NABCEP

Solar Heating Installer Resource Guide

Prepared by:

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www.nabcep.org

North American Board of NABCEP Certified Energy Practitioners ®

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Acknowledgements:

NABCEP wishes to thank the companies and individuals who have made this Resource Guide possible. This document is the result of the efforts of its principal authors: Chuck Marken and Vaughan Woodruff of Kennebec Valley Community College and Insource Renewables. We also wish to thank Les Nelson, Technical Editor of the Resource Guide. Les is a founding Director of NABCEP, and is the Director of Solar Heating & Cooling Programs at the International Association of Plumbing & Mechanical Officials (IAPMO).

We could not have produced a document of such high quality without the support of the New York Energy Research and Development Authority (NYSERDA).

Finally NABCEP would like to express our gratitude to Kathryn Sikule at Brownstone Graphics who has turned the work of the contributors into a beautiful document.

Forward/Scope

This document was developed to provide an overview of some of the basic requirements for solar heating (SH) system installations and those who install them. Readers should use this document along the other resources listed on the NABCEP website. These resources include: training materials; reports; and, codes and standards associated with the design and installation of solar heating systems.

This document is a collaborative effort between the authors, editors and you the reader. It is considered a work in progress. Future editions of this guide will incorporate comments, corrections and new content as appropriate to reflect new types of products, installation methods or code requirements. Public comments are welcomed and can be directed to the following: www.shstudyguide.org.

Units of Measure

Both the International System of Units (SI) and the U.S./Imperial customary units of measure are used throughout this document. While SI units are generally used for solar radiation and electrical parameters, U.S./Imperial customary units are used most commonly in the U.S. construction industry for weights or measure. Solar Heating professionals U.S. and Canada are expected to be comfortable with using both systems of measurement and converting between the two given the appropriate unit conversion factors.

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Welcome to the 2012 edition of the NABCEP Certified Solar Heating Installer Study and Resource Guide. This edition follows the most recent version of the NABCEP Solar Heating Installer Job Task Analysis which can be found at www.nabcep.org.

Over the years we have received many suggestions for improving our Study and Resource Guide. We often receive suggested corrections to perceived inaccuracies in the copy. With the publication of this guide we are setting up a special email account to receive comments and suggestion about this publication: SHSG@nabcep.org. We will monitor this email account and the Study Guide Committee will review all submissions. The most relevant and appropriate suggestions that are received will be added to the next edition of the Guide. We think that this approach of actively seeking input from readers will ultimately improve the Study Guide and are looking forward to hearing from you. Please keep your postings positive and as brief and succinct as possible. A second edition of the Guide that reflects the comments and suggestions received will be published in the fall of 2012.

As ever, we wish to remind all readers of this Study and Resource Guide that it is in no way intended to be the definitive word on Solar Heating installation nor is it intended to be viewed as the sole study resource for candidates for the NABCEP Certification Examination. The NABCEP website has a list of additional study resources that are useful for candidates who are preparing for the Installer Exam. However all candidates should be cognizant that there are many other sources of good information on the topics covered by the JTA and they should use them. The ultimate way to prepare for the NABCEP exam is by reviewing the Job Task Analysis and Exam Blueprint. An honest and thorough self-evaluation of these will best help the candidate to see what areas in the body of knowledge required to pass the exam they need to study the most.

Table of Contents

Introduction

The *Solar Heating Installer Resource Guide* was written for those individuals seeking Solar Heating Installer Certification through the North American Board of Certified Energy Practitioners (NABCEP). This guide provides an overview of solar heating technology and discusses a number of skills required for successful installation of these systems. Candidates should use this resource in conjunction with the NABCEP Solar Heating Job Task Analysis (JTA) and the primary and supplemental references listed on NABCEP's website—www.nabcep.org—to prepare for the Solar Heating Installer Exam.

Solar Heating

In late 2011, NABCEP decided to begin using "Solar Heating" for its Installer Certification and Entry Level Programs. This transition was made to provide greater clarity regarding the scope of NABCEP's work. "Solar Thermal" has become the term of choice when referring to Concentrating Solar Power (CSP), a utility-scale technology that utilizes heat generated by the sun to produce electricity. NABCEP's focus is on distributed systems that are smaller in scale and utilize solar radiation to produce heat for use in buildings, including water and space heating, and for swimming pool heating. NABCEP believes that "Solar Heating" better defines the family of solar-related products this guide focuses on, and will help prevent confusion with other technologies.

Les Nelson, *NABCEP Board of Directors*

Job Description

for NABCEP
Certified Solar Heating Installer

Given basic instructions, manufacturer installation manual(s), major components specifications, and schematics and drawings, the installer is required to install a solar water heating system that meets the performance and reliability needs of customers in the United States and Canada by incorporating quality craftsmanship and complying with all applicable codes, standards, and safety practices.

The JTA

The NABCEP Solar Heating Installer Exam serves to assess the knowledge of a professional engaged in the installation of solar heating systems. To be eligible for the exam, a candidate must demonstrate a combination of experience and training directly related to solar heating system installation. NABCEP recognizes several pathways, or *qualifying categories*, for meeting these eligibility requirements. Details are available at www.nabcep.org/certification.

Exam Blueprint

The table below shows the blueprint (test specifications) for the NABCEP Certified Solar Heating Installer Examination. It is provided for candidates' and educators' use to determine which specific knowledge areas to focus on when preparing for the examination.

NABCEP Certified Solar Heating Installer Exam Blueprint

	% of exam	# of items
A. Prepare for project	12%	7
B. Evaluate the site	13%	8
C. Plan system installation	19%	11–12
D. Install the system	30%	18
E. Commission the system	14%	8–9
F. Service and maintain the system	12%	7
TOTAL	100%	60

The content of this guide is based on the JTA, which details the minimum tasks necessary for the successful installation of a solar heating system. The guide addresses the six content areas of the JTA and the subtasks for each. In order to effectively prepare for certification, a candidate must be familiar with all aspects of the JTA. The primary purpose of this guide is to supplement and augment the content of the JTA and the reference documents listed by NABCEP for Solar Heating Installer Certification.

The NABCEP Solar Heating Installer Exam itself is also based on the JTA. The exam questions are weighted as in the chart above.

While this guide serves to assist candidates in their preparation for NABCEP Solar Heating Installer Certification, it should not be taken as an all-inclusive overview of the exam. Questions on the exam are not necessarily based on the content of this guide. A discussion of the rigor of the exam and several questions from previous versions of the exam are presented at the end of this guide to assist candidates with their exam preparation.

The JTA was constructed and reviewed with the consensus of over 100 solar heating professionals in the US. The workflow associated with a larger installation company is the criteria used in the order given for the six areas of tasks in the JTA. Smaller companies that purchase materials on a job-to-job basis may find that the areas do not conform to their customaryworkflow. For example, Evaluate the Site might logically come before Prepare for Project for some unique projects, rather than in the opposite order as presented in the JTA and this RG.

Sections 5 through 10 of this Solar Heating Installer Resource Guide are aligned with the content areas of the JTA. Tasks and subtasks in the JTA are listed in order of their criticality in each section (area) of this guide. These tasks and subtasks are organized in this guide to follow the normal flow of work on a job site and may not correspond exactly with the JTA ordering.

Glossary

absorber – the portion of a solar collector that receives radiant solar energy and transforms it into heat energy

active system – a solar heating system that utilizes mechanical means, such as a dedicated pump or fan, to circulate heat from collectors to a point-of-use or storage

albedo radiation – solar radiation that is reflected off the Earth's surface

altitude angle – measure of the angle formed between the sun and the horizon

anode rod – a sacrificial metal component installed in coated steel tanks to protect the tank vessel from corrosion

Antifreeze system (AF) – indirect forced circulation system that utilizes a nontoxic heat transfer fluid

aquastat – a mechanical device that opens and closes a switch based on the temperature of a fluid

azimuth – the orientation of a collector array, expressed in degrees

batch heater – a type of water heater that utilizes an uninsulated black tank to collect and store solar energy

brazing – a process in which a heated metal filler is used to join two metals

British Thermal Unit (BTU) – the amount of energy required to raise the temperature of one pound of water by one degree Fahrenheit

chase – an enclosed cavity that conceals piping

check valve – a valve that allows flow in one direction only

circulator pump – electromechanical device used to circulate fluids in forced circulation systems

closed loop – system containing a fixed amount of fluid that is isolated from the atmosphere or other piping systems

collector – device that captures the sun's energy, converts it to heat, and allows transport of the collected heat to storage tanks and/or end-use locations, such as hot water fixtures or space heating systems

collector loop – portion of a solar water heating system's plumbing that contains the solar collectors. In an indirect system, this includes the piping and other components on the collector side of the heat exchanger. In a direct system, this includes all of the components between the collector(s) and the storage tank.

collector tilt – the measure of the angle between the collector slope and a horizontal plane

Concentrating Solar Power (CSP) – high temperature, large-scale solar systems used to generate electricity by means of a turbine; also known as "solar thermal"

condenser bulb – heat exchanger at the top of a heat pipe in an evacuated tube collector

conduction – the transfer of heat through a solid or fluid

convection – the transfer of heat by the circulation or movement of a liquid or gas — solids don't convect

counter flow – heat exchanger type in which two fluids flow through the heat exchanger in opposite directions

cycling, pump – pump on and off states, one on and one off is a cycle

datalogger – a device used to measure system properties, such as temperatures, pressure, and flow rates, over a period of time; may be integral to the differential controller or a standalone device

differential controller – control that provides power to a relay based on the difference in temperature between two sensors

diffuse radiation – solar radiation that is transmitted to the Earth's surface after significant scattering by the atmosphere

direct beam radiation – solar radiation that is transmitted to the Earth's surface with minimal scattering by the atmosphere

Direct Forced Circulation system (DFC) – system that utilizes a bronze or stainless steel pump to circulate potable water from the solar storage tank through the collectors

direct system – system in which potable water flows through the collectors

double-wall heat exchanger – device that utilizes an air gap between two walls to prevent contamination of potable water by a heat transfer fluid

