covered with multiple glazing layers. The multiple glazing layers and selective coatings are designed to reduce the heat loss of water stored in the absorber.

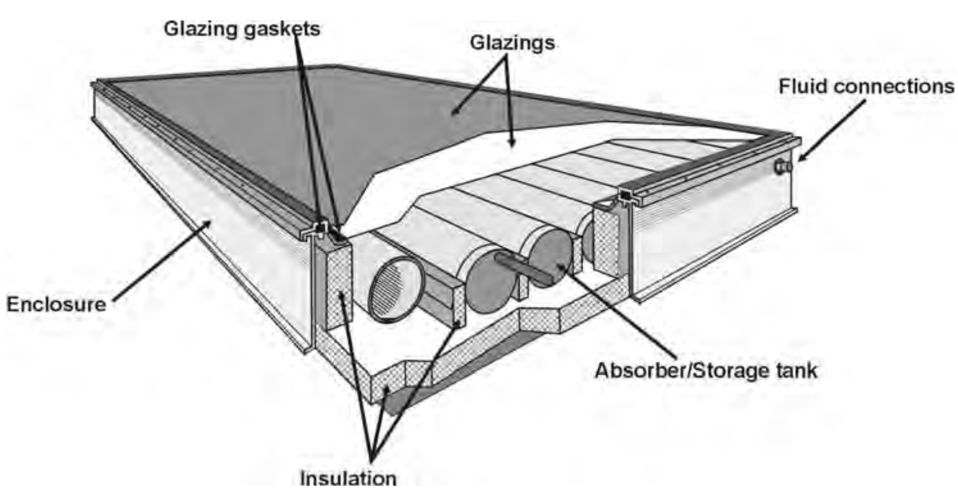


Figure 4 ICS collector

The simplest of all water-heating collectors, a batch collector (Figure 5) usually is made of just one black-painted metal tank inside an insulated enclosure covered with some type of glazing.

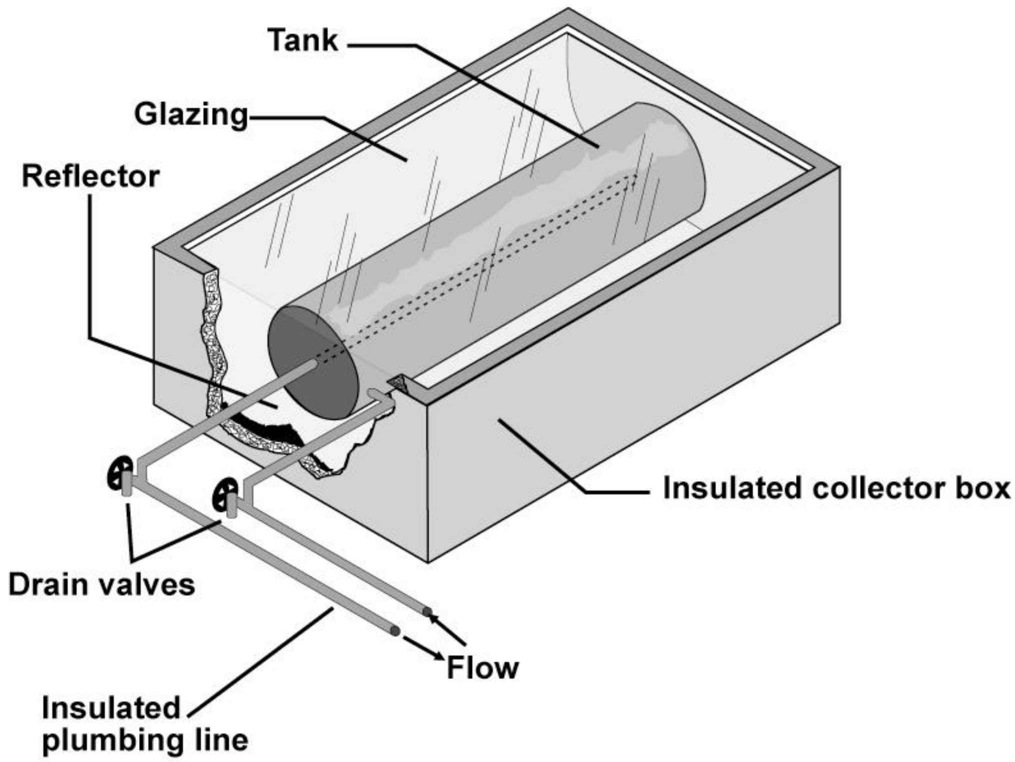


Figure 5 Batch collector

STORAGE TANKS

The storage tank holds the water that has been heated by the collector. The water can be stored in any vessel suitable for high temperatures. The tanks can be pressure rated depending on the application and whether or not a back-up heating system is used.

In subtropical and tropical climates, solar water heating systems usually have a single solar storage tank. This tank usually incorporates an electric heating element. Gas water heaters are not usually used for solar storage. The reason for this is that the gas burner is at the bottom of the tank. As cold water enters the tank and activates the gas burner, the whole tank is heated and the gas heat reduces the contribution from the solar system. When gas water heaters are used for back-up, a thermosyphon or ICS system that preheats water entering the gas back-up heater may be used. Or, a two-tank system may be used where the solar tank preheats the water for the gas back-up tank.

In colder regions and industrial applications, two tanks may be required to store sufficient solar-heated water over very cold or cloudy periods. In these cases a solar storage tank, to which the solar loop is plumbed, is connected in a series to an auxiliary water heater or boiler that has "back-up" electric or gas heating. This auxiliary tank or boiler provides hot water in the event there is insufficient solar-heated water. Solar thermal systems that supply heated water for applications other than potable domestic water, such as space heating, may employ more than one storage tank.

The most popular tanks are made of steel with an inner glass, stone or epoxy lining to protect the steel from galvanic corrosion caused by the water's chemistry. (Dissolved oxygen in the water becomes corrosive to untreated steel). Steel tanks also have an internal aluminum or magnesium "sacrificial" anode rod to attract the oxygen away from the steel. Stone-lined tanks and stainless steel or copper tanks normally do not require anode rods.

Where hard or highly conductive water will be stored in the tank, the anode rod should be replaced periodically. Even in areas with good quality water supplies, the solar storage (and auxiliary) tank should be drained periodically to remove sediment build-up.

Solar storage tanks should be well insulated, especially if they are installed in an air conditioned space. If they are installed outside a building, they should also be well protected from environmental conditions and corrosion, including ultraviolet degradation, by an ultraviolet (UV) resistant plastic, stainless steel or aluminum jacket. Painted steel or powder coated steel jacket materials on storage tanks require continuous maintenance in coastal or high moisture areas. If the system design requires that tanks be buried below ground, they should have additional insulation and accessible ports for valves and wiring connections. Heat loss from buried storage tanks is accelerated by high water tables or wet ground. Ground conditions should be considered in heat loss calculations.

Single Tank Systems

The design of conventional water heater tanks encourages mixing water in the tank, producing a tank full of water at the highest selected temperature. For this reason, natural gas and propane system burners are located at the bottom of the tank and conventional electric units have heating elements located in both the top and bottom third of the tank.

Electric

Solar systems with single tanks (Figure 6) are designed to encourage temperature stratification so that when water is drawn for service, it is supplied from the hottest stratum in the tank (top of tank). While a solar system tank in the U.S. normally contains a heating element, the element is deliberately located at the upper third of the tank. The electric element functions as back-up when solar energy is not available or when hot water demand exceeds the solar-heated supply. To further encourage stratification of cold and hot water in a storage tank, the cold supply water inlet is located at the bottom of the tank, as is the opening of the collector feed tube. In addition, the collector return tube opens below the heating element, returning the solar heated water to the hottest stratum.

Gas

Gas back-up systems may use passive (thermosyphon or ICS) solar preheating plumbed in series for proper operation. Or two separate tanks may be used for active solar systems with gas back-up heating systems. The solar storage tank is piped in series to the auxiliary tank sending the hottest solar preheated water to the gas back-up tank. (See Figures 8a and 8b.)

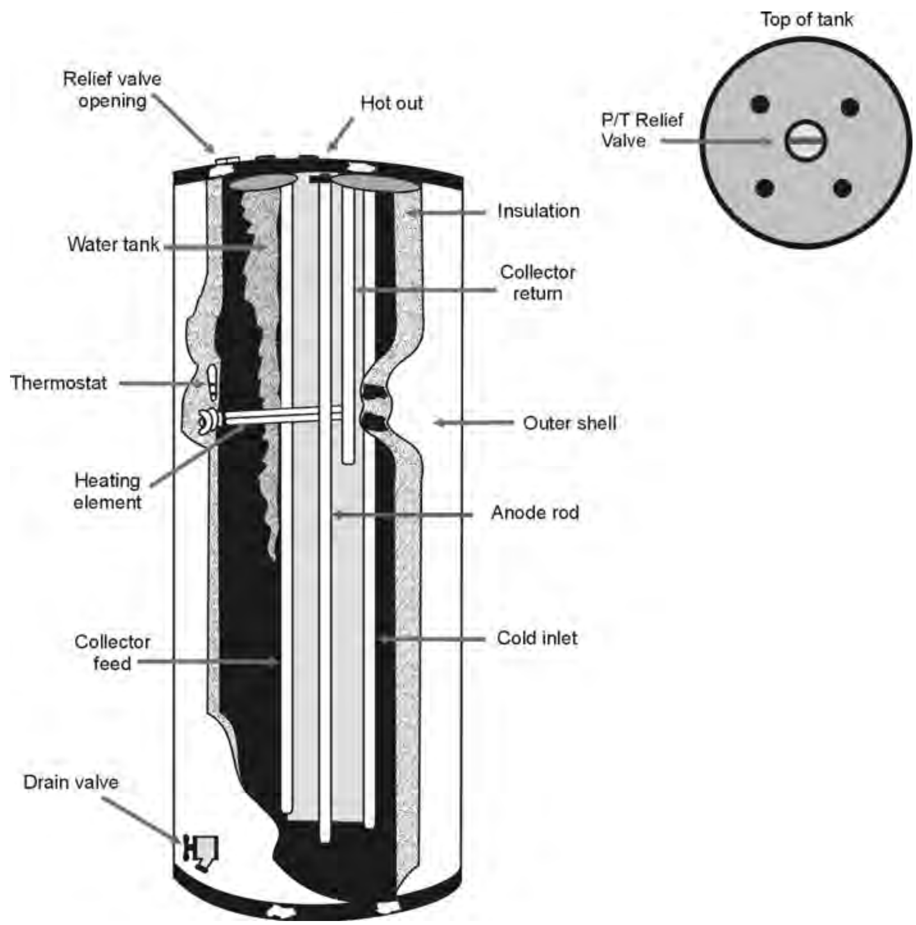


Figure 6 Vertical solar storage tank

Depending on the system design, solar tanks may be vertical, as shown in Figure 6, or horizontal as shown in Figure 7. Stratification is generally better in a vertical tank than in a horizontal tank. Yet, aesthetics and mounting considerations favor the horizontal tank design if the tank is mounted on the roof as in a thermosiphon roof-mounted system.

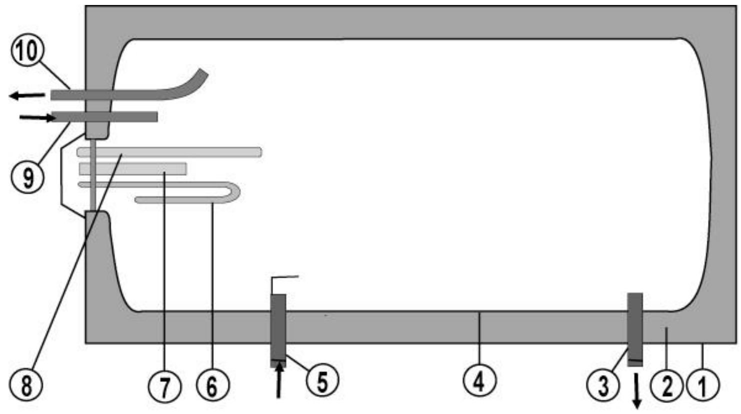
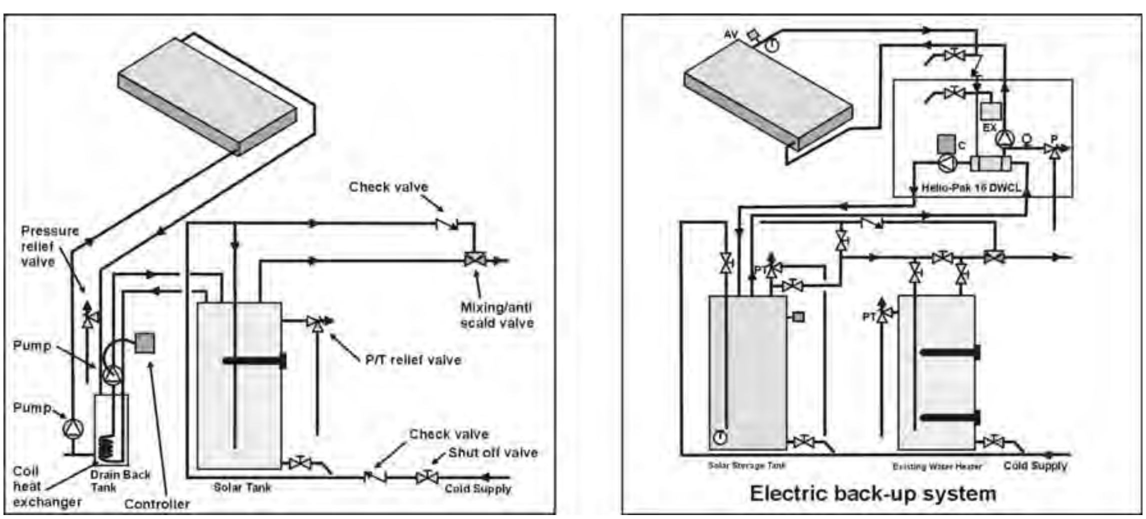


Figure 7 Horizontal solar storage tank

Multiple-Tank Systems

In two-tank systems (Figures 8a and 8b), one tank provides storage for solar-heated water. It is plumbed directly to the solar collector and does not contain any back-up heating source. This solar storage tank is plumbed to a second tank, which contains an auxiliary power source that can be used when no solar energy is available. This type of configuration is most commonly used in residential and light commercial applications.

Larger commercial and industrial solar system storage tank strategies can incorporate a single large solar storage tank or multiple smaller solar storage tanks. In these systems, all the tanks are typically plumbed in parallel, thereby acting as a single storage mechanism. The fluid flow is balanced so an equal amount of water enters each of the tanks as hot water is drawn for service. These storage tanks supply hot water directly to the back-up (auxiliary) heater or conventional commercial boiler. In certain situations, multiple tank storage systems use parallel piping between most of the tanks and series piping to a single tank with back-up capabilities.



Gas back-up **Electric back-up**

Figure 8a Two-tank solar water heater storage

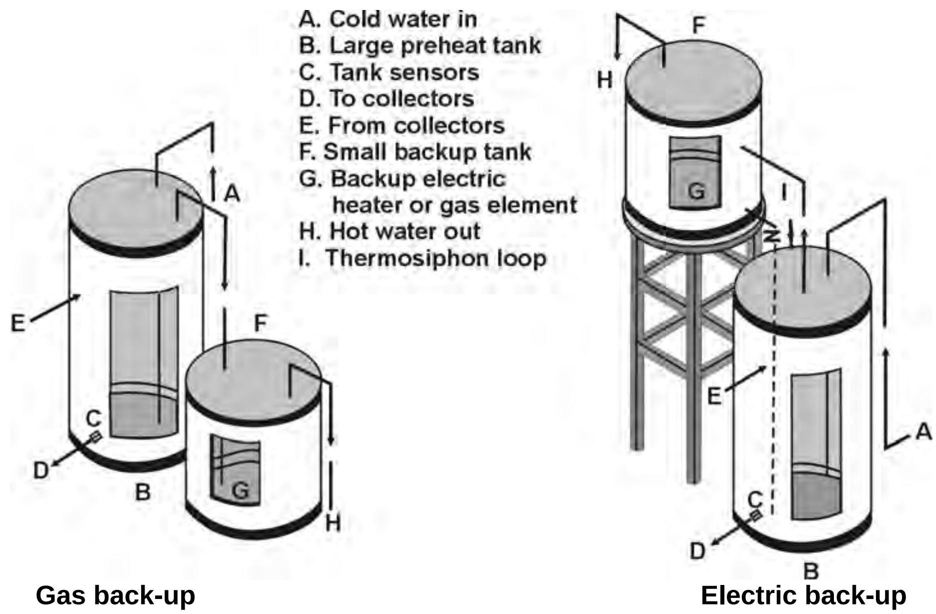


Figure 8b Two-tank solar water heater storage

PUMPS

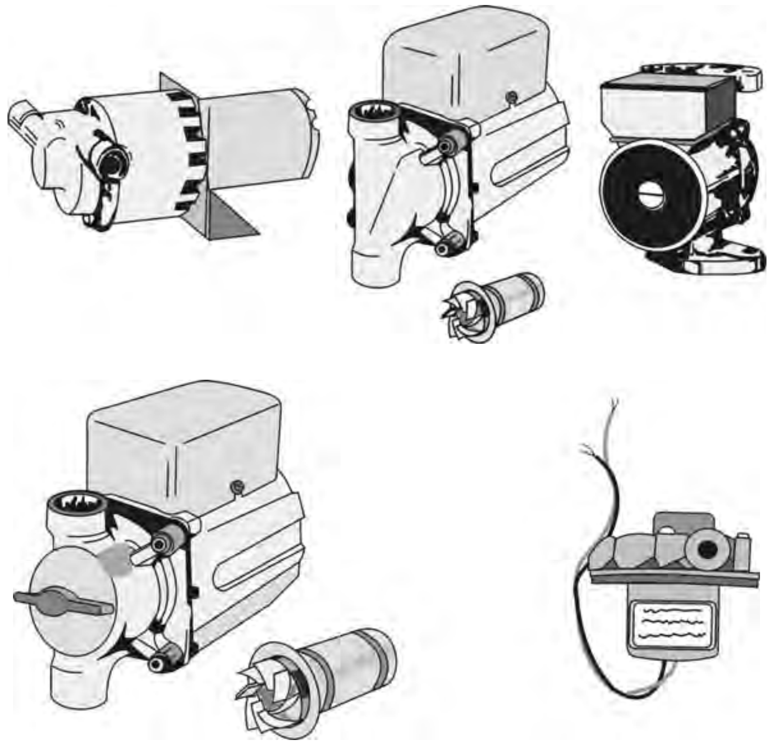
An active system uses a pump or circulator (Figure 8a) to move the heat transfer fluid from the storage tank to the collector. In pressurized systems, the system is full of fluid and a circulator is used to move hot water or heat transfer fluid from the collector to the tank. Pumps are sized to overcome static and head pressure requirements in order to meet specific system design and performance flow rates. (It is advisable to refer the pump manufacturer's pump curve to determine the proper pump size.)

Drain-back and other unpressurized solar water heating systems require a high head pump to lift the water from the storage vessel to the collector and force the air out of the collector or collector array. This requires a centrifugal pump or other pump that will provide adequate pressure.

Most active solar systems use centrifugal pumps. Pump selection depends on the following factors:

- System type (direct or indirect)
- Heat collection fluid
- Operating temperatures
- Required fluid flow rates
- Head or vertical lift requirements
- Friction losses

The most common pump (circulator) used in solar systems is the “wet rotor” type in which the moving part of the pump, the rotor, is surrounded by liquid. The liquid acts as a lubricant during pump operation, negating the need for manual lubrication.



AC Pump DC Pump

Figure 10 Pumps used in solar water heating systems

Pumps used on active direct systems must have bronze or stainless steel housings and impellers to prevent corrosion from water chemistry. Simply put, using cast iron pumps in systems in which the potable water comes into contact with the pump will cause the cast iron to rust. Cast iron pumps can be used with certain heat transfer fluids used in indirect systems. Table 1 lists pump options for various applications.

Application	Pump type and size
Potable water, pressurized, direct active system	Bronze or stainless steel, low head
Potable water, pressurized, direct active drain-down system	Bronze or stainless steel, low to medium head
Potable fluids, unpressurized, drain-back	Bronze or stainless steel, low to high head
Glycol fluids, pressurized	Cast iron, low head
Glycol fluids, unpressurized	Cast iron, medium to high head

Table 1 Pump Applications

PIPING

Piping provides the path for fluid transport in the system. The piping must be compatible with system temperatures, pressures and other components. Most systems use copper piping because of its durability, resistance to corrosion and ability to withstand very high temperatures. Type L, K or M is commonly used, depending on the application, local codes and traditions.

Copper, brass, and bronze are normally the only materials that should be used in active direct solar systems using potable water. In cases where galvanized piping already exists, it should either be replaced, or dielectric unions should be used to isolate the different metals.

Pipe hangers

When installing-long system piping runs, pipe hangers are commonly used for support. The piping, depending on the type, may be pliable due to high temperatures and therefore, must be supported.

Since the slope of the piping must be maintained for proper operation and drainage of many systems, pipe hangers are also required to properly orient the pipe runs.

Solder

Solder used in system piping is normally 95/5 tin/antimony or 95/4 tin/silver, depending on the material to be soldered. Leaded solder should not be used in potable water system piping.

Incompatible materials

Corrosion caused by the contact between dissimilar metals is called galvanic corrosion. Such corrosion usually results in an accelerated rate of attack on only one of several dissimilar metals. In the language of the corrosion expert, the protected material – the one that remains virtually unattacked – is called the cathode. The material that is attacked is called the anode.

Metals can be listed in a galvanic series that is useful in predicting which metals are acceptable for use in contact with one another and which materials are likely to be corroded. The following is a simplified galvanic table that can be used as a reference source.

CORRODED END - ANODIC
Magnesium
Zinc, Galvanized Steel
Aluminum
Mild Steel, Cast Iron
Lead, Tin
*Brass, Copper, Bronze
*Nickel-Silver, Copper-Nickel Alloys
*Monel
Stainless Steel
PROTECTED END - CATHODIC

The coupling of two metals from different groups will result in accelerated corrosion of the metal higher in the series. The farther apart the metals are in the series, the greater the galvanic corrosion tendency. Material groups marked with an asterisk (*) have no strong tendency to produce galvanic action and from a practical standpoint are safe to use in contact with one another.

Pipe insulation

The most common type of pipe insulation used in solar systems is the closed cell flexible elastomeric foam type (rubber), commonly marketed as Rubatex and Armaflex (Figure 11). Plastic insulation such as polystyrene or polyethylene should never be used due to their low operating temperatures (Figure 12). All exterior piping insulation must be protected from environmental and ultraviolet ray degradation by using special ultraviolet ray resistant coatings, paints or shielded wraps.

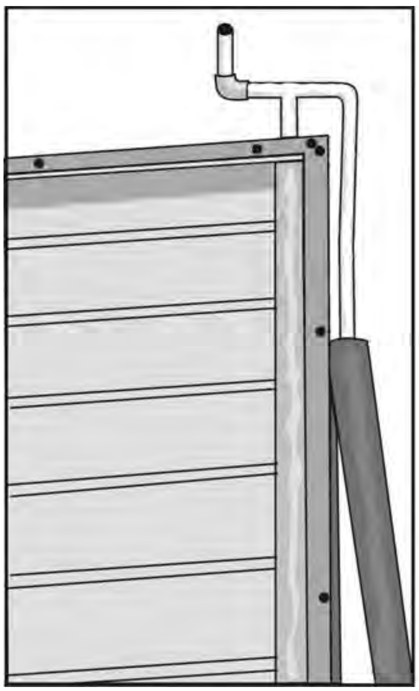


Figure 11 Rubber insulation being installed

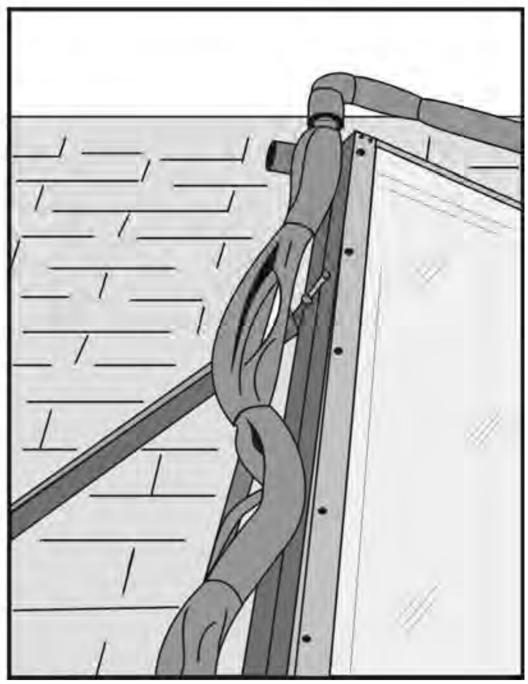


Figure 12 Plastic insulation should not be used in high temperature or external applications

CONTROLLERS

In active solar water-heating systems, the controller acts as the “brains” of the system. When the controller determines that sufficient solar energy is available at the collector, it activates the pump to circulate water to the collector and back to the storage tank. The most frequently used types of controllers include differential, photovoltaic and timer.

Differential controller

Differential controllers (Figure 13) work in conjunction with two sensors (Figure 14) – one at or near the hottest point of the collector and another near the bottom of the storage tank. When the temperatures measured by the two sensors reach a preset difference of 5 to 20^{o}F, the controller starts the pump. On many controllers, the installer has the added option of selecting the differential setting. For instance, the installer can set the differential at 9, 12, 15 or 20^{o}F depending on the characteristics of the system. For systems with long pipe runs, it is suggested that higher temperature differentials be used, systems with short pipe runs can use smaller differentials.

When the temperature difference between the sensors falls to about 3 to 5^{o} F, the controller stops the pump. The off temperature differential is usually set at the factory and cannot be adjusted by the installer.

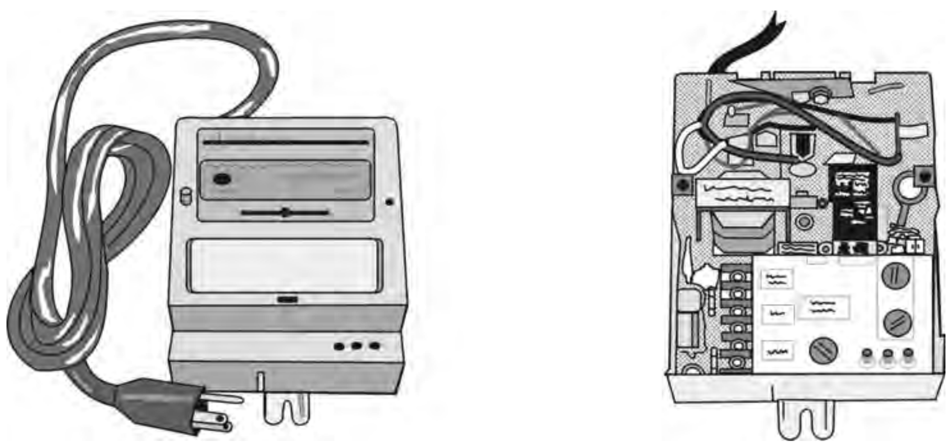


Figure 13 Differential controller

Differential controllers commonly have an on, off and auto position switch. In the on position, the sensor signals (and their interaction with the controller) are ignored and the controller operates the pump on a continuous basis. In the off position, the sensor signals are also ignored and the pump remains turned off. In the auto position, the sensors and controller interact to control the operation of the pump.

Many differential controllers also incorporate a freeze control to activate the pump during freezing conditions. A manual adjustment must be made by the installer to activate the freeze control option. Always check the manufacturers instructions when installing solar controllers. Installer selected features may be required to activate the controller functions designed into the unit.

Some differential controller models also incorporate high temperature limit settings that turn the pump off when a preset tank temperature has been reached. It is important to remember this is the temperature of the sensor at the bottom of the tank - the top of the tank may be even hotter.

Sensors

The sensors used with differential controllers are thermal resistors that change their electrical resistance with temperatures. They are commonly called thermistors. Understanding the relationship in a thermistor between electrical resistance and temperature is quite simple. It works in reverse. When the sensor's temperature increases, its resistance goes down. When its temperature decreases, its resistance increases.

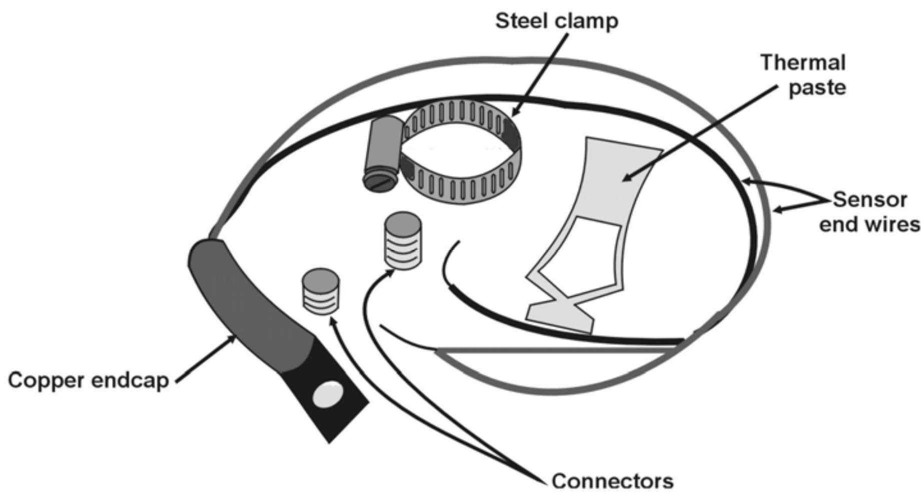


Figure 14 Sensors

Thermistors come in both 10K and 3K-ohm types (K=1,000). At 77º F, a 10K thermistor should have a 10,000 ohms resistance, while a 3K should have a 3,000 ohms resistance. Currently, most controller manufacturer use 10K thermistors. A few manufacturers have used more accurate resistance temperature detectors (RTDs), but, since they are more expensive than standard thermistors, they are not frequently used.

Special care must be made to avoid installing sensor wiring near sharp edges or close to 110V or 220V wiring as this could adversely affect the performance of the sensors and controller due to electrical interference. In addition, exterior runs of sensor wiring should also be protected from environmental degradation.

Photovoltaic (PV) Controller

In this control scheme, a photovoltaic module (Figure 15) is installed adjacent to the solar thermal collector and generates direct current (DC) electricity to power a DC pump motor. Because the PV module generates electricity only when the sun shines, the pump circulates water to the collector only when sufficient solar energy is available. To maximize solar collection, some systems also incorporate a pump activator (linear booster) that electronically assists pump start-up.

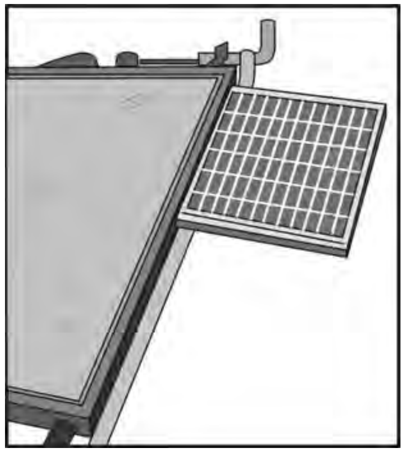


Figure 15 Photovoltaic module

The use of a photovoltaic controller offers increased heat collection efficiency, as the pump speed is proportional to the amount of power generated by the PV module. When more heat energy is available in the thermal collector due to increased solar radiation, the module also receives more solar radiation, which increases the pump speed sending more heat collecting fluid through the collector.

Timer Controller

A timer controller (Figure 16) turns the pump on only during the brightest portion of the day (from approximately 9 a.m. to 4:30 p.m.). To keep the system from losing energy in cloudy weather, the collector feed and return lines for timer-controlled systems are usually positioned at the bottom of the solar tank. Since both the feed and return lines are connected through a special valve installed in the tank's common drain port, special care must be taken to ensure the valve's feed and return ports do not accumulate a large amount of sediment and scale build-up which could eventually affect system performance. Routine maintenance of the feed and return valve should be observed.

Figure 16 Timer

HEAT EXCHANGERS

Indirect systems have heat exchangers that transfer the energy collected in the heat-transfer fluid from the solar collector to the potable water. Heat exchangers can be either internal or external to the storage tank. Common heat exchanger designs are the tube-in-tube, shell-in-tube, coil-in-tank, wraparound-tube, wraparound-plate and side-arm designs. A technical discussion of the design and performance of these heat exchangers follows.

Tube in tube

This type of heat exchanger, as its name implies, consists of a tube within a tube (Figure 17). Heat transfer occurs when one fluid moves through the inner tube while a second fluid moves in a different direction through the space between the inner and outer tubes. These heat exchangers are most commonly used in smaller systems. For example, in an indirect system using a tube in tube heat exchanger, the collector heat-transfer solution would be in the inner tube, while the potable water would be in the space between the inner tub and the outer tube. The heat gained at the collector by the heat-transfer fluid would be transferred to the potable water passing over the inner tube.

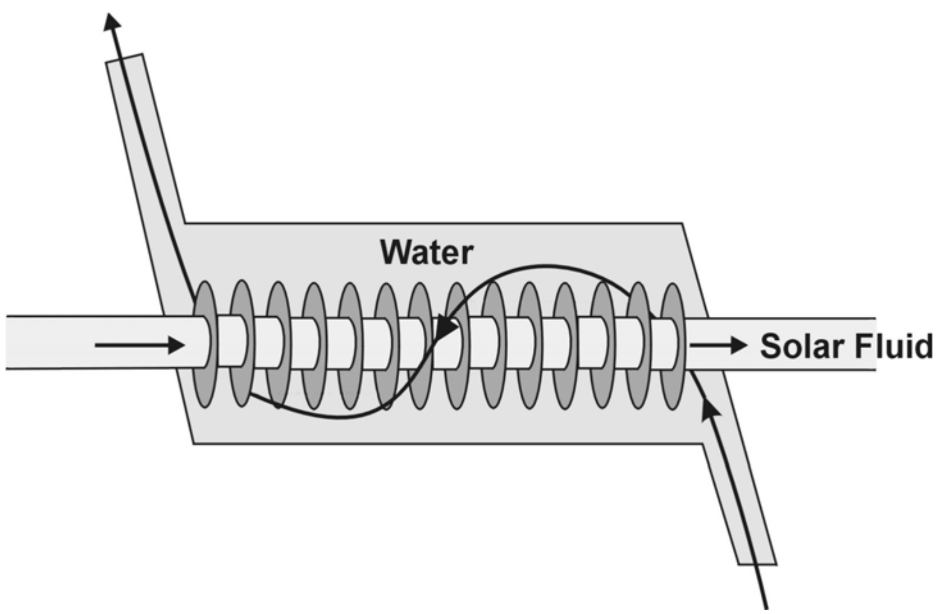


Figure 17 Tube-in-tube heat exchanger

Shell in tube

Similar to the tube-in-tube is the shell-in-tube heat exchanger (Figure 18) in which potable water flows through multiple tubes while the collector loop heat-transfer fluid passes over the tubes through the shell. This type of heat exchanger is used in numerous other technologies and available in single- or double-wall configurations.

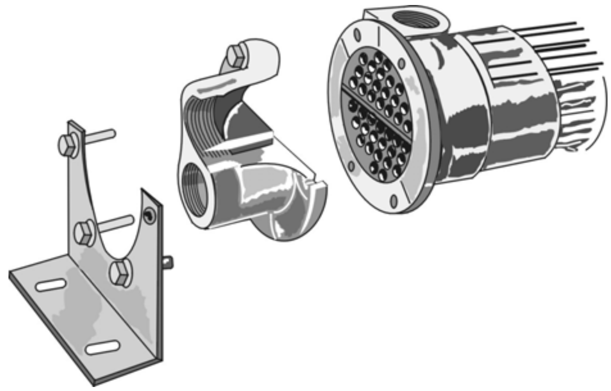


Figure 18 Shell-in-tube heat exchanger

The coil-in-tank heat exchanger (Figure 19) is immersed in the lower section of the storage tank. The wraparound-tube (Figure 20) heat exchanger uses tubes welded to the outside of the water vessel. It is located on the lower half of the storage tank. The wraparound-plate design (double jacket) is similar to the wraparound-tube but it uses a separate plate welded around the lower half of the storage tank.

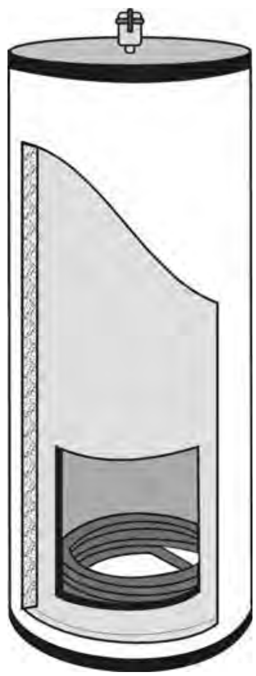


Figure 19 Coil-in-tank type heat exchanger

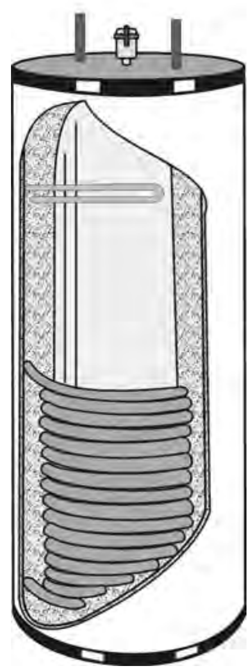


Figure 20 Wraparound type heat exchanger

A side-arm heat exchanger is a tube–in-shell design that can be installed on the side of the storage tank to allow thermosiphoning of the water from the storage tank through the heat exchanger. The heat transfer fluid in the solar loop side of the heat exchanger heats the water in the shell side of the heat exchanger and heat exchange initiates the thermosiphon action between the water storage (potable) and the heat exchanger.

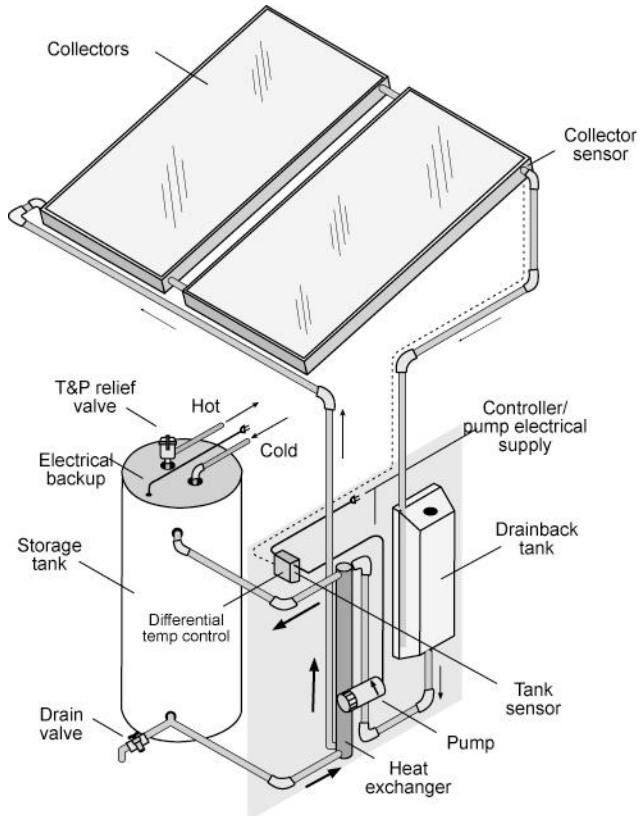


Figure 21 Side-arm heat exchanger

Single and double-wall heat exchangers

Heat exchangers may have one or two walls (Figure 22). Double-wall heat exchangers have two walls that separate the heat-transfer fluid from the potable water. Double-wall heat exchangers often incorporate small passageways between the two walls to provide leak detection. An area between the two walls allows leaking fluid to pass outside, thereby revealing any leaks. In the event a leak occurs, system owners or service personnel can visually see the fluid flowing out from these passageways.