Drainback system (DB) – indirect forced circulation system that is flooded only when the pump is operating; the system is protected from freezing and overheating by allowing the heat transfer fluid to drain from the collectors and exterior piping by means of gravity when the pump is off

drainback tank or reservoir – a tank of a size adequate to hold the entire fluid volume of a collector loop

dynamic head – the resistance that occurs between a fluid and the pipe through which it travels

emissivity – a measure of a surface's ability to radiate heat

equinox – the two times each year (March 20th or 21st and September 22nd or 23rd) when night and day are approximately equal; the sun is directly overhead at the equator and rises true east and sets true west

Glossary

evacuated tube collector – collector that utilizes cylindrical tubes containing a vacuum to limit thermal losses

expansion tank – device that utilizes a pressurized air bladder to buffer a heating system from pressure variations that result from changes in temperature

flat plate collector – collector that captures the sun's energy by means of a flat absorber plate

flat plate heat exchanger – a device that utilizes narrow, alternating channels to allow efficient heat transfer between two fluids

flow rate – a measure of the quantity of fluid that moves through piping during a fixed period of time

frictional head – see dynamic head

glazing – transparent cover on solar collector

glycol – a heat transfer fluid with a lower freeze point than water that is used to provide freeze protection

gravity head – the resistance that a pump must overcome to raise a fluid above its static level

hardwired – refers to electrical equipment that is connected directly to line voltage via wiring, rather than connected via a cord and outlet

header – the portion of a collector that serves as the inlet and/or outlet for the primary heat transfer fluid

heat exchanger – a device that conducts heat through a solid material, such as metal, to transfer energy from one medium to another

heat transfer fluid – a liquid or gas that is used to capture and distribute heat energy

heat pipe – device in an evacuated tube collector that transfers heat from the absorber to the manifold

hydronic system – a system that uses water or glycol to collect and distribute heat for space heating

hysteresis – the dead temperature band between a turn-on and turn-off setting in a control

immersed coil – a heat exchanger that is contained in the storage fluid volume of a solar storage tank

incidence angle – the measure of the angle between the solar radiation and the collection surface of the collector

Indirect Forced Circulation system (IFC) – a system that utilizes a heat exchanger and a pump

indirect system – system in which solar energy is transferred from the collectors to the potable water and/or space heating system through the use of a heat transfer fluid and a heat exchanger

input – a measuring device, such as a sensor, that is used by a controller to determine system functionality

insolation – the amount of solar radiation received from the sun over a period of time

Integrated Collector Storage system (ICS) – a system in which the solar storage is also the absorber

International Association of Plumbing & Mechanical Officials (IAPMO) – nonprofit corporation that certifies and rates collectors and systems

interrow shading – the obstruction of solar radiation caused by a bank of collectors positioned in front of another bank of collectors

irradiance – an instantaneous measurement of power received from the sun

low iron glass – glass with most of the metallic iron removed; has a higher transmittance than window glass

magnetic declination – measure of the difference between true north and magnetic north at a particular site, expressed in degrees

manifold – a system of piping with a single inlet and multiple outlets or multiple inlets and a single outlet

open loop – system that introduces new water into the collector loop from the water supply or is vented to the atmosphere

optimal efficiency – the efficiency of a collector when there is no temperature difference between the inlet temperature and the ambient environment; also referred to as the y-intercept

output – power that is provided from a controller by means of a relay for running pumps, valves, or other devices

passive system – a solar heating system that relies on natural convection to circulate the heat transfer fluid

personal fall arrest system – fall protection that consists of a safety harness and lanyard that connects to a safety rope or lifeline

pH – a measure of hydrogen ions used to determine the acidity, neutrality, or alkalinity of a solution

photovoltaic (PV) – the process or device used to convert solar radiation into electrical energy

potable – water that is drinkable

propylene glycol – non-toxic heat transfer fluid

pressure relief valve – a safety valve that actuates on excessive system pressure

radiation – the transfer of heat from one medium to another

Glossary

refractometer – a device used to measure the specific gravity of a fluid; a glycol refractometer is calibrated to determine the concentration of glycol in a solution

relay – a powered switch that provides — or disconnects — power to a pump or valve

riser – flow channel in a flat plate or pool collector that transports the heat transfer fluid through the absorber

selective surface – absorber coatings that have high absorptance and low emissivity

sensor – device that creates a change in electrical resistance with a change in temperature

sight glass – transparent tubing that is installed on the side of a drainback tank to indicate the water level in the vessel

solar noon – the time of day at which the sun reaches its highest point in the sky

short cycling – a pump turning on and off repeatedly, a symptom of a differential setting that is too narrow

Solar Rating & Certification Corporation™ (SRCC™) – nonprofit corporation that certifies and rates collectors and systems

solar south – true south

solar storage tank – a vessel used to store quantities of heat in liquid (usually water) for later use

solar window – the portion of the sky that is defined by the sun's path on the winter solstice and the summer solstice and the three hours on either side of solar noon

solstice – the two times of the year when the sun is at its lowest and highest altitude angles; in the Northern Hemisphere these days correspond with the shortest day of the year, December 21st or 22nd, and the longest day of the year, June 21st or 22nd

SRCC Standard 100 – SRCC Standard 100 Test Methods and Minimum Standards for Certifying Solar Collectors

SRCC Operating Guidelines 100 (OG-100) – SRCC Document OG100 Operating Guidelines and Minimum Standards for Certifying Solar Collectors

SRCC Operating Guidelines 300 (OG-300) – SRCC Document OG300 Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems — protocol used to certify and rate solar water heating systems

stagnation – phenomenon that occurs when there is no flow through a solar collector when there is sufficient solar radiation for providing heat to the system

standby losses – heat that is lost from a solar storage tank due to the difference in temperature between the fluid in the tank and the surrounding environment

static head – see gravity head

stratification – the layering of heat in a solar storage tank in which the hottest water is at the top and the coldest water is at the bottom

temperature and pressure relief valve (T&P valve) – a safety valve required on all water heaters set to actuate at dangerous temperatures or pressure

tempered glass – safety glass that breaks into small pieces rather than large shards; used in patio and shower doors and in solar collectors

thermal losses – heat lost by a collector due to the difference in temperature between the collector temperature and the ambient outdoor environment

thermostat – device that closes or opens a switch based on air temperature

thermosyphon – circulation of a fluid based on the phenomenon of natural convection, in which heated fluids rise and colder fluids sink

Thermosyphon system (TS) – passive system that utilizes natural convection for heat transfer fluid circulation

three port valve – a valve with three ports that allows flow in two paths, one at a time in each of two settings

unglazed collector – a collector that does not utilize an insulated casing, such as a standard pool collector

Uniform Solar Energy Code (USEC) – Code established by the International Association of Plumbing and Mechanical Officials (IAPMO) relating to the proper installation of solar energy systems

volute – the main flow path through a circulation pump that houses the impeller, also known as the impeller housing

warning line system – fall protection method that utilizes temporary stanchions and a line that meets specific OSHA guidelines; a safety monitor may be required to keep workers within the warning line depending upon the application and jurisdiction

wraparound heat exchanger – a heat exchanger that is in direct contact with the outside of the fluid containment vessel of a solar storage tank and covered by the tank insulation

zenith – the point in the sky that is directly above the head of the observer

3 Basic Solar Principals and Knowledge

Written records of modern solar heating techniques date back to the use of passive solar architecture in ancient Roman bathhouses. The use of glass to trap heat and the importance of proper orientation were implemented at the community scale in Europe and made their way to America with European settlers. Indigenous cultures in North America already had a profound understanding of the importance of solar orientation and the solar cycles, as is readily apparent in the indigenous architecture of the American Southwest.

Modern solar water heating (SWH) and solar pool heating (SPH) systems are more technologically advanced uses of the sun's energy, but their design is based upon collecting the same solar resource. In order to maximize the production of these systems, it is critical to understand basic solar principles and how they affect the performance of solar heating systems.

3.1 Irradiance and insolation

Irradiance is a measure, usually expressed in watts per square meter (W/m^2), of the sun's power at a given moment. Insolation is the total amount of solar energy available over a period of time and is typically measured in kilowatt-hours per square meter per day (kWh/m^2/day). For example, the irradiance on a solar collector may vary from 700W/m^2 to 900W/m^2 from 9am to 3pm on a sunny day at a given location. The insolation that this collector receives during this period might be 4–5kWh/m^2. The efficiency of a SWH system is based on its ability to convert insolation to usable energy.

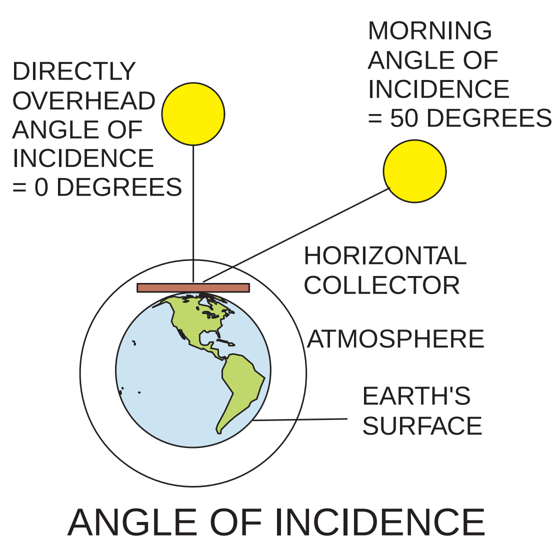


Figure 3-1 – Illustration demonstrating the effects of the angle of incidence on the amount of atmosphere through which irradiation must pass. The sun's energy must pass through more atmosphere in the morning and afternoon, which leads to more reflection and absorption of the sun's energy by the atmosphere. Similarly, the sun's energy must pass through more atmosphere during different times of the year, which contributes to seasonal fluctuations in solar insolation.

Insolation may also be described using the unit of sun hours. One sun hour is the equivalent of 1000 Wh/m^2, or 317 BTU/ft^2.

Irradiance and insolation are influenced by the earth's atmosphere. Due to solar angles, the amount of atmosphere the solar energy must pass through varies with the day and time of the year. Irradiance is most intense during midday and in the summer when the sun's radiation travels more directly through the atmosphere, thus minimizing the absorption and reflection of the sun's energy (Figure 3-1).

Figures 3-2 and 3-3 illustrate the monthly distribution of average daily insolation on the Earth's surface in Honolulu, HI and Anchorage, AK. While the insolation is greater in the summer than the winter in both locations, in Anchorage the summer insola-

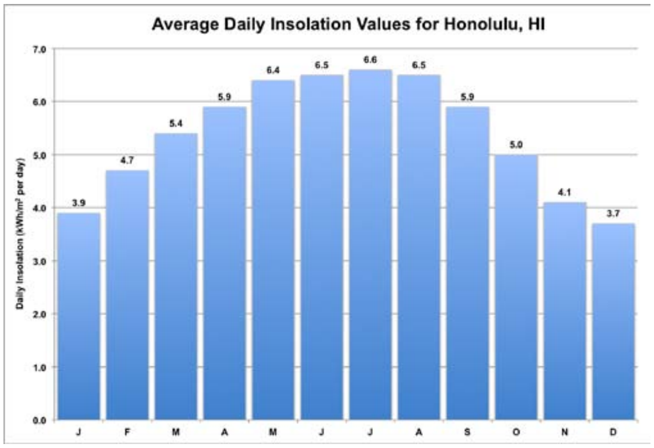


Figure 3-2 – Average daily insolation values by month for Honolulu, HI.

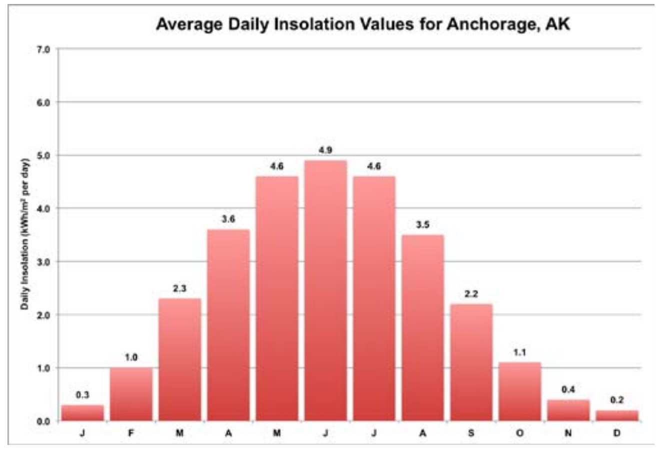


Figure 3-3 – Average daily insolation values by month for Anchorage, AK

tion is far greater than the winter insolation. This is due to Anchorage's more northerly latitude, which causes greater seasonal variations in the length of day. As a rule, sites closer to the equator experience less seasonal variation in insolation than those toward the poles.

The amount of irradiance that strikes the Earth's surface is also dependent upon weather. Moisture in the air—including clouds—will absorb and reflect significant portions of the sun's energy. The energy that is transmitted through clouds is called diffuse radiation, which is far less intense than direct beam radiation. During an overcast day, the earth's surface receives roughly 60% less solar energy than on a clear day.

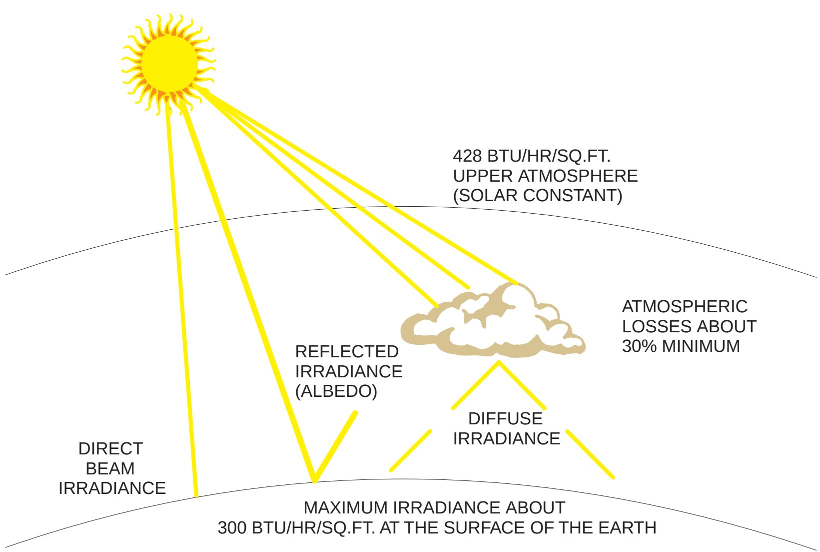


Figure 3-4 – The effects of the atmosphere on irradiation.

3.2 Solar angles

Seasonal variations result from the tilt of the Earth's axis, which is 23.5° from the plane of its orbit around the sun. At winter solstice, which occurs on December 21st or 22nd in the northern hemisphere, the earth is tilted 23.5° away from the sun. On summer solstice—

June 21st or 22nd in the northern hemisphere—the Earth is tilted 23.5° towards the sun. This results in the variance of the daily sun path across the sky at any given latitude. The sun path, and thus the total hours of sunlight, is shortest on winter solstice and longest on summer solstice.

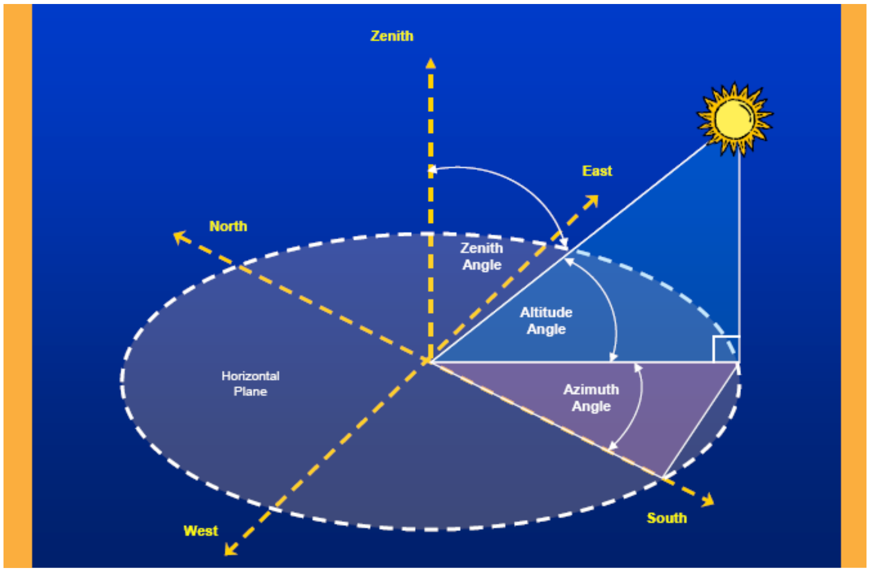


Figure 3-5 – Solar angles. (Courtesy of the *NABCEP PV Resource Guide* 2011, Brooks/Dunlop)

The solar angles at any given site are determined by the site's latitude. A site's latitude represents the measure of the angle between the zenith—a theoretical point in the sky that is directly overhead—and the sun's altitude angle at solar noon on the spring or fall equinox. The equinoxes occur on March 21st or 22nd and on September 21st or 22nd and represent the days in which there is an equal amount of day and night. The sun's altitude angle is the angle formed between the sun and the horizon (see Figure 3-5); solar noon is the time of day when the sun has reached its highest point in the sky. At a latitude of 30°N, the measure of the sun's altitude angle at solar noon on either equinox is 60°.

When the Earth reaches its maximum tilt toward the sun—on the summer solstice—the sun's altitude angle at solar noon is 23.5° greater than on the equinox. At a latitude of 30°N this equates to an altitude angle of 83.5°. Conversely, the sun's altitude angle at solar noon on the winter solstice is 23.5° less than on the equinox. At the same site, the sun's altitude angle is 36.5° at solar noon on the winter solstice.

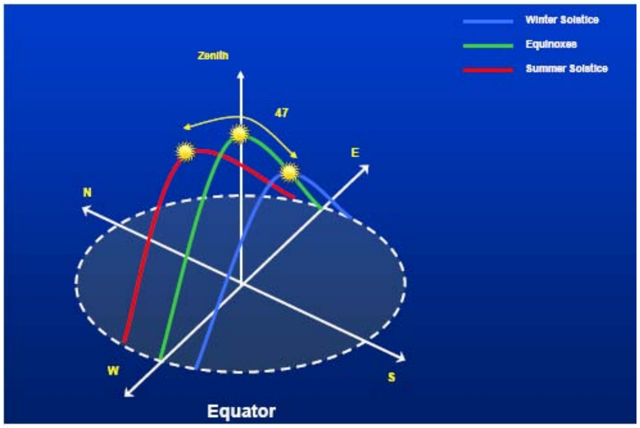


Figure 3-6a

Figure 3-6a, 3-6b, and 3-6c – Sun paths for sites at latitudes of 0°, 23.5°N, and 47°N. Note that each location has 47 degree difference between the summer and winter solstices. (Courtesy of the *NABCEP PV Resource Guide* 2011, Brooks/Dunlop)

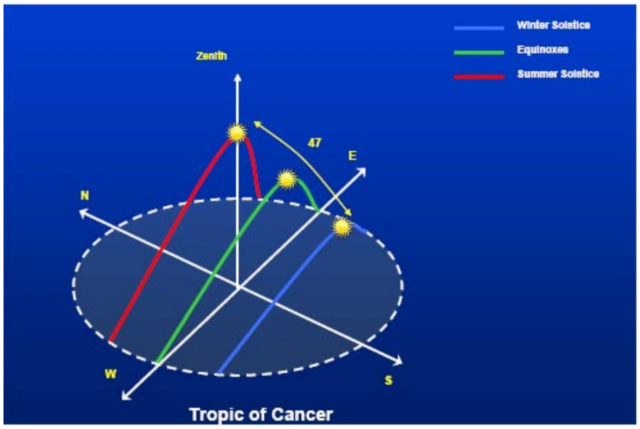


Figure 3-6b

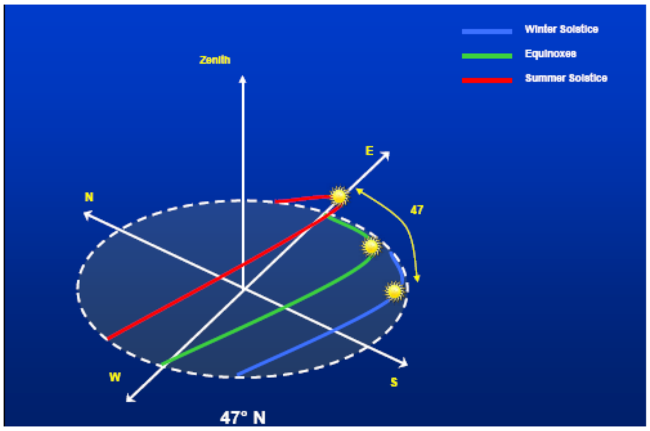


Figure 3-6c

These altitude angles are important in determining the collector tilt angle required to maximize the usable energy produced by a SWH system, as well as to determine whether nearby obstructions might shade the collector array.