Whether a single- or double-walled exchanger is used depends on the heat-transfer fluid used in the system. Nontoxic fluids such as propylene glycol can be used with a single-walled heat exchanger. But ethylene glycol, a toxic fluid, should be used only with a double-walled heat exchanger.

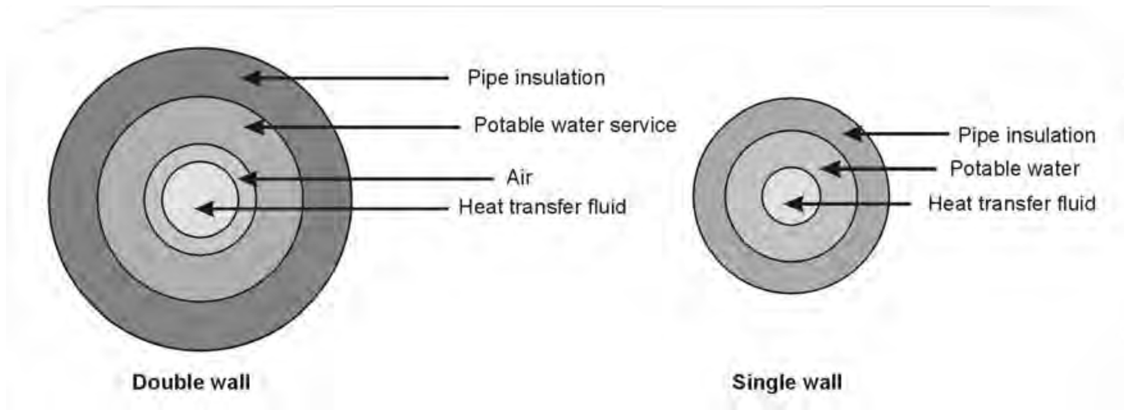


Figure 22 Single- and double-wall heat exchangers

Heat exchanger materials

Heat exchanger materials must be compatible with the system's fluid and piping. These materials can be steel, aluminum, bronze, stainless steel or cast iron, but copper is by far the most common. Copper prevents corrosion and also acts as a good thermal conductor. Alloys of copper and nickel may also be used for aggressive or hard water areas.

Heat exchanger efficiency

Systems with heat exchangers can experience a 10-20 percent loss in total efficiency in the transfer of heat from the collection loop to the stored water. However, economic savings and fail-safe freeze protection may offset that efficiency loss.

For example, heat exchange systems can use corrosion-inhibiting heat-transfer fluids that allow the use of less-expensive aluminum or steel in collectors, exchangers and piping. If aluminum is used anywhere in the system, no red metal (copper, brass or similar alloys) should be used unless the heat-transfer fluid is non-ionic or an ion trap is placed upstream of each aluminum component to reduce galvanic corrosion. Ion traps require periodic servicing.

Heat exchanger sizing

Heat exchangers are sized based on their heat-transfer capabilities, flow rates and the temperatures of incoming and outgoing fluids. For packaged and approved or certified systems, the manufacturers have sized the heat exchanger and matched its performance to the collector array and flow rates of the system. Under sizing the heat exchanger is a common mistake of home-built systems.

HEAT-TRANSFER FLUIDS

All solar systems use some types of heat-transfer fluid. Potable water is the heat-transfer fluid in active direct systems and is the most common. Indirect systems in cold climates use a non-potable solution that will freeze only at extremely low temperatures. The most common of these fluids are:

- Propylene glycol
- Ethylene glycol
- Hydrocarbon oils
- Synthetic oils such as silicone.

Some of these fluids are toxic (notably, ethylene glycol) and require double-wall heat exchangers.

Glycols are the most commonly used heat-transfer solutions for indirect systems. Special inhibitors are added to the glycol during the manufacturing process to prevent the fluid from becoming corrosive. Thus glycol fluids must be checked periodically (follow manufacturers instructions) to ensure they remain chemically stable. PH tests of the glycol can be conducted using either pH test strips or standard pH testing color charts.

When using glycol, materials, such as gaskets and seals used in the various system parts (pumps, valves, expansion tank, etc.), must be compatible. Glycol compatible materials include Teflon, Viton and EPDM. The use of certified systems will assure that all system components and materials are compatible.

In some cases, the glycol is mixed or diluted with distilled or demineralized water during the system charging process. As always, follow the manufacturer's recommendations. Some heat transfer fluids should not be diluted since dilution can change the level of freeze protection.

Synthetic and silicon oils have unique characteristics. Both have long lifetimes and require little maintenance. Their toxicity is also low. Nevertheless, the lower thermal conductivity and viscosity of these oils increase pump and heat exchanger requirements. As in the case of glycol, one must pay special attention to component material selection and their compatibility with the specific oils. The surface tension of the oils is very low so sometimes leaks can be a recurring problem. Special care must be taken to avoid mixing any water with the oils.

EXPANSION TANK

Most indirect systems that use a heat-transfer fluid other than water also incorporate an expansion tank (Figure 23). As the heat-transfer fluid temperature rises, it expands. The expansion tank provides room for this change in volume. Inside the expansion tank, a flexible bladder maintains a constant pressure on the fluid while allowing it to expand and contract as it heats and cools. The expansion tank prevents damage from over-pressurization and eliminates the potential creation of a vacuum inside the collector loop.

Expansion tanks are normally pre-charged by the manufacturer to a set psi. The system pressure-relief devices provide overpressure protection. The size of the expansion tank depends on the volume of fluid in the system and the rate of fluid expansion at higher temperatures. The higher the temperature the more the fluid expands. The size of the expansion tank must allow for the total potential expansion of the fluid or elevated pressures will be experienced causing the pressure relief valve to open and result in complete pressure loss in the solar loop. Some solar systems have an expansion tank on the cold water supply line when a check valve or back-flow prevention device is on the cold-water line.

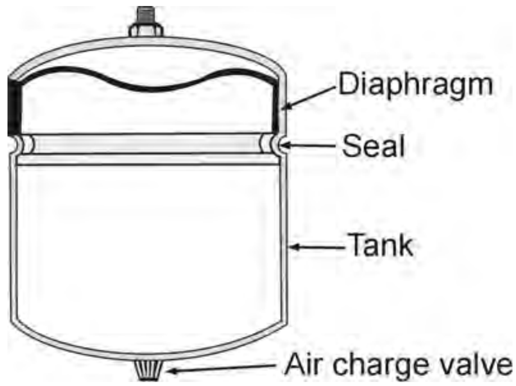


Figure 23 Expansion tank

VALVES, GAUGES AND METERS USED IN SOLAR SYSTEMS

As indicated in Figure 24, a variety of valves, gauges and meters can be incorporated as part of a solar system's design. These components serve to:

- Expel and vent air from the system (air vents)
- Safely limit excessive temperatures and pressures (pressure relief and temperature-pressure relief valves)
- Prevent vacuum locks during drainage (vacuum breakers)
- Isolate parts of the system (isolation valves)
- Prevent thermosiphon heat losses and maintain flow direction (check valves – mechanical and motorized)
- Provide freeze protection (freeze-prevention valve)
- Monitor the system (pressure gauges, temperature gauges and flow meters).

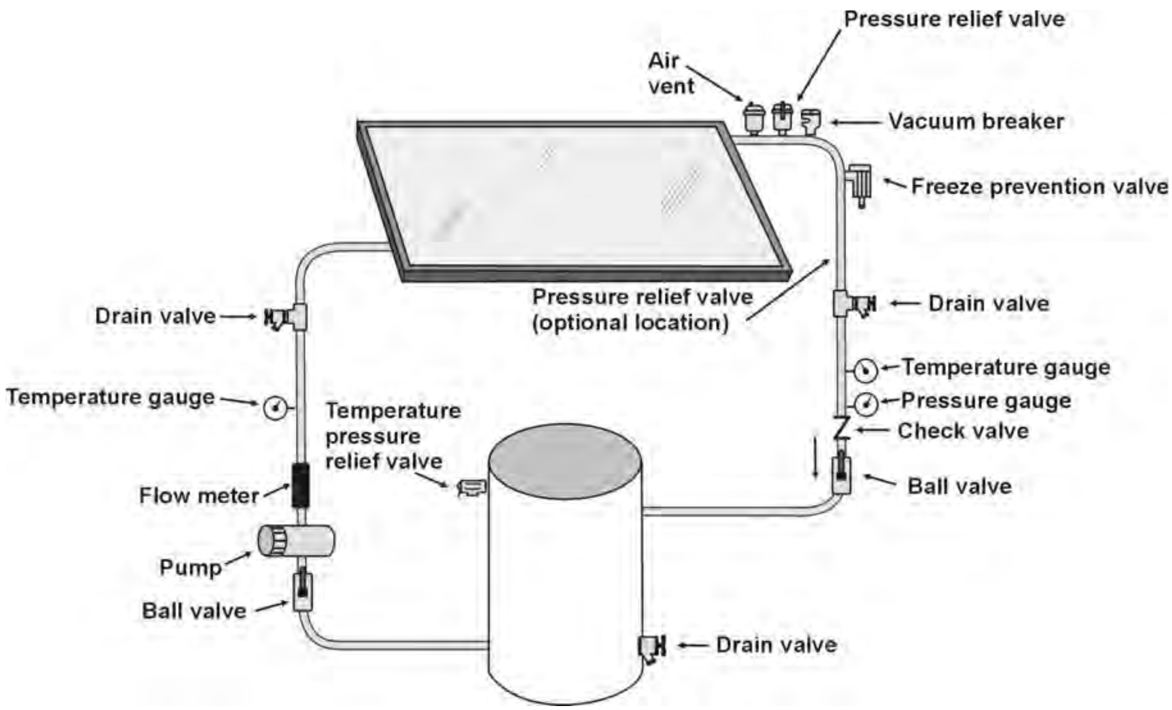


Figure 24 Solar water heating system valves and monitoring equipment

AIR VENT

This valve (Figure 25) allows air that has entered the system to escape, and in turn prevents air locks that would restrict flow of the heat-transfer fluid. An air vent must be positioned vertically and is usually installed at the uppermost part of the system. In active direct systems supplied by pressurized water, an air vent should be installed anywhere air could be trapped in pipes or collectors. Indirect systems that use glycol as the heat-transfer fluid use air vents to remove any dissolved air left in the system after it has been pressurized or charged with the heat-transfer fluid. (Once the air has been purged in these indirect systems, the air vent mechanism is manually closed.)

A popular option to using a separate air vent and vacuum breaker, when both are required, is a combination air vent and vacuum breaker valve.

Manual air vents should be used in indirect systems to avoid any loss of heat-transfer fluid, which would affect the system's pressurization. Using a manual air vent that the installer opens during charging to relieve trapped air in the loop will not only vent trapped air, but once the air has been expelled and the installer then closes the vent, it will in turn prevent any additional venting from the system. If an automatic, instead of manual air vent is used, the dissolved air bubbles that had accumulated during the charging process will eventually vent through the automatic air vent causing the system loop to lose pressure. Some automatic air vents have a dust cap that can be closed to prevent additional venting or loss of pressure.

Figure 25 Air vent

TEMPERATURE-PRESSURE RELIEF VALVE

A temperature-pressure relief valve is also called a pressure-temperature relief valve or P&T valve or T&P valve. These names are used interchangeably in the industry. This valve (Figure 26) protects system components from excessive pressures and temperatures. A pressure-temperature relief valve is always plumbed to the solar storage (as well as auxiliary) tank. In thermosiphon and ICS systems, where the solar tanks are located on a roof, these tanks may also be equipped with a temperature-pressure relief valve since they are in some jurisdictions considered storage vessels. These valves are usually set by the manufacturer at 150 psi and 210° F. Since temperature pressure relief valves open at temperatures below typical collector loop operating conditions, they are not commonly installed in collector loops. (See pressure relief valves below.) Temperature-pressure relief valves located inside a building must drain to the outside. If uncertain, follow local code requirements.

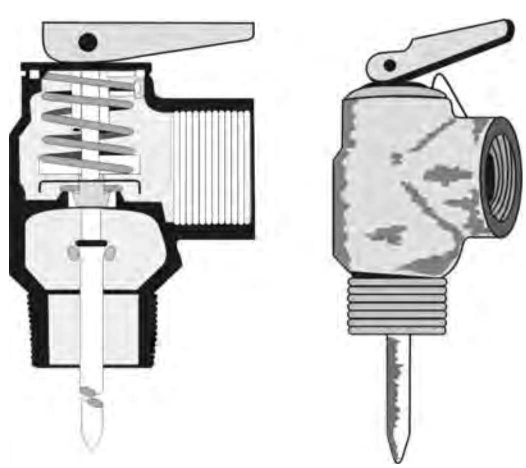


Figure 26 Pressure-temperature relief valve

PRESSURE RELIEF VALVE

A pressure relief valve (Figure 27) protects components from excessive pressures that may build up in system plumbing. In any system where the collector loop can be isolated from the storage tank, a pressure relief valve must be installed on the collector loop. The pressure rating of the valve (typically 125 psi) must be lower than the pressure rating of all other system components, which it is installed to protect.

The pressure relief valve is usually installed at the collector. Because it opens only with high pressure, it operates less frequently than does a temperature-pressure relief valve. For this reason, it offers a higher degree of reliability and is the valve of choice for protecting the solar collector. Indirect systems typically use pressure-relief valves with even lower psi settings. Pressure relief valves located inside a building should be piped to discharge to a safe location.

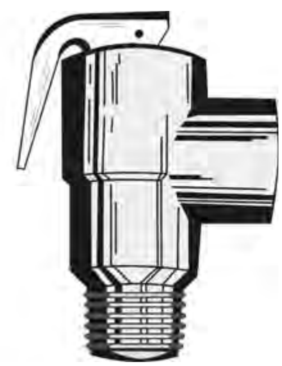


Figure 27 Pressure relief valve

PRESSURE GAUGE

A pressure gauge (Figure 28) is used in indirect systems to monitor pressure within the fluid loop. In both direct and indirect systems, such gauges can readily indicate if a leak has occurred in the system plumbing.

Figure 28 Pressure gauge

VACUUM BREAKER

A vacuum breaker (Figure 29) admits atmospheric pressure into system piping, which allows the system to drain. This valve is usually located at the collector outlet plumbing but also may be installed anywhere on the collector return line. The vacuum breaker ensures proper drainage of the collector loop plumbing when it is either manually or automatically drained. A valve that incorporates both air vent and vacuum breaker capabilities is also available.

Figure 29 Vacuum breaker

ISOLATION VALVES

These valves are used to manually isolate various subsystems. Their primary use is to isolate the collectors or other components before servicing. Two common types of isolation valves are ball valves (Figure 30) and gate valves (Figure 31).

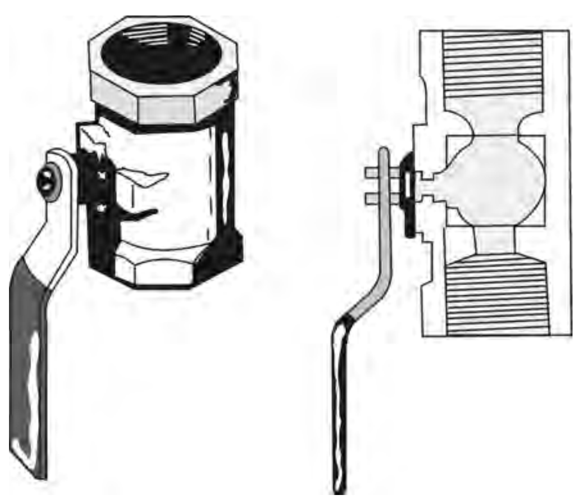


Figure 30 Ball valve

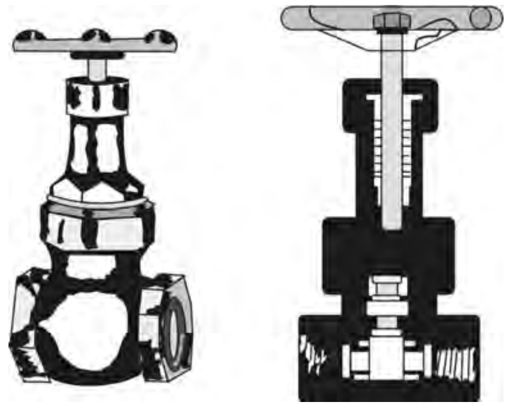


Figure 31 Gate valve

Ball valves provide a complete flow barrier and are less likely than gate valves to leak, corrode or stick. Ball valves may also be used as flow balancing valves in multiple collector arrays. Three-way ball valves may be used for both isolation and draining at the collector loop. An isolation valve is also required in the cold-water service line in the event water flow to the storage tank and system must be stopped.

DRAIN VALVES

These valves (Figure 32) are used to drain the collector loop, the storage tank and, in some systems, the heat exchanger or drain-back reservoir. In indirect systems, they are also used as fill valves. The most common drain valve is the standard boiler drain or hose bib.

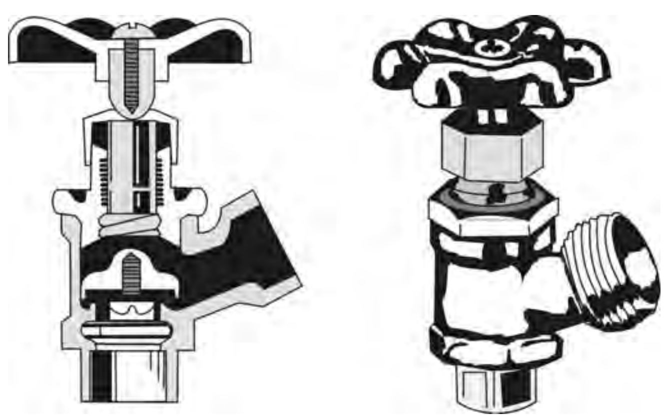


Figure 32 Drain valve

CHECK VALVES

Check valves allow fluid to flow in only one direction. In solar systems, these valves prevent thermosiphoning action in the system plumbing. Without a check valve, water that cools in the elevated (roof-mounted) collector at night will fall by gravity to the storage tank, displacing lighter, warmer water out of the storage tank and up to the collector. Once begun, this thermosiphoning action can continue all night, continuously cooling all the water in the tank. In many cases, it may lead to the activation of the back-up-heating element, thereby causing the system to lose even more energy.

The various types of check valves include motorized, vertical and horizontal swing. A motorized check valve (Figure 33) is wired to the pump. When the pump is on, the valve opens; when the pump is off, the valve closes and forms a positive seal.

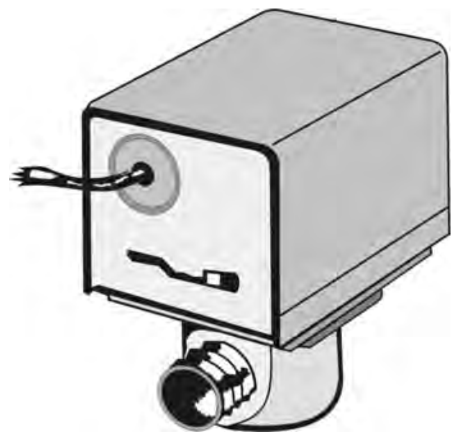


Figure 33 Motorized check valve

Vertical check valves (Figure 34) must open easily with activation of the low-flow, low-head PV-powered pumps used in some solar systems. The seat of these valves should resist scale and high temperatures.

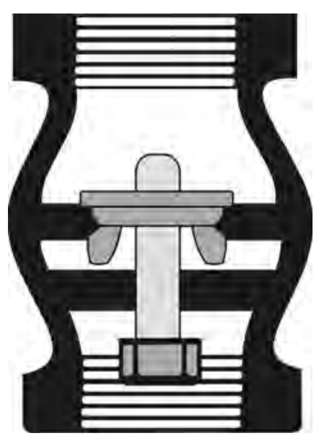


Figure 34 Vertical check valve

Horizontal swing check valves (Figure 35) must be installed horizontally because gravity and the flapper's weight close the valve.

Corrosion and scale may build up on the internal components of any (motorized, vertical or horizontal) check valve; therefore, a regular service schedule should be maintained. The chemical makeup of the local water supply is a major determinant in how scale build-up affects system components.

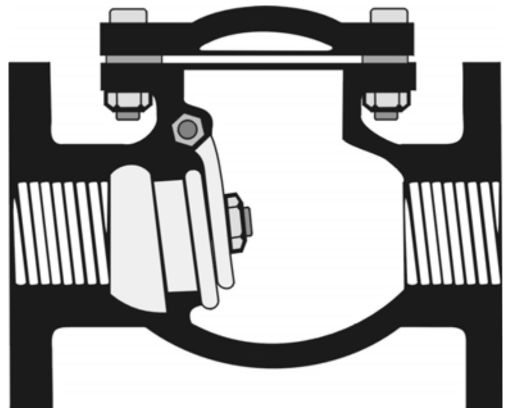


Figure 35 Horizontal swing check valve

MIXING OR TEMPERING VALVE

This valve will mix cold water with the hottest water from the storage tank, delivering water at a preset temperature. Such a valve increases the total amount of hot water available. The intended use of this valve is to conserve hot water – not as a safety device (Figure 36).

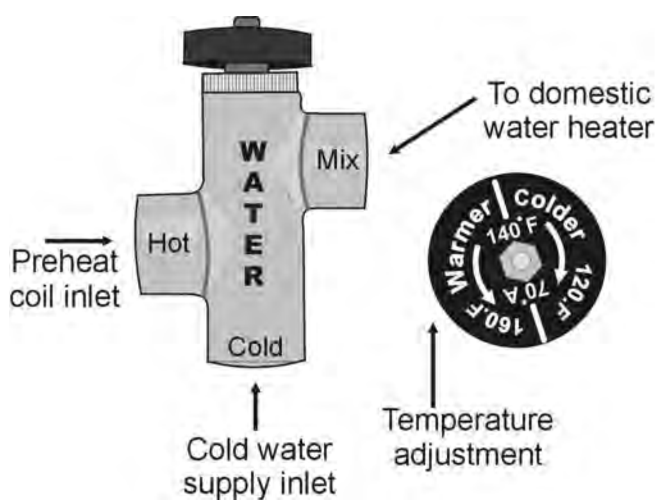


Figure 36 Tempering valve

ANTI-SCALD VALVE

An anti-scald valve (Figure 37) also mixes cooler water with hot water to deliver water at a preset temperature. However, unlike a mixing valve, an anti-scald valve also functions as a safety device, closing off the flow into the house if the hot or cold mixing supply fails.

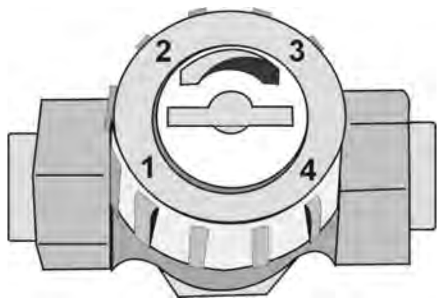


Figure 37 Anti-scald valve

FREEZE-PROTECTION VALVES

Freeze-protection valves (Figure 38), are set to open at near freezing temperatures, and are installed on the collector return line in a location close to where the line penetrates the roof. Warm water bleeds through the collector and out this valve to protect the collector and pipes from freezing. A spring-loaded thermostat or a bimetallic switch may control the valve. Figure 39 shows where a freeze-protection valve is typically located on a solar system.

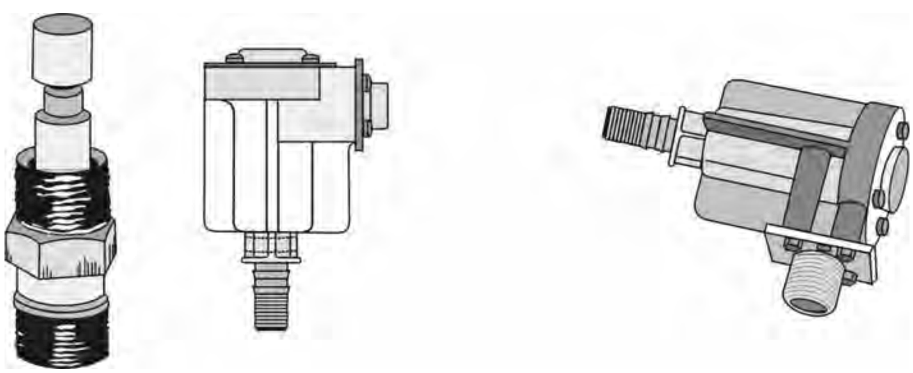


Figure 38 Freeze-protection valves

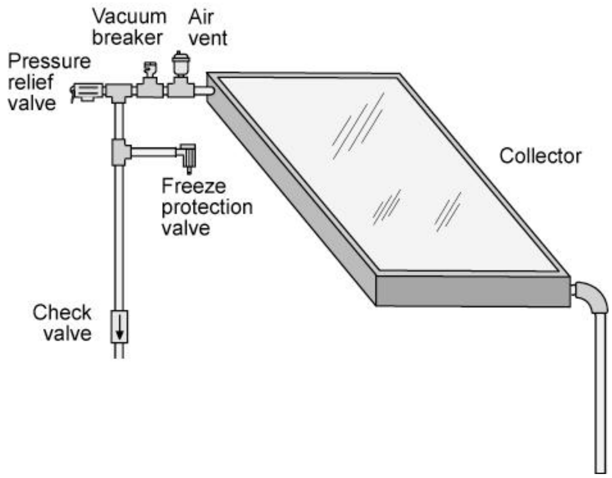


Figure 39 Location for freeze-protection valves

A check valve must be used in all systems with freeze-protection valves. This check valve prevents tank water from going straight from the tank to the freeze valve, thus bypassing flow through the collector.

If these valves are installed on well water or cistern systems, low-pressure valves should also be installed, which enable freeze protection to function when power outages create low pressures.

OTHER COMPONENTS

The following components are not as crucial to system operation as the previously listed valves, but they do provide the homeowner and service technician with important information.

TEMPERATURE GAUGES

These gauges (Figure 40) provide an indication of system fluid temperatures. A temperature gauge at the top of the storage tank indicates the temperature of the hottest water available for use. Temperature wells installed at several points in the system will allow the use of a single gauge in evaluating system operation.

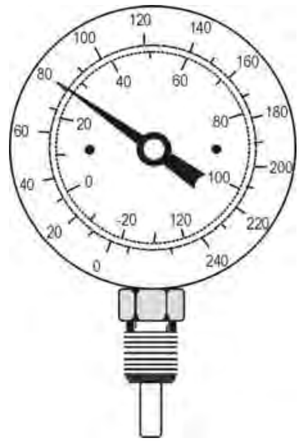


Figure 40 Temperature gauge

FLOW METERS

Flow meters (Figure 41) enable the owner and service person to determine if the pump is operating and, if so, at what flow rate. The flow meter is usually located in the collector feed line above the pump to protect the meter from extreme temperatures.

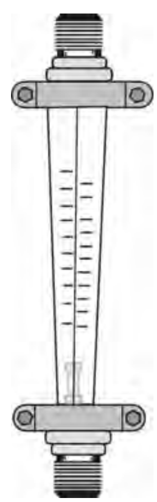


Figure 41 Flow meter

WATER SUPPLY

While not necessarily a component of a solar water heating system, the method for cold water supply to the system can influence both system selection and operation. Most solar water heating systems must operate under pressure. Pressure is supplied though the service water entering from the municipality, a pressure pump on the water system of the building (well, cistern), or pressurized by an elevated cold-water supply tank mounted above the solar system.

Section 3: Solar Water Heating System Installation covers the steps involved in installing a solar water heating system.

- **Module: Collector Mounting** describes methods for properly placing and installing solar collectors.
- **Module: Component Installation,** provides guidelines for the proper and safe placement and connection of the remainder of solar system components.
- **Module: System Installation Checkout and Start-Up** presents start-up and checkout procedures for systems being installed.

Section 3
Module: Collector Mounting

Introduction

This chapter addresses where and how to mount flat-plate collectors that are most often used in solar water heating systems.

Collector Positioning

Flat-plate collectors for solar water heating are generally mounted on a building or the ground in a fixed position at prescribed angles. The angle will vary according to geographic location, collector type and use of the absorbed heat.

Since residential hot water demand is generally greater in the winter than in the summer, the collector ideally should be positioned to maximize wintertime energy collection, receiving sunshine during the middle six to eight daylight hours of each day. Minimize shading from other buildings, trees or other collectors. Plan for lengthening winter shadows, as the sun's path changes significantly with the seasons (Figure 1).

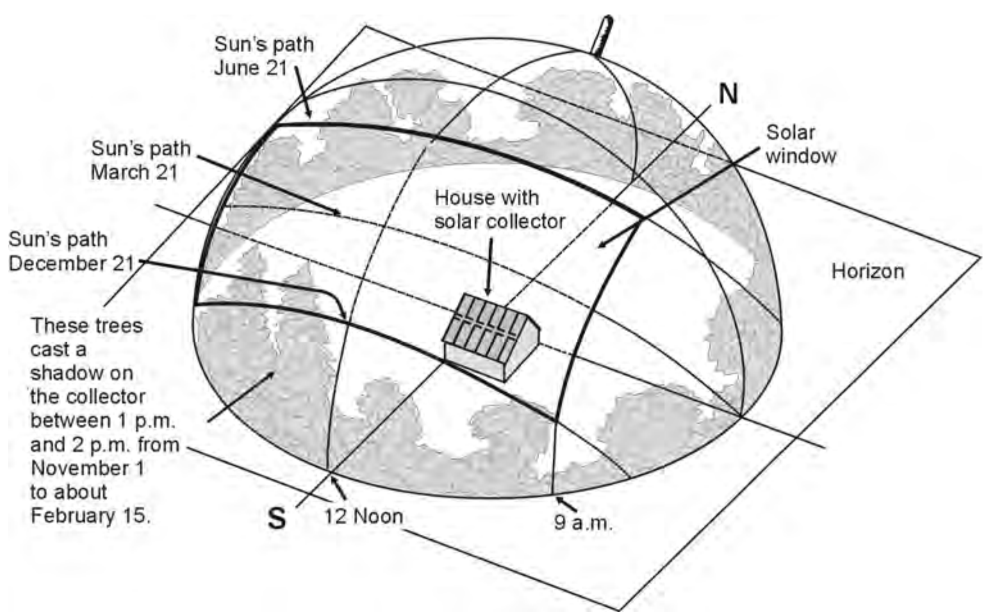


Figure 1 Solar window

Ideally, the collector should face directly south in the northern hemisphere and directly north in the southern hemisphere. However, facing the collector within 30° to 45° either east or west of due south or north reduces performance by only about 10 percent. A compass may be used to determine true south or north. The closer to the equator, the less the need to maintain the orientation and direction of the collector, but be aware of the seasonal position of the sun in the sky and how it may affect the seasonal performance of the system.

The optimum tilt angle for the collector is about the same as the site's latitude plus or minus 15°. An inexpensive inclinometer will aid in determining tilt angles. If collectors will be mounted on a sloped roof, check the roof's inclination to determine whether the collectors should be mounted parallel to the roof or at a different tilt. In general, collectors should be mounted parallel to the plane of a sloped roof unless the performance penalty is more than 30 percent. The mounted collector should not detract from the appearance of the roof.

Total length of piping from collector to storage should not exceed 100 feet. The longer the pipe run, the greater the heat loss. If a greater length is necessary, an increase in piping diameter or pump size may be required.

If the collectors will be roof-mounted, they should not block drainage or keep the roof surface from properly shedding rain. Water should not gather or pool around roof penetrations. Roof curbs may be required.

Wind Loading

A mounted collector is exposed not only to sunlight and the rigors of ultraviolet light but also to wind forces. For example, in parts of the world that are vulnerable to hurricanes or extreme wind storms, the collector and its mounting structure need to be able to withstand intermittent wind loads up to 146 miles per hour (Figure 2). This corresponds to a pressure of about 75 pounds per square foot. Winds, and thermal contraction and expansion may cause improperly installed bolts and roof seals to loosen over time. As always, follow local code requirements for wind loading.

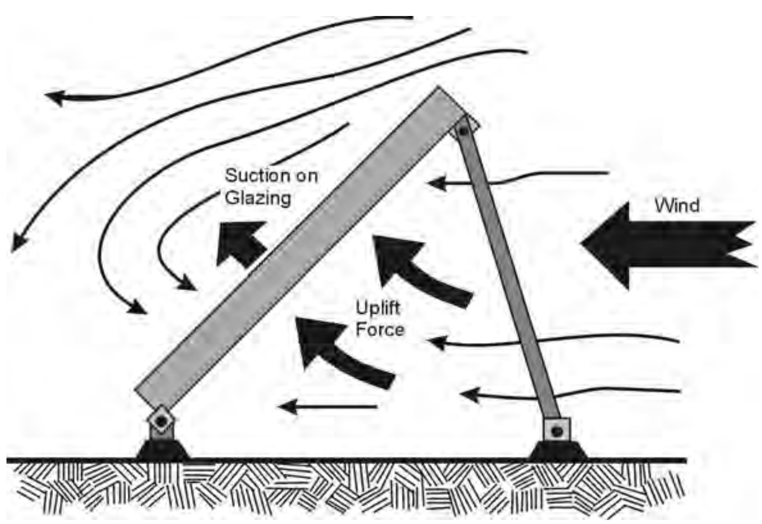


Figure 2 Conceptual drawing of wind loading

Do not mount collectors near the ridge of a roof or other places where the wind load may be unusually high. Figure 3 shows a desirable location for a roof-mounted collector. Mounting collectors parallel to the roof plane helps reduce wind loads and heat loss.

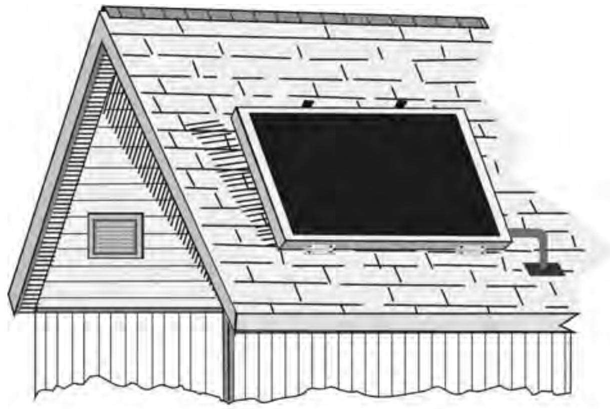


Figure 3 Collector mounted down from roof ridge to reduce wind loading and heat losses

Determining the actual wind-load effect on collector anchors and fasteners is difficult, and most collector suppliers employ professional engineers to approve collector-mounting details. This may be required by some local code jurisdictions.

Ground Mounting

In an alternative to roof mounting, the collector for a solar water heating system may be mounted at ground level. The lower edge of the collector should be at least one foot above the ground so it will not be obstructed by vegetation or soaked by standing water. Figure 4 depicts ground-mounting details.

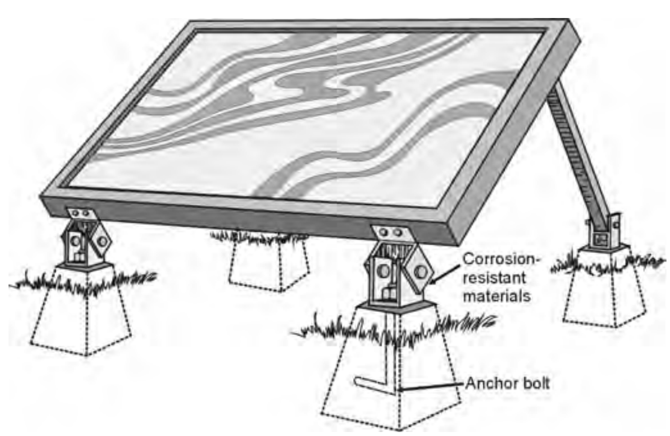


Figure 4 Ground mount

Important points to keep in mind when using ground mounting include:

1. Keep threads protected with masking tape when setting anchor bolts in concrete.

2. Avoid the use of dissimilar metals. If they must be used, isolate them with neoprene pads or silicone.

3. Coat threads with durable elastic material before tightening the nuts to prevent rusting.

4. When possible, use galvanized anchors, which are very durable. Before installing these bolts, check the threads – hot dip galvanizing sometimes puddles in the grooves.

Roof Mounted Collectors

There are four ways to mount flat-plate collectors on roofs:

1. Rack Mounting. This method is used on homes with flat roofs. Collectors are mounted at the prescribed angle on a structural frame (Figure 5). The structural connection between the collector and frame and between the frame and building, or site must be adequate to resist maximum potential wind loads.

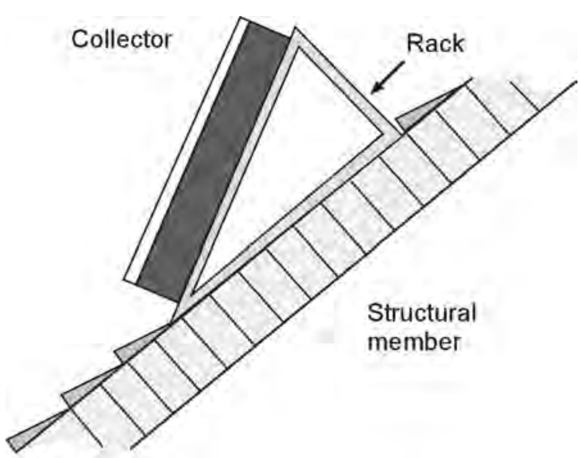


Figure 5 Rack-mounted collector

2. Standoff Mounting. Standoffs separate the collector from the finished roof surface; they allow air and rainwater to pass under the collector and minimize problems of mildew and water retention (Figure 6). Standoffs must have adequate structural properties. They are sometimes used to support collectors at slopes that differ from that of the roof angle. This is the most common mounting method used.

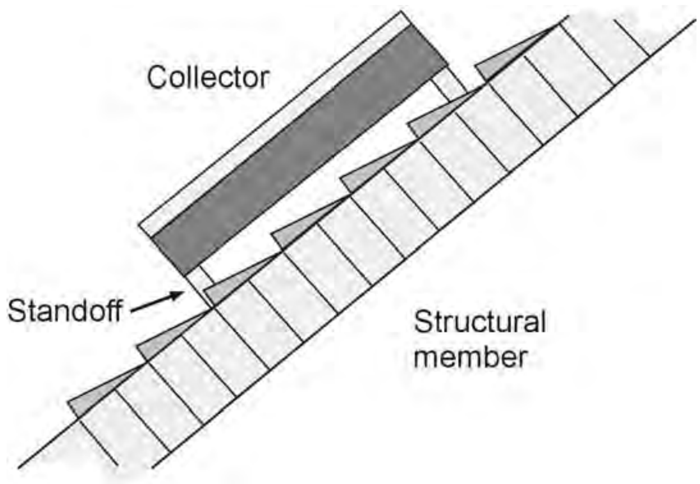


Figure 6 Standoff-mounted collector

3. Direct Mounting. Collectors can be mounted directly on the roof surface (Figure 7). Generally, they are placed on a waterproof membrane covering the roof sheathing. Then the finished roof surface, the collector's structural attachments, and waterproof flashing are built up around the collector. A weatherproof seal must be maintained between the collector and the roof to avoid leaks, mildew and rotting.

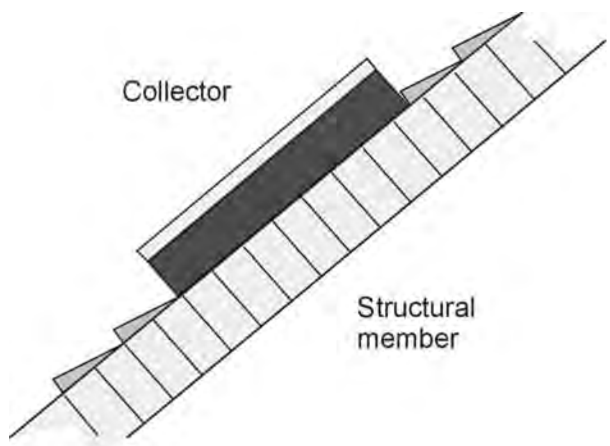


Figure 7 Direct- or flush-mounted collector

4. Integral Mounting. Integral mounting places the collector within the roof construction itself. The collector is attached to and supported by the structural framing members (Figure 8). The top of the collector serves as the finished roof surface. Weather tightness is crucial in avoiding water damage and mildew. Only collectors designed by the manufacturer to be integrated into the roof should be installed as the water/moisture barrier of buildings. The roofing materials and solar collectors expand and contract at different rates and have the potential for

leaks. A well sealed flashing material allows the expansion and contraction of the materials to maintain a water seal.

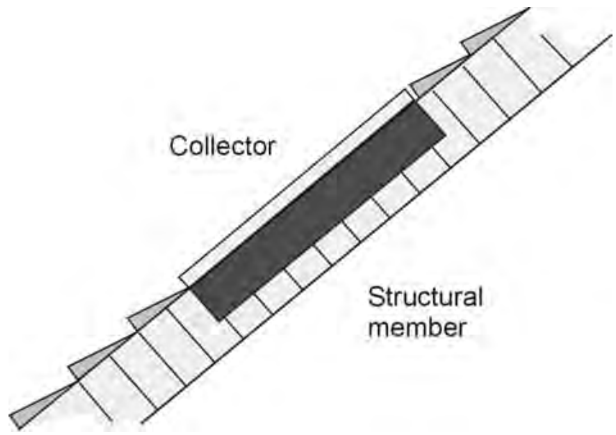


Figure 8 Integral-mounted collector

Roof Work Considerations

The most demanding aspects of installing roof-mounted collectors are the actual mounting and roof penetrations. Standards and codes are sometimes ambiguous about what can and cannot be done to a roof. Always follow accepted roofing practices, be familiar with local building codes, and communicate with the local building inspector. These are prime roof work considerations:

1. Perform the installation in a safe manner.

2. Take precautions to avoid (or minimize) damage to the roof area.

3. Position collectors for the maximum performance compatible with acceptable mounting practices.

4. Seal and flash pipe and sensor penetrations in accordance with good roofing practices. Use permanent sealants such as silicone, urethane or butyl rubber.

5. Locate collectors so they are accessible for needed maintenance.

Site Preparation

Roof-mounted collectors often are placed on supports or brackets. Preparation of the roof area and procedures for anchoring to the roof members must be done carefully to avoid causing leaks or weakening the roof. In a new home installation, much of the mounting work can be performed after the roof has been framed and sheathed, but before the waterproof membrane is applied.

The best position for a collector is over the roof rafters or trusses (Figure 9). Avoid placing it at the roof ridge and areas where the roof slope changes, as wind loading and heat loss are greater there.

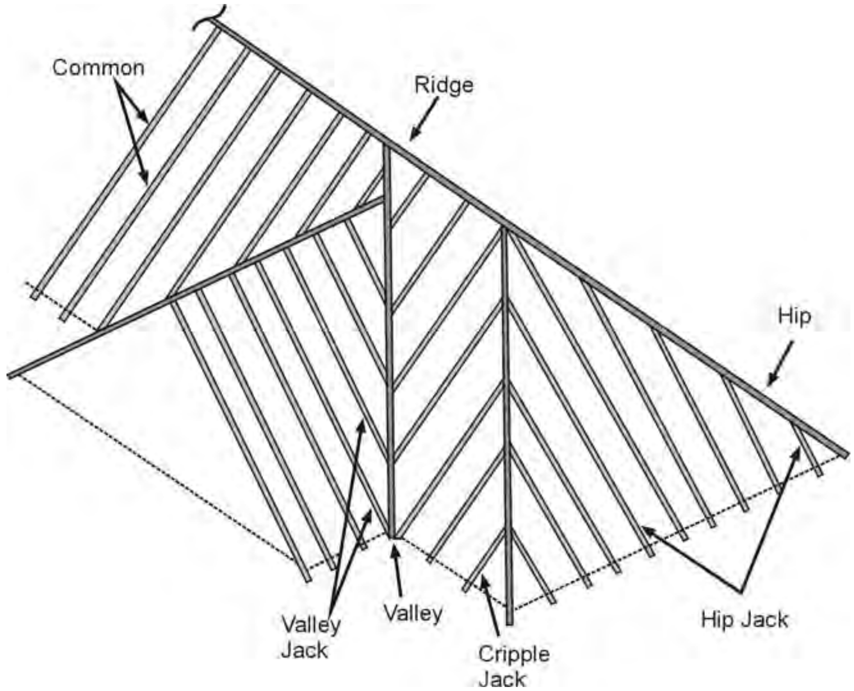


Figure 9 Roof structures

The collector or its supports should be anchored to the roof rafters or trusses, not the sheathing. Following are recommended procedures:

1. Choose an appropriate site for the collector.

2. Locate the specific rafters to be used for mounting.

3. Measure and mark the roof penetration points for the anchor bolts.

4. Prepare the roof surface and install proper flashing or other waterproofing devices.

5. Properly anchor the mounting brackets to the rafters.

6. Reseal the roof (retrofit) or complete the installation of the roof (new construction).

In retrofit situations, rafters or roof trusses may be located from inside an attic if the space is large enough to permit access. Very small galvanized nails may be driven up beside the rafter at the desired anchoring points; this locates the points for the workers on the roof, and roof preparation can begin.

If access to the attic is not adequate, trusses can be located by looking for nails in the fascia board. They indicate the location and spacing of the trusses. Locate the mounting points by measuring across the roof ridge and popping a chalk line between the ridge and the fascia along the run of the truss (Figure 10). The truss may not be perfectly straight, so the chalk line will be close to (but not precisely on) the truss run. Many installers use the variation in tone associated with external hammer blows to locate the run of the truss. A mechanical or digital truss finder can also be used to locate the position of the truss.

After the anchoring points have been selected, prepare the roof for penetration.

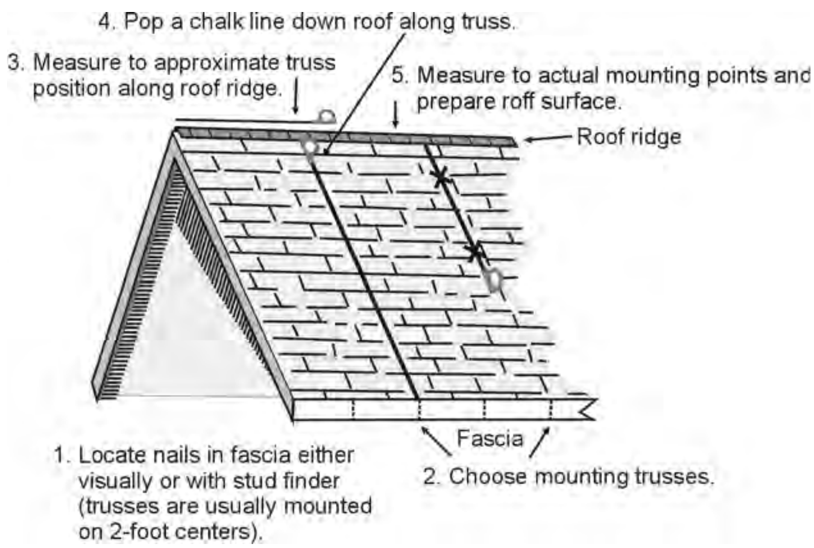


Figure 10 A method of locating mounting points

Roof Penetration

Modern roof finish materials cover a wide range. The most commonly used materials are asphalt or fiberglass shingles, clay or concrete tile, and tar and gravel.

Shingles are applied in an overlapping pattern, nailed, or stapled to the roof sheathing below. Old, brittle shingles may break underfoot. Use care until the condition of the shingles is ascertained. Brackets can be mounted directly over pliable shingles; no special preparation is necessary. Holes for the mounting bolts may be drilled through the shingles. The entire penetration must then be sealed.

Tile roofs require extensive preparation. When walking on these roofs, care must be taken not to break the tiles or slip on loose tiles. On barrel tiles, never walk on the crowns. Broken tiles must be replaced, increasing installation time and cost. Tiles in the area of the anchoring spots should be sawed out. Remove as few tiles as possible, because the area must be sealed later to protect the underlying watertight membrane. When the tiles are removed, the exposed waterproof membrane may be treated as if it were an asphalt shingle roof. The area where tile was removed may be filled with cement that is colored and molded to correspond to the undamaged roof configuration.

There are many ways to penetrate tile roofs. Most methods used to seal the tile will depend on the type, shape and base material of the tile. Cement, clay, ceramic rounded, or flat tiles may require different methods of attaching the collector to the structure and sealing the roof penetrations.

For example, installation methods can include penetrating the tile and attaching the mounting hardware to the roof truss assembly and flashing the riser as shown in Figure 11 or attaching the mounting hardware to the roof and using a flashing that allows installation of the tile around the mounting hardware.

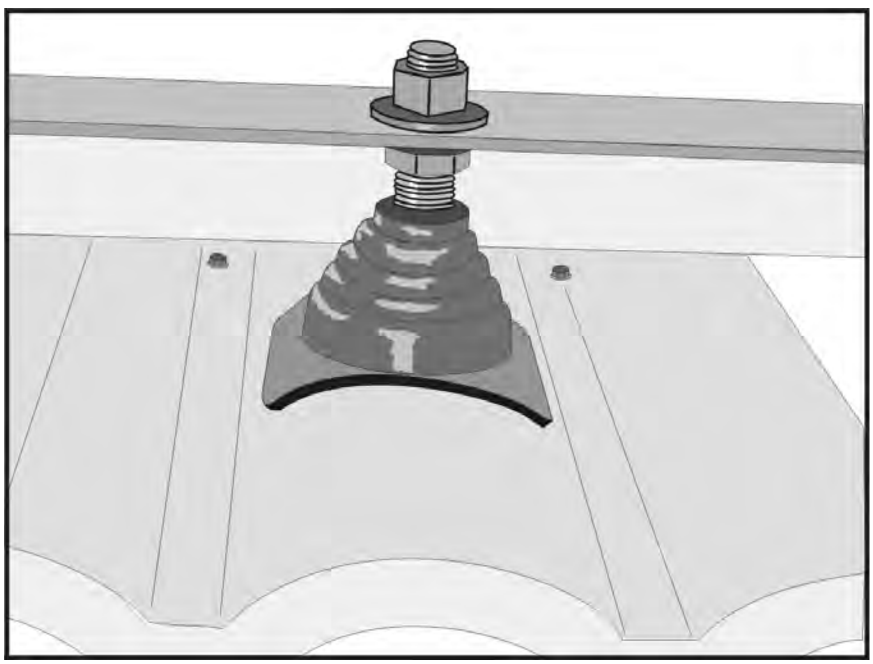


Figure 11 Tile roof mount

Or, the solar collectors may be supported above the tile on a rack or bracket as shown in Figure 12.

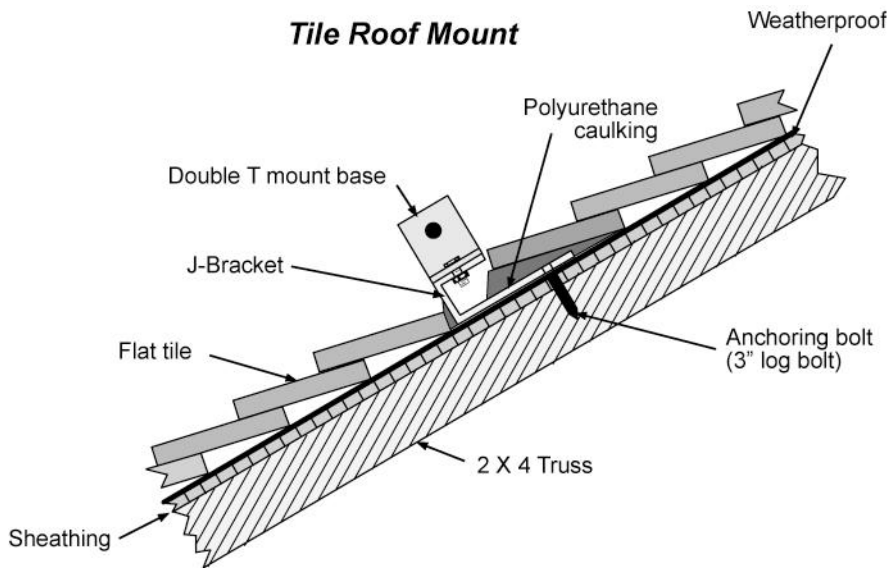


Figure 12 Tile roof-bracket mounting

Yet another method may include using lead roof vent stack flashing that can be shaped to the style and contour of the tile and sealed on the top with a cap or the mounting hardware support base as shown in Figure 13.

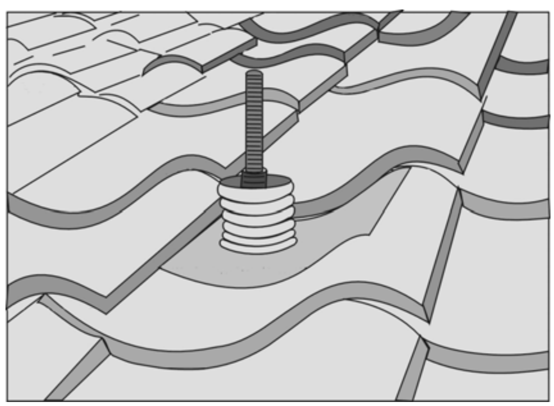


Figure 13 Vent stack flashing

A built-up, roof is composed of alternating layers of weather-resistant membrane (such as roofing felt) and tar, which is covered with loosely bound gravel that reinforces the semi-viscous roof tar and protects it from excessive heat and ultraviolet rays. This roof finish is typically used on flat roofs. The rafters in this case can be located by hammering on the roof surface – the roof pebbles will not jump when a rafter is struck.

Remove all of the gravel under the mounting bracket and for a space of at least four inches in each direction from its edges. When bolts penetrate the waterproof membrane, pitch pans will be required. Pitch pans can be made from six-ounce sheet copper, galvanized iron or lead. Figure 14 shows a pitch pan.

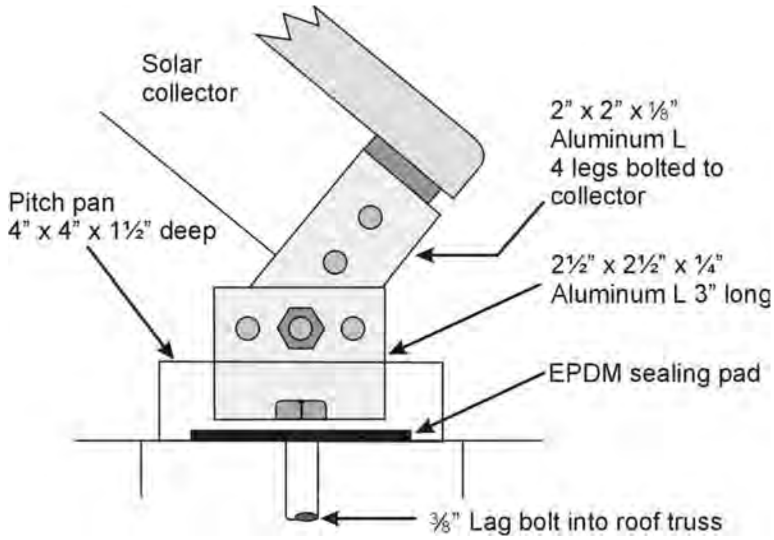


Figure 14 Pitch pan detail

Use high quality roof cement and four-inch strips of asphalt-impregnated roofing to waterproof the penetration. Also, avoid creating any “pools” in the pitch pan sealing material where water can accumulate. Then cover it with gravel.

Bracket Mounting and Sealing

Brackets attach the collector to the roof. The brackets themselves must be securely attached to the underlying rafters or trusses.

If the site has working room in an attic or crawl space, wood or angle iron spanners can be used to secure the mounting brackets, acting as an anchor for a threaded rod. Spacers must be pre-drilled and placed directly under the threaded rod to relieve any tension pulling down on the roof deck. A clip angle or collector mounting bracket is attached on the "roof" end of the threaded rod. Figure 15 illustrates spanner mounting.

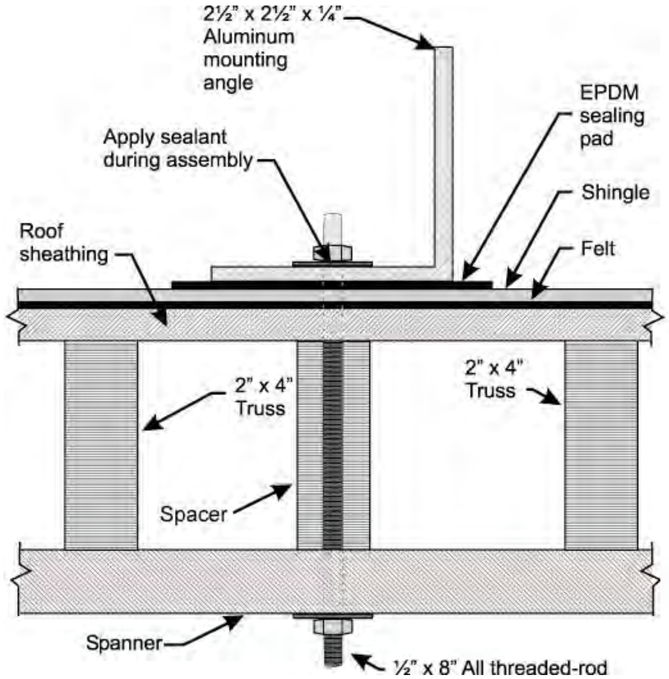


Figure 15 Spanner mounting

If under-roof access is not available, J-bolts or lag bolts may be required. J-bolts must be long enough to grip under a rafter and still leave enough threading outside the roof sheathing for easy bracket and nut installation. (Follow the collector manufacturer's length and diameter recommendation to the letter.)

To mount a lag bolt:

1. Drill a pilot hole of 50-75% of the bolt diameter into the centerline of the truss to the actual length of bolt penetration.

2. Liberally apply a high quality sealant around the pilot hole opening.

3. Place the pre-drilled sealing pad and mounting bracket angle on the roof.

4. Apply the flat washer, lock washer and bolt with a high quality sealant between the bracket and flat washer.

Figure 16 shows an acceptable sequence in lag bolt mountings.

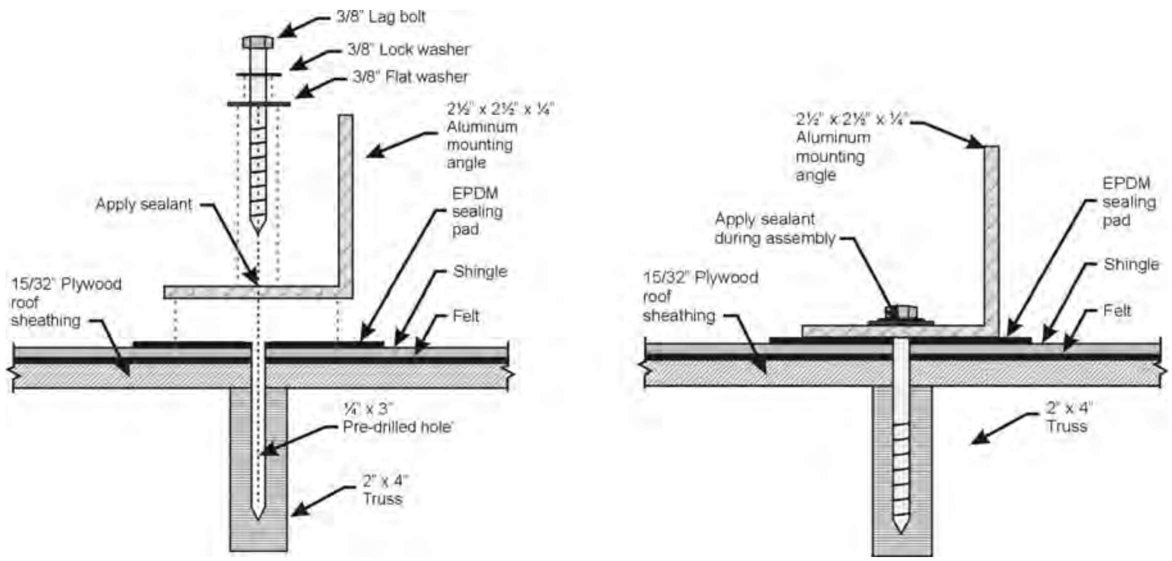


Figure 16 Lag-bolted mounting assembly

For J-bolt mounting as illustrated in Figure 17:

1. Drill a hole directly beside the rafter; the hole size must be slightly larger than the bolt diameter.

2. Fit the bolt through the mounting bracket (angle).

3. Insert the bolt (hook side first) through the hole in the roof.

4. Work the hook underneath the rafter.

5. Pull the hook snug against the rafter before tightening the nut.

6. Use double nuts or lock washers to securely fasten the mounting bracket to the J-bolt.

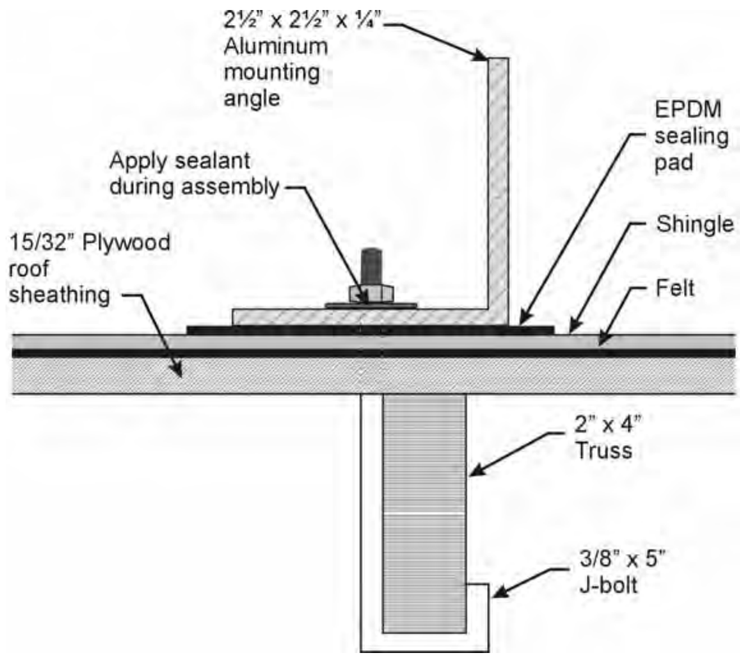


Figure 17 J-bolt mounting

Collector Attachment

If the collector is to be rack-mounted make sure the rack (if adjustable) is tilted to the desired angle and the collector (when mounted) will drain by gravity. Follow the collector manufacturer's guidelines regarding rack adjustment and attachment. Make sure the rack is structurally sound and firmly secured and not skewed. If it is skewed, tightening the collector in place may break its glass cover. If collector and rack are made of dissimilar metals, provisions must be made to prevent galvanic corrosion.

If the collector is to be mounted with standoffs, allow at least one inch of clearance between the collector bottom and roof surface to prevent water or material build-up. The bracket-to-collector attachment must be strong enough to withstand the maximum expected wind loads. Follow the manufacturer's instructions.

After the collector has been mounted, check the entire assembly for rigidity. As a rule of thumb, if you can shake it by hand, it is not fastened securely enough.

Roof Piping and Penetrations

Select the spots to penetrate the roof for the piping runs close to the mounted collector. In some cases it may be necessary to pipe both the feed and the return lines through the same penetration. In gravity drain systems, the feed line should penetrate the roof below the collector. Pitch all lines at least 1/4 inch per foot of pipe run to allow proper drainage. Make roof penetrations between trusses to allow for thermal expansion and slight flexing of the pipe from wind buffeting.

There are several methods of roof penetration that comply with accepted practices of the U.S. National Roofing Contractor's Association (NRCA) as well as local building codes. If there are any conflicts between the recommendations made here and those of local building codes, follow the building codes.

One method of providing a watertight penetration uses a standard plumbing roof vent stack flashing (Figure 18). Remember to protect the rubber or plastic boot from the sun.

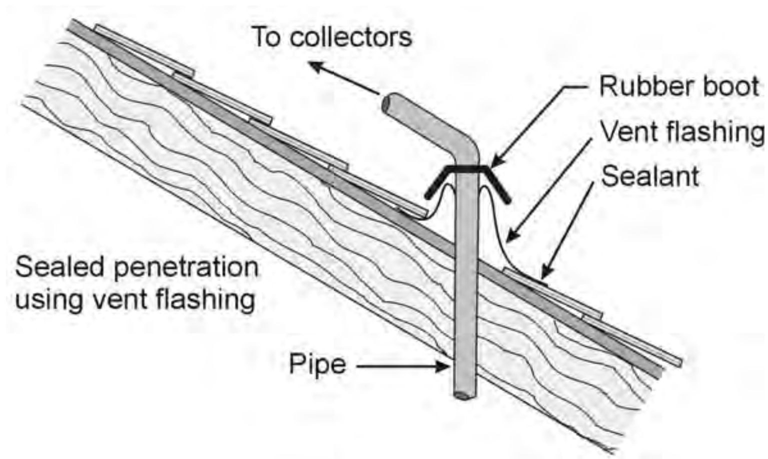


Figure 18 Penetration with vent stack flashing

Another method is to make a flat copper flashing with an oversize collar that is penetrated by the fluid line (Figures 19 thru 21). Note the base of the flashing should be mounted under the shingle above. A flashing cap is then soldered to the pipe at their junction. This type of flashing is available for both pipe only (Figure 20), and pipe and wire penetrations (Figure 21).

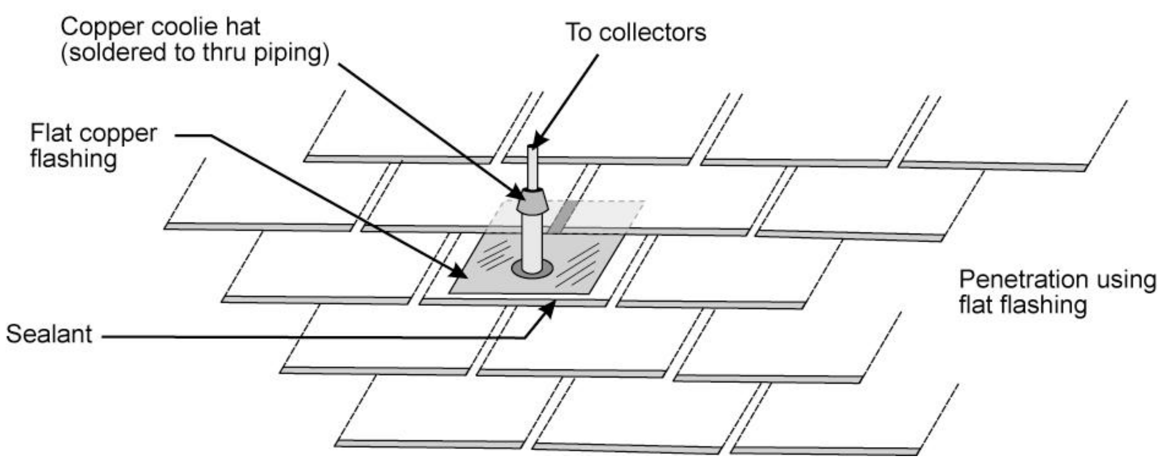


Figure 19 Penetration with flat flashing

Figure 20 Copper flashing for pipe only

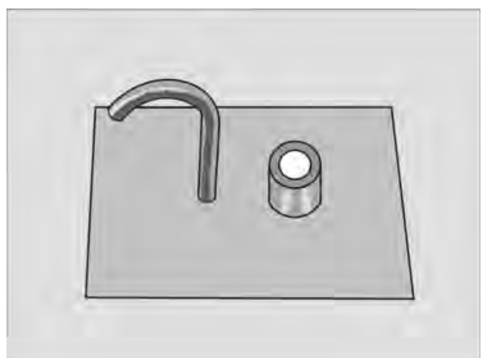


Figure 21 Copper flashing for both pipe and wiring

A less desirable method brings both pipes up through a pitch pocket (Figure 22). Such an open bottom pitch pocket requires periodic maintenance and inspections over the life of the solar system.

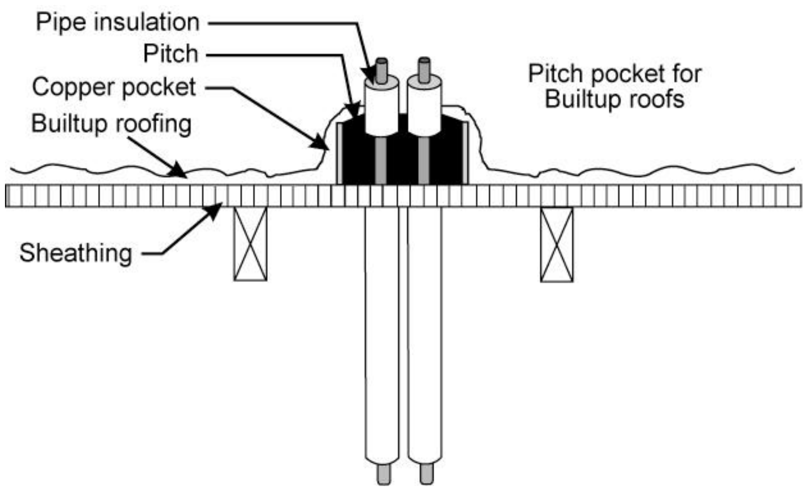


Figure 22 Penetration with pitch pocket

For larger commercial installations on flat, built-up roofs, the installer should follow specific recommendations of the most current NRCA Roofing and Waterproofing Manual.

Valves

Most solar systems may have valves on the roof for venting, filling, freeze protection and other aspects of operation. In order to eliminate air traps, air-vent valves must be at all high points in the system where air is most likely to accumulate (Figure 23).

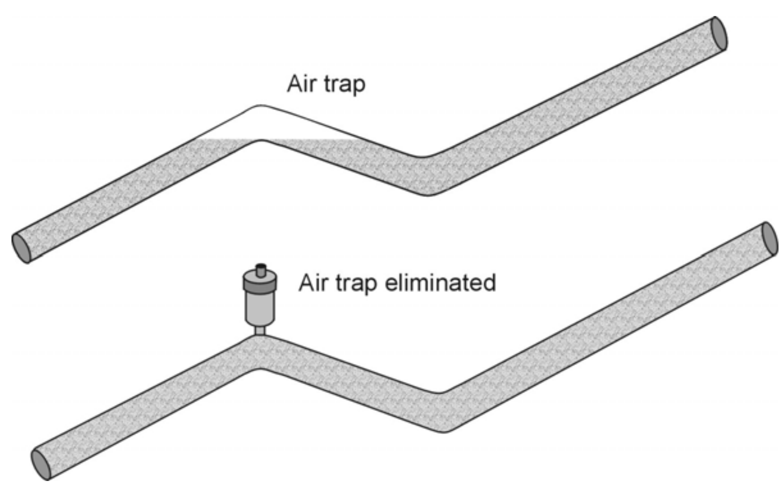


Figure 23 Elimination of an air trap with an automatic air vent

If multiple collector arrays are used, an air vent should be installed on each array. The system must be piped to prevent air traps and allow for gravity draining (Figure 24).

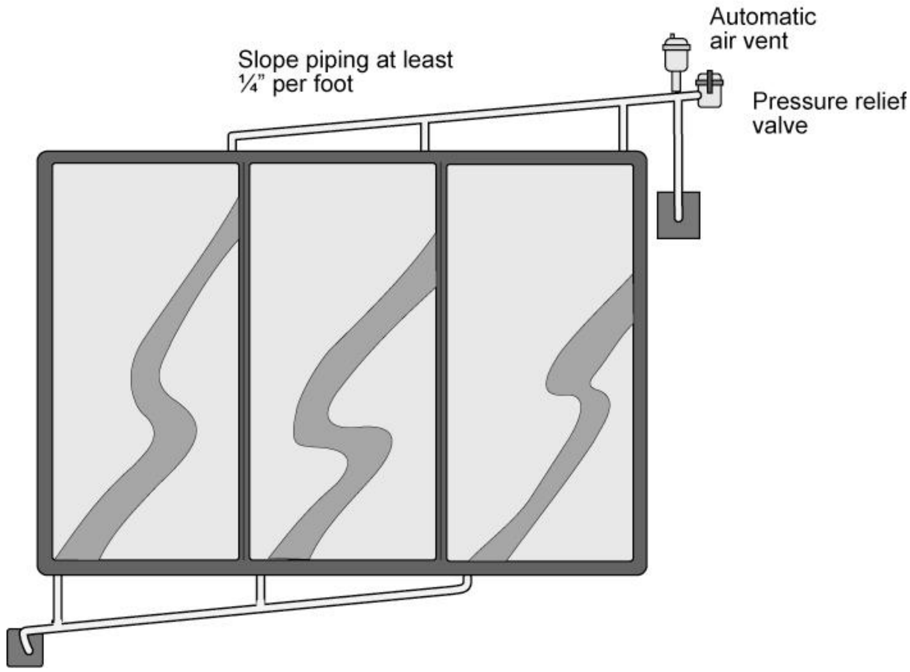


Figure 24 Piped and vented collector array

By code, a pressure relief valve is required in any portion of the system that can be isolated that contains a pressure producing fixture. For example, a circulating pump might have isolation valves so it can be removed for maintenance, but it is not considered a pressure producing fixture from the standpoint of the risk of bursting the system, so you don't need a pressure relief valve on this part of the system. However, the collector, or tanks with heater elements (connected or not), and even tankless water heaters are pressure producing fixtures, so if any can be isolated, there must be a pressure relief valve somewhere in that portion of the isolated loop that contain them. Most solar water heaters have the pressure relief valve for the collector loop installed at the collector. Special care should be taken to ensure the hot overflow from this valve does not come into contact with people or pets; some codes specify how this should be accomplished. The discharge pipe must be large enough to safely handle the overflow volume from indirect antifreeze systems, which usually operate at low pressure. Special low-pressure relief valves are often used on these systems.

Piping Collector Arrays

Cover all roof piping with insulation. Protect the insulation from degradation through exposure to ultra violet (UV) light by completely covering it with UV-resistant paint, or metallic or vinyl tape. Painted insulation will need to be repainted periodically, as the paint will deteriorate over time.

Slip the pipe through the insulation sleeve before soldering, or slit and re-glue insulation in difficult areas. Insulation that has been slit must be glued or taped properly because it will shrink from the pipe as it ages. Insulate joints only after the entire system has been pressure-tested for leaks.

The collectors in multiple-collector arrays should be plumbed in parallel unless the manufacturer specifies otherwise. Parallel, reverse-return piping (Figure 25) ensures a fairly uniform flow in a collector array with no more than four collectors. Use 3/4-inch (ID) pipe for the interconnections. A parallel connection without reverse return leads to uneven flow throughout the collector array.

If the array cannot be piped in parallel with reverse return, use flow-balancing valves to reduce the flow in the collector of least resistance, equalizing the flow rate through the entire array (Figure 25 b). A balancing valve is a fairly expensive valve with which accurate flow adjustment may be made. Gate valves should not be used for this purpose, as they will not allow accurate flow equalization over time, but ball valves have been used successfully for balancing.

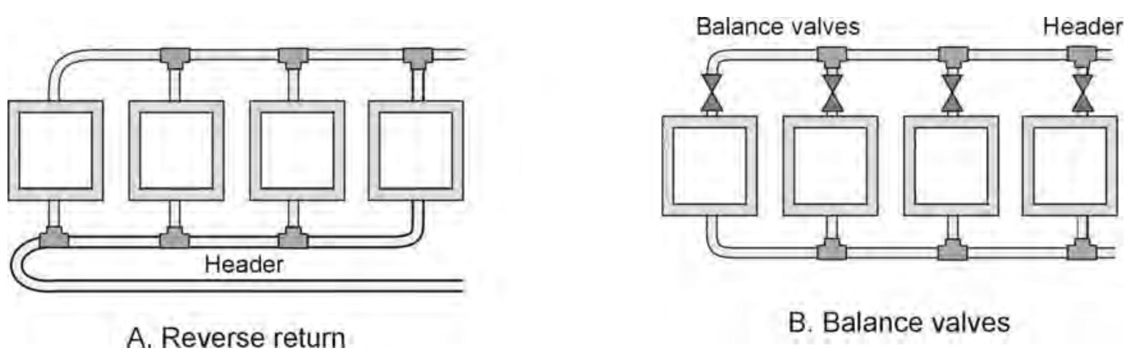


Figure 25 Multiple collector piping arrangements

Avoid flexible connectors from the array header to the individual collectors, as they have been shown to fail or leak over time. However, flexible hoses may be acceptable in indirect antifreeze systems, which are not subject to high operating pressures.

Section 3
Module: Component Installation

Collector-to-Storage Piping Installation

Piping from the tank to the collectors should be as short as possible and insulated to reduce heat loss. Increase the pipe insulation if the collectors are a long distance from the storage tank.

For direct residential systems, use 1/2- or 3/4-inch (ID) copper pipe. Smaller sizes tend to become constricted by boiler scale when the water contains salts with reversed solubility characteristics. Use 3/4-inch (ID) or larger feed and return lines for multiple collector systems containing three or more collectors piped in parallel to prevent unwanted pressure drops between collector connections.

Copper tubing, like all piping materials, expands and contracts with temperature changes (about 100°F in most solar systems). Using expansion loops or offsets can accommodate this expansion. A typical piping run (for a domestic water heater) will increase in length about 1/2 inch when hot. This expansion can be absorbed by a one foot in diameter loop on each run, a U-bend, or an offset of the same length for each run (Figure 1). An alternative is to use soft copper tubing in each line. Prevent air traps or low spots in systems when installing expansion loops, and allow for thermal expansion of the pipes.

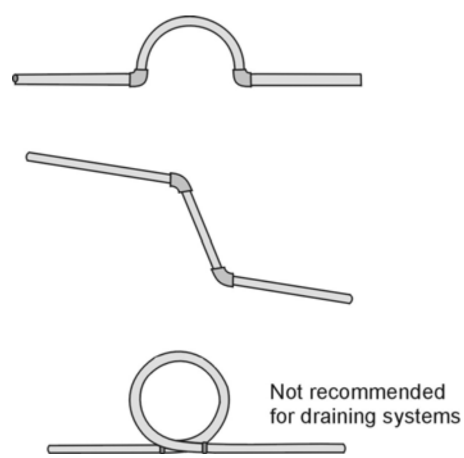


Figure 1 Expansion loops – systems must be able to drain

The following installation practices should be observed:

1. If possible, utilize an electric-operated (motorized) check valve to prevent back-siphoning. As a second choice, use a vertical spring-check valve with a high temperature (e.g., Teflon, not neoprene) seal. Use of a horizontal swing-check valve is not highly recommended.

2. The solar system must have isolation valves – one on each side of the solar loop. An isolation valve should be provided between the pump and the tank on the feed line and between the check valve and the tank on the return line.

3. Drain valves should be provided on both sides of the collector loop. Drain valves should always be readily accessible. When installed above the check valve it can be used to back flush the collector and when installed below the pump it can be used to drain the pump for service.

4. If a vertical spring-check valve is utilized, the drain valve placed between the check valve and the tank can be used to test the check valve at low pressure to determine if it closes properly. In order to back flush the collector loop, the drain valve must be above the check valve. The location used for the drain valve is based on installer preference.

5. Use only nontoxic heat transfer fluids with single-walled heat exchanger systems. Label the heat exchanger so that it can be identified as a single-walled unit.

6. Thermometer wells on both the inlet and outlet sides of the solar loop are desirable.

7. Before leaving the premises, check the flow through the collector loop to make sure there are no major obstructions. Recommended flow rate: about 1/2 gallon per minute (gpm) for each 40 ft^2 of panel area (unless the manufacturer specifies to the contrary).

8. For residential forced circulation systems, use a minimum of 1/2-inch (ID) pipe for total runs over 100 feet, or when the flow requirement is greater than one gpm and the pump is less than 1/20 hp, use 3/4-inch pipe. For a thermosiphon system, use of 3/4-inch (ID) piping helps eliminate undesirable resistance to fluid flow. If two or more collectors are to be connected in parallel, use 3/4-inch pipe for interconnections.

9. Use 1/2-inch thickness (minimum) rubber type insulation on all piping and make sure the insulation is protected from environmental degradation, especially ultraviolet rays.