Solar altitude angle at solar noon			
Latitude	**Winter Solstice**	**Spring/Fall Equinox**	**Summer Solstice**
0 (the equator)	66.5°	90°	66.5°
10	56.5°	80°	76.5°
20	46.5°	70°	86.5°
23.5 (the Tropics)	43°	66.5°	90°
30	36.5°	60°	83.5°
40	26.5°	50°	73.5°
50	16.5°	40°	63.5°
60	6.5°	30°	53.5°
70		20°	43.5°
80		10°	33.5°
90 (the Poles)		0°	23.5°

In the early morning and the late afternoon when the sun's altitude angle is low, sunlight must pass through more atmosphere or air mass. This results in significantly less irradiance reaching the earth's surface. As a result, approximately 90% of daily insolation strikes a site during the six hours that bracket solar noon. The area of the sky that falls between these hours and between the sun's paths on the winter and summer solstices is called the solar window (Figure 3-7). Ideally, collectors should be sited in a location that is not shaded within the solar window. When shading is unavoidable, considerations should be made for the impact on system performance. Considerations could include a reduction in performance estimates or the addition of extra collectors to accommodate the diminished available solar energy. Tools used to evaluate shading and its effects are addressed in Section 5.

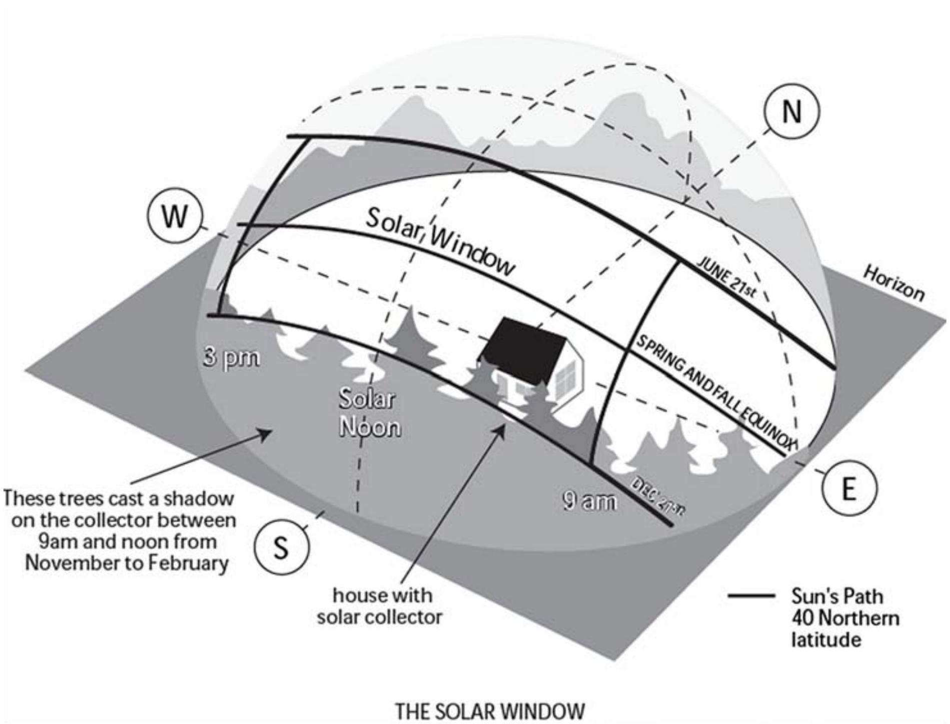


Figure 3-7 – Illustration of the solar window. The top and bottom of the window are defined by the solstices; the edges of the window are defined by a 6-hour span centered on solar noon. (Courtesy of Solar Energy International—www.solarenergy.org)

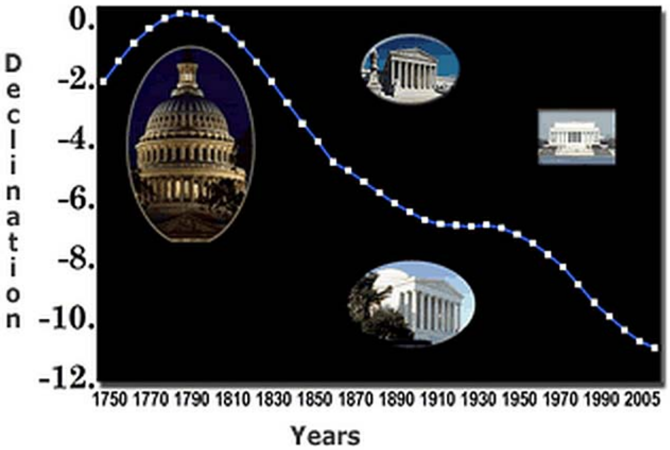


Figure 3-8 – Variation of magnetic declination in Washington, DC between 1750 and 2005. (Courtesy of NOAA)

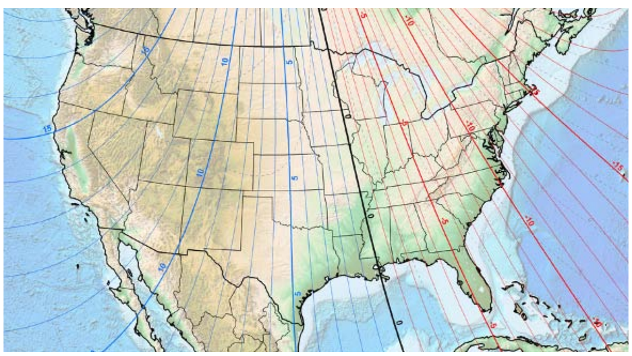


Figure 3-9 – 2010 Isogonic Map of the United States. The dark line in the middle represents the locations where magnetic north and true north are equivalent. Locations east of the line have a western declination; locations west of the line have an eastern declination. For example, the magnetic declination in San Francisco, CA is between 14° and 15° east. This means that magnetic north is roughly 14.5°east of magnetic north there. At the 10° blue line, the azimuth angle is 170° on the compass. At the 10° red line the azimuth angle is 190° on the compass. (Courtesy of NOAA)

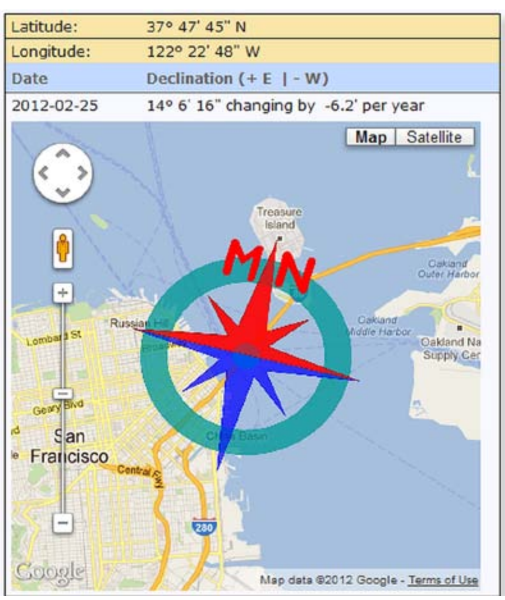


Figure 3-10 – Magnetic declination of San Francisco, CA. (Courtesy of NOAA and Google Maps)

3.3 Collector orientation

Solar collectors are most effective at collecting solar energy when the surface of the panel is perpendicular to the sun's rays. When the incidence angle of the sunlight on the collector is not perpendicular, more energy is reflected from the collector surface and the intensity of irradiance is diminished.

For this reason, collectors typically gather the most solar energy annually when oriented toward true south. True south can be determined at solar noon—it lies on the line between the observer and the sun. True south can also be determined by using a magnetic compass and accounting for the site's magnetic declination. Magnetic declination is the difference between magnetic north and true north. This difference changes over time (in some locations up to a degree difference a decade, due to gradual movement of the magnetic north pole over time) and varies by location (Figure 3-8). In 2010, the Mississippi River Valley demarcated the approximate line where true north and magnetic north were the same (Figure 3-9). The declination in North America varied from about 17° to the east of true north on the west side of the Mississippi to 17° to the west of true north on the east side of the Mississippi.