10. Minimize piping distances wherever possible.

11. Install all piping with a continuous slope of 1/4 inch per foot toward the drains.

12. Pipe runs should use hangers to maintain their slope and stability. When constructing hangers, use wide plumbing straps. (Do not use wire.) Follow plumbing code requirements for hanger spacing.

13. Install collectors so internal piping will drain itself completely by gravity.

14. Use lead-free solder for soldering system joints and components. Follow local code requirements.

15. If piping requires high points, install air vents at those locations.

Storage Tank Installation

Because of their size and weight, solar storage tanks must be carefully sited in new installations, and finding suitable locations sometimes challenges the solar contractor's ingenuity on retrofit installations. A 100-gallon tank full of water weighs about 1,000 pounds, and should be located on a well-braced area if it is above grade. Since it will eventually require replacement, locate the tank so it can be removed with the least possible effort. Make sure it is placed where a leak will not cause damage, there is adequate working room for making piping connections, and it is protected from detrimental environmental conditions.

New wiring is a job for the electrical contractor, but the solar installer will want to tell the electrician whether 110 VAC, 220 VAC or both are needed for operating the pump, controller and electric water heater. Amperage information can be found in the installation brochures for the pump and the tank controller.

Configurations for two-tank system piping with electrical backup are shown in Figure 2. Gas water heaters should be used with the system shown in Figure 3. Gas water heaters do not work well in single-tank solar systems because the gas tank’s burner heats the entire tank of stored water from the bottom up. Gas water heaters should be used with passive solar systems which preheat water or with auxiliary solar storage tanks (See Figure 3). (By contrast, electric tanks can be configured to heat only the top portion of the stored water.)

The following installation practices should be observed:

1. If possible, provide a separate switch, conveniently located, to turn on and off the hot water heating element(s) on the tank. (This will require a double pole, 220 VAC switch.) Also point out to the homeowner the hot water heater circuit breaker switch.

2. If a dual element tank is used for solar storage, disconnect the lower tank element wires at the upper thermostat. Or, turn the bottom thermostat to its lowest setting.

3. Maintain enough clearance to the tank's heating element/thermostat plate(s) so the thermostat setting device can be accessed and the heating element can be replaced.

4. Install a heat trap on the cold-water inlet line and the hot water line to the building, as required.

5. Add an insulating blanket to a conventional electric water heater tank (a minimum of 2 to 3 inches of fiberglass equivalent is needed). Do not cover the thermostat access doors. To prevent heat loss, set all tanks on 1/2- to 3/4-inch plywood (preferably with a layer of insulation board between the plywood and the floor).

6. Add insulation to the temperature and pressure relief valve and any other tank mounted pipe or fittings. (Don't restrict the pressure temperature relief valve test lever movement.)

7. The solar return on a standard electric water heater should have a dip tube to return heated water approximately 6" below the upper element's thermostat.

8. If a standard “mixing” valve is to be installed, be sure it is below the top of the tank. Remove the element when soldering if the valve utilizes soldered fittings. Specific models of "anti-scald" valves can be installed in the piping above the tank.

9. Pressure temperature relief valve piping should be piped to the outside and/or into a suitable drain six inches above ground level. Follow local code requirements.

10. For thermosiphon systems the hot water storage tank should be located at least one foot above the solar panel (except in the case of factory-made unitized systems).

11. Insulate both the hot water fixture line and the cold water supply line at the top of the tank.

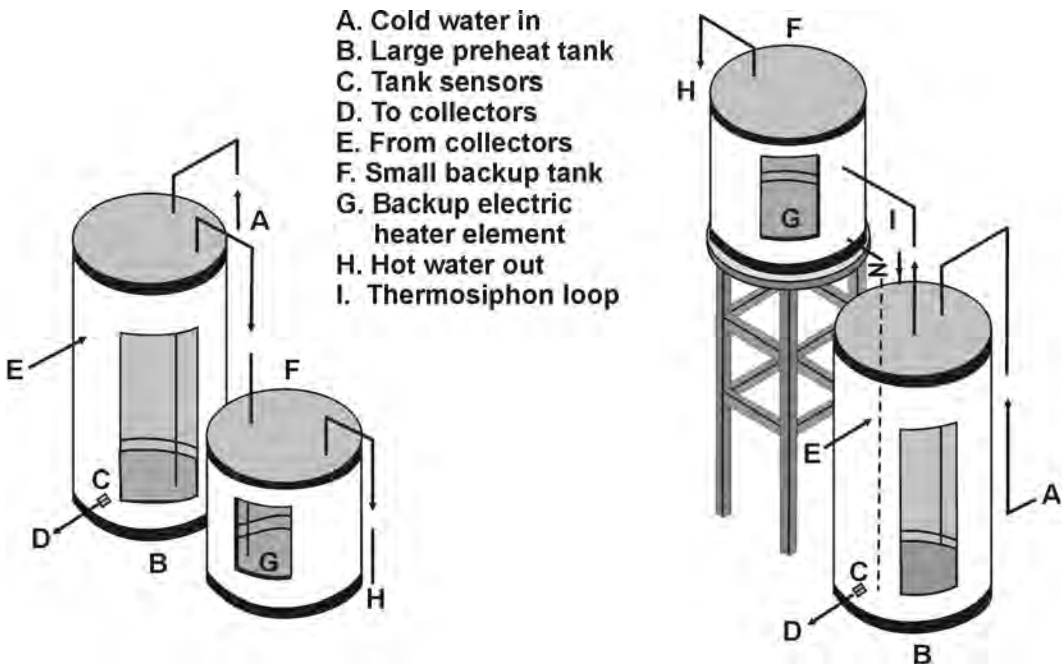


Figure 2 Multiple tank connection

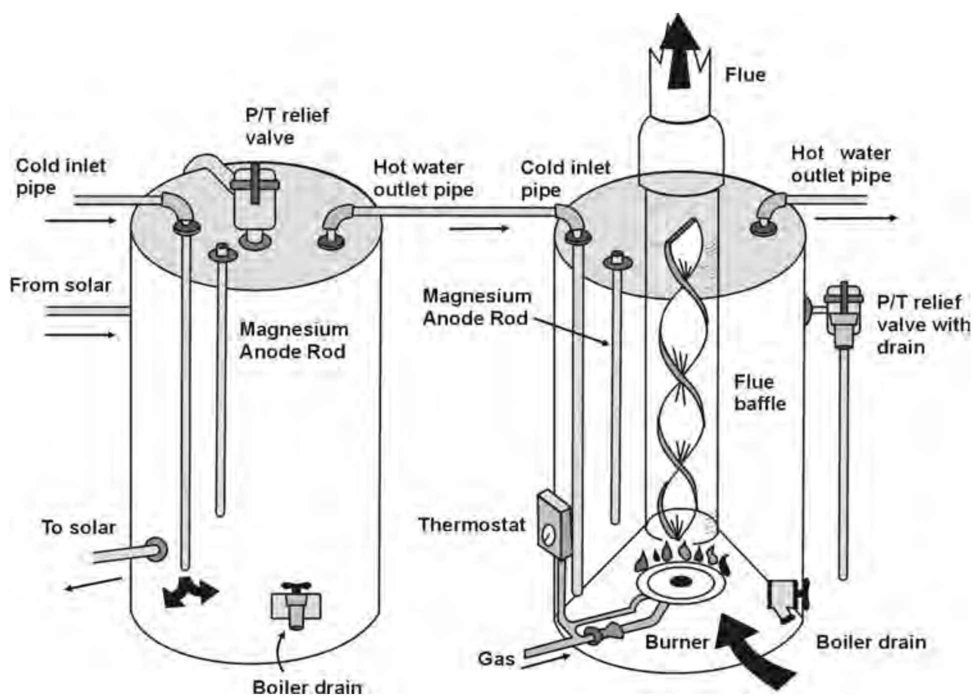


Figure 3 Gas heater connection

Pump Installation

In many solar water-heating applications, inexpensive, low-horsepower pumps will circulate enough liquid through the heat collectors for efficient operation. When the entire circulation loop of a collector system is full of liquid, as is the case with most pressurized systems, only the friction resistance of the piping and valves must be overcome.

Drain-back systems must use higher head pumps to lift the water (overcome the static head) between the storage water level and the highest point in the system. That same pump must have enough reserve pressure capacity to overcome the friction head. Fortunately, the friction head is usually very low when compared to the static head.

The location of the pump is also important in a drain-back system. Since most solar pumps are not self-priming, the impellers must be below liquid level at all times. Pumps may be mounted in any orientation unless the position prevents air from escaping from the volute (pump cavity). Pump rotation must push the fluid in the right direction. Some pump motors may require lubrication, and the homeowner should be shown how and when to lubricate the pump motor.

Minimize noise and vibration by mounting the base solidly or allowing the pump to be supported by its mounting flanges from a secured section of pipe. All pumps and motors must be UL-listed.

Controls and Sensor Installation

Differential Controller

The differential controller is usually boxed and mounted inside the building to protect it from the weather and tampering. It often is connected directly to the pump with pre-formed conduit and equipped with 110 VAC wire and a wall plug.

The low-temperature sensor of the differential control is usually attached near the bottom of the storage tank.

The high-temperature sensor may be placed:

1. On the outlet pipe of the solar collector.
2. In the air space between the collector absorber and the transparent cover.
3. Against the absorber surface.

Follow the instructions from the controller manufacturers. In any one of the three sensor locations, the basic on-off modes are the same. When the collector sensor senses temperatures 5-20°F hotter than the tank sensor, the pump is turned on. When that difference is reduced to about 3°F, the pump is turned off.

This method of controlling the pump's operation guarantees water circulates through the collectors only when such circulation will result in an energy gain to the storage tank.

There is no guarantee water returning to the tank will be hotter than the water stratified at the top of the tank; therefore, solar tanks introduce the returning water about one-third of the way down the side of the tank. This is done with a sideported tank or with a short dip tube, as shown in Figure 4.

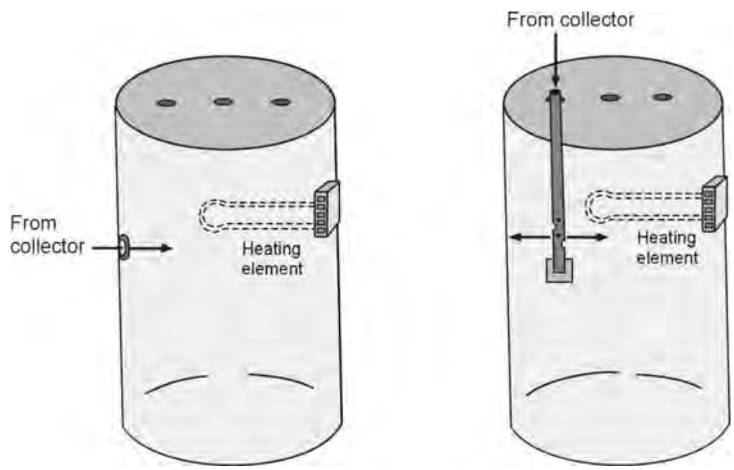


Figure 4 Side port and "dip tube" arrangement of collector return port

The following installation practices should be observed:

1. The tank sensor should be located on the storage tank as close as possible to the bottom. If the tank is not accessible, it should be located on the collector supply pipe as close as possible to the tank outlet. All sensors should be insulated from the surrounding air.

2. Perform a controller checkout procedure before leaving to be sure collector and tank sensors are calibrated. This procedure should utilize a digital ohm meter and/or a controller tester.

3. Check all freeze sensors before installation. This can be done by placing them in an ice water bath. They must activate the pump or freeze control strategy above 32°F (usually 38-42°F).

4. For adequate freeze protection, use at least two methods of freeze protection. Connect the collector sensor and freeze sensor in parallel if the freeze sensor closes on temperature fall, series if it opens on temperature fall. (The sensors must be used with a controller that responds to a closing or opening freeze signal as required.)

5. A collector sensor mounted on piping should be well covered with insulation and thermally in contact with the piping.

6. All sensors must be mounted according to manufacturer's specifications.

7. Connections for sensors should be made with silicone-filled wire nuts or telephone style waterproof connections. They should be coated weather tight with sealant and protected from exposure to sunlight.

8. Use Teflon (or other high-temperature insulation) insulated wire within or close to the solar collector.

9. Do not run low voltage sensor lines near higher voltage 110 VAC lines. The controller may be affected by induced voltage fluctuations. When running sensor wiring in the attic, secure it at regular intervals overhead, stringing it from one rafter to the next or along piping insulation to prevent potential damage by people moving about or storing objects in the attic. Near the tank, run sensor wiring along piping insulation and tape it in place. Do not leave any wire dangling anywhere.

10. Do not stretch sensor wires taut before securing them to supports. Thermal expansion and contraction may cause premature failure of the circuit because of damaged insulation and the resulting short circuits.

11. Check completed circuits for unwanted grounding. Some controller sensor's circuits contain one grounded leg. Observe proper polarity in such cases.

12. It is recommended that 24 VDC or less be used for all sensor circuits. If 120 VAC circuits must be used, follow local electrical codes.

Timer Controller

1. Use a UL listed timer incorporating battery back-up capability.

2. Provide the homeowner with the timer instruction booklet. This will become very important during battery changes and if the homeowner ever has to reset the timer.

Photovoltaic Controller

1. Follow the photovoltaic manufacturer's recommendations for gauge size of wiring.

2. Follow the differential controller wiring guidelines regarding securing wiring runs and stretching of wiring.

3. The photovoltaic module should be covered before the DC pump is connected to avoid an electrical spike to the motor.

Section 3
Module: System Installation Checkout and Start-Up Procedures

Introduction

This chapter presents recommended steps for checking out and starting up a newly installed solar water heating system. In most cases, the manufacturer of the system will have included specific instructions. If the following recommendations differ, follow the manufacturer's instructions. The general steps for activation and start-up include pressure testing and flushing the system, testing the operation of individual components, cleaning up the work area, and instructing the owner on system operation and maintenance.

Pressure Testing

Direct systems should be pressurized to the maximum pressure they will encounter plus the safety factor specified by any local codes. Indirect systems should be pressurized to their design pressure. Use a charging or testing kit that includes a tank of compressed gas, charging fittings, charging liquid and a pressure gauge.

Some indirect systems require pressurization and testing with a liquid other than water. Follow the manufacturer's recommended procedure.

When the system is full of liquid and pressurized, check for any leaks. Check the collector, joints and valve stem seals. If any leaks are detected, correct them and then *retest* before applying insulation over those areas.

Flushing the System

Once the system is leak-free it should be flushed to remove flux, solder droplets and debris from the piping. In most direct systems, faucet water pressure may be used for flushing. Flush the collector loop first and the storage tank second. In indirect systems with expensive heat-transfer fluids, flush the system with water first.

An important factor to note after flushing and checking the collector loop with water is that some heat-transfer fluids, such as silicone and synthetic oils, must not be mixed with water. Ensure that all water has been removed from the system piping and that the piping is dry before adding the oils. Blowing dry compressed air through the system for a time can do this. Most glycols can be mixed with water, thereby, the system piping does not have to be dry before introducing the glycols.

Isolate and flush the collector loop, preferably in the reverse direction of normal flow. If the check valve is located on the collector supply, use the cold-water service pressure to back flush the collector return. If the check valve is located below the collector return hose bib drain, use a garden hose with a double female adaptor connected to both an outside faucet and the collector return drain.

In both cases, force water out the collector supply drain through an attached hose leading to a point of safe discharge. Check this water for dirt, scale or other signs of blockage. Stop when the discharge no longer contains any debris.

Except in the case of drain-back systems, it is important that all air be vented out of the collection loop; otherwise, it may accumulate in a column of sufficient height to stop or seriously impede circulation. The air vent at the high point in the piping is installed for this purpose. When water reaches the air vent, the vent should close quickly, without leaking. Many vent valves have a stem that can be depressed to allow fluid to escape, flushing the valve seat clean.

Manual air vents should be used to purge air from the collector loop in indirect systems using glycol or oil heat transfer solutions. Once the air has been purged, the air vent should be sealed tightly to prevent loss of fluid or fluid vapors.

Testing the Pump and Controls

1. Check the operation of the pump. Confirm it is plugged in or wired correctly and power is available. If the system's controller has an on/off automatic switch, manually place the switch "on" to activate the pump. In systems so equipped, an LED will signal if the pump is on. In systems without such an indicator, check for other signs of pump operation, as an audible hum, motor fan rotation, slight vibration, or temperature differences in the feed and return piping.

   a. *Sunny day*. On a sunny day, the pump should run most of the time. If the system has a differential or direct PV controller, passing clouds may cause the pump to cycle on and off occasionally.

   b. *Cloudy day*. On a heavily overcast day or at night, the pump should not run. To determine if a pump powered by 110V residential power is working, unplug it from the controller and plug it directly into a wall outlet. If the pump does not have its own plug, direct wire the pump to power (bypassing the controller and/or switches).

   CAUTION: Do not attempt this procedure if you are not familiar with safe electrical practices.

   It is generally easier and safer to "fool" the controller into turning on the pump. See item 3c, *Differential controller test.*

2. Check for flow in the collector loop. If there is a flow meter or indicator in the collector loop, determine if fluid is actually moving. If the system has no flow indicator, use the following methods:

a. *Sunny day.* If it is a sunny day and the pump is running, pull back a portion of the insulation on both the collector supply and return pipes (at points a few feet from the tank). Carefully feel (or measure with a thermometer) the pipes to make sure that the return line from the collector is hotter than the supply line going to the collector. On a sunny day, such a temperature difference (usually 5-15°F) indicates fluid is flowing in the collector loop.

If you cannot detect a temperature difference, turn the pump off by disconnecting its power supply. Leave the pump off for a few minutes – long enough for the fluid in the collector to heat up. Then restart the pump and feel the pipes again. Within several seconds, you should feel the hotter fluid from the collector pass through the collector return line into the tank. If you do not feel this surge of hot fluid on a sunny day, there is probably some blockage in the collector, the pump, the valves or the pipes.

b. *Cloudy day or at night.* On a very cloudy day or at night, you can still use the above procedure to check for flow in the collector loop. However, make sure the pump has been off for a long time, so the fluid in the collector is relatively cool. Then, when you turn on the pump again, you should feel a surge of cool fluid pass from the collector into the tank. Note that this method works best on colder nights.

To determine the actual flow rate through the solar collectors, use a flow meter or one of the methods discussed in *Appendix: Solar System Flow Rates*.

3. Test control system operation. Conduct the following tests to check the control system.

WARNING! For any procedure involving electrical equipment, always turn off or disconnect the unit from the power supply before making any adjustments or resistance measurements.

a. *Detailed controller test.* A complete method of checking the controller involves the use of a differential controller test set. Containing fixed and/or variable resistances, the test set is generally calibrated for a specific manufacturer's line of controllers, though it can be adapted to test other brands of controllers. Instructions for its use are usually supplied with the tester.

The test set enables you to determine the exact “turn-on” and “turn-off” temperatures of the controller. Compare these differential temperatures to the manufacturer's specifications. If the measured temperatures do not match the specifications, and if the setting is adjustable, you can change the setting to match the manufacturer’s recommendations.

b. *Sensor test.* To check the temperature sensors of a differential controller, measure their resistance. Disconnect the sensors from the controller terminals or lead wires and use a volt-ohmmeter to measure the resistance across the sensor wires. (See *Appendix: Volt-Ohmmeter or VOM) or Multimeter Operation* for instructions on use of a volt-ohm-meter.) For thermistors and metal film sensors, compare their resistance to the manufacturer's temperature-versus-resistance specifications.

Temperature (°F)	**3000-Ω Thermistor**	**10,000-Ω Thermistor**	**Temperature (°F)**	**3000-Ω Thermistor**	**10,000-Ω Thermistor**
Thermistor open	Infinite	Infinite	92	2,100	7,000
Thermistor shorted	0	0	94	2,010	6,683
30	10,400		96	1,920	6,383
32	9,790	32,660	98	1,830	6,098
34	9,260	30,864	100	1,750	5,827
36	8,700	29,179	102	1,670	5,570
38	8,280	27,597	104	1,600	5,326
40	7,830	26,109	106	1,530	5,094
42	7,410	24,712	108	1,460	4,873
44	7,020	23,399	110	1,400	4,663
46	6,650	22,163	112	1,340	4,464
48	6,300	21,000	114	1,280	4,274
50	5,970	19,906	116	1,230	4,094
52	5,660	18,876	118	1,180	3,922
54	5,370	17,905	120	1,130	3,758
56	5,100	16,990	124	1,040	3,453
58	4,840	16,128	128	953	3,177
60	4,590	15,315	132	877	2,925
62	4,360	14,548	136	809	2,697
64	4,150	13,823	140	746	2,488
66	3,940	13,140	144	689	2,298
68	3,750	12,494	148	637	2,124
70	3,570	11,885	152	589	1,966
72	3,390	11,308	156	546	1,820
74	3,230	10,764	160	506	1,688
76	3,080	10,248	165	461	1,537
77	3,000	10,000	170	420	1,402
78	2,930	9,760	175	383	1,280
80	2,790	9,299	180	351	1,170
82	2,660	8,862	185	321	1,071
84	2,530	8,449	190	294	982
86	2,420	8,057	195	270	901
88	2,310	7,685	200	248	828
90	2,200	7,333	210	210	702

Table 1 Temperature and Thermistor Resistance

Generally, differential controllers now have 10,000 ohm thermistor sensors or an RTD. In the past, 3,000 ohm sensors were more prevalent. Sensor resistance should match the measured temperature as closely as possible, as shown in Table 1. Refer to the manufacturer's installation guide for specific instructions and specifications.

For example, the table shows that when the environment temperature is 77°F, the 3,000 ohm sensor should read 3,000 ohms, and the 10,000 ohm sensor should read 10,000 ohms. As the temperature increases, the resistance decreases. At 90°F, a 3,000 ohm sensor reads 2,200 ohms and a 10,000 ohm sensor reads 7,333 ohms.

The general range of solar system temperatures is 70-140°F for the tank sensor and 100-150°F for the collector sensor, depending on the time and conditions of day. If an "open" or "short" condition is indicated, check the wiring between the controller and sensor.

A common cause for an "open" condition is a broken connection between the wiring and the sensor. A "short" may be caused by a piece of metal pinching the sensor wire and conducting it to ground.

For temperature-actuated switches, such as freeze sensors and upper limit sensors, you can also check the switch position with a volt-ohmmeter. The switch is either normally open or normally closed and changes position at a particular temperature. Check the freeze sensor by placing it in ice water and determining that the switch changes position.

c. *Differential controller test.* Follow the manufacturer's checkout procedures if they are provided. However, if the procedure is unavailable, follow these steps to check differential controllers with thermistor sensors that have a negative temperature coefficient in which resistance decreases as the temperature increases.

   i. Disconnect and separate all sensor inputs. Identify the sensor wires for proper reconnection.

   ii. With the controller in its normal operation or automatic switch position, short the collector sensor input wires or terminals together. This simulates a very hot collector. The control should turn on (indicated by the LED and/or pump operation).

   iii. Remove the short and the control should turn off. Be aware that some controllers may utilize a time delay circuit to keep the pump from cycling on and off too often.

iv. The controller is (probably) in good condition if it responds correctly to these steps. Test the temperature sensors next before proceeding to a more detailed test of the controller.

For the differential controllers that use resistance temperature devices (RTDs), which are positive temperature coefficient sensors, the tank sensor input should be shorted in Steps iii and iv above. Shorting the collector sensor indicates a low temperature, and the pump should stay off. Shorting the tank should turn the pump on. If freeze protection and the collector sensor functions are combined, shorting the collector terminals simulates a freeze condition. The pump should again turn on. Use a volt-ohmmeter to ensure that temperature matches resistance as shown in Table 2.

Temperature (°F)	**Resistance**	**Temperature (°F)**	**Resistance**
30	861.8	35	876.1
40	890.5	45	905.1
50	919.2	55	933.9
60	948.7	65	963.7
70	978.2	75	993.4
80	1008.7	85	1024.0
90	1039.0	95	1054.6
100	1070.3	105	1086.1
110	1101.5	115	1117.5
120	1133.6	125	1149.9
130	1165.6	135	1182.1
140	1198.7	145	1215.4
150	1231.5	155	1248.4
160	1265.4	165	1282.5
170	1299.1	175	1316.5
180	1333.9	185	1351.4
190	1368.5	195	1386.2
200	1404.1	205	1422.0
210	1439.5	215	1457.7

Table 2 Temperature and RTD Resistance

d. *Photovoltaic (PV) controller test.* Use the following procedure to check the voltage and current output of the photovoltaic module on a sunny day:

i. Disconnect the pump from the wires coming from the PV module or pump starter box.

ii. With a volt-ohmmeter, check the voltage between the positive and negative terminals of the PV module. Given almost any amount of sunlight, this open-circuit voltage should be between 14 and 22 volts.

You should also check the PV module's short-circuit current with a volt-ohmmeter that has milliamp measurement capability. Under sunny conditions, the short-circuit current should be between 200 and 1000 milliamps, depending on the voltage rating of the PV module.

If there is no amperage at good sun conditions, the PV module or the connecting wiring may be defective. In this case, check the amperage of the module at its roof location to eliminate the effect of connecting wiring.

iii. To check the DC-powered pump, use a 12-volt power supply or two 6-volt lantern batteries connected in series (12V). Disconnect the PV panel from the pump and connect the pump to the proper terminals of the batteries. If the pump does not operate off the batteries, the pump is defective. If the pump does run off the batteries, the PV module or connecting wire is defective.

e. *Check valve test.* Use the hose bib drains and service water pressure to check these two valves: a horizontal swing check valve or a vertical in-line ring check valve.

Send water against the normal flow direction. Water flowing past the valve indicates a faulty seat or stuck hinge that will not seal under the low back flow of unwanted thermosiphoning.

Check a solenoid-actuated or motorized ball valve by using the manual lever (if it is present) to open and close the valve while checking for flow. Some motorized valves are not designed to close off against municipal water pressure.

After you have tested these valves, verify their normal operation by listening to and watching the valve open and close as the pump turns on and off. Check valves are prone to problems from sedimentation build-up, so they should be inspected periodically.

If the check valve cannot be tested by the above back flow procedure and it is suspected it might cause nighttime thermosiphoning, examine the system at night. When the fluid in the collector has cooled to a temperature sufficiently below that of the fluid in the tank, feel the collector supply and return pipes a few feet from the heat of the tank. If one pipe is warm, the check valve might not be sealing.

Sometimes a leaking check valve can cause the differential control to cycle the pump at night. To confirm this speculation, unplug the pump from the differential controller and plug a clock into the controller instead. Note the clock's time. Note the time again the next morning before the solar system would normally start. If the clock has advanced because the controller supplied power to it, the check valve is not sealing and needs to be replaced.

f. *Mixing valve test.* To check a mixing valve, feel or measure the temperature of the service hot water at the closest hot water faucet. As you measure, adjust the mixing valve over its range of motion, moving it to the desired temperature setting. These valves may stick open or closed after prolonged use, in which case they must be repaired, replaced or eliminated.

Cleaning Up

Collect and remove all tools. Dispose of any debris created during the installation. Make sure arrangements have been made to repair any damage that may have occurred during installation (such as broken roof tiles). Ask the owner to look things over and approve the installation and clean up.

Instructing the Homeowner

Carefully instruct the owner on the operation of the solar water heater. This reduces "false alarm" callbacks and enables the owner to make minor adjustments. With active systems, the owner should understand the pump and "pump operating" indicator on the control system.

Carefully explain any freeze protection devices. Demonstrate the steps for manually draining the collectors and piping, if that is a freeze protection mechanism for the system. Also, show them how to reactivate the system.

Show the owner how the back-up electric element may be turned off during warm months. Explain that the system should provide some hot water on its own. If the system shortly runs out of hot water, consider if it could have been subjected to a temporary abnormal load or lack of sunshine. Otherwise, it may need service.

Demonstrate how to isolate the storage tank from the collector loop. Then show the owner how to drain several gallons of water from the tank to remove built-up sedimentation. Instruct the owner to follow this procedure at least annually. Advise the owner that hot water use patterns can affect system efficiency. Let them know the system will provide the hottest water during late afternoon and early evening. Suggest they adjust their hot water use to accommodate the solar cycle.

Affix the name and contact information of the installing firm and installation mechanic to the tank or controller so the homeowner can contact the right people quickly if service is required. If possible, make arrangements with the owner for periodic professional inspection and maintenance of the system. Make sure that the owner has a copy of the system manual and that the manual is kept in an accessible location for future reference.

Section 4: Solar Water Heating System Troubleshooting presents structured methods to follow in diagnosing and correcting system problems.

- **Module: Problem Assessment and System Checkout** provides guidelines for assessing installed system problems.

- **Module: Troubleshooting Checklist** provides a comprehensive checklist for determining probable causes and the appropriate corrective actions.

Section 4
Module: Problem Assessment and System Checkout

I. PROBLEM ASSESSMENT

To diagnose system problems, you must not only understand the system type and its components and how they work, but you must also know what questions to ask to determine the problem and find out when and why it occurred. The more experience you have servicing solar systems, the more you will learn what questions to ask the customer.

The Initial Service Call

When you first receive a service call, record the caller's name, address and telephone number and be sure to get directions to the service location. Also, verify the caller is the system owner and is authorized to have you service the system.

Determine what kind of service the caller is requesting. Is it a routine service call or is the system not working properly? If the system is not working, what exactly is wrong? Is there no hot water? Is the system leaking? If it is leaking, where is the leak – on the roof or at the storage tank? The more you know about the system, the better prepared you will be when you arrive at the site. For example, if the system has an expansion tank and the system is over two years old, you will want to take new glycol with you to replace the old glycol. If the system has a drainback tank, you will want to have distilled water with you.

Avoid any misunderstanding by making your payment policy clear at the outset. For example, if the caller is renting the home, clarify whether or not you expect to be paid at the time service is rendered.

Find out the type of system, who installed it, how old it is and what previous service has been performed. Also, find out if the caller has a manual, a schematic, and a parts list for the system and what, if any, service contracts, warranties and insurance policies cover the system or its components.

System Records

All collectors and systems sold or manufactured in the state of Florida must be certified by the Florida Solar Energy Center (FSEC) in Cape Canaveral. As part of the certification requirements, each system must include a homeowner's manual that lists system components and describes the system design, operation and maintenance requirements. In addition to the manual, each system should have a freeze protection information label displayed at a prominent location on the system – on the storage tank, heat exchanger or controller. This label describes the system's freeze protection mechanism and any actions the homeowner must take when freezing occurs.

Information pertaining to a specific FSEC certified system can be obtained by contacting FSEC at http://www.fsec.ucf.edu.

The Solar Rating and Certification Corporation (SRCC), a national solar collector and system certification agency certifies many systems sold throughout the United States. Information pertaining to a specific SRCC certified system can be obtained by contacting SRCC at http://www.solar-rating.org/.

Warranty Coverage

Find out if the system or its components are covered by warranties. Typically, the term of the collector warranty will be from 5 to 20 years, with other components varying from 90 days to 5 years. It is also important to know whether the warranties are full or limited. This designation is required to appear on the warranty document. A full warranty is required by law to provide the following:

- A defective product will be fixed (or replaced) free, including removal and reinstallation if necessary.
- The product will be fixed within a reasonable time after the customer complains.
- The customer will not have to do anything unreasonable to get warranty service (such as shipping components back to the factory).
- The warranty is good for anyone who owns the product during the warranty period.
- If the product cannot be fixed (or has not been after a reasonable effort to do so), the customer may choose to receive a new product or a refund.

Limited warranties provide less protection than the full warranty. For example, a limited warranty may:

- Cover only parts, not labor
- Allow only a prorated refund on credit
- Require the customer to return the product to the manufacturer for service
- Cover only the original buyer
- Charge for handling the service order

Be aware, too, that some companies include a provision that unauthorized service may void their warranties. In these cases, be sure to contact the manufacturer for approval. If you provide unauthorized service, you may be held liable and be forced to take over that warranty.

Typically, a solar water heating system has a system or installation warranty separate from the individual component manufacturer warranties. Be prepared to explain this to the customer if necessary. Some service problems that arise during the warranty period may not be covered by the warranty for the item in need of repair or replacement. For example, if a component fails because of faulty installation rather than a product defect, the manufacturer of the product may not be required to repair the component. In this case, the contractor's system warranty, if still in force, should cover the cost to repair the problem.

Another potential gap in warranty coverage falls in the area of freeze damage. Some collector warranties will specifically exclude damage as a result of freezing. In addition, the freeze protection component will typically exclude coverage of incidental damages. If the freeze protection device fails, causing damage to the collector, this exclusion normally relieves the manufacturer of the component of liability for repair or replacement of the collector. The customer can usually seek recourse from the homeowner's policy to recover these costs.

If the customer has warranties that appear to be in force, but the company is no longer in business, all hope is not necessarily lost. If the system was financed, the finance company may be liable for all warranty claims as a "holder in due course." A review of the installment sales contract will usually specify what rights the customer may have in this regard.

Even when the warranty is no longer in force, some contractors replace components at no cost as a goodwill gesture toward the customer. But they are not obligated to absorb this expense. Ask about warranties at the outset so neither you nor the customer is surprised when you prepare the repair estimate.

Service History

Many contractors offer service contracts to their customers, providing either the labor or materials for free, depending on the type of contract. So it is important to determine whether or not you are doing something you do not need to do because the customer has a service contract with another company.

Find out about past service and repairs on the system. If you know a system is five years old, you may think the controller is no longer under warranty. But if the controller was replaced just 90 days ago and is under a one-year warranty, you can take the controller back to the supplier for exchange. The customer will appreciate not having to pay for another controller and will call you back the next time service is needed.

Contractor Liability

Some contractors give customers advice over the telephone about how to correct a problem. If you do this, be aware of potential liability. For example, pushing the reset button on the storage tank is a very simple procedure, and you may suggest that your customers do this themselves. It saves you time and saves them the cost of a service call. But tell them first to turn off the circuit breaker. Emphasize that they should never remove the front plate on the tank until they have turned off the power.

You might rather not give any instructions over the telephone. Even if you only need to reset the heater you can make the visit worthwhile for the customer and for yourself by performing a routine service check while you are there.

Overall Checkout

You should always check the entire system while you are on a service call because many times more than one problem exists. For example, you may replace a defective pump. Later, when this new pump also fails, you find that a defective valve was preventing water from getting to the pump, causing the pump failure. Keep in mind that a “system” requires proper performance of all the components working together.

While you check the system, consider ways you can improve its performance. For example, open-loop systems can include an air vent, a vacuum breaker, a pressure relief valve and a freeze valve. You will find many direct systems do not have all of these components, even though each one has a definite function. You can give the customer a better working system by adding these useful components.

At the same time, do not change the system for change’s sake. Some contractors do not like or do not understand controllers or PV systems. So rather than make repairs, they change the whole system. If you do not want to work on one type of system, refer the job to someone else.

When you first look at a system, prepare an estimate for the customer including the cost, the results and the benefits of the repairs. After you complete the repairs, test the system completely once again. Be sure that it is right. If you have to go back on a second or third call, you lose whatever money you made on your first call. And finally, point out your work so the customer knows what you have done.

Investigating Consumer Complaints – An Example

Suppose a collector loop pipe has burst, but the customer manually drained the system to prevent freeze damage. The collectors were drained using the proper isolation and drain valves; yet the next morning water was trickling from the collector and a pipe was ruptured. Somehow water had gathered in the collector. You should check several possible causes.

First, is the homeowner sure all the water was drained from the collector? Is the system installed to prevent water being trapped when the collectors are drained? Investigation reveals the system contains a vacuum breaker at the collectors and the drain valves are installed in such a manner that one is at a higher level than the other. You determine the amount of water the homeowner says was drained represents what would have been in the collectors and piping – unless, of course, there is a small water trap in the collector or collector piping. If the collector is large and mounted in a horizontal position, are the flow tubes bending in the midsection (creating a water trap)? Investigation reveals no trap.

There could be another culprit – the isolation valve. Although the valve was closed by the homeowner, sedimentation build-up or a malfunction could have caused the valve to leak, allowing water to slowly seep to the collectors, freeze and rupture the pipe.

Lifestyle Analysis

Some people think when they acquire a solar DHW system, they have an unlimited supply of hot water. Be sure they understand the DHW system storage can provide the hottest water during the late afternoon and early evening hours. Keeping this in mind, they should use hot water during these periods to achieve the best results from the system. To minimize their back-up heating expense, they could, for example, take showers and use the dishwasher during the evening and use only small amounts of hot water in the morning. Here are some questions that you may want to ask if the complaint is "not enough hot water" or "high electric use":

1. How many people are using the hot water?

2. Have recent guests added to the water use? How many guests?

3. Have extra washing (clothes or dishes) demands recently been put on the system?

4. When is the family's major use of hot water?

5. Has the weather been clear, allowing the maximum solar heating? Or has it been overcast, especially around the middle of the day?

6. Are water bills higher than usual (perhaps indicating a leak in the system – perhaps a leak under the slab)?

Note: Remember, this is only a sample of the questions service personnel might ask.

II. COMMON PROBLEMS

Some common problems are easy to identify and correct. Other problems, such as "not getting enough hot water" require investigating numerous components, the system design and location, as well as the homeowners' lifestyle. This section first discusses problems that are easy to identify and then describes problems that demand more investigation. A detailed and concise listing of these problems, the components to check, the possible causes, and the corrective actions are listed in Section 4, Module: Troubleshooting Checklist.

The simplest way to find out if the system is working is by turning off or disconnecting the electric back-up element (or other source of back-up heat). Some installers provide a switch near the storage tank for this purpose. In most cases it is necessary to turn off the appropriate circuit breaker at the electrical load center.

Certain symptoms are obvious, but you may find more than one problem. Therefore, once you identify the initial symptoms, continue the diagnostic procedure.

Before you begin the diagnostic procedure, ask the owners to describe any symptoms they have noticed (for example, insufficient hot water, pump running at night, noisy pump or leaking collectors). Use this information and the Troubleshooting Checklist Module to quickly identify the causes. Then follow this procedure to identify other, less obvious problems.

The most common problems are related to the following:

- Controls and sensors
- Pumps and flow rates
- Thermosiphoning and check valves
- Freeze damage
- Collector shading
- System sizing and consumer lifestyle

Controls and Sensors

If the pump operates constantly or does not operate at all, the problem may be in the control system.

The controller itself, a sensor or the wiring might have been damaged by lightning strikes, line voltage surges or short circuiting from water, rust or abrasion. Each of these components should be examined. But if the pump does not operate, the problem could also be in the pump itself or the piping.

Pumps and Flow Rate

If the system controls are working correctly, an inoperative pump may be due to a stuck impeller, a burned-out motor or a broken shaft. These types of problems may be expected over the lifetime of any component subjected to the temperature and cycling stresses of a solar system pump.

Even though a solar pump is operating and is being controlled correctly, there still may be problems with the actual flow rate in the collector loop. If the pump has been sized to just barely overcome the pressure head of the collector loop, an unexpected added resistance can stop all flow through the collector. For example, air in the fluid may, over a period of time, collect in a section of piping, especially if it cannot escape through a vent to the atmosphere. This "air lock" can prevent any flow if the pump does not have the capacity to compress the air completely and force it through the system.

In an indirect system, loss of collector fluid pressure can also prevent flow in the collector loop. The pump is generally not sized to overcome the static head or pressure due to the difference in height between the top and bottom of the collector loop. It is usually sized to maintain the desired flow against the dynamic head or pressure due to the resistance to flow in the pipes, fittings and valves. If the fluid pressure to overcome the static head is lost, then the pump may not be able to maintain flow against the combined static and dynamic head of the system.

Thermosiphoning and Check Valves

As the liquid in the active system collector loop becomes cooler in the evening or in colder weather, it becomes denser and heavier, flowing down into the storage tank. In turn, it forces less dense, heated liquid up into the collector where this heated liquid cools. This action, if not stemmed with a properly operating check valve, can result in excessive loss of heat. In addition, this action often deceives the collector sensor and controller into believing the collector is hot and thereby activating the pump intermittently during the evening and colder nights.

The most common check valve utilized in active solar systems is the vertical ring check valve. Unfortunately, scale and sedimentation build up over time may prevent this valve from seating completely. Defective valves must be cleaned of all sedimentation and corrosion or replaced. A simple and relatively accurate method of determining if the check valve is defective is to check the operation of the pump at night. If the pump is turning on and off (on differential controlled systems), leaking through the check valve and thermosiphon heat loss is indicated.

Freeze Damage

Burst collector tubes and piping are a result of an improperly functioning freeze protection system. In a differential controlled system, the fault may lie in the freeze sensor operation, in the sensor's location or in the controller itself. If the system has a freeze sensor but no freeze protection valve, a power failure during a freeze could result in pipe rupture. It is not uncommon to have a power failure during a freeze.

In a system using an automatic freeze prevention valve, the valve or its location may be at fault. This type of valve often fails to reseat properly after opening. Extreme temperatures during summer conditions can affect the calibration and internal components of the valve, which in time may lead to failure or leakage. A leaking valve should be removed, serviced and recalibrated per manufacturer's recommendations or replaced to ensure proper operation during the winter season.

Freeze damage can also occur when the collector is "drained." (Some systems have "traps" in the piping that prevent complete drainage.)

Other Potential Problems

The common problems discussed above are fairly easy to diagnose. The following problems require more investigation because they cannot readily be seen.

Shading the Collector

Collector shading may not be a problem in the summer months, but during winter months, the sun is at a lower position in the sky and shading from adjacent trees or man-made structures may occur. Relocation of the collector or trimming vegetation causing the shade are the only solutions. In both cases, use the *Crome-Dome Collector Siting Aid* provided in the Appendix or an appropriate site selection device to make sure that shading of the collector does not occur.

Pipe Insulation Degradation

Ultraviolet (UV) rays and extreme system temperatures accelerate degradation of many materials, especially exterior pipe insulation. Although many manufacturers claim their pipe insulation contains ultraviolet inhibitors and does not require a protective coating, sustained exposure appears to degrade almost every unprotected material.

Therefore, all insulation should be inspected for degradation and be replaced as necessary. Exterior insulation should be coated with UV resistant material. Several insulation manufacturers offer a coating for this purpose. Latex paint that matches the roof color and has pigments that inhibit UV degradation is also available.

Insulation that has degraded due to high temperatures must be replaced with a brand that can withstand such temperatures. This is critical for insulation that is used on the collector return line directly adjacent to the collector. When replacing exterior insulation on the roof area valves, take care not to restrict the operational parts of these valves.

Equipment Sizing

If solar system equipment is sized improperly, the homeowner might not have enough hot water or might have excessive utility costs. Use the *FSEC Simplified Sizing Procedure for Solar Domestic Hot Water Systems* provided in the Appendix to determine proper system sizing.

III. SYSTEM CHECKOUT

Use the following procedures to diagnose system problems and can also be used to verify that new systems are installed correctly and working properly.

The simplest way to find out if the system is working is by turning off or disconnecting the electric back-up element (or other source of back-up heat). Some installers provide a switch near the storage tank for this purpose. In most cases it is necessary to turn off the appropriate circuit breaker at the electrical load center.

With the electric back-up element off, the system – if it has been properly sized to the owner's demand – should provide ample hot water on bright, sunny days and even on days with a modest amount of cloud cover. If the system fails to provide enough hot water, or if the water is not hot enough (lower than 115°F), something may be wrong with the system operation. Use the following procedure to identify the problem and its cause.

Certain symptoms are obvious, but you may find more than one problem. Therefore, once you identify the initial symptoms, continue the diagnostic procedure.

Before you begin the diagnostic procedure, ask the owners to describe any symptoms they have noticed (for example, insufficient hot water, pump running at night, noisy pump, or leaking collectors). Use this information and the *Troubleshooting Checklist Module*, to quickly identify the causes. Then follow this procedure to identify other, less obvious problems.

1. **Collectors**. Standing on the ground outside and looking at the collectors, verify these details:

   a. They receive very little shading, if any, from three hours before solar noon to three hours after, for all seasons of the year. (*Appendix: Crome-Dome Collector Siting Aid* gives a method for estimating the sun's location in relation to the collector for all seasons of the year.)

   b. They face approximately south (within 45° east or west of south). If they are oriented outside of this range, collector surface area should be increased above normal sizing requirements.

   c. They have a reasonable tilt. To maximize solar system performance in the winter, proper tilt is latitude plus 10°-15° from horizontal. For example, in Orlando, Florida, optimum tilt is 43° (28° + 15° = 43°).

   d. They are not leaking. Water running off the roof or collector fluid stains from the collector area indicates an obvious leak.

   e. For systems utilizing PV modules as the control method, the PV module is not shaded or covered with dirt.

   Any of these problems reduces the performance of the system. However, avoid climbing on the roof at this stage unless you have determined the exact problem and need to perform repairs or service.

2. **Back-up heating element**. At the storage tank, check to see if the electric back-up element is on or off. Solar tanks usually have only one element, located in the upper area of the tank. The element may be wired to a separate switch, but by code, it must also be controlled by a 230 VAC breaker at the house load center.

If it has been off for some time and the area has just experienced a period of cloudy weather, the storage tank won't contain much hot water. If it is on and it is also a bright sunny day, turn the element off so only the solar system operates for the rest of the procedure. For your own *safety*, make sure that it stays off for the remainder of the procedure.

If the symptoms warrant it, remove the element cover plate and check the setting on the tank thermostat. Set it to the lowest necessary temperature (usually about 120-125°F). Finally, make sure the bottom element, if any, is properly disabled or if a conventional tank is used, set to a low temperature. Sometimes, the over-temperature breaker above the thermostat has deactivated the element. To reset this breaker, simply press the reset button. (See *Appendix: Electric Water Heater Circuitry* for a description of the operation of an electric water heater.)

3. **Plumbing attached to the tank.** Inspect the plumbing attached to the tank(s). Identify and verify the proper connection of each of the following elements according to the system manual or the plumbing schematics in this publication. (In some cases, the tank may be different from the one diagrammed in the manual and have different plumbing connections. Note these variations.)

   a. *Hot and cold water service connections.* If there is a tempering valve, is it connected properly? Generally, the hot, cold and mixed ports of the valve are marked, as are the connections to the tank.

   The mixing valve should also be located below the top of the tank so it is not continuously exposed to the hottest water of the system. Check the temperature setting of the valve. (Keep in mind that some anti-scald valves can be installed above the top of the tank.)

   b. *Collector supply and return connections.* Does the supply line run from the bottom of the tank and the return line from the collector deliver water below the thermostat of the back-up heating element? Systems that utilize a timer as the pump control method can have collector supply and return lines located at the bottom of the storage tank.

   Finally, note where the pipes penetrate the ceiling/roof so the lines may be traced for proper connection at the collectors).

   c. *Control valves and their settings.* A serious problem can sometimes be traced to a valve being incorrectly open or closed or having been installed in the wrong location.

   d. *Pump and check valve.* Generally an arrow or some other symbol on the pump and the check valve indicates the direction of water flow. Be sure these devices have been installed so flow is in the right direction. (The check valve may be covered by insulation. You can usually find it by feeling the pipes through the insulation.)

e. *Piping insulation.* Check the insulation around the tank. Ensure there are no uninsulated pipes or valves. At least two feet of the “cold-in” and “hot-out” lines should be insulated. If convenient, check for pipe insulation in the attic. Note deficiencies for later service.

Pressurized Indirect Systems Only:

f. *Expansion tank.* Check the expansion tank location. The commonly used diaphragm type tank may be installed anywhere in the collector loop and in any position. However, for the most efficient pump operation, it should be located on the suction side of the pump with the distance between the pump and expansion tank as short as possible.

An expansion tank may also be used in the water side of an indirect solar system if a back-flow preventer is installed on the cold-water supply line. The tank must be sized to accommodate any expansion in the total storage capacity of the hot water system.

g. *Pressure gauge.* The system fluid is generally charged to a static pressure (pump not running) of 10-30 psig. If the collectors are located more than one story above the pump, system pressure will be increased. On the discharge side of the pump, the pressure gauge normally registers additional pressure (about 3-5 psig) when the pump is running. The pressure also fluctuates depending on the temperature of the collector fluid.

4. Control system. Locate the control sensors, temperature sensors and the electronic controller box (if one is present). Determine which type of control system is used:

a. *Thermosiphon and integral collector storage (ICS) systems.* Controls and sensors are not needed.

b. *Snap-switch (absolute).* These sensors are attached to the pipes with #14 to #18 gauge wire connected to the 115 VAC supply to the pump motor. Although usually this type of control system does not have a control box, occasionally a control box houses a step-down transformer to supply low voltage to the collector snap-switch.

c. *Timer.* The pump is connected to a simple clock timer plugged into an electrical outlet. Check the time and on/off settings and that the timer functions properly.

d. *Differential temperature.* Sensors are attached to a controller by two small wires. The controller is plugged into a 115 VAC electrical outlet. Once you have located everything in the control system, consult the manufacturer’s information or controller labels to ensure everything is connected properly.

e. *Photovoltaic (PV).* The PV module is generally wired directly to a DC motor pump with from #14 to #18 gauge wire. Sometimes an electronic pump starter is connected in between the PV module and the pump to facilitate current matching. There may also be an on/off switch. Check the switch position and all connections.

5. **Pump operation.** Check the operation of the pump. Confirm that it is plugged in or wired correctly and power is available. Some controllers have an on/off automatic switch and you can manually place the switch "on." You can usually hear a slight hum when the pump is running. You might also be able to see the motor fan moving or feel a slight vibration.

WARNING! Many pump motors are very hot after operating continuously for some time.

In some systems, an indicator lamp on the controller signals when power is supplied to the pump. When this indicator is on, the pump should run.

a. *Sunny day.* On a sunny day, the pump should run most of the time. If the system has a differential temperature controller or PV module, passing clouds may cause the pump to cycle on and off occasionally.

If the system has a snap-switch control, the pump tends to turn on and off more often.

b. *Cloudy day.* On a heavily overcast day or at night, the pump should not run. To see if an AC-powered pump is defective, unplug it from the controller and plug it directly into a wall outlet. If the pump does not have its own plug, direct wire the pump to power (bypassing the controller and/or switches).

CAUTION: Do not attempt this procedure if *you* are not familiar with safe electrical practice.

It is generally easier and safer to "fool" the controller into turning on the pump. See item *7a., Differential controller test.*

6. **Flow in the collector loop.** If there is a flow meter or indicator in the collector loop, determine if the fluid is actually moving. If there is no flow indicator, use the following methods:

a. *Sunny day*. If it is a sunny day and the pump is running, pull back a portion of the insulation on both the collector supply and return pipes (at points a few feet from the tank). Carefully feel (or measure with a thermometer) the pipes to make sure that the return line from the collector is hotter than the supply line going to the collector. On a sunny day, such a temperature difference (usually 5-15°F) indicates fluid is flowing in the collector loop.

If you cannot detect a temperature difference, turn the pump off by disconnecting its power supply. Leave the pump off for a few minutes; long enough for the fluid in the collector to heat up. Then restart the pump and feel the pipes again.

Within several seconds, you should feel the hotter fluid from the collector pass through the collector return line into the tank. If you do not feel this surge of hot fluid on a sunny day, there is probably some blockage in the collector, the pump, the valves or the pipes.

b. *Cloudy day or at night.* On a very cloudy day or at night, you can still use the above procedure to check for flow in the collector loop. However, make sure the pump has been off for a long time, so that the fluid in the collector is relatively cool.

Then, when you turn on the pump again, you should feel a surge of cool fluid pass from the collector into the tank. Of course, this method works best on colder nights.

To determine the actual flow rate through the solar collectors, use a flowmeter or one of the methods discussed in *Appendix: Solar System Flow Rates*. Check the controller operation before determining the exact flow rate.

7. Control system operation. Conduct the following tests to check the control system.

> **WARNING:** For any procedure involving electrical equipment, always turn off or disconnect the unit from the power supply before making any adjustments or resistance measurements.

a. *Differential controller test.* You may need to follow the manufacturer's checkout procedures to not void the warranty. If their procedure is unavailable, you can follow these steps to check most differential controllers with thermistor sensors.

i. Disconnect and separate all sensor inputs. Identify the sensor wires for proper reconnection.

ii. On drain-down controls that use normally closed freeze sensors, short the freeze sensor input wires or terminals at the control.

iii. With the controller in its normal operation or automatic switch position, short the collector sensor input wires or terminals together. The control should turn on (indicated by lights and/or pump operation).

iv. Remove the short and the control should turn off. (Some older-model controllers may utilize a time delay circuit to keep the pump from cycling on and off too often.)

v. The controller is probably in good condition if it responds correctly to these steps. Test the temperature sensors next before proceeding to a more detailed test of the controller.

For the differential controller that uses resistance/temperature devices (RTDs) – positive temperature coefficient sensors – the tank sensor input should be shorted in Steps iii and iv. Shorting the collector sensor indicates a low temperature and the pump should stay off. Shorting the tank sensor should turn the pump on. If freeze protection and the collector sensor functions are combined, shorting the collector terminals simulates a freeze condition. The pump should turn on if recirculation freeze protection is used.

b. *Sensor test. To* check the temperature sensors of a differential controller, measure their resistance. Disconnect the sensors from the controller terminals or lead wires and use a volt-ohmmeter to measure the resistance across the sensor wires.

For thermistors and metal film sensors, compare their resistance to the manufacturer’s temperature versus resistance specifications. Also, see *Appendix: Volt-ohmmeter (VOM) or Multimeter Operation.*)

Generally there are two types of thermistor sensors: a 3,000 ohm sensor and a 10,000 ohm sensor. Sensor resistance should match the measured temperature as closely as possible. (See Table 1 in *Appendix: Volt-ohmmeter (VOM) or Multimeter Operation.*

For example, when the environment temperature is 77°F, the 3,000 ohm sensor should read 3,000 ohms, and the 10,000-ohm sensor should read 10,000 ohms. As the temperature increases, the resistance decreases. At 90°F, a 3,000 ohm sensor reads 2,200 ohms; a 10,000 ohm sensor reads 7,333 ohms.

The general range of solar system temperatures is 70-140°F for the tank sensor and 100-150°F for the collector sensor depending on the time and conditions of day. If an “open” or “short” condition is indicated, check the wiring between the controller and sensor.

A common cause for an “open” condition is a broken connection between the wiring and the sensor. A “short” may be caused by a piece of metal pinching the sensor wire and conducting it to ground or causing it to short across the wires.

For temperature-actuated switches (freeze sensors, upper limit sensors, and snap-switch controls), you can also check the switch position with a volt-ohmmeter. The switch is either normally open or normally closed, and changes position at a particular temperature. You can check the freeze sensor by placing it in ice water and measuring with the VOM to see that the switch changes position.

c. *Detailed controller test.* A complete method of checking the controller involves the use of a differential controller test set. Containing fixed and/or variable resistances, the test set is generally calibrated for a specific manufacturer’s line of controllers, though it can be adapted to test other brands of controllers. Instructions for its use are usually supplied with the tester.

The test set enables you to determine the exact “turn-on” and “turn-off” temperatures of the controller. Compare these differential temperatures to the manufacturer’s specifications. If the measured temperatures do not match the specifications, and if the setting is adjustable, you can change the setting to match the manufacturer’s recommendations.

d. *Photovoltaic (PV) module controller test.* Use the following procedure to check the voltage and current output of the photovoltaic module on a sunny day:

i. Disconnect the pump from the wires coming from the PV module or pump starter box.

ii. With a volt-ohm-meter, check the voltage between the positive and negative terminals of the PV module. This open-circuit voltage should be between 14 and 22 volts, in almost any amount of sunlight.

You should also check the PV module's short-circuit current with a volt-ohm-meter (with milliamp measurement capability). Under sunny conditions, the short-circuit current should be between 200 and 1000 milliamps, depending on the voltage rating of the PV module. If there is no amperage at good sun conditions, the PV module or the connecting wiring may be defective. (Do not exceed the amperage measurement capacity of your meter.)

If there is no amperage at the pump, check the amperage of the module at its roof location to determine if there is a break in the connecting wiring.

iii. To check the DC-powered pump, use two 6-volt lantern batteries connected in series (12V). Disconnect the PV panel from the pump and connect the pump to the proper terminals of the batteries. If the pump does not operate off the batteries, the pump is defective. If the pump does run off the batteries, the PV module or connective wiring is defective.

8. Heat-transfer fluids and the collector loop. For indirect systems, inspect the heat transfer fluids; for direct systems, inspect the collector loop.

Perform item 8a for pressurized indirect systems only:

a. *Evaluate heat-transfer fluids.* All heat-transfer fluids must be inspected and evaluated periodically. Most fluid manufacturers and system vendors recommend periodic inspections. To check the fluid, remove a few ounces from a fill or drain point. (Be careful not to spill any fluid and do not allow air to enter the system.)

To determine the average condition of the fluid, take the sample from a point above the bottom of the collector loop, during a period when the system is operating.

Examine the sample for rust, scale, water deposits, sludge and gummy materials. Rust or scale accumulation is probably the result of degradation of iron in the system. If you find water in the sample, look for system or heat exchanger leaks.

Sludge in the sample indicates heat transfer fluid degradation, which in time can lead to clogs in the collector and heat exchanger loop. Fluids can deteriorate some plastic seals and gaskets. Gummy materials in the sample usually indicate this deterioration is occurring.

Test the various fluids using the specific manufacturer's recommended procedures. Be sure to obtain the fluid manufacturer's recommendations for filling, flushing and refilling of various heat-transfer fluids. Some fluids must be completely drained and the system recharged with new fluid. Other fluids may not need to be drained, only more fluid added. In addition, systems using one type of fluid can be flushed with water while other systems must be flushed with specified fluids.

Perform items 8b-f for direct systems only:

b. *Drain the collector loop.* Disconnect the pump and controller from the power supply.

CAUTION: The PV module can be disconnected from the pump only for short periods of time (4-5 hours).

Isolate and drain the collector loop, if drains are available.

CAUTION: If you drain the collector loop on a sunny day, direct the hot water to a safe point of discharge.

A loop that drains easily indicates properly pitched (or tilted) pipes and a path for air to enter the system. A vacuum breaker valve or a system air vent at the top of the collector loop may supply this path. Sometimes air enters during draining only through a second drain valve at the bottom of the loop.

c. *Flush the collector loop.* Isolate and flush the collector loop, preferably in the reverse direction of normal flow. If the check valve is located on the collector supply, use the cold-water service pressure to back flush the collector return. If the check valve is located below the collector return hose bib drain, use a garden hose with a double female adaptor connected to both an outside faucet and the collector return drain.

In both cases, force water out the collector supply drain and through an attached hose leading to a point of safe hot-water discharge. Check this water for dirt, scale and other signs of blockage. Stop when the discharge no longer contains any debris.

If sedimentation build-up in the tank is a problem, isolate the tank and drain several gallons of water to remove any sedimentation. Advise the owner this draining should performed at least once per year and preferably every six months.

d. *Test the check valve.* Use the hose bib drains and service water pressure to check these two valves: a horizontal swing check valve or a vertical in-line ring check valve.

Send water against the normal flow direction. Water flowing past the valve indicates a faulty seat or stuck hinge that will not seal under the low backflow of unwanted thermosiphoning.

Check a solenoid-actuated or motorized ball valve by using the manual lever (if it is present) to open and close the valve while checking for flow. Some motorized valves are not designed to close off against normal city water pressure. Verify the normal operation of these valves by listening to and watching the valve open and close as the pump is turned on and off. Since check valves are very prone to problems from sedimentation build-up, they should be inspected periodically.

If the check valve cannot be tested by the above backflow procedure and it is suspected of being the cause of nighttime thermosiphoning, you need to examine the system at night. When the fluid in the collector has cooled to a temperature sufficiently below the fluid in the tank, feel the collector supply and return pipes a few feet from the heat of the tank. If one pipe is warm, the check valve might not be sealing.

Sometimes a leaking check valve can cause a differential control to cycle the pump at night. To confirm this speculation, unplug the pump from the differential controller and plug a clock into the controller instead. Note the clock's time. Note the time again the next morning before the solar system would normally start. If the clock has advanced because the controller supplied power to it, the check valve is not sealing and needs to be replaced.

To check a mixing valve, feel or measure the temperature of the service hot water at the closest house hot water faucet. As you measure, adjust the mixing valve over its range of motion, leaving it at the desired temperature setting. Sometimes these valves stick open or closed after prolonged use and must be repaired, replaced or eliminated.

e. Purge *air from the system.* With the collector supply isolation valve open, close the collector return isolation valve. Force water out of the collector return line drain (and hose). Close the return line drain when air no longer bubbles out the drain hose. Open the collector return isolation valve.

f. *Plug the pump and controller back in.* Check for proper operation and return the electric heating element switch (if provided) to its original on/off position.

9. Inspect the collectors up close.

Caution: Some roofs can be damaged by a person's weight. Walk slowly and make sure the roof can support you wherever you move. Be careful that you do not break concrete tiles or brittle asphalt shingles.

Look for the following items:

a. *Dirty glazing.* Rain generally does a good job of keeping collectors clean, but occasionally in very dry and dusty weather they will gather a visible layer of dirt and dust. If so, they should be cleaned with mild soap and water. Clean the collectors only when they are not hot to the touch, in the early morning or late evening. Spraying the collectors with a garden hose during early morning or late evening hours is also effective.

b. *Condensation or outgassing on the inside of the glazing.* A major part of the solar energy striking the collector may be blocked by moisture or chemical deposits from outgassing of the collector insulation on the inside of the collector box.

To remove extreme and lasting condensation, take off the glazing, wipe it dry and dry the box. To minimize future water collection, drill small holes (weep holes) in the frame – a few in the bottom of the frame for drainage and two at the top corners to allow warm moist air to escape. Screen the holes to keep out insects.

To clean off inner outgassing deposits, the glazing will have to be removed and the glazing cleaned with a detergent or a solvent such as alcohol. (Depending on the amount of time they have been on the glazing, these deposits may be difficult to remove.)

c. *Leaking connections.* Repair small leaks around fittings and pipes to minimize heat loss from the system. Freeze damage causes many leaks. Generally, leaks appear in the collector flow tubes.

d. *Temperature-pressure relief valve.* Look for stains on the roof around this valve, indicating repeated discharge of collector fluid from over-temperature conditions. This symptom generally indicates a lack of flow in the collector loop even though solar heat is available. (Note that most installations now use pressure relief valves in the collector loop.)

Overtemperature of the collector may be due to a low use of hot water, a faulty upper limit sensor, or air in the collector loop that prevents the pump from maintaining flow. An air vent at the highest point should discharge this air from the system.

WARNING: Lifting the test lever of the temperature pressure relief valve may cause the valve to fail. Be prepared to replace the valve before manipulating the test lever.

e. *Air vent*. When you fill the system, you might hear and even feel a stream of air leaving a properly operating air vent. Most air vent caps must be loose (to permit the air to escape).

NOTE: The cap should be in place to prevent dirt from entering the valve or insects from plugging it, but it should not be completely tightened.

When water reaches the air vent, the vent should close fast, without leaking. Many valves have a stem that can be depressed to allow fluid to escape, flushing the valve seat clean.

CAUTION: When filling a system that has been solar heated, the escaping air may be extremely hot and contain steam until the system reaches normal operation.

f. *Vacuum breaker*. When draining the collector loop, you should be able to hear air entering the valve, permitting water drain-down.

NOTE: In reference to air vents and vacuum breakers, the interior valve seats and float pivots may collect deposits and become inoperative. Disassemble the valve, if possible, and clean it thoroughly to ensure proper operation and to eliminate air pockets and drainage problems.

g. *Pipe insulation.* Look for cracks or splits, opened joints or deteriorating insulation. Most closed cell foam insulation should be wrapped or covered with a protective paint to shield it from ultraviolet radiation. Plasticized vinyl lacquer and exterior latex with a white pigment both protect well and may be found at air conditioning supply stores.

h. *Sensor location.* Sensors placed on the collector outlet need to be in good thermal contact with the pipe and insulated from the surrounding air. Sensors placed inside the collector box generally do not require the same intimate contact and may even have to be separated from the absorber plate. Refer to the manufacturer’s recommendations.

Check the wire leads to these interior sensors to ensure they are not crimped or exposed to the metal of the box. Sensor wires that cross over the metal edges of the box will wear through and short due to weather induced movement of the box and wires.

Also, if a freeze sensor is used, check that it is indeed a freeze-actuated switch, different from the actual collector sensor, and is either wired separately or according to the controller manufacturer’s recommendations. The freeze sensor also needs to be in good thermal contact with the pipe or collector plate and to be insulated from the surrounding air.

i. *Collector anchoring.* While not directly affecting the efficient operation of the solar system, improper mounting of the collectors can cause serious problems, such as roof leaks or building damage from high winds.

Supports should be durable, materials tightly fastened, and mountings strong enough to resist the near-hurricane force winds to be expected in Florida. Roof penetrations should be well sealed with a durable roofing sealant to prevent leaks and interior water damage.

j. *Collector piping.* When the system has two or more collectors, they should be plumbed in a parallel configuration, unless the manufacturer suggests otherwise. The pipes and interior collector tubes should all have a continuous slope (1/4 inch per foot).

They should not contain any low pockets that do not drain or high pockets that capture air. Use a builder's level to correctly determine proper pipe slope, as the roof or shingle line may not be level.

k. *Photovoltaic (PV) module.* Ensure the PV module is securely mounted and properly oriented for the geographical area and collector mounting. Check that all electrical connections are secure and wiring is protected from environmental degradation.

Section 4
Module: Troubleshooting Checklist

Introduction

When the symptoms for problems have been identified, the following checklist can be used to determine the probable causes and the appropriate corrective actions. During system evaluation, the complete system should be checked to identify any other situations that might lead to more problems. A well-maintained system is the best insurance against future problems.

Solar system problems are difficult to organize because no problem is more important than another – to the solar system owner, any problem is important.

The checklist begins with problems relating to water temperature. It continues with general system problems and problems relating specifically to the controller, and then system leaks and drainage.

PROBLEM	CHECK THIS	POSSIBLE CAUSE	CORRECTIVE ACTION
No hot water	Auxiliary Heater (electric)	No power to auxiliary back-up heating element	Check high temperature protection and push reset button above thermostat. (Use caution when dealing with electricity.)
	Auxiliary heater (gas)	Failure to ignite	Check pilot light mechanism
		Safety switch malfunctioning	Check and replace
		Defective automatic pilot valve	Check and replace
		Pilot wont stay lit:	
		Too much primary air	Adjust pilot shutter
		Dirt in pilot orifice	Clean and open orifice
		Pilot valve defective	Replace
		Loose thermocouple connection	Tighten
		Defective thermocouple	Replace
		Improper pilot gas adjustment	Adjust
	Auxiliary heater thermostat	Thermostat defective	Replace
	Mixing and/or anti-scald valve	Improper adjustment	Check water temperature at house faucet and adjust valve setting
		Valve defective	Replace or remove from system plumbing
	Distribution piping	Leak (under slab or in walls)	Locate leak and correct
Not enough hot water	Auxiliary heater	Undersized for hot water demand load	Replace
		Storage tank losses	Insulate tank
		Thermostat set too low	Increase set point temperature

Not enough hot water (Cont.)		Element failure	Replace element
		Thermostat failure	Replace thermostat
		Lower element disconnected in conventional rank system	Reconnect element and set thermostat to low temperature
	Check valve	Heat loss due to defective or improperly installed check valve	Inspect valve and repair or replace
	Solar return dip tube	Missing, wrong location, defective	Replace dip tube
	Cold water supply dip tube	Missing or wrong location	Install in proper location
	Collector(s)	Absorber coating degradation	Recoat or replace absorber (Contact manufacturer)
		Area undersized	Increase collector area (See FSEC Sizing Guide)
		Excessive condensation	Inspect and repair glazing seal, pipe gaskets and weep holes and vents at bottom
		Glazing dirty	Clean as required
		Leaks	Repair
		Orientation	Check orientation. Face collector " 45° east or west of south
		Outgassing inside collector glazing	Clean surface and contact manufacturer
		Plastic glazing deteriorating	Replace
		Reduction of glazing transmission	Replace glazing
		Shaded by tree(s) or building(s)	Remove obstacle and shading or relocate collectors(s)
		Improper tilt	Check tilt for geographic area. Set " 15° of latitude
		Improperly plumbed	Compare with system schematic in installation manual
	Differential controller	Improper operation (cycling, late turn on)	Check sensor placement and insulation from ambient conditions
		Faulty sensors or controller	Conduct resistance measurement or check by placing sensors against hot and cold-water glasses and watching pump function. Replace defective units.
		Improper wiring or loose connections	Compare with system schematic. Check for proper connections. Seal all splices against moisture.
		Shorted sensor wiring	Check wiring for breaks, metal contact, water exposure and corrosion.

Not enough hot water (Cont.)	Heat exchanger	Sized too small	Replace with properly sized heat exchanger. Insulate.
		Scaling, clogging	Back flush, clean
	Isolation valves	Closed	Open
	Mixing/Anti-scald valve	Improperly adjusted	Reset temperature indicator
	Owner	High water usage	Check system size and discuss solar system and owner's lifestyle
	Piping	Clogged with corrosion or sediment	Replace excessively corroded components
		Insufficient insulation	Add insulation where required
		High heat losses	Check insulation for splits, deterioration, absence
		Nighttime thermosiphoning	Check for pump operation at night.
		Improperly plumed	Compare with system schematic. Check flow direction.
		Isolation valves closed	Open valves
		Isolation valve failure after closing	Replace valve
		Flow blockage	Flush system. Check effluent for dirt/scaling.
		Low system pressure	Check pressure gauge. Refer to owner's manual for correct pressure.
	Pump	No power	Check breaker, pump, and controller. Repair or replace.
		Flow rate too high or too low	Adjust flow rate
		Defective	Check and replace
		Activation switch off	Check for switch on PV to pump wiring
		No power	Check breaker, pump cord, controller fuse, if any. Replace if necessary.
		Faulty pump	Listen for irregular noises in pump operation. Feel collector feed and return pipes for temperature difference.
		Runs continuously	Check control system for breaks and shorts
		Improperly installed	Compare with system schematic
	Sensors	Improper wiring, cuts, or loose connections	Check and correct
	Sensor wiring	Shorted wiring	Check and repair
	Storage tank	Too small	Install larger tank
		Storage losses	Insulate tank with insulation blanket

Troubleshooting Checklist

PROBLEM	CHECK THIS	POSSIBLE CAUSE	CORRECTIVE ACTION
No hot water in morning	Check valve	Stuck open or does not seat	Replace check valve
	Controller	Sensor wires reversed	Check wiring and reconnect
	Water heater circuit breaker	Water heater circuit breaker shutoff	Turn breaker back on
	Freezing conditions at night	Recirculation freeze protection (with back-up power off)	Turn back-up power back on (circuit breaker)
	Occupants	Excessive consumption	Discuss hot water usage. Check system size and auxiliary heater status.
Water too hot	Auxiliary heater	Thermostat set point too high	Reduce set point temperature
	High limit sensor	Improper calibration	Check, recalibrate and replace
	Occupants	No hot water use (vacation, etc.)	Run hot water to reduce tank temperature
	Mixing or anti-scald valve	Temperature set too high	Adjust
	Mixing/anti-scald valve	Valve failure	Replace valve
No water	Cold-water supply valve	Valve closed	Open valve
High electric use	Piping, hot water distribution	Leak	Repair leak
	Tank	In dual element tank, lower heating element	Turn to low setting or disconnect
	Tank thermostat	Thermostat set too high	Check setting and adjust to desired temperature
		Inaccurate temperature dial	Recalibrate or replace
	Tank dip tubes	Collector return above tank thermostat	Increase length of dip tube
	Piping	Collector return above tank	Check tank plumbing. Contact installer, if necessary.
Pump does not start	Differential controller	Controller switch in “off” position	Turn to “automatic” or normal operating position.
		Unplugged	Return power to controller
		On and/or off temperature differential set points too high	Reset according to specifications
		Loose contacts	Clean contacts and tighten connections or replace
		Defective components	Replace components or controller
	Controller circuitry	Sensors connected to wrong terminal	Correct per manufacturer’s recommendations
	DC pump	Loss of circuit continuity	Check and repair or replace
	Electrical power supply	On/off switch is “off”	Turn to “on”
		Blown fuse or breaker tripped on overload	Determine cause and replace fuse or reset breaker
		Brownout	Await resumption of utility power
	Photovoltaic module	Shaded	Relocate or eliminate shade

Pump does not start (Cont.)		Defective	Check and replace, if required
	Photovoltaic wiring	Improper wiring, cuts or loose connection	Check and repair
	Pump	Motor failure	Check brush holders and other mechanical components that may be loose, worn, dirty or corroded. Replace as appropriate and reasonable. Check for thermal overload.
		Pump motor runs when started by hand. Capacitor failure.	Replace capacitor
		No power	Check breaker, cord and controller
		Stuck shaft, impeller, or coupling	Replace
		Frozen bearings	Replace
	Sensors	Defective sensor(s)	Replace
		Improper installation	Clean and reinstall properly
		Sensors out of calibration	Recalibrate or replace
	Sensor wiring	Defective sensor wiring	Repair or replace
		Open collector sensor wiring	Check wiring continuity. Repair or replace.
		Shorted tank sensor wiring	Check wiring for continuity. Repair or replace.
	Timer	Defective	Replace
		Wrong on and/or off time	Reset, check battery.
Pump starts, but cycles continuously	Differential controller	On and off temperature differential set points are too close together	Reset according to specifications
		Freeze protection setting too high	Reset according to specifications
		Faulty controller	Use controller test set to perform operation check. Repair or replace.
	Piping	Reversed connections to collector	Reconnect properly
	Sensors	Improper location	Relocate sensors as per system design or manufacturer’s requirements
		Not properly secured	Secure properly and insulate from air
		Faulty	Test sensors. Replace if necessary.
Pump cycles after dark	Sensor wiring	Interference from radio or garage door opener, etc.	Use shielded sensor wire
		Radio frequency interference from close proximity to antenna.	Use shielded sensor wire
	Check valve	Does not seat	Replace

Troubleshooting Checklist

PROBLEM	CHECK THIS	POSSIBLE CAUSE	CORRECTIVE ACTION
Pump runs continuously	Controller	Off temperature differential set point too low	Reset according to specifications
		Lightning damage	Replace controller
		Controller in "on" position	Turn to "automatic" or normal run position
	Sensor(s)	Sensor(s) out of calibration	Recalibrate
		Defective sensor	Replace
		Improper installation	Reinstall
	Sensor wiring	Interference from radio/garage door opener, etc.	Shielded cable may be necessary
		Shorted collector sensor wiring	Check wiring for continuity. Check wiring connections for weather tightness. Repair or replace.
		Open tank sensor wiring	Check wiring for continuity. Check wiring connections for weather tightness. Repair or replace.
Pump operates but no fluid flows from collector	Air vent	System air-locked. Air vents closed.	Disassemble and clean seat and seal. Replace if necessary.
		Improper location	Install at the highest point. Install at all high points if possible air trap locations exist. Install in true vertical position.
		Air vent cap tight	Loosen ¼ turn
	Check valve	Installed improperly	Check flow arrow on valve to ensure direction is per system design
	Collector	Flow tubes clogged	Flush collector tubing
	Drain-down valve	Drain-down valve stuck in drain position	Clean cause of sticking. Check power to valve.
	Fluid	No fluid in direct system	Open cold-water supply valve
		Loss of fluid in indirect system	Locate leak and refill
		Loss of fluid in drain-back system	Cool system, locate leak, refill properly
	Isolation valves	Valves in closed position	Open valves
	Piping	Clogged or damaged piping	Unblock piping or repair damaged piping
	Pump	Broken impeller shaft	Replace shaft
		Impeller broken or separated from shaft	Replace impeller and/or shaft or replace pump
		Improperly installed	Install to ensure correct flow
		Not vented properly	Install in correct orientation
		Undersized	Check pump specifications. Change pump if required.
	Valves	Valves closed	Open valves

Troubleshooting Checklist

PROBLEM	CHECK THIS	POSSIBLE CAUSE	CORRECTIVE ACTION
Pump cycles on and off after dark	Check valve	Corroded or defective check valve	Repair or replace
Pump runs after dark, but eventually shuts off	Sensors	Defective	Change sensor
		Improper location	Relocate
		Sensor not insulated	Insulate
No power to pump with switch on	Sensor (freeze)	Open circuits	Check sensor and wiring. Repair or replace.
	Controller output relay	Weak or failed relay	Replace relay or controller
Noisy pump	Air vents	Air trapped in system	Open automatic air vent
	Pump bearings	Dry or excessive wear	Lubricate or replace
	Pump impeller	Loose impeller	Tighten or replace impeller
	Pump location	Pump enclosed in small room (closet)	None
		Pump attached to wall – wall acts as amplifier	Relocate pump if noise is unacceptable
	Pump volute	Corrosion or particles in volute	Clean volute and impeller. Replace if required.
	Vent port on pump (if applicable)	Air trapped in pump	Open vent port and/or vent valve and bleed air
Noisy system	Pump	Bearings need lubrication (if applicable)	Oil per manufacturer's recommendation
		Air locked	Bleed air
	Piping	Entrapped air (direct systems only)	Purge system by running water up supply pipe and out drain on return line (isolation valves closed)
		Pipe vibration	Isolate piping from walls
Controller does not turn on or off in the "automatic" mode but operates in the "manual" mode	Controller	Defective	Conduct function check and repair or replace
	Sensors	Defective sensors; resistance problem; sensors off scale	Check with multimeter (ohm). Correct or replace sensors.
		Improper contact or insulation	Ensure proper contact is made. Insulate sensors.
		Improper location	Relocate
	Wiring	Short or open	Replace or splice wire
System shuts off at wrong high limit or continues to run	Controller	Defective	Repair or replace
	Sensors	Defective sensor	Check with multimeter (ohm) and replace
		Improper location	Relocate
System leaks	Collector(s)	Pipe burst due to freeze or defective joint	Repair or replace. Check freeze-protection mechanisms.
	Freeze-protection valve	Did not reseal after opening	Recalibrate, if required, or replace.
System leaks (Cont.)		Valve out of calibration	Recalibrate per manufacturer's instructions or replace

		Normal operation (most open at 42°F)	No action
	Hose connection	Clamps not tightly secured	Tighten clamps. Replace clamp or hose.
	Pipe joints	Thermal expansion and contraction.	Replace and provide for flexibility
		Joint improperly made	Reassemble
		Improper seal in system using glycol solution	Make a good seal. Use recommended sealer. Note: glycol will leak through joints where water would not.
	Pressure-temperature relief valve	Did not reseal after opening	Replace
		Defective	Replace
		Improper pressure or temperature setting	Reset, if possible, or replace
	Valves	Valve gland nuts loose	Tighten nuts. Replace seal or packing if necessary.
		Seats deteriorating	Replace seat washers. Redress seat. Replace valve if necessary.
Water comes off the roof	Pressure-temperature relief valve	Defective seal	Replace
		Activates due to no circulation through collector(s)	Check flow in collector loop. (See “Pump does not start” and “Pump operational but no flow to collector.”)
	Freeze-prevention valve	Out of calibration	Calibrate, if possible, or replace.
		Defective seal	Repair or replace
		Normal operation (most open at 42°F)	No action
	Collector piping	Ruptured piping due to freeze	Repair or replace
		Defective piping	Repair or replace
	Low-pressure valve installed on collector supply line	Power loss. Pressure loss from well.	No action required.
System does not drain	Collector (parallel)	Fins and tubes are horizontal and are sagging, preventing drainage from occurring	Straighten fins and tubes. Realign collector so it will drain completely
	Collector (serpentine)	Serpentine design prevents drainage	Blow water out of tubes with air compressor
	Piping	Insufficient slope for drainage	Check and ensure piping slopes ¼" per foot of piping
	Vacuum breaker	Does not open. Defective due to internal mechanism or corrosion.	Clean or replace

Section 5: Solar Swimming Pool Heating Systems is devoted to solar systems that heat swimming pools.

- **Module: System Components, Installation and Operation** illustrates and describes the physical elements of solar pool heating systems. Guidelines for component and system installation are provided.