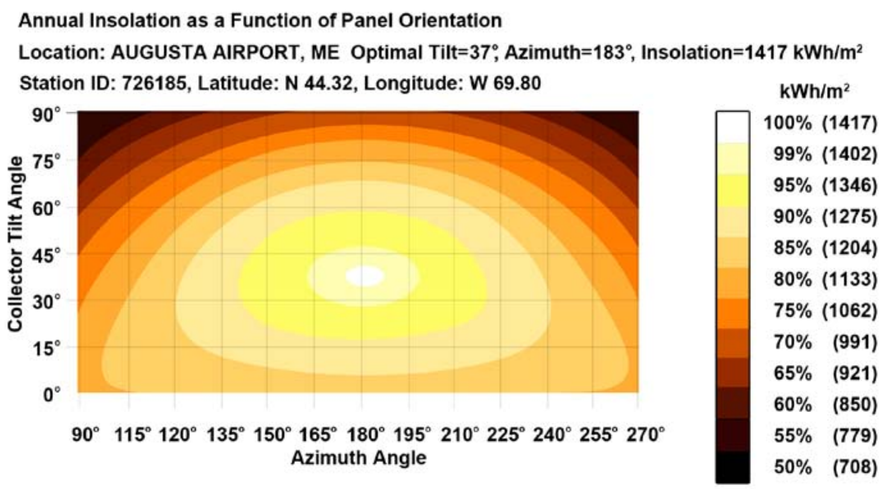
Declination is an important consideration when orienting collectors or considering the orientation of collectors. In order to determine the true orientation of the collector array, the installer must adjust the magnetic declination on the compass. The installer must first locate magnetic north. Once facing magnetic north, s/he must rotate to his/her right by the correct number of degrees to adjust for a west declination or to their left to adjust for an east declination. Once properly aligned toward true north, the installer must rotate 180° to face true south.

When collectors are oriented facing a direction other than true south, this may impact the performance of the system. This angular orientation of the collector array is called the azimuth. The azimuth may be referred to in absolute terms, such as 200°, or in relative terms, such as 20°W of true south. When using absolute terms, 180°S represents true south.

The collector tilt angle also affects the incidence angle of irradiance on the collector array. Collectors that are installed at a tilt angle equal to the site's latitude will be perpendicular to the sun during midday on the equinoxes and will have varying angles of incidence during other times of the year. In most cases, the tilt angle is determined based upon the slope of the roof and/or the time of year in which the capture of solar energy is most beneficial.

Surface Orientation Factor (SOF) charts illustrate the effects of collector tilt and azimuth on the amount of annual solar insolation available at a site (Figure 3-11). These charts illustrate either the percentage of the maximum solar insolation that is available for a given orientation or quantify the average total energy that falls on the collector annually when mounted at a specified tilt and azimuth. SOF charts for various locations in the U.S. are available via the Annual Insolation Lookup tool at http://www1.solmetric.com/cgi/insolation_lookup/go.cgi.

SOF charts illustrate that perfecting the tilt and azimuth of the collector array is not necessary. For many sites, orienting the collectors to the southwest or the southeast will have minimal impact on system production. Often, a less-than-optimal collector tilt will not reduce the annual system output significantly either.



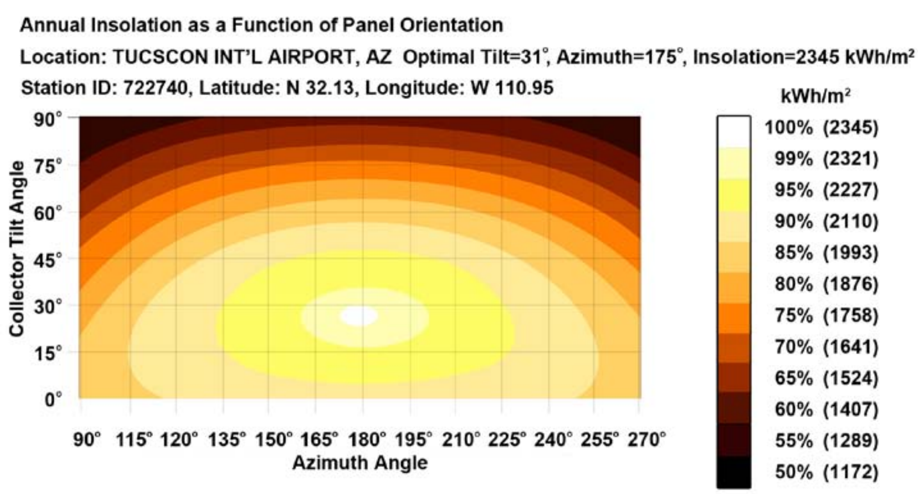


Figure 3-11 – Surface Orientation Factor Diagrams for Augusta, ME and Tucson, AZ. The center of the diagram represents the optimal tilt angle and azimuth for maximum annual insolation. This value is also given in the diagram heading.
(Courtesy of Solmetric)

While SOF charts will help quantify the effects of orientation on annual solar insolation, their application has some limits when applied to SWH:

- *The charts are based on data collected for flat surfaces.* For curved surfaces, such as evacuated tube collectors, the effects of azimuth may be less pronounced.
- *It is not always beneficial to orient collectors to maximize the annual solar insolation.* Due to the limitations of storing large quantities of hot water, SWH systems should be designed to maximize *usable* solar insolation. If a SWH system is designed to maximize *annual* solar insolation, it is likely to produce more heat than can be used or stored in the summer and less heat than is needed in the winter. The standard recommendations for collector tilt are as follows:
    - To maximize usable solar energy annually, such as for domestic water heating systems, the collector tilt angle should be equal to the latitude of the site.
    - To maximize usable solar energy in the summer, such as for solar pool heating, the collector tilt angle should be fifteen degrees less than the latitude of the site.
    - To maximize usable solar energy in the winter, such as for winter space heating, the collector tilt angle should be fifteen degrees more than the latitude of the site.

Exceptions to the collector tilt guidelines above are common with installers in particular regions. For example, the winter solar resource is so diminished in the Pacific Northwest that installers often mount collectors at a tilt angle that is 15 degrees less than the latitude. When collectors are mounted at lower tilt angles, care must be taken to alleviate the potential for overheating under summer insolation levels. In desert areas with an intense solar resource, many installers will mount collectors at a tilt angle that is 15 degrees more than latitude to mitigate overheating in the summer.

Collectors may also be mounted at low tilt angles if they are flush-mounted on an existing roof to provide for a more aesthetically pleasing appearance. This may contribute to overheating and will make it more difficult for the collector array to shed snow in colder climates.

It should be noted that adjusting the tilt or azimuth by a few degrees to achieve an "optimal" orientation may result in very little additional energy collection, require substantial cost for collector racking hardware, and result in a less aesthetically pleasing installation.

3.4 Effects of ambient air temperature

Ambient air temperature has a significant effect on the performance of SWH systems. The amount of heat loss from a solar collector is directly proportional to the temperature difference between the operating temperature of the collector and the temperature of the surrounding air. Summer has ideal conditions for collecting solar energy due to the high amount of solar irradiance, longer days, and warmer ambient temperatures. Clear winter days provide high solar irradiance, but the collectors are less efficient due to thermal losses from the collector to the colder outdoor air.

Regulation, certification, and research relating to SWH systems

The following agencies and organizations are involved in regulation, certification, and research relating to SWH systems.

The **Database of State Incentives for Renewable Energy (DSIRE)** is a searchable, interactive database of incentives for energy efficiency and renewable energy available in the U.S.

The **Florida Solar Energy Center (FSEC)** tests and certifies collectors and systems, engages in research and development, and provides educational programs relating to solar energy.

The **International Association of Plumbing and Mechanical Officials (IAPMO)** develops and publishes the Uniform Plumbing Code (UPC), the Uniform Mechanical Code (UMC), the Uniform Swimming Pool Code (USPC), and the Uniform Solar Energy Code (USEC), and certifies solar heating collectors and systems.

The **International Code Council (ICC)** develops and publishes the International Plumbing Code (IPC), the International Mechanical Code (IMC), and the International Energy and Conservation Code (IECC).

The **Interstate Renewable Energy Council (IREC)** is a nonprofit organization that works with stakeholders to advance the implementation of renewable energy technologies. IREC is the National Administrator of the DOE Solar Instructor Training Network, which works to implement high quality solar training across the U.S. and is the North American affiliate for the **Institute of Sustainable Power Quality (ISPQ)**, which accredits renewable energy educational programs, trainers, and instructors.

The **National Renewable Energy Laboratory (NREL)** provides support for research and development in the solar heating and photovoltaic industries.

The North American Board of Certified Energy Professionals (NABCEP) certifies professionals in the fields of photovoltaics, solar heating, and wind energy, and provides entry level testing programs for selected technologies.

The Occupational Safety and Health Administration (OSHA) is the office of the U.S. Department of Labor that provides regulations for workplace safety.

Sandia National Laboratories engages in research and development supporting the solar industry.

The Solar Rating & Certification Corporation™ (SRCC™) certifies solar heating collectors and systems.

The U.S. Department of Energy (DOE) is responsible for research, development, and education programs relating to technologies that address the country’s energy and environmental challenges.

4 Collectors, Systems, and Applications

Solar Heating encompasses three solar technologies that are used in residential and commercial applications—Solar Water Heating (SWH), Solar Space Heating, and Solar Pool Heating (SPH). Two other related technologies are Solar Cooling, which uses solar heat to drive absorption and adsorption chillers, and Concentrating Solar Power (CSP), which is used for utility-scale electricity production.

This Resource Guide is focused solely on solar heating technologies—SWH, Solar Space Heating, and SPH. Each of these solar heating technologies is characterized by different components, systems, and applications. An installer must have a strong understanding of how these technologies differ from one another and how each collects and utilizes the sun's energy.

4.1 Collectors

Solar collectors produce the heat in solar heating systems. Collectors vary in design from very simple to quite complex. Four standard collector designs are in wide use throughout the world today—unglazed flat plates, glazed flat plates, evacuated tubes, and concentrators. These collector types are used in complete systems that address applications ranging from heating swimming pools to generating electricity for the utility grid.

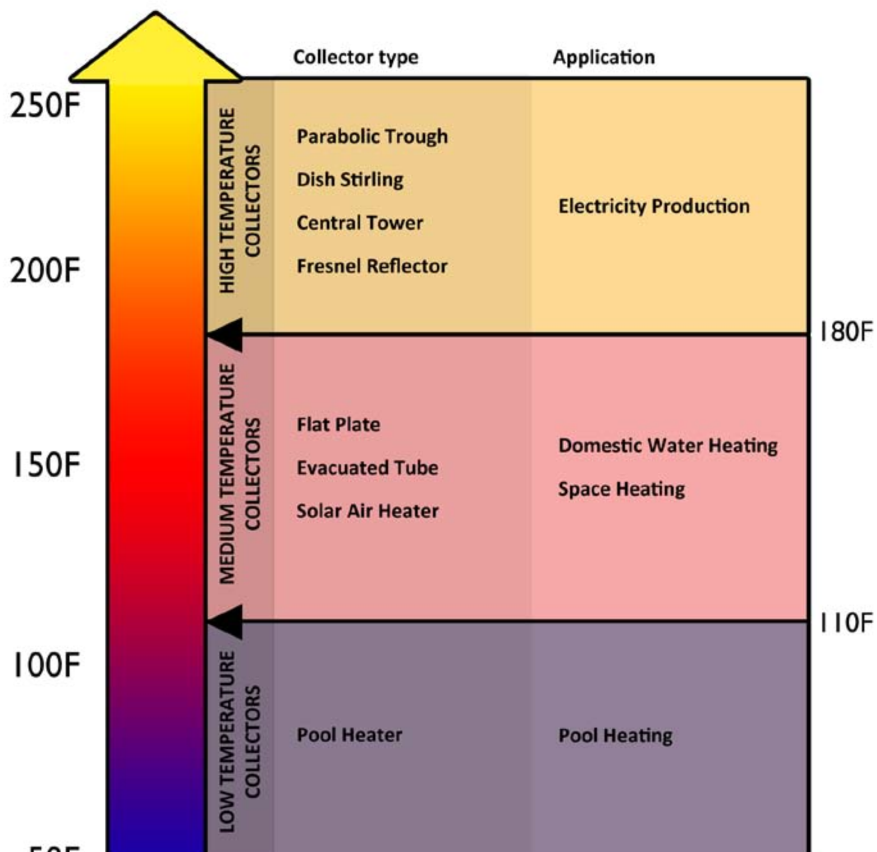


Figure 4-1 – Classifications of solar collectors are based upon the end-use temperatures of the application. (Based on United States Energy Information Administration's *Solar Thermal Collector Manufacturing Activities* report)

The classifications for solar heating collectors are based on the approximate operating temperatures that can be produced under normal levels of solar radiation. Low temperature collectors are used for applications where operating temperatures are below 110°F (45°C), such as for heating swimming pools. Medium temperature collectors are used in applications ranging from 110°F (45°C) to 180°F (80°C), including domestic water heating (DWH), space heating, indoor pool heating, car washes, and other commercial applications with sufficient heat demand. High temperature collectors concentrate the sun's heat and are used for industrial process heating and other applications that require temperatures above 180°F (80°C), including the production of steam for utility-scale electricity production.

Due to the fundamentals of physics and economic considerations, particular styles of collectors best correspond with specific applications. For example, high temperature collectors can be used for DWH, but the return on investment and overall system effectiveness will usually be far greater if medium temperature collectors are used instead.

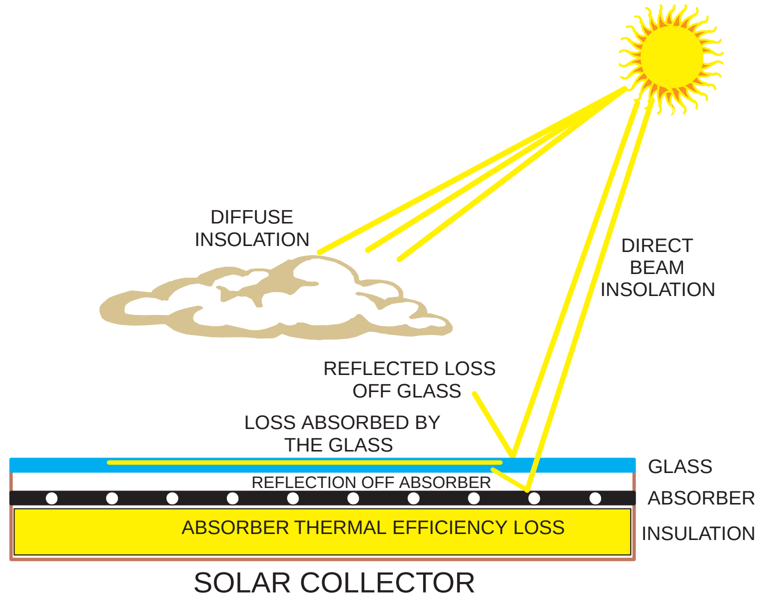


Figure 4-2 – Illustration showing efficiency losses of a solar collector. Optical losses in a collector are constant; thermal losses vary based on the temperature difference between the absorber and the ambient air.

The suitability of collectors for specific applications is based upon their performance under specific conditions. The optimal efficiency of solar collectors occurs when the fluid inlet temperature is equal to the temperature of the ambient environment (Figure 4-2). Thermal losses occur due to temperature differences between the absorber and ambient air surrounding the collector. Collector insulation, glazing, and low-emissivity absorber coatings are used to limit these thermal losses. Collectors used in low temperature applications are less concerned with thermal losses than collectors used in medium and high temperature applications. These considerations impact the design of each style of collector.

4.1.1 Low temperature collectors

Low temperature collectors are also commonly known as unglazed collectors or pool panels. These collectors are commonly used for swimming pool heating (SPH), which is currently the most popular type of solar heating system in the United States. Low temperature collectors are simple and inexpensive. In many locations, SPH systems offer such good returns on investment that they are often excluded from incentive programs. Pool collectors are specifically designed for heating large amounts of water to relatively low temperatures, typically 80°F (27°C) to 90°F (32°C).

Solar pool heating collectors are usually made of polypropylene, a high temperature polymer that contains inhibitors to protect it from ultraviolet (UV) degradation from sunlight. Most pool collectors used for heating outdoor swimming pools are unglazed and uninsulated, meaning they do not have a glass cover plate or an insulated enclosure. These characteristics limit pool collectors from producing the operating temperatures typical of medium temperature applications except in very mild climates.

Figure 4-3 – Cutaway view of a corner of a standard solar pool collector.

Polymer-based pool collectors are usually warranted for 10–12 years, but some types last 20 years or more. These collectors have large header tubes—typically 1½″ or 2″ in diameter—and small riser tubes that connect the headers. The riser tubes—typically

¼″ in diameter or less—are adjacent to each other, providing a surface area with a high proportion of tube area to total absorber area (the wetted surface area). This characteristic helps to alleviate the inefficiency of using polypropylene, which has relatively low heat conductance.

Because pool collectors have no glass to absorb or reflect light from the sun, a larger portion of incoming sunlight reaches the collection surface than medium temperature glazed collectors. This means that the panels can reach efficiencies of 85% or more when the ambient air temperature and the pool water temperature are equivalent. However, due to the lack of glazing and insulation, low-temperature collectors have high thermal losses—their efficiency falls off quickly if the pool temperature is more than 15°F (8°C) to 20°F (11°C) above the outside daytime temperature. Therefore, they aren't capable of producing usable heat for pools during the winter in moderate or cold climates.

Distributors typically stock pool collectors in 4′x8′, 4′x10′, and 4′x12′ sizes, and a normal residential system consists of 6–12 collectors depending on the pool size, location, and length of the pool heating season. Pool collectors have also been used for heating domestic hot water in mild climates.

4.1.2 Medium temperature collectors

Medium temperature collectors are used for DWH systems, space heating, indoor pool heating, commercial systems, and other applications. The two categories of medium temperature collectors are flat plates and evacuated tubes. The type of collector selected by the designer or installer depends upon the application and local climate. To be eligible for federal residential solar investment tax credits, the collectors must be certified by the Solar Rating & Certification Corporation™ (SRCC™). In some jurisdictions, an equivalent state-recognized certification is acceptable in lieu of SRCC certification to qualify for the federal tax credit. Commercial- and industrial-scale projects do not require collector certification to be eligible for the 30% credit.

4.1.2a Flat plate collectors

Flat plate collectors have been commercially available since 1909. The collectors are named for their flat absorber plate. All medium temperature flat plate collectors are comprised of an absorber enclosed within an insulated and glazed casing.

The casing provides the structural integrity for the collector; it is usually constructed from extruded aluminum, though some models are made from fiberglass or a UV-protected polymer. The insulation—typically rigid foam or mineral wool—must be rated for high temperatures and provides thermal protection on the back and sides of the casing. Low-iron tempered glass is the most common glazing used in flat plate collectors due to its durability and ability to transmit more light than standard tempered glass. Despite the advantages of low-iron tempered glass, some collectors utilize standard tempered glass or polycarbonate glazing to reduce cost.

The use of tempered glass is critical, as it is strong enough to withstand all but the largest hail. Tempered glass can break, however breakage results in thousands of small pieces

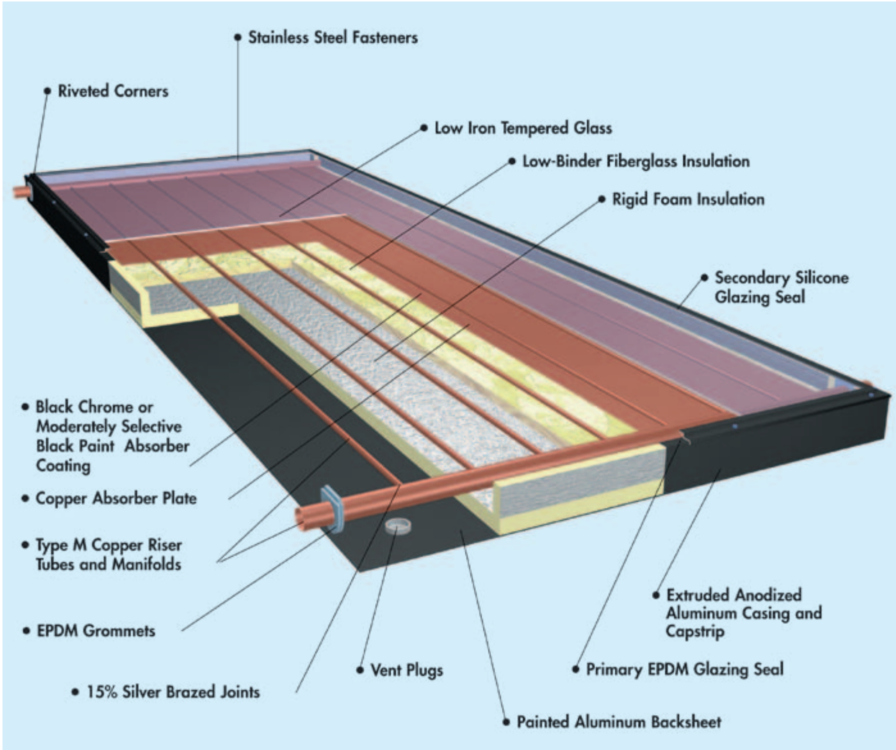


Figure 4-4 – Cutaway image of a standard flat plate collector
(Courtesy of SunEarth)

that will result in little or no injury. Glazing durability requirements must be met in order to achieve SRCC Operating Guidelines (OG-100) Certification. In areas where the *Uniform Solar Energy Code (USEC)* applies, all glazed collectors must use tempered glass. This is a controversial requirement in those jurisdictions that have adopted the USEC, since it excludes evacuated tube collectors from being used in SWH projects.