Section 5
Module: Pool System Components, Installation and Operation

Solar pool heating is a task for which solar energy is admirably suited. Desired pool temperatures range from 72°F to 85°F, only slightly above the winter daytime mean temperature in most of Florida. This small temperature differential permits the installation of solar pool heating systems which are simple and inexpensive and which operate with high efficiencies.

Economics

Solar swimming pool heaters save money. They represent an outstanding example of a use of solar energy that is economical today. Everyone benefits from their use – the pool owners reduce their monthly pool heating expenses, the installation contractor can make an acceptable profit and our nation has more gas and oil for critical needs.

Heat Loss Mechanisms

Evaporative Losses

Heat loss due to evaporation is familiar to anyone who has ever stood in a breezy spot, wearing a wet bathing suit. Evaporation cools the surface of a swimming pool in the same way.

The rate of evaporation from a pool surface is dependent upon wind velocity, air temperature, relative humidity and pool water temperature. Common everyday living experiences illustrate the way in which these variables affect that rate. Standing in the wind or in front of a fan accelerates evaporation, making a person feel cooler, but on warm, muggy days with high relative humidity, evaporation is inhibited and it is hard to stay comfortable.

Warm water evaporates more rapidly than cool water. Up to 70 percent of a swimming pool’s heat energy loss results from evaporation of water from its surface. Evaporative losses are directly proportional to wind velocities at the pool surface and are higher from warm pools than from cooler pools.

Because most of the heat loss from a swimming pool is caused by evaporation of water from the surface, every effort should be made to reduce the evaporation process. Air temperature and relative humidity (both of which influence the rate of evaporation) are beyond our control.

Convective Losses

Convective losses occur when air cooler than the pool water blows across the pool surface. The layer of air that has been warmed by contact with the water is carried away by the wind and replaced with cooler air – a process that continues as long as the air is in motion. Anyone who has been exposed to a cold winter wind knows that convective heat loss can be substantial and that it increases with the wind's speed. Detailed observations show the heat energy lost from a pool in this fashion is directly proportional to the wind speed at the surface – doubling when the air velocity doubles.

In Florida, as much as 20 percent of a swimming pool's thermal energy loss is caused by convection. Because pools openly exposed to the wind will lose proportionally more energy than will shielded pools, windbreaks are desirable to reduce wind speed at the pool surface. Windbreaks such as hedges, trees, solid fences, buildings and mounds should be placed so as to shield the pool from cool winds. The direction of prevailing winds for any given month is available from your nearest weather station. Remember that cool winds come from the N, NE or NW in Florida.

Radiative Losses

Swimming pools radiate energy directly to the sky, another important energy loss mechanism.

Under normal conditions, clouds, dust and Florida's high humidity raise the year-round average sky temperature to only about 20°F less than the air temperature. Even with a small difference in temperature between the pool surface and the sky, radiative losses may exceed 10 percent of the total swimming pool energy losses.

Conductive Losses

Since a swimming pool is in direct contact with the ground or air around it, it can lose heat energy by conduction. The amount of energy transferred even from above ground pool walls to the air is quite small compared to the amount lost from the pool surface to the air. Dry ground and concrete are relatively good insulators, so the energy lost through the sides and bottom of an in-ground pool is also small. In fact, much of the energy conducted into the ground during the day is recovered when the pool temperature drops slightly during the night. In general, conductive losses through the walls of in-ground pools may be ignored.

However, pools immersed in groundwater that is influenced by tidal motion will lose an increased amount of energy through their walls. Heat flows from the pool to the ground-water surrounding it. As the groundwater is moved by the tides, it will be replaced periodically by cooler water. The quantity of heat loss in this situation is higher than for pools in dry ground and is not negligible. This loss is still low compared to losses through evaporation, convection and radiation.

Figure 1 summarizes the principal heat loss mechanisms for underground pools and shows their relative magnitude under one hypothetical set of Florida weather conditions.

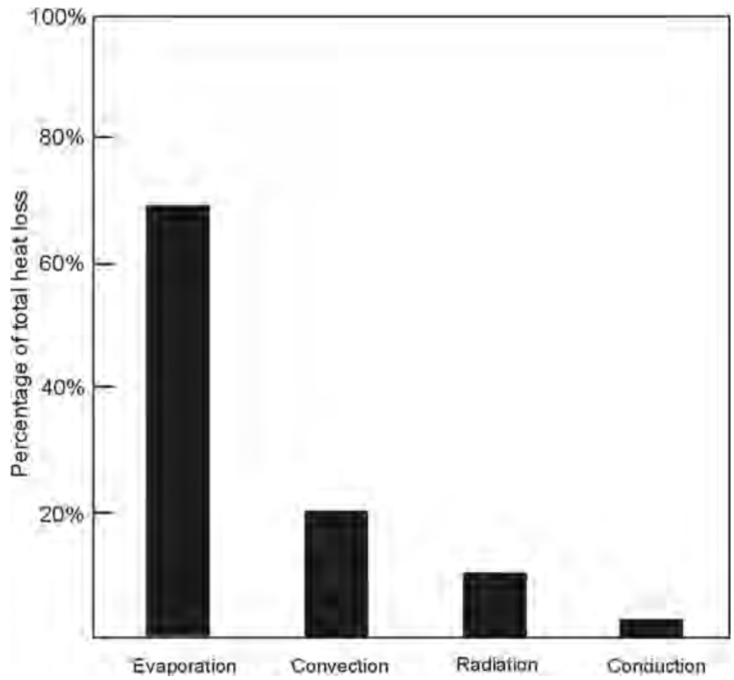


Figure 1 Swimming pool heat loss mechanisms

Passive Pool Heating

The use of passive techniques is the simplest and most cost-effective method of keeping swimming pools warm. A passive solar system is one in which the heat flows naturally – without the assistance of pumps and fans. Every effort should be made to incorporate the following three features in new pool construction to minimize the expense of supplementary energy for pool heating:

1. Place the pool in a sunny spot.
2. Reduce the wind velocity at the pool surface with suitable windbreaks.
3. Use a pool cover when the pool is not in use to minimize evaporation losses.

Swimming pools themselves are very effective solar energy collectors. The water absorbs more than 75 percent of the solar energy striking the pool surface (Figure 2). If possible, locate the swimming pool so it receives sunshine from about three hours before until three hours after solar noon. During this time period, the sun's rays travel through a relatively short atmospheric path and thus are at their maximum intensity. Additionally, there is less tendency for the sun's rays to be reflected from the pool surface during midday than during early morning and late afternoon, because they strike the pool surface at a small angle of incidence.

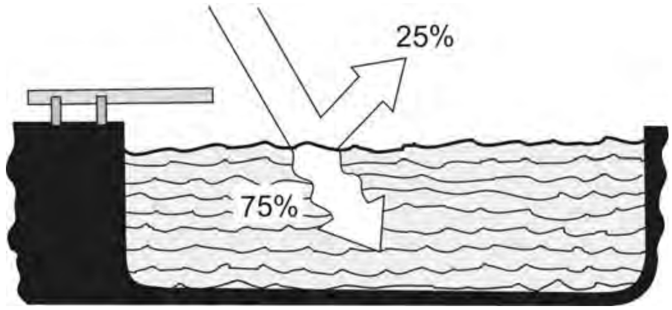


Figure 2 The swimming pool as a solar collector

Screen Enclosures

Screen enclosures reduce the amount of solar energy that strikes the pool surface. When the sun shines perpendicularly to the screen material, only about 15 percent of the energy is obstructed since the screen area is 85 percent open air space. However, when the sun strikes the material at an angle, much less of the radiation gets through, and the amount available to warm the pool is reduced. Experiments conducted at FSEC place this reduction as high as 30-40 percent on a clear day. More auxiliary energy will be required to maintain comfortable swimming temperatures if the pool has a screen enclosure.

Windspeed Reduction

Reducing wind velocity at the water surface reduces convective and evaporative losses. Solid fences or tall hedges located close to the pool perimeter are effective windbreaks. Buildings, trees and mounds also protect the pool from the cooling effect of prevailing winter winds. Locate the pool to take maximum advantage of these obstructions, being careful they do not shade the water surface from the sun. Windbreaks are particularly desirable near the ocean or adjacent to lakes, where the average wind speed is higher than in more sheltered locations. Figure 3 shows an example of a well-shielded pool.

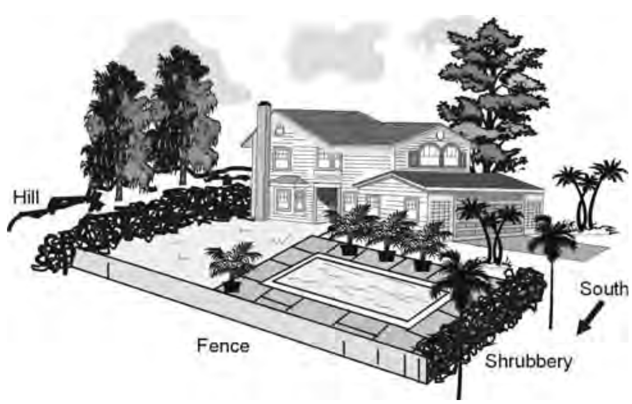


Figure 3 A well-protected pool

Pool Covers

Pool covers are effective in reducing heat losses. There are two basic types of pool covers on the market today: opaque and transparent. By reducing evaporation they reduce the quantity of chemicals needed, and they help to keep dirt and leaves out of the pool. Pool covers also reduce pool maintenance costs.

Transparent Pool Covers. Transparent covers will not only reduce evaporative losses. They will also turn the pool into a passive solar collector. Sunlight passes through the cover material and is absorbed by the pool water.

Because evaporation accounts for about 70 percent of pool heat loss, the beneficial effect of pool covers can be dramatic.

Figure 4 shows the approximate number of additional days annually that an unshaded, sunscreened pool, well protected from the wind, can be maintained above 80°F through the use of transparent covers. Climatic regions are shown in Figure 5. For example, in Gainesville, which is in the north central zone, a pool cover used for 14 hours each day extends the swimming season by approximately two months. The 14-hour period is assumed to include the coolest part of the day. Values presented must be used cautiously because the figures are based on historical weather data and a future month or even year may deviate substantially from the average.

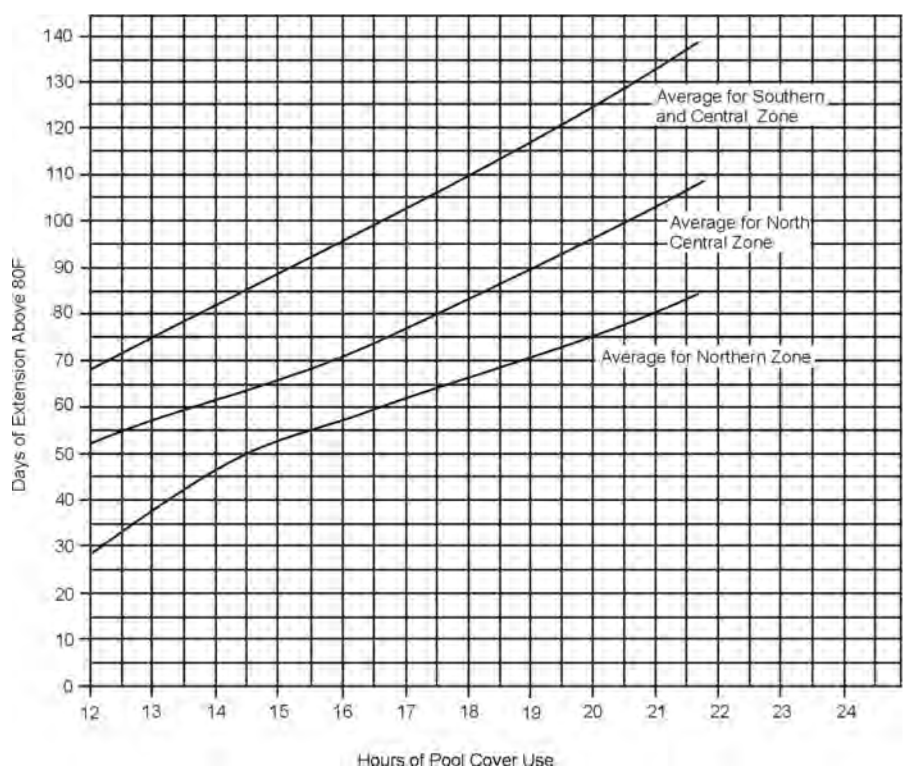


Figure 4 Effect of pool covers

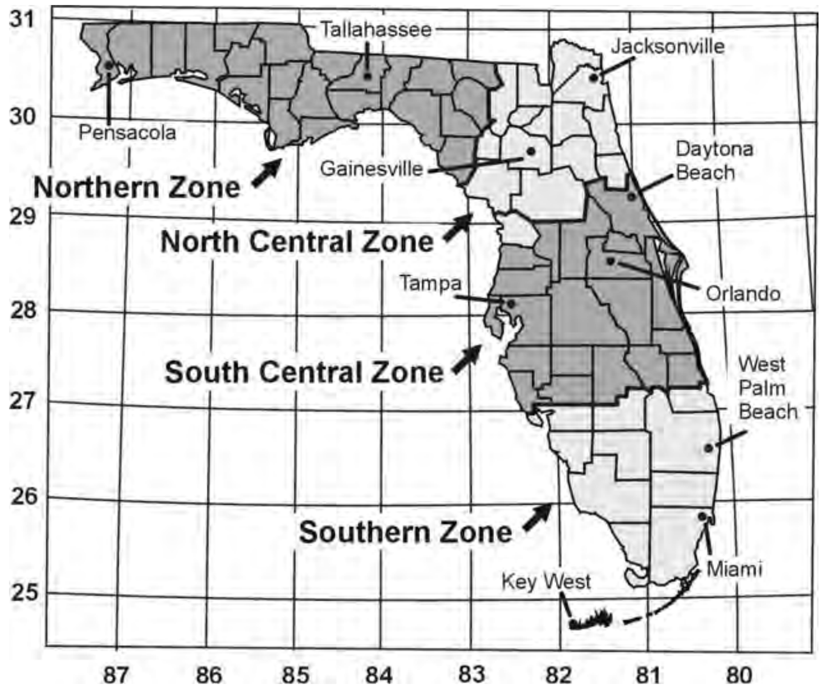


Figure 5 Climatic zones of Florida

Transparent pool covers are made from a variety of materials, such as polyethylene-vinyl copolymers, polyethylene and polyvinylchloride (PVC).

Attention to a few details will extend the life of transparent pool covers. They should not be left folded or rolled up on a hot deck or patio. The sunlight will overheat the inner layers and may even burst the air pockets in bubbled covers. When removing or installing a pool cover, avoid dragging it over the pool deck or any rough surface or sharp obstruction. Although it is recommended that a single, continuous pool cover be used whenever possible, the use of sectioned covers can ease handling in the case of larger pools.

Liquid Films. Some companies that supply pool chemicals offer a liquid evaporation retarder, which may be dropped in minute quantities onto the pool surface. Materials like cetyl alcohol spread to form a layer only a few molecules thick on a water surface. They can reduce evaporation by nearly 60 percent. Of course the materials offered for this purpose are not toxic but they are fairly expensive and must be re-dosed frequently (usually at the close of the daily swimming period). The chemical films do not reduce convective or radiation losses, but they do allow solar gains.

Opaque Covers. Opaque covers are useful for pools that must remain uncovered during daylight hours. Most commercial pools fall into this category. The following types of opaque covers are the most common: woven, plastic safety covers; skinned, flexible foam covers; and rigid or semi-rigid closed cell foam blocks or blankets. The woven safety covers will reduce evaporation losses (if they float and are waterproof) though not as well as a continuous film type cover. Skinned foam covers vary in thickness from less than 1/8 inch to more than 1/2 inch. In common insulating terms, their effectiveness in reducing heat losses ranges from R-1 to R-4. If they fit snugly to the edges of the pool, they will virtually eliminate evaporation losses during the periods when they are in place. Foam block covers such as expanded polystyrene have insulating values between R-4 and R-12, depending on their thickness. If properly fitted and placed on the pool surface, they, too, will nearly eliminate evaporation losses during the hours they are used. Their effectiveness in reducing convective and radiative losses increases directly with their R-value.

Active Pool Heating

Many types of solar collectors are suitable for pool heating. The temperature difference between the water to be heated and the surrounding air is small, so expensive insulating boxes and transparent covers that reduce collector heat loss are not often required. Cool winds above 5 mph substantially reduce the efficiency of unglazed collectors.

Low-Temperature Collectors

Types of low-temperature collectors include black flat-plates, black flexible mats (both with passages for pool water) and black pipes.

Flat-Plate Collectors. Several types of flat-plate collectors, specifically designed for pool heating, are available in both plastic and metal – plastic being the least expensive and most popular in Florida.

Flat-plate collectors for pools feature large-diameter headers at each end and numerous small fluid passageways through the plate portion. The header's primary function is to distribute the flow of pool water evenly to the small passageways in the plate. The header is large enough to serve as the distribution piping, which reduces material and installation labor costs. The fluid passageways, which collect energy from the entire expanse of the surface, are small and are spaced close together across the plate (if it is made of plastic) so most of the collector surface is wetted on its back side. Representative cross sections of plastic collectors are shown in Figure 6. EPDM flexible mat collectors have the same general cross section, as do plastic collectors.

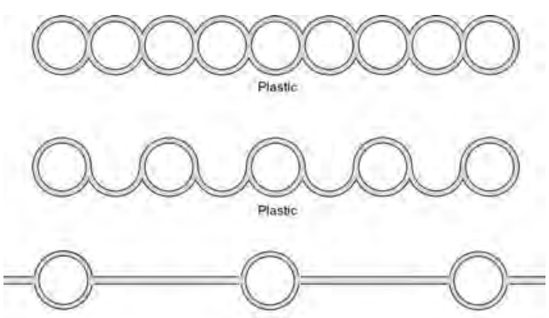


Figure 6 Typical collector designs

High water flow rates also tend to keep collector-to-air-temperature differences low. The total amount of energy delivered to the pool (the most important variable) is the product of the amount of water flowing through the collector multiplied by the water's temperature rise. Five hundred gallons of water raised 1°F contains as much energy as 10 gallons of water raised 50°F, but the collector operating at 10°F above pool temperature will operate less efficiently. Thus, high flow rates increase collector efficiency. Many manufacturers frequently recommend a flow rate as high as one gallon per minute for each 10 square feet of collector area. But such high flow rates are not needed to keep the temperature rise in the collectors below 10°F for best efficiency. Higher flow rates result in high-pressure drops across the collector array. This requires an increase in the horsepower of the circulating pump. Thus, flow rates are usually limited to about one gallon per minute for each 10 square feet of collector area for the configurations shown in Figure 6.

Because even plastic pool heating collectors are expensive, the plastic used must withstand years of exposure to sunlight. The ultraviolet portion of sunlight can break chemical bonds in most plastics and will eventually destroy the material if the process is not retarded. Collector manufacturers use several proprietary combinations of additives or stabilizers and UV inhibitors in the chemical mix of the collector material. These stabilizers and UV inhibitors provide protection from the damaging radiation and retard degradation of the plastic in addition to improving the collector's ability to absorb and conduct the sun's energy. Accurate estimation of plastic durability is difficult; therefore, explicit warranties are desirable. Most manufacturers currently offer a five-year or longer limited warranty. Some plastic collectors are expected to last 25 years.

Plastics are available in numerous formulations and types, many of which are relatively immune to attack from common chemicals. Polypropylene, acrylonitrile-butadiene-styrene (ABS), polyethylene, polybutylene, polyvinylchloride (PVC) and ethylene-propylene with diene monomer (EPDM) are frequently used collector materials. Some have been used to make pool collectors for more than 20 years and have demonstrated their ability to withstand attack by swimming pool chemicals and sunlight for at least that period of time.

Flat-plate collector designs utilizing metals are slightly different from plastic configurations. Metal is a better heat conductor, so relatively long fins can separate the tubes without causing excessive operating temperatures on portions of the collector surface. However, metal collectors are generally not used for pool collectors in Florida because they are subject to corrosion from pool chemicals.

Plumbing Schematics

Flow Control Devices

Solar pool heaters are generally connected to existing pool plumbing systems. This section explains how to make the connections.

A schematic of a frequently used pool filtration loop is shown in Figure 7a. The pump draws the water from the skimmer and main drain, forces it through the filter and returns it to the pool through the conventional heater. Lint, hair and leaf catching strainers are usually installed ahead of the pump.

Solar systems designed to operate with small pressure losses can be added as shown in Figure 7c. A spring-loaded check valve is installed downstream from the filter to prevent collector water from backwashing through the filter and flushing trash into the pool from the strainer when the pump is shut down. A manually operated or automatic valve is placed in the main line between Ts that feed the collector bank and return the solar heated water (Figures 7b and 7c). Ball valves may be placed in the feed and return lines for isolating the solar system from the pool filtration system when the filter is being backwashed or when adjustments are being made to the solar system. When solar heating is desired, the pump timer is adjusted to operate during daylight hours, and the valve in the main line is closed somewhat to restrict or fully interrupt the flow and force water up through the collectors. Valves on the lines to and from the solar system should be fully open.

Closing the valve in the main line may increase flow through the collectors. It may seem logical to reduce the flow rate through the solar array to make the return water warmer, and this can be done; however, it is not logical – the collectors will be forced to operate at higher temperatures, their efficiencies will drop, and less solar energy will be delivered to the pool. The temperature rise through the collectors should be kept low, less than 10°F on warm, sunny days, unless the manufacturer's specifications call for a higher temperature differential.

Forcing water through the solar system uses some of the pump's power, thus reducing the flow rate through the pool filtration system. As the main line valve is closed, pressure on a gauge mounted on the filter or discharge side of the pump will rise slightly. If the valve is closed entirely, all of the flow is diverted through the solar array and the collection efficiency increases. If the pressure at the filter does not rise unduly, the solar system should be operated in this way. However, the more the pressure rises, the slower the flow through the filtration system. This will increase the length of time required for the entire pool's contents to be filtered. Thus, it may be necessary to allow some of the flow to bypass the collectors. An inexpensive plastic flow meter can be used on the main line connection to monitor flow rates through the filtration system. Check with local building officials to determine minimum filtration flow rates or pool turnover times required in your area.

When the existing pool pump lacks enough power to circulate sufficient flow through the solar system and the filtration system, a booster pump may be required. It should be installed as shown in Figure 7d. Common pool-circulating pumps with or without the strainer basket are suitable for this application.

The booster pump should be placed in the line feeding the solar collectors, not in the main circulation line. In this position it will operate (consuming electricity) only when circulation through the solar collectors is wanted. Of course, the booster pump may be operated by the same time clock as that for the filter pump, but more often it will have a separate control. If both pumps operate from the same timer, it should be set so the pumps come on during daylight hours. In this case, the timer must be rated for the sum of the circulation pump and the solar booster pump.

If the booster pump is separately controlled, the filter pump may run for a longer portion of the day, and the booster pump should turn on during appropriate periods but only when the filter pump is operating.

Manual flow control or control with time clocks is simple and inexpensive but has drawbacks. Since clocks do not sense weather conditions, the circulating pump may be running when there is insufficient solar energy available to warm the pool water. Collectors may lose energy rather than gain it if weather conditions are unfavorable. Automatic flow controls overcome this difficulty. The most common plumbing schematic for systems using these devices is shown in Figure 8.

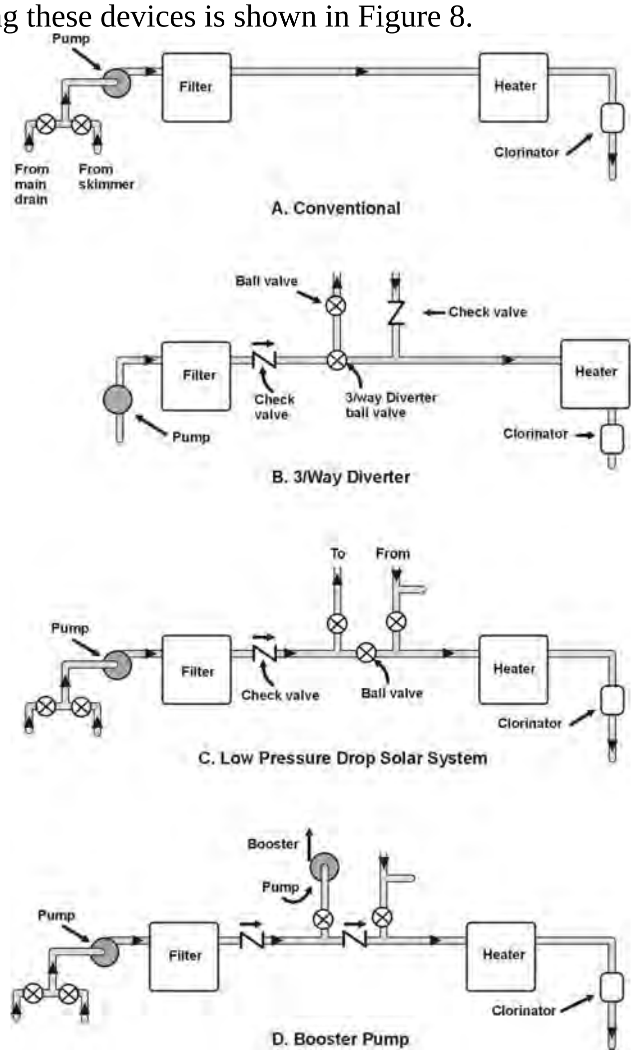


Figure 7 Plumbing schematics

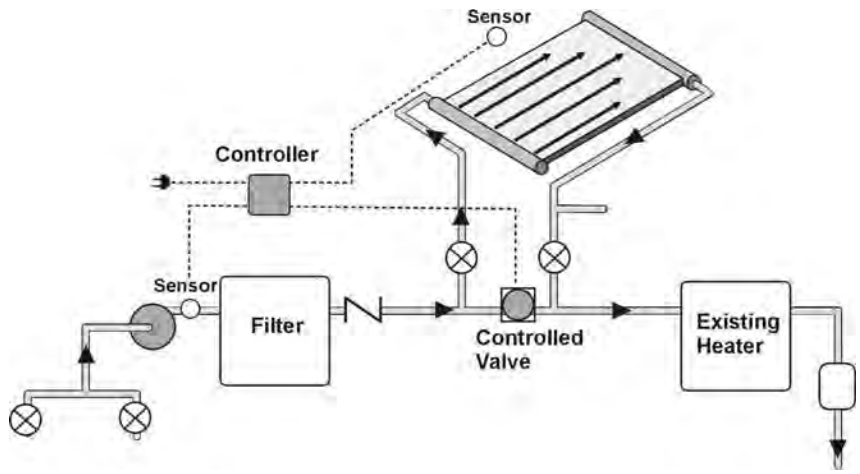


Figure 8 Automatic control plumbing schematic

Accurate differential temperature control is difficult to achieve because of the small temperature rise that takes place in solar pool heaters. A sensor, tapped into the piping at a convenient place ahead of the collector return line, measures the pool water temperature. Another sensor is housed in a plastic block and placed near the solar collectors, so its temperature parallels that of the collector (or it may be attached to the collector outlet). When the pool water temperature exceeds the collector temperature, the control valve remains in the open position and the flow bypasses the collector loop. When the collector temperature exceeds the pool water temperature, the valve is closed, forcing the flow through the collectors. In practice it has proven equally effective to control the flow through the collectors with a single solar sensor, which turns on the solar pump and/or activates the diverting valve above a fixed solar intensity level.

When operating properly, a differential controller automatically adjusts to changing conditions, monitoring variations in collector temperature caused by clouds, other weather factors and the approach of evening. When collector temperature drops, the control de-energizes the valve and flow bypasses the collector. Maximum pool temperature limits can be programmed into some controls.

Control valves may be actuated hydraulically or electrically. One of the earliest valves used was a hydraulically operated pinch valve consisting of a cylinder with an expandable bladder inside. A high-pressure line connected to the discharge side of the pump is used to expand the bladder, pinching off the flow and diverting it through the solar system. A low-pressure line connected to the suction side of the pump deflates the bladder and allows the flow to pass unimpeded. An automatic controller accomplishes switching between the high- and low-pressure lines.

Electrically operated valves are also used. A differential controller may be used to operate a solenoid that, in turn, activates the main valve in much the same way the pinch valve is activated. Be sure the valve you select is specifically designed and constructed for use on pool systems. Automatic control schematics, taken from the installation diagrams of two low-temperature collector manufacturers are shown in Figures 9 and 10.

The most common method to divert the flow of water to the solar collectors from the pool is to use a 3-way valve on the solar supply line. Similar to the in-line ball valve or isolation valve, the three-way diverter valve is commonly used in the swimming pool and spa industries.

Some of the 3-way manual valves are made to be used for solar pool heating. The 3-way valve has a motorized diverter that attaches to the top of the valve to convert the manual valve into an automatic or motorized valve. Other 3-way diverter valves are manufactured with the motor assembly on the valve. In this case, a differential controller sends low voltage power to the diverter actuator (or motor) and rotates the valve sending the water from the filter to the solar collectors. A check valve after the 3-way valve allows the solar collectors to drain into the pool when the pump is not operating. This may provide freeze protection if the system tilt and piping was installed to allow continuous drainage.

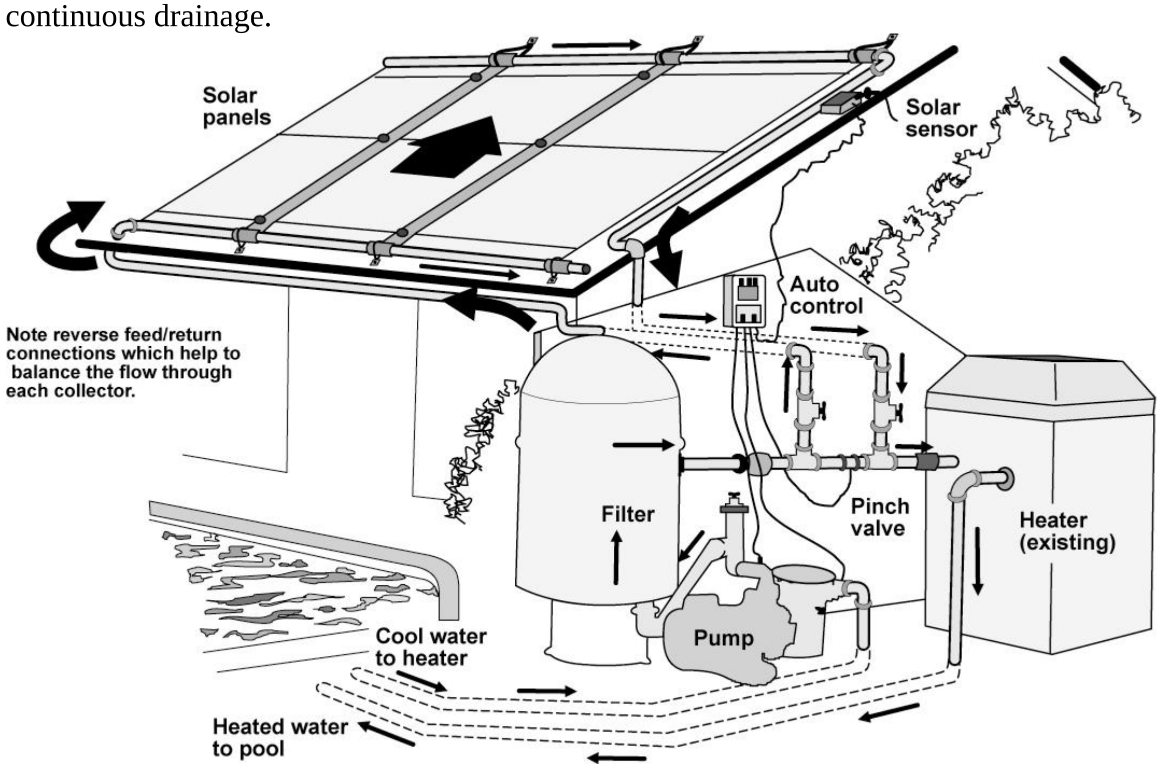


Figure 9 Plumbing schematic

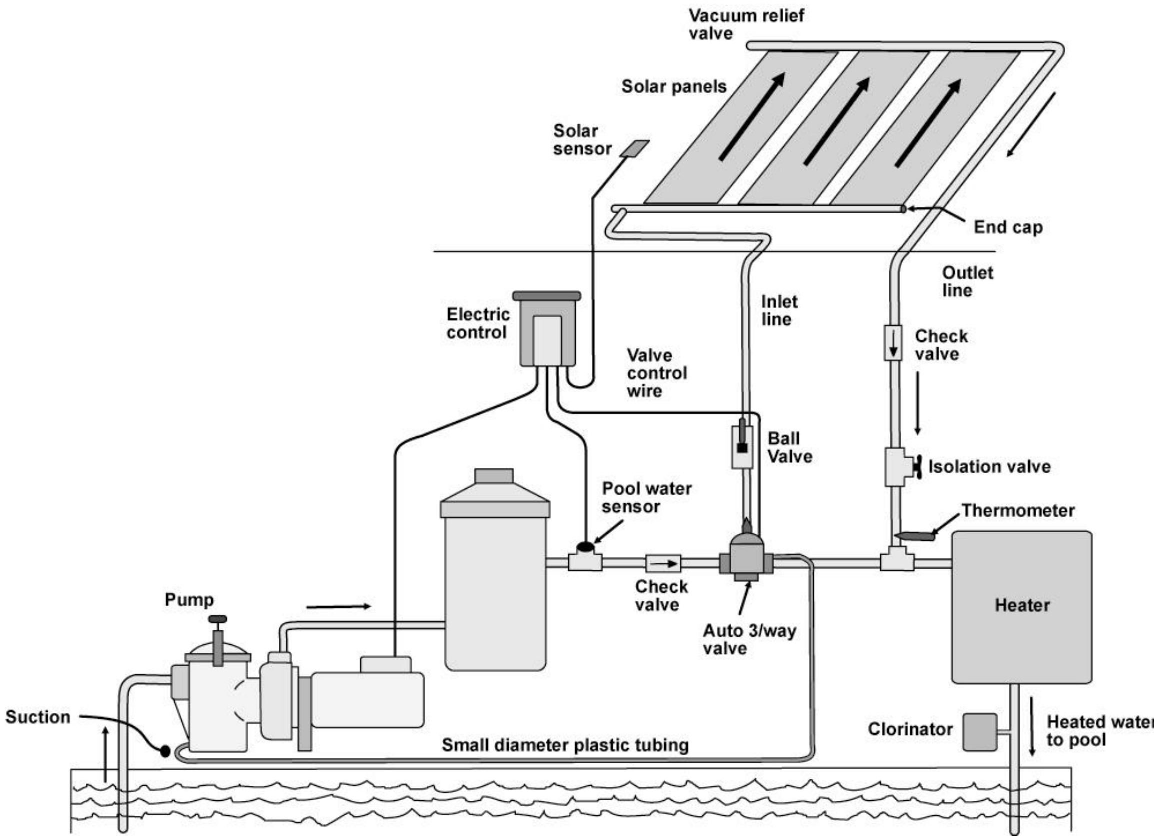


Figure 10 Plumbing schematic

Corrosion Problems

Improper pool chemistry can cause accelerated corrosion. The pool water pH should normally be maintained between 7.4 and 7.8. PH is a measure of the acidic and basic character of a solution. A pH of 1-7 is on the acidic side. The lower the number the more acid it is. A pH of 7-14 represents increasing alkalinity. Low pH (less than 7.2) may be caused by improper use of pool additives. Under acid conditions (low pH), chloride and sulfate ions in the pool combine with water to form acids capable of breaking down protective films. Low pH also accelerates the corrosion of most metals.

Excessive concentrations of copper ions in pool water may lead to the formation of colored precipitates on the pool wall if the pH is allowed to drop. Several copper compounds have been identified as causing this problem; however, since many common algaecides are based on copper compounds, the concentration of free copper ions in pool water may relate to the use of these chemicals as well as the corrosion of copper piping materials. Care should be exercised in maintaining proper pH levels whether copper or plastic piping is used in a solar pool heater.

Sizing Filter Pumps and Pipe Runs

For simple installations, sizing the filters, pumps and pipe runs to circulate and keep the necessary pool water clean and heated may be successfully accomplished by following the instructions contained in the following sections. For large or complex installations, more detailed manuals or a person knowledgeable with hydraulics should be consulted.

A basic knowledge of the characteristics of a swimming pool's circulation system will be useful to installers in selecting the components appropriate for the solar heating of a specific pool.

Sizing Filtration and Circulation Systems

Proper sizing of swimming pool filters, circulation pumps and pipe runs may be accomplished by using the information provided in this section in conjunction with data routinely provided by manufacturers of those components.

Filter Sizing Graphs. Filter sizing is accomplished by using graphs, such as Figure 11, provided by filter manufacturers. The following types of filters are those most often used to keep swimming pools clean.

Sand, gravel or anthracite filters are sometimes operated at a flow rate as high as 20 gallons per minute (gpm)/ft^2. It should be noted that some code jurisdictions limit the flow rate through these filters to three gpm/ft^2. Diatomaceous earth (DE) filters usually operate well at about two gpm/ft^2. Both sand and DE filters may be cleaned by backwashing and discharging the dirty water into a sewer or other appropriate outlet. An air gap in the discharge line is often required to ensure against backflow contamination from the sewer. Cartridge filters are usually operated at a flow rate of about one gpm/ft^2 and may be reverse flushed and reused. When the cartridges become excessively dirty they are simply replaced.

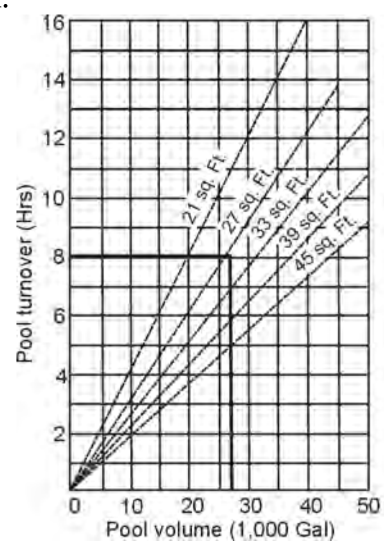


Figure 11 Diatomaceous earth filter sizing graph for flow rate of 2 gpm/ft^2

In pool filtration systems, the need for cleaning is indicated by high readings on a pressure gauge, which is located between the filter and the pump. Filter manufacturers specify the readings at which they recommend maintenance. The pressure drop due to properly sized clean filters is usually about five psi. The backwashing valve assembly on DE and sand filters may add another five psi.

Pump Sizing Graphs. To size the pumps it is necessary to establish a flow rate in gpm and then add up all the pressure drops that occur when water flows through the system at that rate. Figure 12 is a graph on which pressure drop and flow rate are plotted for typical swimming pool circulation pumps.

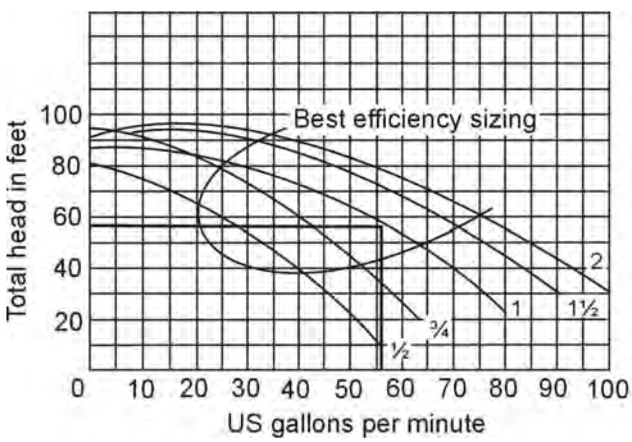


Figure 12 Pump performance

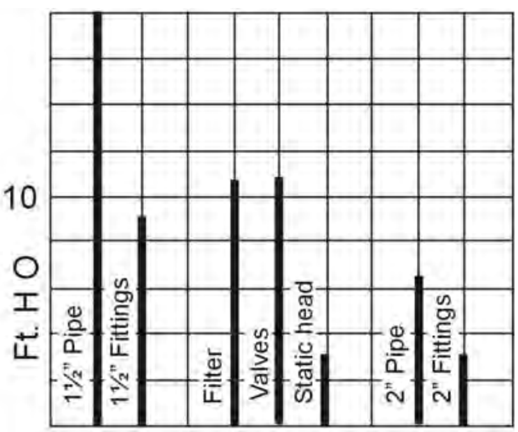


Figure 13 Relative pressure

Sizing Connecting Piping. Connecting piping may be sized using pipe flow charts (Figures 14 and 15). Piping should be large enough to prevent excessively high flow rates that cause erosion of interior pipe and fitting surfaces. Some code jurisdictions limit the rate of water flow through copper pipes to five feet per second. Adequately sized piping and pumps help reduce maintenance and operating costs.