Flat plate collectors available in North America also vary by the type of absorber plate, the configuration of internal tubing, the connection between the absorber and tubing, and the type of absorber coating.

Absorber plates

Absorbers can be categorized by the configuration of their tubing. One design utilizes multiple riser tubes spaced a few inches apart and brazed to larger headers. The entire tube assembly is then mechanically bonded to the plate. This design minimizes flow restriction through the collector by splitting the flow into several parallel paths. These harp-style, or grid-style, collectors are the predominant style of flat plate produced by U.S. manufacturers.

Another design utilizes a single tube bent back and forth in a serpentine pattern. The tubing may be connected to headers, depending upon the manufacturer. This single tube is bonded to the plate. These serpentine, or *meander*, designs are utilized in many systems and are preferred by many European manufacturers. They can also be used in Direct Forced Circulation (DFC) systems.

In both designs, the absorber plate is constructed from copper or aluminum; usually one or two thin sheets span the entire collector or multiple sheets are attached to individual risers. Standard flat plate collectors range in size from 20–40 ft^2 (1.8-3.7 m^2);

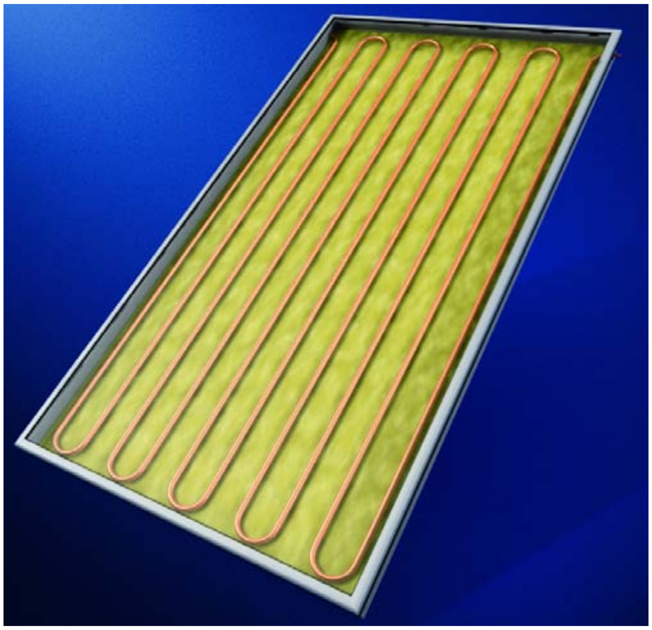


Figure 4-5 – Cutaway image of the tubing in one type of serpentine collector.
(Courtesy of Schüco)

the largest collectors used in residential systems are typically 4 ft (1.2m) x 10 ft (3.0m). Regardless of the design, the tubing is bonded to the plate by soldering, brazing, or welding to promote efficient transfer of heat between the absorber plate and the tubing. Many manufacturers use laser or ultrasonic welders and automated machinery to complete this labor-intensive bonding process.

Absorber coating

The finish on the absorber plate has a significant impact on collector efficiency. The ideal finish absorbs nearly 100% of the solar energy that strikes the surface and emits, or reradiates, minimal amounts of the collected energy to the surrounding environment. Due to its high absorbance, flat black paint was used on all absorbers until recent decades. Flat black paint absorbs about 95% of solar radiation, but it also emits about 95% of the collected heat as infrared radiation. To reduce the inefficiencies that result from this high emissivity, or radiative loss, selective surface coatings were developed in the 1970s. These coatings absorb about as much radiation as black paint but emit only 10% to 20% of the collected heat. This amounts to a gain of a few percentage points in overall collector performance. A selective coating is a more complex and expensive process than painting the absorber but is worthwhile in colder climates or applications that require elevated system temperatures. Selective surface coatings may be referred to as black chrome, black crystal, sputtered aluminum, or other trademarked names. Many U.S. manufacturers still offer painted absorbers for use in mild climates where the performance gains of the selective surface absorber is not significant enough to justify the added expense. In areas with intense sunlight, like the southwestern U.S., use of collectors with a selective surface may lead to system overheating in the summer.

4.1.2b Evacuated tube collectors

Like flat plates, evacuated tubes derive their name from the physical configuration of the collectors. Tube collectors are a more recent development in the industry. During the 1970s, two styles of evacuated tubes were developed. One design—the single-wall evacuated tube—placed the absorber inside a vacuum. Another design isolated the absorber from the ambient environment by utilizing two layers of glass with a vacuum between them. In this twin-glass evacuated tube the absorber is not in the vacuum itself, but is insulated from the vacuum by being placed against the inner layer of glass. The vacuum in both designs is used as insulation to provide heat retention capability. Thermos® bottles have gained significant commercial success using the same principle to keep liquids hot or cold. Even a relatively small space filled with a vacuum prevents heat loss better than the insulation in a flat plate collector. Due to the superior heat retention, evacuated tubes are often marketed to regions with cold, cloudy, harsher climates or in higher temperature applications where flat plates might experience significant thermal losses. Today, most evacuated tubes are made in China, where the technology has seen widespread market adoption.

Twin-glass

Twin-glass evacuated tube collectors are constructed by melting together, or otherwise bonding, two separate glass tubes, an inner and an outer. All air is removed from the thin space between these tubes, leaving a vacuum between the glass walls that acts as a highly effective insulator. Within the inner glass tube (not within the vacuum) is the absorber assembly. There are two primary designs for the absorber: *flooded tube* and *heat pipe*.

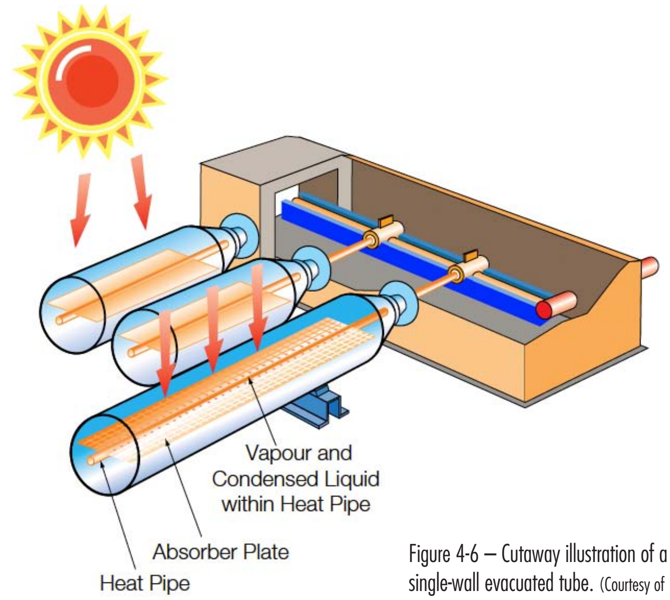


Figure 4-6 – Cutaway illustration of a single-wall evacuated tube. (Courtesy of RETScreen® International)

In a *flooded tube* style collector, the system's primary heat transfer fluid (HTF) flows through the evacuated tube. Solar heat is transferred directly from the absorber surface to the fluid, which is pumped through heat exchangers to deliver the heat to an end-use application such as water or space heating.

In a *heat pipe* style collector, a device called a heat pipe is used to absorb the sun's energy. A heat pipe design utilizes a fluid that boils at a relatively low temperature due to a vacuum inside the partially filled, sealed heat pipe. This pipe is in physical contact with a small absorber inside each tube to collect available solar energy. In most twin-glass evacuated tube collectors, the selective surface is applied to the inside of the inner wall, which is in contact with the absorber and heat pipe. The solar radiation heats the glass, which transfers its heat to the absorber and heat pipe. The fluid in the heat pipe boils and the vapor rises in the tube. A condenser bulb is located at the top of the heat pipe and transfers the collected heat to the system's primary HTF in the manifold.

The heat pipe design utilizes each tube as a separate collector, making the entire system modular. This modularity is popular with some installers because it allows the collector to be assembled on the roof by one person, in contrast to flat plate collectors that require multiple installers. The design also facilitates the replacement of individual tubes without the need to drain the system.

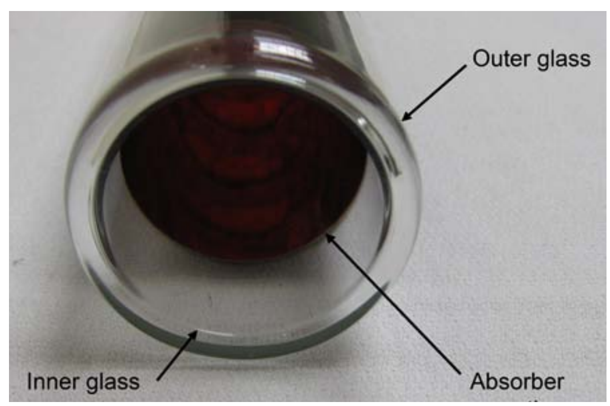


Figure 4-7 – Twin-glass evacuated tube.