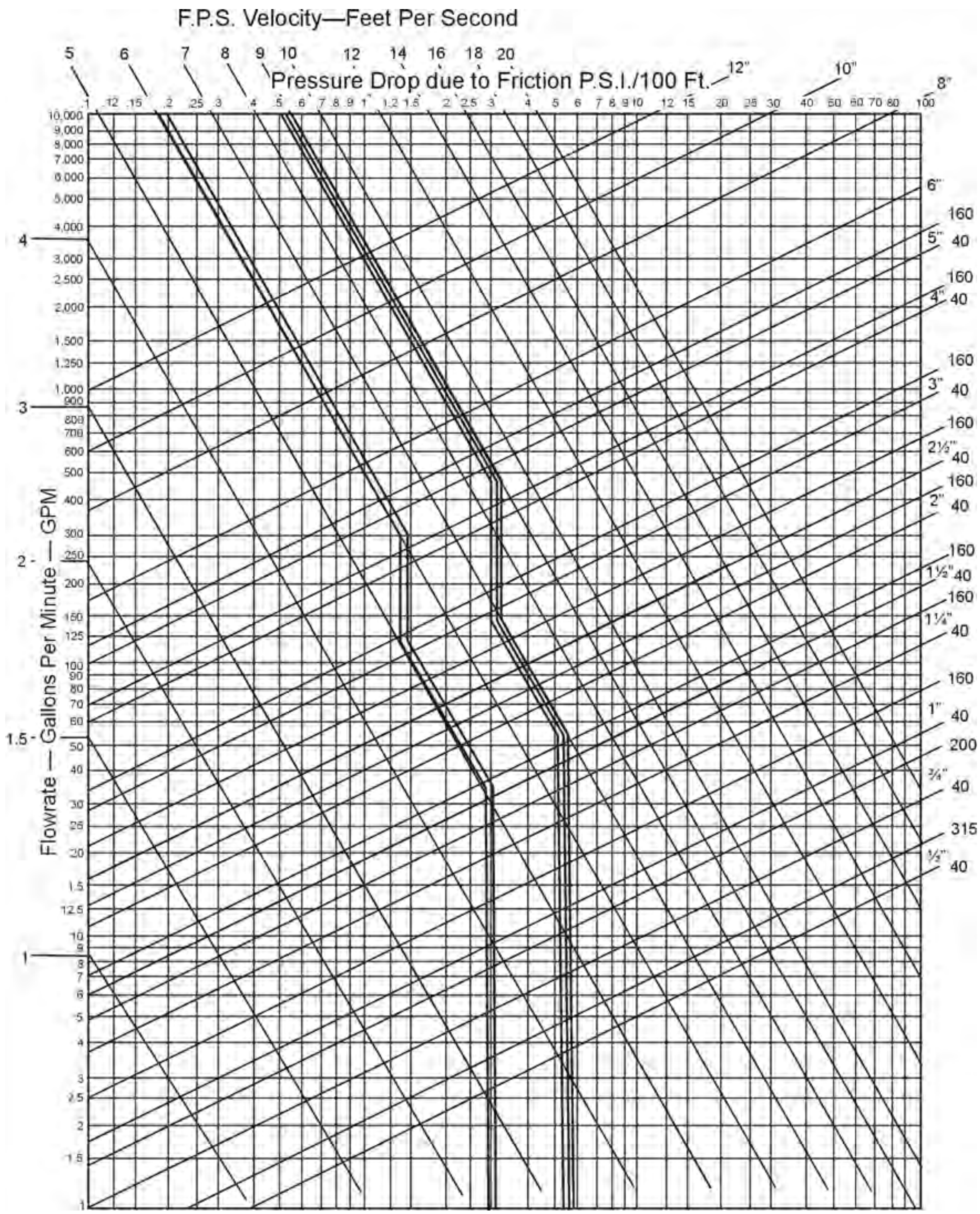


Figure 14 Pressure drop plastic pipe

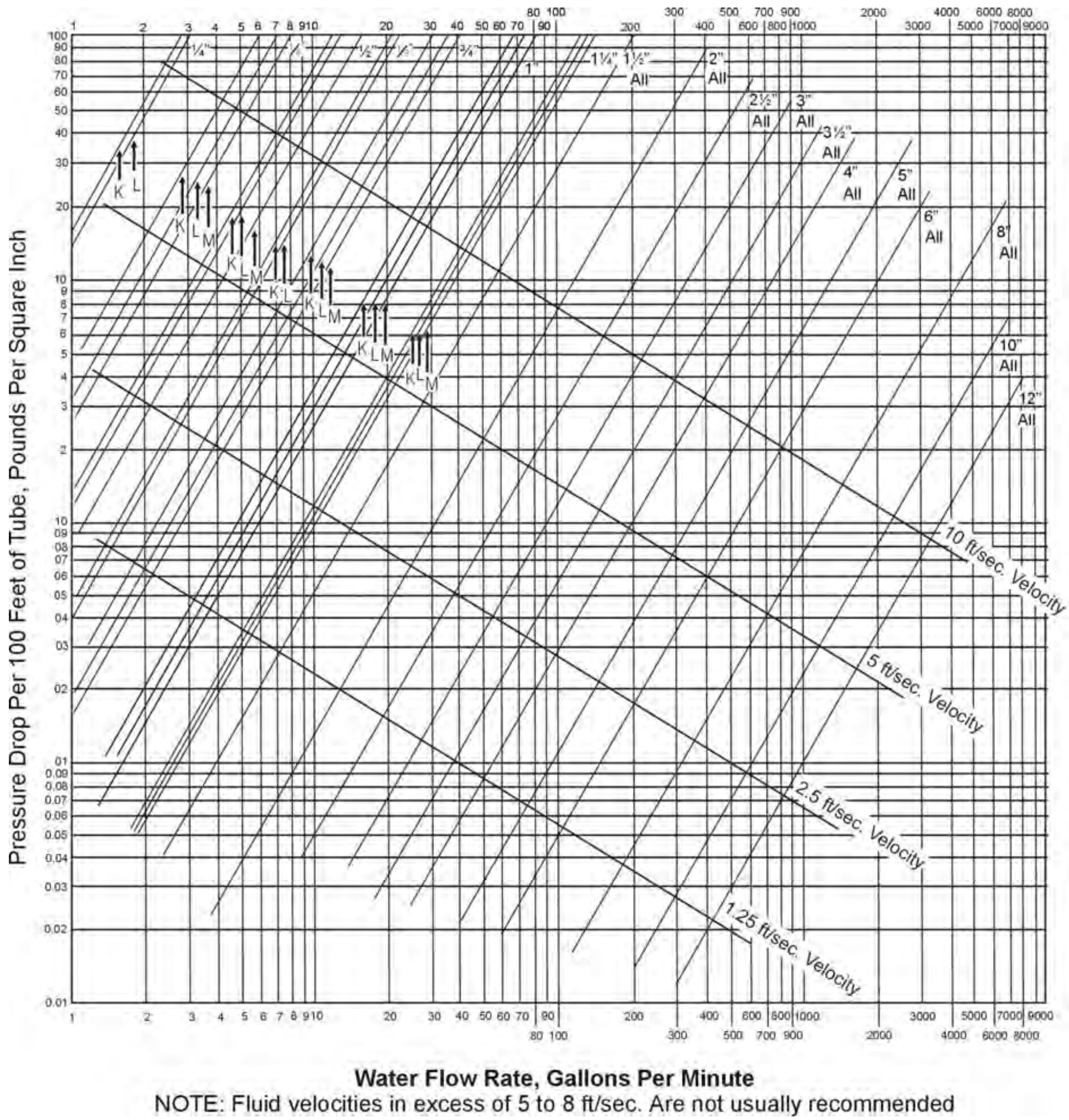


Figure 15 Pressure loss and velocity relationships for water flowing in copper pipe

Examples

The following examples are intended to help clarify sizing procedures.

The owner of a 20-by-40-foot swimming pool with an average depth of 4.5 feet wants to circulate the total pool volume through the filtration system in eight hours. (The turnover rate *is* currently one complete recirculation per eight hours.) The owner plans to use a DE filter and wants to know what size filter and pumps will be required (1) with no heater, (2) with a gas heater, (3) with a solar heater and a gas heater for back-up and (4) with a solar heater without a back-up. The pump will be located so the center of its impeller is three feet above the surface of the pool. One hundred feet of pipe will be required unless solar collectors are used. In that case, 200 feet of connecting pipe will be required. The high point of the solar collector array will be 12 feet above the center of the pump impeller. The solar collectors will be connected to the circulation piping as shown in Figure 8b. The owner also wants to know what size connecting pipe should be installed under any of the four alternative conditions.

STEP 1. Determine the pool volume.

$$\text{Pool volume (gal)} = 20' \text{x } 40' \text{x } 4.5' \text{x } 7.48 \text{ gal/ft}^2 = 26{,}900 \text{ gal.}$$

STEP 2. Determine the DE filter cross sectional area if 2 gpm/ft^2 of filter area is an acceptable flow rate through it, and the pool volume of 26,900 gallons must turn over every eight hours.

Figure 11 shows a cross sectional area between 27/ft^2 and 33/ft^2 will be required. The filter that provides 33/ft^2 of cross sectional area will be the better choice because it will allow a turnover time of slightly less than eight hours.

STEP 3. Determine the flow rate through the filtration system.

Because the entire volume must turn over once each eight hours,

$$\text{Flow rate} = \frac{26{,}900}{8} = 3360 \text{ gallons per hour (gph)}$$

$$\text{Flow rate} = \frac{3{,}360}{60} = 56 \text{ gpm}$$

STEP 4. If no heater is included in the system, determine the total pressure, which the pump will be required to overcome at a flow rate of 56 gpm.

Cause of Pressure Drop	Source of Information	Pressure Drop Lbs/In^2 (Psi)	Pressure Drop Ft of Water (Psi x 2.31)
100 ft 1-1/2" schedule 40 plastic pipe	Figure 14	8	18.5
Fitting	About 1/2 of pipe drop	4	9.2
Valves	Manufacturer’s specs.	5	11.6
Filter	Manufacturer’s specs.	5	11.6
Lift head			3
Total			**54**

Figure 12 shows a one-hp pump (of the specific design covered by that graph) will circulate 56 gpm against a 57-foot head. A 3/4-hp pump will circulate only 45 gpm against a 51-foot head, so the one-hp pump will be the safest choice.

Discussion*:* It is interesting to note if 2-inch schedule 40 pipe is used, the pressure drop in the pipe is only three psi or seven feet of water, so the total pressure drop is about 37 feet of water. Figure 12 shows a 3/4-hp pump is powerful enough to circulate 52 gpm against a total head of 37 feet of water. (Turnover time increases to 8.6 hours.) Figure 13 illustrates the relative magnitude of the pressure drops.

STEP 5. Determine the size pump that will be required if a gas-fired pool heater is added which causes an additional pressure drop of five psi.

	Pressure Drop	
Cause of Pressure Drop	**Psi**	**Ft of Water**
100 ft –1 1/2" schedule 40 plastic pipe	8	18.5
Fittings	4	9.2
Valves	5	11.6
Filter	5	11.6
Pool heater	5	11.6
Lift head		3
Total		**65**

Figure12 shows a one-hp pump will pump about 50 gpm against 65 feet of water. This is probably close enough to the required volume for practical purposes. (The turnover time is a littler longer – nine hours.)

Discussion*:* Under these conditions, using two-inch pipe reduces the total pressure drop to about 50 feet of water but this does not allow us to use a 3/4-hp pump because the smaller pump will only circulate 46 gpm against a 50-foot head. (In this case, the turnover time would be increased to 10 hours should the 3/4-hp pump be used.)

STEP 6. Determine the size pump that will be required if we add a solar collector system and a gas-fired back-up heater. A pressure drop of two psi is expected across the solar collectors. The system contains an extra 100 feet of pipe and a vacuum breaker located 12 feet above the center of the pump’s impeller.

Using 1 1/2" and 2" Pipe

Cause of Pressure Drop	Pressure Drop	
	Psi	**Ft of Water**
100 ft of 1 1/2" pipe	8	18.5
Fittings for 1 1/2" pipe	4	9.2
100 ft of 2" pipe	3	6.9
Fittings for 2" pipe	1+	2.3+
Valves	5	11.6
Filter	5	11.6
Solar panels	2	4.6
Gas heater	5	11.6
Static head (3' + 12')		15
Total		**92**

Using Only 2" Pipe

Cause of Pressure Drop	Pressure Drop	
	Psi	**Ft of Water**
200 ft of 2" pipe	6	13.9
Fittings for 2" pipe	3	6.9
Valves	5	11.6
Filter	5	11.6
Solar panels	2	4.6
Gas heater	5	11.6
Static head (3' + 12')		15
Total		**75**

Figure 13 shows if 100 feet of 1-1/2-inch pipe and 100 feet of two-inch pipe are used to make the connections, a two-hp pump will move only 35 gpm against the 92-foot water head. This increases the turnover time to about 13 hours, so a 2 1/2-hp pump will be required. If 200 feet of two-inch pipe is used, a 1 1/2-hp pump will move 52 gpm against the 75-foot head. Again, in this example, 52 gpm will probably turn the pool volume over in an acceptable period of time (8.6 hr).

Discussion: Another option applicable to retrofitting a gas-heated pool piped initially with 1-1/2-inch pipe and a one-hp pump is the addition of a second small pump installed as pictured in Figure 7d. The additional pump will be required to overcome a static head of 12 feet of water and a friction head of 28 feet of water if 1 1/2-inch pipe is used to connect the solar panels to the system. The pressure loss across the panels will still be 4.6 feet of water. The total pressure drop, which the added pump will be required to overcome, will be 12 + 28 + 4.6 or about 45 feet of water head. Figure 12 shows a 3/4-hp pump will circulate 49 gpm against a 45-foot head. It should be noted the two pumps working in series will assist each other and in most cases the turnover times will be no more than eight hours.

Two pumps require more maintenance than does one, but the solar booster pump may be turned off when circulation through the panels is not desired. This reduces electrical consumption.

A final option for pool heating is the addition of solar collectors without a fossil-fired back-up system. Referring to the immediately preceding piping options, the elimination of the gas-fired heater reduces the pressure drop from 92 to 80 feet of water if an additional 100 feet of 1-inch pipe and 100 feet of 2-inch pipe are used to make the connections.

Figure 12 shows a 2-hp pump will pump 54 gpm against an 80-foot head. (The turnover time is 8.3 hours.)

If 2-inch connecting pipe is used throughout, the total pressure drop is reduced to about 63 feet and a 1 hp pump will deliver 50 gpm against a 63-foot head (the turnover time is nine hours). A 1.5 hp pump will circulate about 65 gpm against a 63-foot head (the turnover time is 7 1/2 hours).

Table 1 presents each of the pool heating options and the corresponding pipe and pump sizes which yield the various pool turnover time periods.

Components	**Pipe Size**	**Pump Size Required**	**Turnover Time (In hours)**
System with no heater	100 ft of 1 1/2" schedule 40 plastic	1 hp	8
	100 ft of 2" schedule 40 plastic	3/4 hp	8.6
System with gas or oil heater (5 psi pressure drop)	100 ft of 1 1/2"	1 hp	9
	100 ft of 2"	1 hp	7.2
System with gas and solar (15 ft static head)	100 ft of 1 1/2" plus 100 ft of 2"	2 1/2 hp	8
	200 ft 1 1/2"	2 pumps (1 hp+3/4 hp)	8
	200 ft 2"	1 hp	8.6
System with solar only (15 ft static head)	100 ft 1 1/2" plus 100 ft 2"	2 hp	8.3
	200 ft 2"	1 hp	9
		1 hp	7.5

Table 1 Pool Heating Options

None of the stated options alter the turnover rate of the pool sufficiently to require resizing the DE filter. It should contain between 27/ftp^{2}p and 33/ftp^{2}p of filtration area.

Pressure Drop Across the Valves and Fittings

Many swimming pool installers use the simple rules of thumb cited in the previous examples to determine pressure drops caused by the resistance to liquid flow of valves and filters. However, it is important for the solar installer to realize the actual pressure drops vary with both flow rate and mechanical characteristics of specific valves and fittings. Table 2 presents frictional losses expressed in equivalent lengths of pipe for commonly used fittings. (Most fitting manufacturers supply similar tables.) The sum of the equivalent length of all the fittings on the circulation system may be added to the actual length of pipe in the system before the pressure drop is read from Figure 14 (plastic pipe) or Figure 15 (copper pipe). The pressure drop across the backwash valve assembly is accepted as being five psi in the example. Actually, this pressure also varies with flow rate and the mechanical design of specific valves. The variation from valve to valve is too great to make a generalized tabular presentation of pressure drop much more useful than the five psi rule of thumb value. Most filter and backwash valve suppliers can make available accurate tables or graphs for their valves. The information is usually given in psi, which may be converted to feet of water head by multiplying by 2.31.

Fittings – Friction Losses expressed as equivalent lengths of pipe (feet).

Type of fitting	**Material (in ")**	**1**	**1 1/4**	**1 1/2**	**2**	**2 1/2**	**3**	**3 1/2**	**4**	**5**	**6**	**8**	**10**	**12**
Standard tee with flow through branch	Steel	6	8	9	11	14	16	-	20	26	31	40	51	61
	Plastic	9	12	13	17	20	23	-	29	-	45	-	-	-
	Copper	6	8	9	11	14	16	18	20	26	31	40	-	-
90 degree long radius elbow, or run of standard tee	Steel	1.7	2.3	2.8	3.6	4.2	5.2	-	6.8	8.5	10	14	17	20
	Plastic	3	4	5	7	8	10	-	12	-	17	-	-	-
	Copper	1.7	2.3	2.8	3.6	4.2	5.2	6.1	6.8	8.5	10	14	-	-
Adapter slip/ solder fitting to thread insert coupling	Plastic	3	3	3	3	3	3	-	3	-	3	-	-	-
	Copper	1	1	1	1	1	1	1	1	1	1	1	-	-
	Plastic	3	3	3	3	3	3	-	3	-	3	-	-	-
Gate Valve (fully open)	-	.60	.80	.95	1.15	1.4	1.6	1.9	2.1	2.7	3.2	4.3	5.3	6.4
Swing Check Valve	-	7	9	11	13	16	20	23	26	33	39	52	67	77
Ordinary entrance	-	1.5	2.0	2.4	3.0	3.7	4.5	5.2	6.0	7.3	9.0	12	15	17

Table 2 Friction Losses

Energy Conservation

The solar heater for a swimming pool should be sized to provide enough heat to satisfy the purchaser. Virtually all installers and purchasers can agree to that. However, the solar installer's responsibilities do not stop there. The system he or she installs should not increase the electrical consumption of the pool's circulation system any more than absolutely necessary. This requires large enough pipe diameters to keep their friction losses low, proper flow through the solar collectors to maximize heat collection yet minimize pressure drop, and adequate collector sizing to minimize the number of hours the pump must operate each day. Obviously, it is pointless to oversize the solar-related components to an extent that reduces the time required for heat collection below that required for acceptable filtration.

Collector Installation

Acceptable solar collector mounting practices are discussed in this section. Because unglazed, low-temperature collectors are most often used for swimming pool heating in Florida, procedures for mounting unglazed plastic flat-plate collectors, flexible solar mats and pipe arrays will be discussed first.

The optimum collector slope for spring and fall operation is equal to the latitude of the site. The best slope for winter is the latitude plus 15° and the collectors should face south if possible. If roof space, which faces within 45° of south, is available, the collectors can be mounted directly on the roof. Remember that only a small penalty is paid for modest deviations from optimum slope or orientation. Supports can be constructed to mount collectors at the ideal orientation, but except in new construction, the additional cost is generally prohibitive. Occasionally it may be necessary to increase the collector area to compensate for less than optimum slopes or orientations.

Collectors should be securely fastened to withstand maximum expected wind loads. Building code requirements for maximum wind velocities vary within the state of Florida from 100 to 150 miles per hour. Wind loads at roof level may exceed 75 pounds per square foot. Check the local building regulations for wind load provisions in your area.

Procedures. To begin the installation, lay out the collectors on the available roof area avoiding as much as possible any area shaded by trees, parts of the building or other obstructions. If large numbers of collectors are involved, they may have to be divided into several banks with collectors in each bank plumbed in parallel. Plumbing arrangements from bank to bank are discussed in the next section.

Once the placement is established, the collectors should be connected. Short, flexible couplings made of EPDM or butyl rubbers often are used. They usually are slipped over the ends of the headers and are clamped firmly with stainless steel clamps. Once fastened together, the collectors are cumbersome to move about. Be sure they're in their final positions before the connections are made.

Collectors often are usually mounted directly on the roofs. In the past an insulating support structure was sometimes used to protect the panels from abrasive roofing materials and prolong their life by protecting the bottom of the collector from the abrasion caused by expansion and contraction of low temperature collectors. Refer to the manufacturer recommended installation procedure.

Collectors should be laid on the roof and fastened down at the header on both ends. At least two, and preferably three, cross straps should span the panel to further secure it unless otherwise detailed in the manufacturer installation instructions.

Figure 17 shows one possible arrangement. Once again, refer to the manufacturer's recommended installation procedures.

One end of the panel can be fastened to the roof with a short strap or clamp around the header. The other end should be fastened with an elastic material or spring to allow for expansion as the collector temperatures change – a 10-foot plastic collector may expand and contract as much as an inch in length. Straps should be installed across the panel body – one at either end – within a foot of the headers, and one across the middle are recommended. The straps should be made of material, such as nylon or plastic-coated metal, that will not scratch or abrade the collector since they will rub across its surface. The bands should be snugged to clips fastened approximately an inch from the edge of the collector.

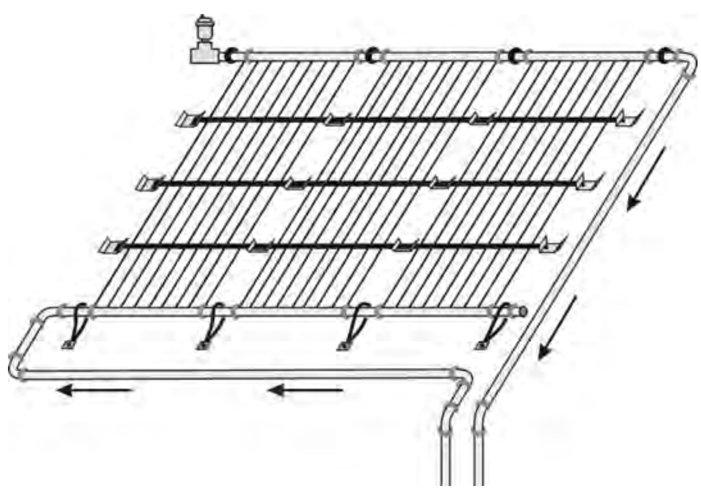


Figure 17 Collector hold-down straps

Figure 18 shows a mounting clip, which may be made of rigid plastic or metal. On asphalt shingle roofs, the clips may be fastened directly on top of the shingles – 1/4-inch lag bolts long enough to penetrate the roof sheathing are generally recommended. In keeping with good construction practice, the lag screws should be screwed into as many roof rafters as possible (rather than just roof sheathing) to keep the collectors secure. A pilot hole should be drilled for the lag screw and after the drill chips are cleared away a sealant should be injected with a cartridge gun into the hole. An excess of sealant should be used to form a seal between the mounting clip and the roofing material when the lag bolt is tightened. Polysulfide and the newer polyurethane sealants adhere well to common building materials and appear to be very durable.

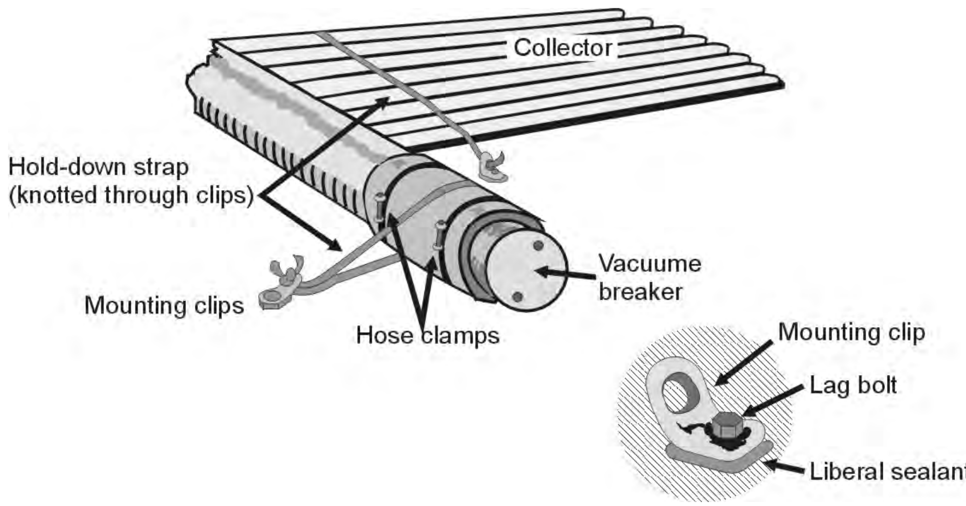


Figure 18 Typical collector mounting clip

Sealing mounting brackets on tar and gravel (built-up roofing) requires careful cleaning around the bracket. Scrape off the old gravel down to the tar, and clear off all dirt and residue. If the tar surface is very dirty or irregular, soften it with a solvent such as mineral spirits. After sealing the clip with polysulfide, pour roofing tar over the bracket base and cover with gravel. This last step is necessary to prevent ultraviolet damage to the tar and premature roof failure.

Mounting collectors on other roof types is more difficult. On cedar shake roofs, mounting screws should pass through the shakes and fasten securely to the plywood or purlins beneath. Don’t be stingy – use good quality sealant and enough of it to form a good, sealed penetration. Don't tighten the fasteners tight enough to split the shake.

Concrete tile roofs, especially common in south Florida, present special mounting difficulties. The safest solution is to construct a rack to support the collectors above the tile surface. The rack should be constructed of a durable material, such as aluminum. It should be strong enough to withstand maximum anticipated wind loads. Substrate and collectors may be fastened to the rack. The rack itself must be securely fastened to the roof trusses, not to the sheathing. This practice should also be used when installing a reverse pitch rack on the backside of a roof.

Figure 19 illustrates a typical mounting bracket arrangement. To install the bracket, a tile must be removed or broken, exposing the waterproof membrane on the sheathing below. This waterproof surface (commonly called slate), not the tiles, forms the moisture barrier and must be resealed where mounting bolts penetrate it.

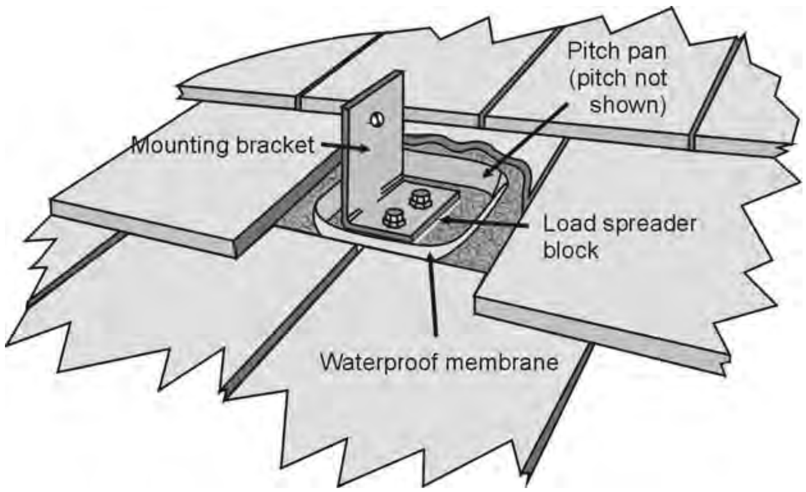


Figure 19 Mounting bracket for tile roofs

The mounting location should be free of dust and debris. Roofing mastic should be applied to the bracket and slate to form a seal when the bracket is drawn down. (Pitch pans around the roof penetrations may be required in some areas.) A substitute for the broken tile may be made from cement mix (using adjacent tiles as a model) and tinted to match the roof. Aluminum and copper materials should be protected from contact with the cement by a layer of tar to reduce corrosion.

Fastening schemes have been proposed which rely upon sealing the roof penetration at the tile surface. Since the waterproof membrane is not the tile itself but rather the slate membrane beneath, these methods are not effective and should be avoided.

Spanish or barrel tile roofs present another tough collector mounting problem. It is extremely difficult to walk on them without breaking some tiles, and it is also difficult to make substitute tiles.

Piping

Solar swimming pool collectors are designed to operate with high flow rates; therefore, the primary objective in piping solar systems is to provide uniform, high-volume flow at the lowest cost and the lowest pump power possible.

Piping to Collectors

For low-temperature collectors, plastic pipe can be used in the plumbing from the pool pump to the solar collectors. PVC and ABS pipe (Schedule 40) are the most commonly used materials for this particular application and have performed satisfactorily. Neither material can withstand high temperatures. Due to the moderate operating temperatures, pipe insulation is not required.

Local plumbing requirements should be adhered to when installing piping leading to and from the collectors. Since large-diameter pipe is quite heavy when filled with water, sturdy supports will be required. Pipe cuts should be deburred before assembly to reduce resistance to flow. Leaks can be avoided by using the correct cement for the pipe involved and properly preparing joints. Because plastic expands and contracts considerably with temperature changes, allowances should be made for change in length. Your pipe supplier can provide you with specific data on the kind of pipe used for a particular job.

Piping Between Collectors

About the same amount of water should pass through each collector. On large installations it is necessary to divide the solar collecting panels into groups and connect the groups with pipe. This requires the piping layout be carefully designed and constructed. Most situations encountered can be satisfied using principles discussed in this section, but for extremely complicated cases it may be wise to consult a hydraulic flow specialist.

Pool heating collectors are almost always connected in parallel. Parallel connections are shown in Figure 20a, series connections in Figure 20b. In the series arrangement, water passes through one collector and then through the next, increasing the pumping horsepower required to maintain adequate flow, as well as causing the downstream collectors to operate at higher, less efficient temperatures. Parallel connections, in which the water is returned directly back to the pool after passing through one collector, are the better choice because those difficulties are avoided.

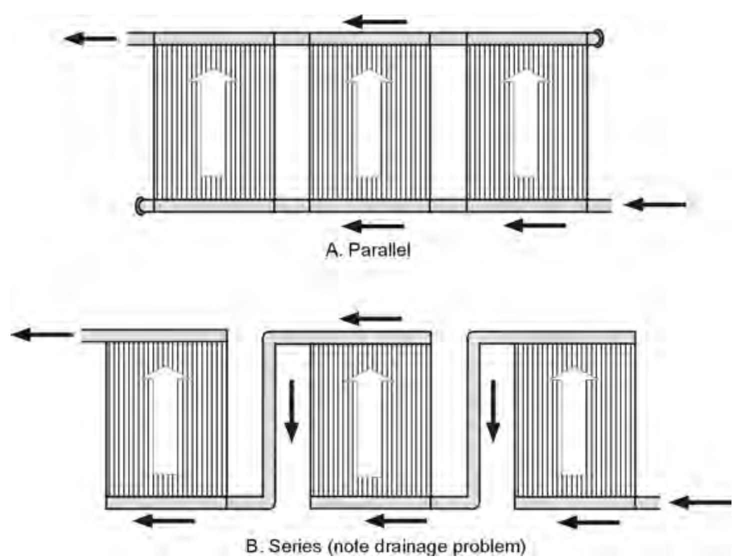


Figure 20 Collector connections

The feed and return lines leading to each collector should be approximately the same length. Figure 21a illustrates the preferred arrangement, and Figure 21b shows a common, but less efficient, connection where the flow tends to be short-circuited through the first few collectors and those at the end are starved for flow (causing a reduction of their performance). In Figure 21a, the length of the water path is the same for all collectors, so the flow is evenly distributed. This style of piping will require extra pipe, but improved collector performance compensates for the additional cost.

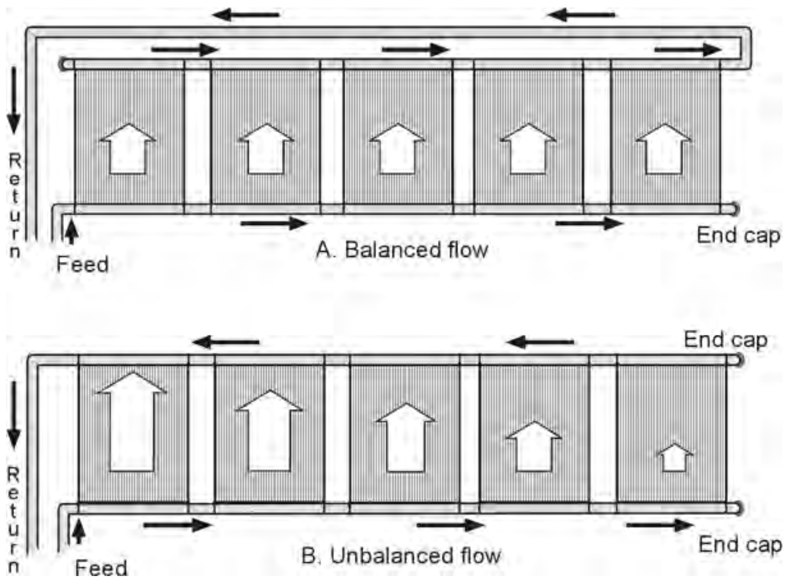


Figure 21 Flow balancing in collector groups

Groups of collectors at different heights should be plumbed in such a way they all receive water from the lowest point in the system and return it from the highest point. Figure 22 illustrates a properly plumbed system. The dashed line indicates a tempting, but unsatisfactory, arrangement. If the return lines do not come from a common height, flow through the panels will be uneven, causing a reduction in performance. Even with this piping layout, a balancing valve may be required to reduce the flow rate in the lower collector(s).

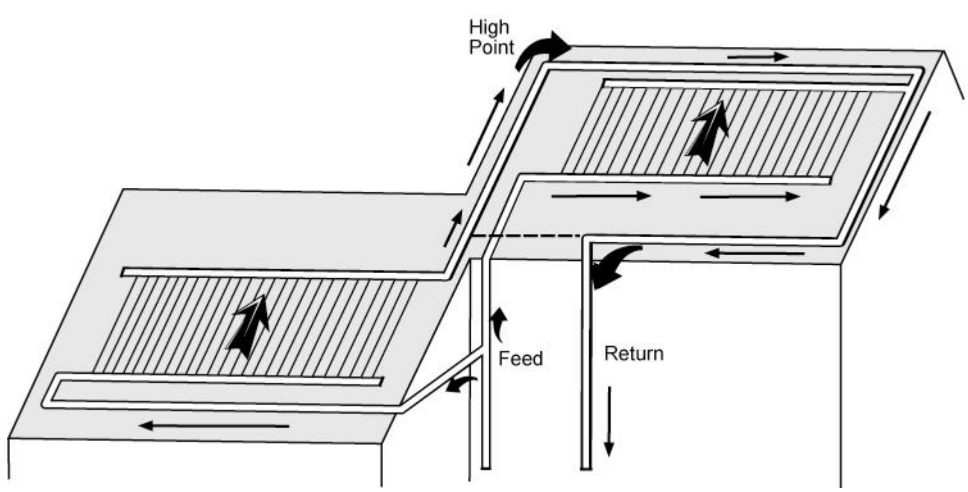


Figure 22 Plumbing collectors at different heights

Balancing valves can be used to obtain uniform flow distribution in other difficult situations, which occur when site requirements make it impractical to balance the flow with simple plumbing arrangements. Balancing valves and, if economics permit, flow meters should be installed in the feed line to each group of collectors. Starting with all valves completely open, gradually close the appropriate valve until the desired flow for each group is obtained. An alternative to the use of flow meters is to measure the outlet temperature of the various collector groups and adjust the balancing valves until these temperatures are within a few degrees of each other.

Connections between collectors and plumbing pipe are commonly made with synthetic rubber couplings, which slide over the header and connecting pipe and are clamped tightly around each by stainless steel bands. To accommodate thermal expansion and misalignment, these couplings are longer than those used between panels.

A vacuum relief valve may be required on the highest collector group to admit air into the system when the pump shuts down and allow the collectors to drain. If necessary, because of height differences, vacuum relief valves can be installed in more than one group of collectors to facilitate drainage. The vacuum relief valve must not admit air into the system during pump operation. If it does, the system may be noisy and will consume excessive amounts of chemicals due to constant bubbling. This means such a valve must be installed at a point where the system pressure is above atmospheric pressure. This requires some experimentation on systems installed on roofs of multistory buildings. In such cases, the water flowing down the return pipe may cause a vacuum in that pipe.

Installing the vacuum relief valve on the return end of the highest supply header will keep the valve pressurized until there is a vacuum caused by draining the supply header. The tilt of the array must allow complete drainage. Unfortunately, some pipe layouts will not allow gravity drainage of the collectors. For example, in piping over the ridge of a roof, the supply and return are higher then the level of the collectors. This prevents proper drainage of the collectors. Installing a freeze protection valve on the bottom header of the collector array may allow gravity to drain the panels during freezing conditions.

Flow Control and Safety Devices

One of the most important components in the flow control system is the control (diverter) valve normally installed in the main filter flow path after the collector feed-line and before the collector return (Figure 7b and 7c). Although this valve can be as simple as a manually operated ball valve, for convenience, it is generally operated automatically.

Several types of control valves are available. These include automatic and manual valves. The automatic valves include:

- 3-way diverter or ball valves
- bladder-type pinch valves
- or specially constructed variations of irrigation valves

Automatic valves

Typically, the valves are operated by an electronic differential controller, which measures collector temperature and compares it to pool temperature. The high temperature (collector) sensor is mounted in a dull plastic housing that has an absorptivity for solar energy approximating that of the solar panel or in-line on the return outlet or pipe near the collector. Since the sensor temperature should simulate the collector temperature, it should be mounted alongside a collector panel and fastened to the same surface to which the panels are fastened. All wire connections should be made secure and watertight, preferably with silicone wire connector nuts, heat-shrinkable insulating tubing or as a last resort, durable sealant.

The lower sensor, which measures pool temperature, should be protected from direct contact with the pool water to prevent galvanic corrosion. Most sensors are a encapsulated with epoxy into a pipe thread brass fitting of ¼" or ½" MIP, installed in a "well" in the pipe between the pool and the circulation pump, or immersed into the water flow. Many times the sensor can be inserted into the drain port of the pump suction basket. It is important to ensure the "cold" sensor registers the temperature of the pool water not the ambient air or warmth from sunshine on the sensor capsule.

The electronic controller itself requires electrical power. Sometimes it can be connected in parallel with the pool pump or timer, but since 120V or 240V electricity is involved installers should consult their local building officials to find out if an electrician is required to make the connection. Approved conduit should be used for this wire.

In the installation of the automatic 3-way actuator and controller, the low voltage output from the controller powers the motor and turns the valve. It is important to ensure proper alignment of the motor, directional flow and direction of diverted flow. Be careful not to actuate the valve and stop flow from the filter. Pressures in excess of the filter's maximum operating pressure could damage the filter.

Normal operation is flow to the pool from the filter. When the signal from the high temperature sensor indicates heat collection is available at the collectors, the controller activates the valve and diverts the flow from the pool to the collectors.

In the installation of a pinch valve control system, it is necessary to connect two pressure lines between the pool pump and the control box. Small-diameter (1/8-inch) plastic lines are generally used. Since most pool pumps have a 1/4-inch, threaded pipe plug in the side of the strainer housing (near the bottom), the low-pressure line is usually attached to an adapter at that point. The high-pressure line should be tapped into the pipe on the discharge side of the pump.

When the high temperature sensor registers the collectors are warmer than the pool water, the electronic control opens the line from the discharge side of the pump and inflates the bladder in the pinch valve. This diverts flow through the solar system. When the high temperature sensor signals the collectors are cooler than the pool water, the line from the suction side of the pump is opened, forcefully deflating the bladder and allowing flow to bypass the collectors.

Another possible control valve, the irrigation style, achieves the same results but operates in a slightly different fashion. It is plumbed into the system by standard piping procedures. A small suction line is tapped into the pump inlet strainer housing, but in this case, the suction line is connected to the valve body itself. A pressure line is not used. A low voltage wire also connects a small solenoid valve mounted on the valve body to the control box. Most irrigation type valves will increase the pressure and reduce the flow rate of the system.

The system control compares collector temperature with pool temperature as before. If solar heat is available, an electrical signal causes the solenoid valve to open the suction line. This suction closes the main valve diaphragm, diverting flow through the collectors. When solar energy is not available, the solenoid valve remains closed, the main valve diaphragm (which is spring loaded) opens, and the flow bypasses the collector array. (In another version the spring loading keeps the main valve diaphragm closed and the solenoid induces its opening.)

Manual valves

Manual valves can be two- or three-way ball valves or standard flow diverter valves. Operation of these valves is completely manual and includes isolating the flow to the pool by diverting flow to the collectors. It is important that the isolation valve to the pool is between the collector supply and return lines in the system piping design.

Activating the System

After installation is completed, it is necessary to activate and test the system for proper operation. A few of the most important checks are discussed here.

Purging the System

Bits of plastic from rough pipe cuts, sand and other debris should be flushed from the system to avoid clogging small fluid passages in the collectors. Purging can be accomplished by leaving one or two strategically placed joints open. The circulation pump can be briefly turned on to flush water through the system, then final connections can be made. Small amounts of pool water can be discharged onto grass or sand, but large volumes should be piped to safe drains.

Pressure Testing

The entire system should be pressurized to the maximum operating pressure. This can be accomplished in a number of ways.

If piping passes through critical areas, such as an attic or public area, which is not recommended, a continuous run of piping is recommended. Avoid couplings and fittings in areas where a leak could cause significant damage. The system should be pressurized with an air compressor and tested for leaks. Testing the pipe to twice the operating pressure is recommended, but be sure not to exceed the pressure rating of the pipe. Leaks can be located readily by listening for the hiss of escaping air.

Installations where all piping is routed through areas where a temporary leak will do no harm may be pressure tested by turning on the circulating pumps. The appropriate valves in the circulation system should be closed to produce the highest possible pressures in the new piping. Be sure to have someone standing by; ready to turn the pump off in the event a leak is discovered.

During the pressure check, every connection should be visually inspected and shaken to ensure that it is well made.

Testing Control Devices

Automatic control devices should be checked for proper operation. Consult the manufacturer's specifications for the controls being used and determine the possible operating modes. Test in all of these modes and make a permanent record of the results. Checking control operation immediately after installation can prevent costly callbacks later.

Testing Flow Rates

Proper flow through the collector array and filtration system is required. Inexpensive flow meters are available and should be used to confirm desired rates have been achieved. As previously mentioned, turnover time must not be increased above an acceptable level.

Testing Temperature Rises

The temperature difference between the feed line to the solar system and the warmer return line should be checked. Remember, the temperature rise on even a sunny day should be quite modest, approximately 5-10°F, for low-temperature collectors. Thermometers installed in these lines can be used to make accurate readings.

If the temperature rise is too large, it indicates not enough water is passing through the collectors. Check the system thoroughly and correct the problem because collector efficiency drops dramatically as the operating temperature rises. It sounds strange to the homeowner but lots of water being warmed slightly provides more heat than a little water being warmed a lot.

Instructing the Homeowner

There are several important reasons to spend a few minutes instructing the homeowner on the operation of the new solar pool heater. First, it will enable the owner to ascertain whether the system is operating and thus reduce “false alarm” callbacks. Second, it will enable the owner to explain the new unit to friends and neighbors. Third, it will equip the owner to make minor adjustments and reduce service calls for the installer.

Explain the operation of all valves and controls and how the water circulates in the various modes. Spend a little time on the automatic control so that the owner can make seasonal or other adjustments that may be required. Provide the owner with the system manual.

It is very important to explain the amount of energy being delivered to the pool is the product of the temperature rise and the flow rate. High temperature rises feel impressive, but they cause the collectors to operate inefficiently and deliver less heat to the pool. Sometimes this point is difficult to make, so you may have to explain it in several different ways.

APPENDIX

Appendix 1: Chrome Dome Collector Siting Aid is a tool for determining the best location for solar collectors in Florida. Its simplicity and ease of use in the field make it ideal for installation and service personnel.

Appendix 2: FSEC Simplified Sizing procedure for Solar Domestic Hot Water Systems is an invaluable guide in sizing solar water heating systems in Florida.

Appendix 3: Electric Water Heater Circuitry describes the electrical connections in a standard hot water tank with two heating elements.

Appendix 4: Volt-Ohmmeter (VOM) or Multimeter Operation, provides basic information on VOM and multimeter operation and includes a standard temperature and thermistor resistance table for 3,000 and 10,000 Ohm thermistors.

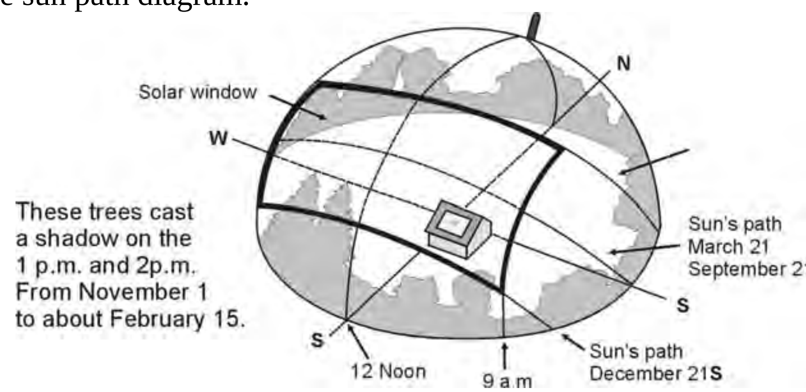
Appendix 5: Solar System Flow Rates describes two simple methods for checking solar system flow rates.

Appendix 6: Tools for Service and Repair lists the tools and equipment that field personnel generally need to service a solar system.

Appendix 1
Crome-Dome Collector Siting Aid

The *Crome-Dome is* designed to determine the best location for a solar collector. It will work well for any location in Florida, but it is not appropriate for use farther north than 31°N latitude (southern Georgia).

A collector should be mounted in an area receiving sunshine during the entire year. The sun's path drops closer to the horizon during winter, and is higher in the sky during summer. The sun's lowest path, its highest path, and its position three hours before and after solar noon define the solar window. (See Figure 1.) The solar window is shown on the Crome-Dome by the heavy black lines on the sun path diagram.

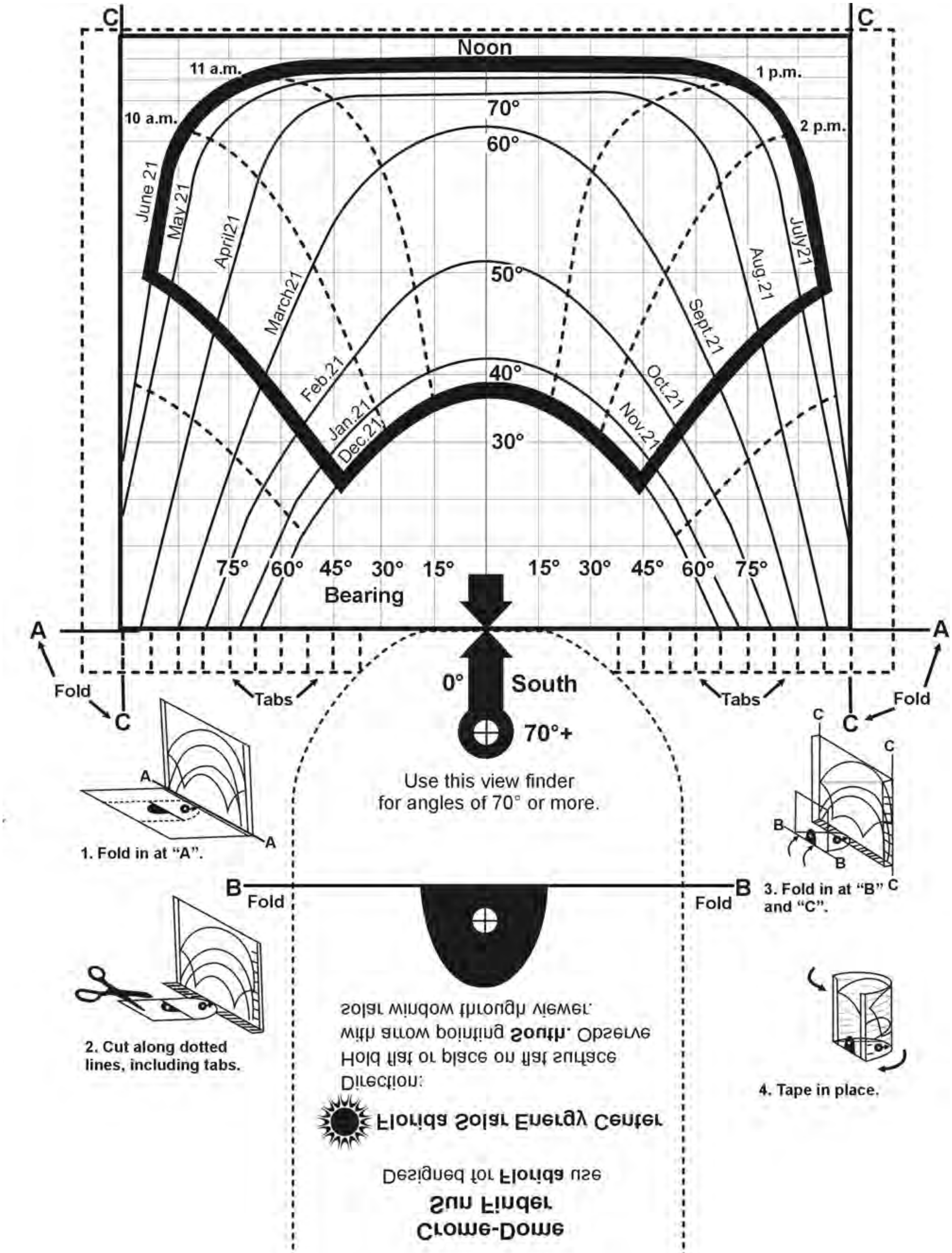


To use the Crome-Dome, stand a few feet in front of the proposed collector site facing south.* (Use a compass to determine south.) Holding the Crome-Dome base as level as possible, and several inches from your eye, look upward through the sighting circle. Align the cross hairs within the sighting circle with the lower edge of the solar window. If you can see any objects (trees, buildings) through the viewer that are within the solar window, these objects will shade the collector site.

By aligning the collector location, your eye, cross hairs and object, (see Figure 2) you can read from the sun path diagram the times of day and times of year a particular object will shade the collector location. When checking for high angles (summer), tilt your head all the way back and peer through the viewer on the base of the Crome-Dome. The summer sun path goes almost directly overhead.

*If you are on a roof, it is safer to squat or sit at the base of the collector location.

The Crome-Dome was invented by Dr. Charles Cromer, P.E. at the Florida Solar Energy Center in 1980.



Noon
11 a.m.
1 p.m.
10 a.m.
2 p.m.
70°
60°
50°
40°
30°
June 21
May 21
April21
March21
Feb.21
Jan.21
Dec.21
July21
Aug.21
Sept.21
Oct.21
Nov.21
75° 60° 45° 30° 15° 15° 30° 45° 60° 75°
Bearing
A
C
Fold
Tabs
0° South
70°+
Use this view finder
for angles of 70° or more.
1. Fold in at "A".
B Fold
2. Cut along dotted lines, including tabs.
3. Fold in at "B" and "C".
4. Tape in place.
Crome-Dome
Sun Finder
Designed for Florida use
Florida Solar Energy Center
Direction:
Hold flat or place on flat surface with arrow pointing South. Observe solar window through viewer.

Appendix 2
Simplified Sizing Procedure for Solar Domestic Hot Water Systems

The following procedure was developed to size residential solar Water heating systems in Florida. See last page for limitation and assumptions.

Hot water demand and tank size

Step 1. Using Table 1. Estimate daily hot water use (GALLONS) And select a nominal tank size (TANK SIZE).

______________ gal/day
GALLONS (1)

______________ gal
TANK SIZE

Table 1. Hot water demand and tank size

.

Average GALLONS and minimum TANK SIZE based upon number of people:

People	GALLONS	Minimum TANK SIZE (Gallons)
1	20	40
2	40	40
3	55	66
4	70	80
5	85	80
6	100	100
7	115	120

(Add 15 gallons per person for each additional person.)

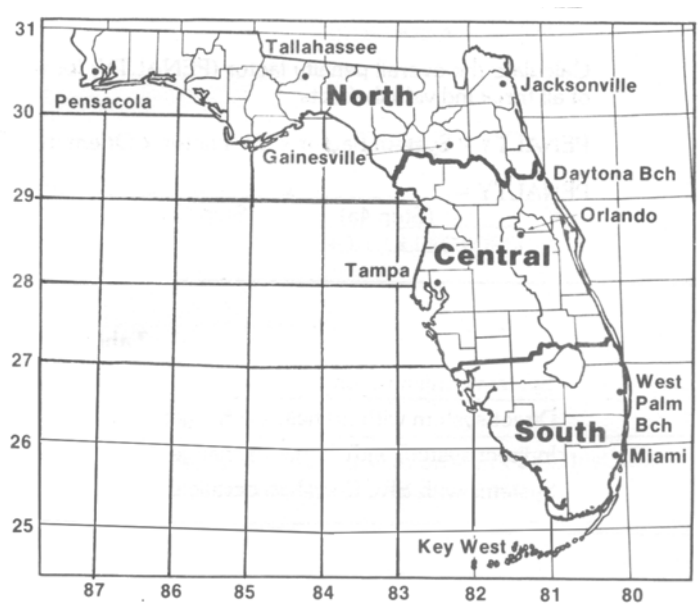
Step 2. Using Figure 1, determine the proper cold water temperature (COLDTEMP) for location.

______________ °F
COLD TEMP (2)

Figure 1. Cold water temperatures

Region	COLDTEMP
North Florida (12,2,3)*	68°F
Central Florida (4,5,6)*	72°F
South Florida (7,8,9)*	76°F

* Correspond to regions for the Florida model energy building code.



Step 3. Calculate how much energy is needed (BTUNEED) to heat the water to 122ºF.

BTUNEED = 8.34 x GALLONS x (122-COLDTEMP) x Standby loss factor

BTUNEED = 8.34 x _________ x (122 - _________) x _________ _____________ Btu/day
(Step 1) (Step 2) (Table 2) BTUNEED (3)

* See last page for explanation.

Table 2. Standby heat loss from storage

Type of tank installation	Standby loss factor
1-in. foam or 2.5 –in fiberglass (R = 8 – 9)	1.20
2-in. foam (R= 16-17)	

(Use linear interpolation to obtain standby loss factor for insulation materials having other R-values.)

Table 2 is to be used for sizing systems with FSEC ratings. If SRCC rating is used and if There are no other backup tanks use a standby loss factor or 1.0.

Example: A thermosiphon water heater with its storage tank containing a back-up element has an SRCC rating. There are not other back-up tanks for the system. In this case use a standby loss factor = 1.0**.**

Example: The same thermosiphon water heater system is used as a preheater to another back-up tank. The element in the thermosiphon tank may not be connected. In this case use a standby loss factor from Table 2 corresponding to back-up tank insulation level.

Collector Sizing

Step 4. Determine penalty factors that affect sizing.

a. Select the System Factor form Table 3. ____________________ System Factor (4a)

b. Select the proper Tilt Factor from Table 4. ____________________ Tilt Factor` (4b)

c. Select the Orientation Factor from Table 5. ____________________ Orientation Factor (4c)

Calculate the overall penalty factor(PENALTY) for the combination Of all three individual effects:

PENALTY = System Factor x Tilt Factor x Orientation Factor

PENALTY = ___________ x ________ x __________ ____________________
(Step 4a) (Step 4b) (Step 4c) PENALTY (4c)

Table 3. System Factor

System configuration	System Factor
Direct system with no heat water exchanger.	1.29
Indirect system with a heat exchanger between collector and storage tank.	1.30
Systems with SRCC system certification and Q_{NET} rating.	1.00

Table 4. Tilt factor

Collector tilt			Tilt Factor		
Tilt angle	Roof pitch	Roof tilt	North Florida	Central Florida	South Florida
0º to 3º	0	0º	1.25	1.22	1.19
3º to 7º	1 in12	4.8º	1.15	1.14	1.12
7º to 12º	2 in 12	9.5º	1.09	1.08	1.06
12º to 16º	3 in 12	14.0º	1.05	1.04	1.03
16º to 20º	4 in 12	18.4º	1.02	1.01	1.01
20º to 25º	5 in 12	22.6º	1.00	1.00	1.00
25º to 30º	6 in 12	26.6º	1.00	1.00	1.00
30º to 37º	8 in 12	33.7º	1.01	1.01	1.02
37º to 43º	10 in 12	39.8º	1.04	1.05	1.06
43º to 59º	12 in 12	45.0º	1.08	1.10	1.12

Table 5. Orientation Factors

Collector orientation	Orientation Factor
South or nearly south	1.00
Southeast or southwest	1.15
East or west	1.40

Step 5 Calculate the rating requirements of the solar system (RATREQD)
To provide 70% of the annual hot water energy needs using the formula:
RATREQD = BTUNEED x 0.70 x PENALTY

RATREQD = ___________ x 0.70 x ___________ (Step 3) (Step 4) — ________________ Btu/day RATREQD (5)

Step 6. For the collector selected, record the thermal performance rating at the intermediate temperature (BTURATING) in Btu/day and the gross collector area (GROSSAREA) in square feet from the required FSEC label.

Collector Manufacturer ____

Model No. __________________________

Thermal Performance Rating at the Intermediate Temperature (Btu/day)
Or SRCC Q_{NET} or Q_{NET} equivalent* — ________________ Btu/day BTURATING (6a)

Gross Collector Area (ft^2) — ________________ ft^2 GROSSAREA (6b)

Estimate the number of collectors needed using:

NUMBER = RATREQD / BTRUATING = ________ (Step5) / ________ (Step6) — ________________ NUMBER (6c)

Step 7. Select the actual number of collectors to be used. This is the nearest Whole number to (6c). — ________________ NO. COLLECTORS(7a)

The total area number of the collector array is:

TOTAL AREA = NO. COLLECTORS x GROSAREA

TOTAL AREA = _____________ x _____________ (Step 7a) (Step6b) — ________________ ft^2 TOTAL AREA (7b)

* For those systems that are SRCC certified use the SRCC Q_{NET} rating here. Systems with only FSEC test and certification may get an equivalent SRCC Q_{NET} from Testing & Operations on request.

Based upon the actual number of collectors to be used, compute the
Solar fraction (SOLAR FRACTION):

$$\text{SOLAR FRACTION} = \frac{0.70 \times \text{NO. COLLECTORS}}{\text{NUMBER}} = \frac{0.70 \times \underset{\text{(Step 7a)}}{\_\_\_\_\_\_}}{\underset{\text{(Step 6c)}}{\_\_\_\_\_\_}} = \underset{\text{SOLAR FRACTION (7c)}}{\_\_\_\_\_\_\_\_\_\_}$$

If the solar fraction (Step 7c) is less than 0.65, the collector array is undersized.
Consider either adding another collector or using a different model/size collector.

This procedure has several constraints:

1. The procedure is valid only for Florida
2. The procedure is based on sizing solar systems to provide between 65% and 75% of the heating load; i.e., a solar fraction of between 0.65 and 0.75. A solar fraction of 0.7 is estimated to be optimum for most installations and, in particular, for solar collectors with a tilt angle of approximately 20º -25º (mounted parallel to the 4-in. -12 or 5-in-12 pitched roofs that are common in Florida). The 20º - 25º collector tilt angle provides for an aesthetic installation and meets 100% of the hot water needed in summer and 50% in winter. Systems can be sized to maximize lifetime saving by providing a larger solar collector that will produce a solar fraction of 0.9 or higher. *At high annual solar fractions however, the production and waste of excess heat during the summertime needs to be considered. To minimize collector size for high annual solar fractions, the collectors can be installed at a tilt angle of between 40*º and *40*º. Optimization of these types of systems is beyond the scope of this simplified sizing procedure. To achieve this solar fraction, the collectors will need to be installed at a tilt angle of between 40º and 50º
3. The hot water delivery temperature of 122ºF in step 3 was obtained by FSEC from analysis of two years of actual experimental data. The 122ºF delivery temperature is consistent with Florida Law, which requires that hot water thermostats be set no higher than 125ºF. It is also consistent with electric water heater energy consumption data as measured by Florida Power and Light Co.

   Automatic dishwashers may not clean dishes very well at 122ºF. However, most dishwashers have a cycle that Uses an electric element in the dishwasher to boost water temperature to about 140ºF.

This form was developed by Subrato Chadra with the assistance of David Block, Mukesh Khattar, David LaHart, Tim Merrigan, Jerry Ventre and Ingrid Melody.

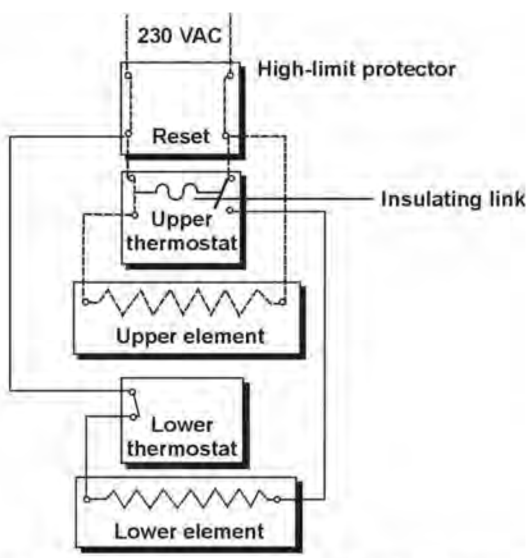
Appendix 3
Electric Water Heater Circuitry

The following illustration shows the electrical connections in a standard hot water tank with two heating elements. Each electrical supply line has a potential of 115 volts measured to ground and 230 volts measured across the two lines. The illustration shows where the high-limit protector is located in the circuit. It also shows how the upper thermostat is used to prevent operation of both heating elements simultaneously.

First, power travels through the high-limit protector: a double-pole, single-throw (DPST) snap-action device. When the water reaches a predetermined temperature (about 180°F), this device opens both contacts of both lines at the same time, which cuts all power to the heater. To restore operation, the reset button must be pressed.

At the output side of the high-limit protector, the circuit splits and forms the parallel circuits that lead to the two elements through their respective thermostats. The upper thermostat is a double-pole, double-throw (DPDT) bimetal type, designed so that when one of the contacts is closed, the other is open, and vice versa. This thermostat is always in operation. Depending on the demand for hot water, it supplies power to either the upper or lower element, but never to both elements at the same time.

The lower thermostat is a single-pole, single-throw (SPST) type and controls the lower element. Before this lower element can be energized, the upper thermostat must be “satisfied” (even though the lower thermostat contacts may be closed).



Typical electrical connections in a tank with two heating elements

Appendix 4
Volt-Ohmmeter (VOM) or Multimeter Operation

The volt-ohmmeter (VOM) measures voltage and resistance. (Some VOMs also measure current but current measurements are not needed in controller troubleshooting.) VOMs have either an analog or a digital readout. The analog display uses a needle pointer on a scale. The digital display gives an LCD numerical reading. Both types of meters operate from batteries and usually have a battery low indicator to signal when new batteries are needed.

The meter contains two probes with wire leads, one black (the common or ground lead) and one red (the positive lead), which plug into color-coded receptacles on the meter. For detailed information about operation of the meter, refer to the VOM manual.

Check the VOM before each use:

1. Turn on the power switch. If the battery replacement indicator signals low batteries, replace them before continuing.

2. Set the function switch to "ohms," and set the range switch to a mid range around 0 to 20K ohms. (Note: K equals 1,000 and V refers to volts.) Connect the probe wires to the proper receptacles and touch the red probe to the black probe without contact with your body.

The meter should read zero (0) or 0.00 (digital), showing continuity. If it does not, adjust to zero. If the meter doesn't respond, check the battery supply for a blown fuse.

Two types of thermistors (sensors that change resistance with changing temperature) are generally used in control systems – the 3,000 (3K) ohm and the 10,000 (10K) ohm. Table 1 lists the usual VOM settings for measuring resistance; Table 2, for measuring AC voltage; and Table 3, for measuring DC voltage.

Thermistor resistance should match temperature as closely as possible, as shown in Table 4. To be accurate, disconnect the thermistor from the circuit before measuring it.

Table 5 lists the resistance setting for a positive temperature coefficient resistance temperature device (RTD) that uses 1,000 (1K) ohm sensors.

Resistance Measurements with the VOM

Remember any circuit must be disconnected to measure its resistance.

Table 1 Measuring Resistance with the Volt-Ohmmeter

	In the Range of		**Function**	**Range**	**Multiply**
Measuring	Minimum	Maximum	Switch at	Switch at	Reading by
Resistance	0	199	Ohms	20000	1
Resistance	200	1,999	Ohms	2 K	1,000
Resistance	2,000	19,999	Ohms	20 K	1,000
Resistance	20,000	199,999	Ohms	200 K	1,000
Resistance	200,000	1,999,999	Ohms	2 M	1,000,000
Resistance	2,000,000	19,999,999	Ohms	20 M	1,000,000

AC Voltage Measurements with the VOM

- Never measure circuits containing over 700 volts AC.
- Always make measurements from one line to the other (this is measuring in parallel).
- Never insert probes in series with a line.
- If the voltage is unknown, start with the highest range on the VOM.

Table 2. Measuring AC Voltage with the Volt-Ohmmeter

	In the Range of		**Function**	**Range**	**Multiply**
AV Voltage	Minimum	Maximum	Switch at	Switch at	Reading by
AV Voltage	0	0.19	AC 0.7 kV	200 mV	0.01
AV Voltage	0.2	1.9	AC 0.7 kV	2 V	1
AV Voltage	2	19.9	AC 0.7 kV	20 V	1
AV Voltage	20	199.9	AC 0.7 kV	200 V	1
AV Voltage	200	700.0	AC 0.7 kV	2 kV	1,000

DC Voltage Measurements with the VOM

- Never measure circuits containing over 1,000 volts DC.
- Always measure in parallel with the lines.
- Never insert probes in series with the circuit.
- If the voltage is unknown, start with the highest range on the VOM.

Table 3. Measuring DC Voltage with the Volt-Ohmmeter

	In the Range of		**Function**	**Range**	**Multiply**
DC Voltage	Minimum	Maximum	Switch at	Switch at	Reading by
DC Voltage	0	0.19	DC 1 kV	200 mV	0.01
DC Voltage	0.2	1.9	DC 1 kV	2 V	1
DC Voltage	2	19.9	DC 1 kV	20 V	1
DC Voltage	20	199.9	DC 1 kV	200 V	1
DC Voltage	200	1,000.0	DC 1 kV	2 kV	1,000

Current Measurements with the VOM

Amperage measurements are not needed in the troubleshooting of controllers. Even if your VOM measures only up to 1 A safely, do not use it as an ammeter placed in series with the pump or motor valves. Some VOMs have extended 10 A ranges, but even these may be damaged if the circuit has a low-resistance short.

Possible Causes for Thermistor Malfunction

To check the thermistors in a solar DHW system, disconnect the thermistor leads at the controller. Remember also, a change in temperature changes thermistor resistance. Make sure the pump is not cycling on and off, changing measurement conditions.

Open Circuit

If the VOM measures an open circuit (an infinite resistance reading), either the sensor is bad or the associated wiring is broken somewhere along its length. A break may occur where the wire crosses a sharp edge of the building or where it has been bent. Run new wires if the break cannot be found and repaired.

High Resistance

A high, but not infinite, resistance may also indicate a bad sensor or lead wire. Disconnect the sensor from the lead wire and check the resistance at or near room temperature. The resistance should measure at or near 3K or 10K, depending on thermistor rating.

Short Circuit

A shorted circuit can also indicate a bad sensor or contact in the associated wiring. This is indicated on the VOM by a zero reading, which shows continuity between the lines.

Drift

On rare occasions, thermistor resistance drifts to the wrong value for its temperature and it must be replaced. This drift is usually due to aging and can be checked with the VOM. Refer to Table 4 of thermistor temperatures. When resistance readings are correct or nearly correct for various temperatures, the thermistor is working properly. There may be resistance in the wiring. To check the associated wiring, use a jumper to short across the sensor. The ohm resistance of the wiring itself should go near zero. If the resistance still exists, make sure all connectors are clean and no breaks with resistance contact are found. If none of these are found, to eliminate the wiring resistance, replace the wiring.

Table 4. Temperature and Thermistor Resistance

Temperature (°F)	**3000-Ω Thermistor**	**10,000-Ω Thermistor**	**Temperature (°F)**	**3000-Ω Thermistor**	**10,000-Ω Thermistor**
Thermistor open	Infinite	Infinite	92	2,100	7,000
Thermistor shorted	0	0	94	2,010	6,683
30	10,400		96	1,920	6,383
32	9,790	32,660	98	1,830	6,098
34	9,260	30,864	100	1,750	5,827
36	8,700	29,179	102	1,670	5,570
38	8,280	27,597	104	1,600	5,326
40	7,830	26,109	106	1,530	5,094
42	7,410	24,712	108	1,460	4,873
44	7,020	23,399	110	1,400	4,663
46	6,650	22,163	112	1,340	4,464
48	6,300	21,000	114	1,280	4,274
50	5,970	19,906	116	1,230	4,094
52	5,660	18,876	118	1,180	3,922
54	5,370	17,905	120	1,130	3,758
56	5,100	16,990	124	1,040	3,453
58	4,840	16,128	128	953	3,177
60	4,590	15,315	132	877	2,925
62	4,360	14,548	136	809	2,697
64	4,150	13,823	140	746	2,488
66	3,940	13,140	144	689	2,298
68	3,750	12,494	148	637	2,124
70	3,570	11,885	152	589	1,966
72	3,390	11,308	156	546	1,820
74	3,230	10,764	160	506	1,688
76	3,080	10,248	165	461	1,537
77	3,000	10,000	170	420	1,402
78	2,930	9,760	175	383	1,280
80	2,790	9,299	180	351	1,170
82	2,660	8,862	185	321	1,071
84	2,530	8,449	190	294	982
86	2,420	8,057	195	270	901
88	2,310	7,685	200	248	828
90	2,200	7,333	210	210	702

Table 5. Temperature and RTD Resistance

Temperature (°F)	Resistance	Temperature (°F)	Resistance
30	861.8	35	876.1
40	890.5	45	905.1
50	919.2	55	933.9
60	948.7	65	963.7
70	978.2	75	993.4
80	1008.7	85	1024.0
90	1039.0	95	1054.6
100	1070.3	105	1086.1
110	1101.5	115	1117.5
120	1133.6	125	1149.9
130	1165.6	135	1182.1
140	1198.7	145	1215.4
150	1231.5	155	1248.4
160	1265.4	165	1282.5
170	1299.1	175	1316.5
180	1333.9	185	1351.4
190	1368.5	195	1386.2
200	1404.1	205	1422.0
210	1439.5	215	1457.7

Appendix 5
Solar System Flow Rates

Determining flow rate

Determining approximate flow rate through the collector loop can help you identify problems in the system such as faulty pump operation, clogged or restricted pipes or failure of the check valve to open properly. Here are two simple methods for checking the solar system flow rate.

Method A

This method uses the "siphon principle" to keep water in the collector loop when the city water pressure is shut off. First, you must purge air from the collector loop. Also, you must vent the storage tank to the atmosphere to prevent a vacuum from forming during the following steps. Refer to the following illustration.

a. Turn off the back-up heating element (to avoid burning out the element should the water level drop to the element's level).

b. Ensure all air is purged from the *collector* loop and close or plug any valves (air vents or vacuum breakers) that may admit air into the pipes.

c. Close the shutoff valve in the cold water supply line to the tank.

d. Open the PT relief valve on the *storage tank.*

e. Attach a hose to the boiler drain on the return line from the collector(s). Drain off a few gallons of water so the standing water level is below the top of the tank and not in the hot and cold supply pipes. If you have a clear plastic hose, you can easily see the water level. When the level is about 1" below the top of the tank, stop the draining process by elevating the open end of the hose above the top of the tank. Leave the boiler drain open.

f. Close the isolation valve between the return line boiler drain and the tank.

g. Lower the open end of the hose to just above the standing water level in the tank. Allow the level to come to equilibrium.

h. Place a vessel of known volume (a gallon milk jug works well) where it can receive all the discharge from the hose attached to the return line boiler drain. Keep this container as close to the water level line as possible to minimize static head influences on the flow rate.

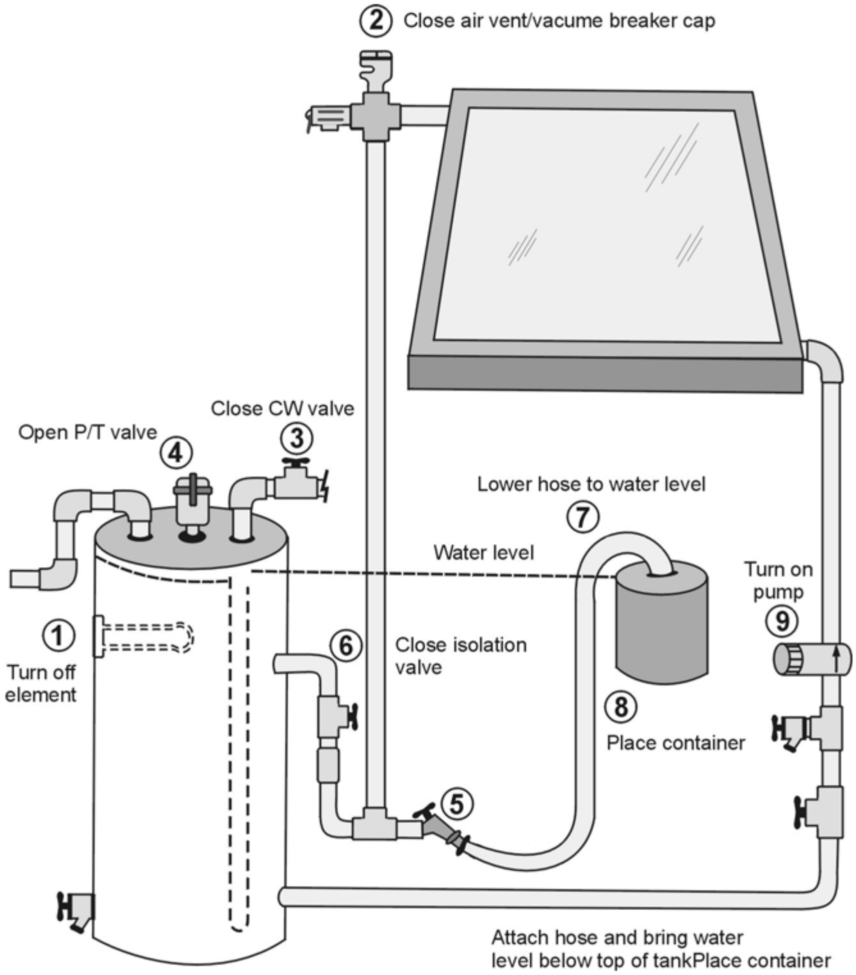
i. Manually turn on the pump and use a stopwatch (or the sweep second hand on a wristwatch) to measure the time required to fill the vessel.

j. Turn off the pump. Use this formula to calculate the flow rate:

$$\frac{\text{Volume}}{\text{Time}} = \text{Flow Rate (usually in gpm)}$$

k. Close the return line boiler drain. Open the shutoff valve in the cold water supply to refill the tank. Bleed off the entrapped air through the PT relief valve, and close it when the tank is full.

1. Open the remaining valves to return the system to normal operation. This avoids prolonged stagnation in the collector loop.



Method B

Another less accurate method can be used when the system is plumbed in such a way that you cannot follow Method A.

a. Determine how much water the collector can hold (volumetric capacity). If the collector has been certified by FSEC, you can find this information on the FSEC Summary Information Sheet.

b. Turn off the pump and allow the collector loop pipes to cool down to equilibrium (and the collector to heat up).

c. Put your hand on the return pipe near the tank and turn on the pump. When you feel the “slug” of hot water warm the area under your hand, start timing. (Again, use a stopwatch or the sweep second hand on your wristwatch.) Continue timing until the pipe starts to cool down again.

d. Calculate the approximate flow rate by dividing the volumetric capacity reported on the Summary Information Sheet by the time measured (gallons/hour or gallons/ minute).

Flow Rates and Water Stratification in Solar Tanks

Flow rates also have a direct correlation to system performance. Low flow rates in single-tank direct systems result in better overall system performance. Low circulation does not mix up the water in the solar tank and thereby enhances stratification.

When water circulates through the collectors and returns at a low flow rate, the hottest water will migrate to the upper portion of the tank. The colder water at the bottom of the tank will not mix with the returning collector-heated water. Thus, the bottom water being fed to the collector is the coldest water in the tank. This in turn improves the collector’s efficiency because the colder the inlet temperature, the more efficient the collector panel.

To improve system performance by using lower flow rates and better stratification, follow these guidelines:

a. Use a flow rate of approximately 0.01 gallons per minute per square foot of collector panel (e.g. 40 square feet of panel x 0.01 = 0.4 gallons per minute).

b. Use dip tube diffusers on your cold and hot ports. You can make these by heat closing the end of the dip tube and drilling holes near the end – so the water exits sideways instead of downward.

c. Return the solar heated water at least 8 to 10 inches below the top heating element.

Appendix 6
Tools for Service and Repair

To avoid costly delays, repair and service personnel must arrive at the scene fully prepared and outfitted. Listed below are the recommended tools and equipment for diagnosis and repair of DHW systems. All tools must meet OSHA guidelines.

Bucket, 5-gallon plastic
Brush, flux
Brush, wire
Chalk-line reel
Compass
Crimping tool
Cutter, copper and PVC
Drill, battery operated
Drill, electrical
Drill bits, assorted size set, high speed steel twist
Drill bits, 3/4" to 3" set, steel hole saw
Drill bits, 3/8" to 1" size set, power wood
Extension drill
Extension cord, 100'
Extinguisher, fire (A:B:C: rated)
Flashlight, industrial
Glasses, safety
Gloves, work
Gun, caulking
Gun, soldering
Hacksaw
Hammer, claw
Hand pump, or small air compressor
Hex key sets, standard and metric
Hose, rubber 25'
Inclinometer
Knife, utility
Ladder, extension 24'
Lamp, heavy duty trouble
Level, 24"
Level, magnetic torpedo
Mask, dust
Mirror, inspection
Multimeter or voltmeter
Nut driver set, standard and metric
Pliers, diagonal cutting 6"
Pliers, locking 10"
Pliers, needle nose 8"
Pliers, 6"
Pliers, slip joint 8"
Plumb bob
Pop riveter

Pressure gauge, testing
Putty knife
Rope, safety 3/8" x 100'
Saw, hand 8 point, general purpose
Saw, skill
Saw, miter
Screwdriver, angle
Screwdriver set, electronic
Screwdriver set, Phillips
Screwdriver set, standard
Sensor stimulator
Slate, nail cutter
Shears, industrial
Shoes, non-skid
Socket wrench set
Torch, acetylene
Torch, propane
Vise, mechanics
Vise grips, 10"
Water meter key
Wire strippers
Wrench set, Allen
Wrench, adjustable
Wrench, pipe 10"
Wrenches, open-end kit, 5/16" to 3/4"