Single-wall

In a single-wall evacuated tube, the absorber is inside the vacuum. The absorber may be a *flooded tube* or *heat pipe* style. The *flooded tube* design provides more efficient collection of solar energy by directly heating the primary HTF, but the design is not modular like the twin-wall design, thus the system must be drained if a tube requires replacement due to a broken tube or loss of vacuum. Unlike twin-tube collectors, the absorber plates in single-wall evacuated tubes are typically mechanically bonded to the heat pipes.

Borosilicate and soda lime are the two most common types of glass used in evacuated tube collectors. Glass tubes are not tempered due to the difficulty of tempering curved glass, thus they are more prone to breakage than standard flat plate collectors.

4.1.2c Air collectors

Solar air collectors are most commonly used for space heating. Modular glazed collectors are used to heat air that is circulated from the building, while unglazed collectors are used to preheat outside air that is used in the ventilation system of large facilities.

Glazed air collectors are similar to liquid flat plate collectors and are difficult to differentiate from a distance. They have a similar enclosure, insulation, and glazing. Because the HTF is air, collectors utilize large flow channels adjacent to or through the absorber plate rather than tubing. Ducting is used for the inlet and outlet of the collector. Air from

Collector Efficiency

A common discussion point for collector manufacturers is the concept of collector efficiency. One method to illustrate the efficiency of a collector for varying temperatures is the use of efficiency curves. These curves can serve to illustrate the differences in the optimal efficiency and the thermal losses for the various types of solar collectors. Where these curves cross the vertical axis, commonly referred to as the y-intercept, the collector temperature and the ambient air temperature are the same. The y-intercept represents the optimal efficiency of the collector. In the diagrams below, optimal efficiency of the flat plate collectors is 75%. This means that the flat plate collector is able to absorb 75% of the available solar radiation. As the temperature difference between the collector and the ambient air increases, the efficiency decreases. This is due to collector thermal losses. The steeper the efficiency curve, the more susceptible the collector is to losing its heat to the ambient environment.

When discussing efficiency, it is important to consider the conditions under which the efficiency is being measured. A collector could be more efficient when producing low temperature heat, but less efficient when producing high temperature heat, such as pool collectors. This all depends upon the types of losses and the application. This is why certain collectors are best suited for specific applications.

Area must also be considered when discussing efficiency. Sometimes efficiency is based on gross area, which is the footprint that a collector has on the roof. Other times, it may be based on the absorber, or net, area. For flat plate collectors, the absorber area is nearly equivalent to the gross area. For evacuated tubes, the absorber area is significantly less than the gross area due to the gaps between the absorbers.

Efficiency may be a consideration, but it is much more valuable to compare collectors based on production. In the end, the client cares more about how much energy is being produced by the system than about how efficiently the system produces that energy.

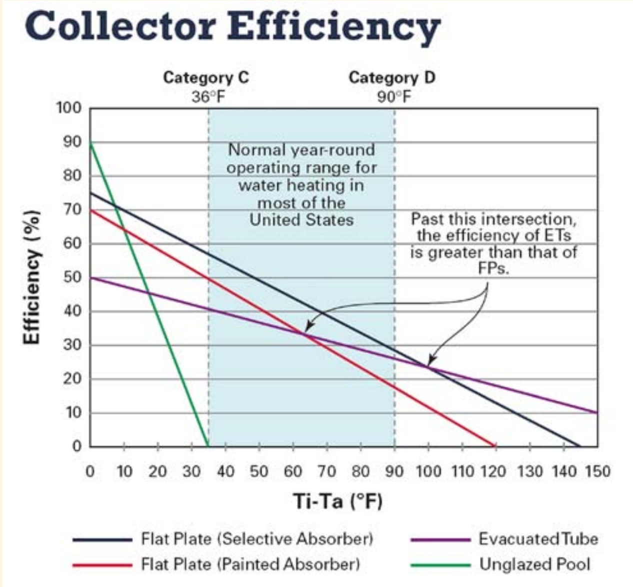


Figure 4-8 – Performance slopes for typical collector styles. (Courtesy of homepower.com) the building is circulated by a blower fan and passes over or through the aluminum absorber. The air is heated and then returns back into the building. The fan is controlled using a thermostat and can be powered by standard line voltage from the building or directly by a PV panel. Air collectors can be mounted vertically on a wall or can be roof-mounted at a desired angle. Mounting air collectors vertically minimizes heat collection in the summer and maximizes heat collection in the winter, especially if albedo radiation can be collected from the reflection of the sun off of snow.

Figure 4-9 – Glazed solar air heater.
(Courtesy of Environmental Solar Systems)

Unglazed air collectors are also referred to as transpired air collectors. Transpired air collectors are typically used on large facilities and are constructed of corrugated sheet metal. The sheet metal acts as the absorber, and small perforations are punched or drilled in the sheeting during the manufacturing process. A large blower fan slowly draws outside air through the perforations in the absorber to preheat makeup air required by the ventilation system. Due to their size and simplicity, transpired air heaters are extremely cost-effective for large commercial applications.

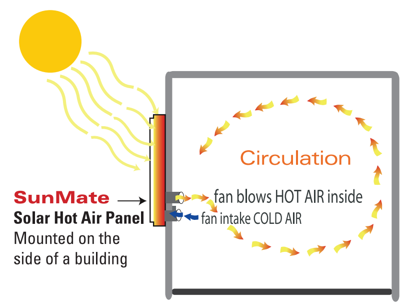


Figure 4-10 – System diagram for glazed solar air heater.
(Courtesy of Environmental Solar Systems)

4.1.3 High temperature concentrating collectors

High temperature concentrating collectors are the most efficient solar collector for producing process heat and are capable of making high pressure steam (400°F–750°F or 200°C–400°C). Due to their operating temperatures, these collectors are typically used in industrial applications and for utility-scale electricity production.

Concentrating collectors used to produce process heat from 180°F (80°C)–240°F (115°C) may look somewhat similar to flat plate and evacuated tube collectors. There are several types of parabolic trough collectors that are contained within a hot box similar to that of a flat plate collector. Rather than having an absorber plate that is bonded to the risers, the collectors utilize reflectors that focus direct radiation on the riser. Evacuated tube concentrators utilize parabolic reflectors behind the evacuated tubes to increase the temperature output of the collector.

Figure 4-11 – Transpired solar air collectors are similar in appearance to corrugated metal siding. This installation utilizes nearly the entire available wall area for solar collection. (Courtesy of the National Renewable Energy Laboratory)

Types of concentrators used for large-scale concentrating solar power (CSP) include dishes, towers, and parabolic troughs. Concentration of the sun's rays requires direct beam solar radiation and the collectors must track the sun through-

Figure 4-12 – Parabolic trough collectors at Kramer Junction, CA. (Courtesy of Sandia National Laboratories, photo credit Greg Kolb)

out the day in order to be effective. In contrast, low and medium temperature collectors can produce heat in cloudy weather. Diffuse radiation cannot be concentrated and limits the geographical locations suitable for efficient use of the collectors. Desert climates are ideal for concentrators.

4.2 Systems

The terminology associated with solar water heating (SWH) systems can be confusing. Open and closed, direct and indirect, passive and active, forced circulation and thermosyphon are all terms used to categorize solar heating system types. An open loop, or direct, system typically circulates potable water in the solar collectors. An indirect system uses a closed loop of fluid circulating through the collectors that is separate from the building's potable water. As a result, indirect systems must have a heat exchanger to transfer the heat from the collector fluid to the domestic hot water. Figure 4-13 illustrates standard SWH systems and their classifications.

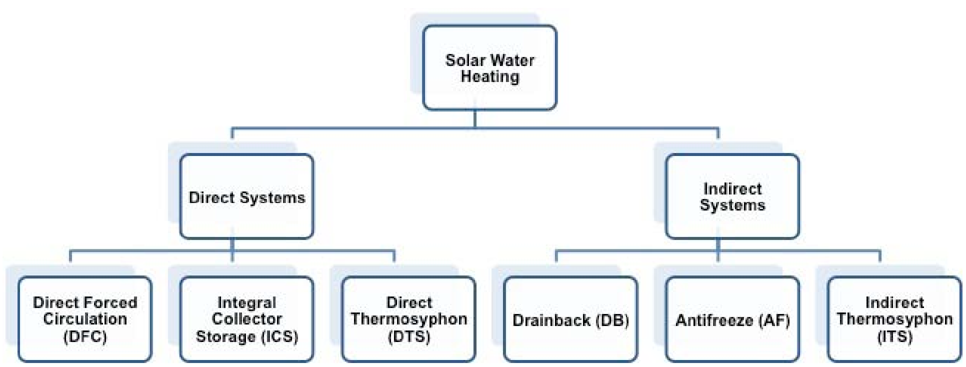


Figure 4-13 – Classification of solar water heating systems.

Systems are also classified by the method in which the fluid moves in the system. Passive systems contain no mechanical moving parts such as pumps or fans. Flow is accomplished in passive systems through the phenomenon of free convection, where warmer, less dense fluids rise and cooler, heavier liquids fall, or by water main pressure (applicable to batch, ICS, and some thermosyphon systems), where the opening of a hot water fixture in a building causes flow of water through the water heating system (and the solar collector) because the water supply to the building is pressurized. Active, or forced circulation, systems rely on a dedicated pump to circulate the fluid(s) in the system.

SRCC OG-300 System Schematics

SRCC certifies systems under the Operating Guidelines 300 (OG-300) protocol. This protocol is illustrated in Figure 4-14.

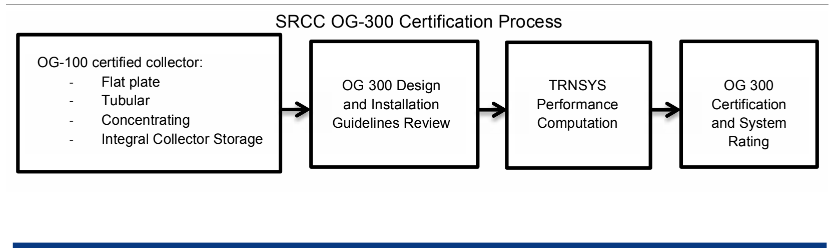


Figure 4-14 – SRCC OG-300 Flow Chart. (Courtesy of SRCC)

The purpose of OG-300 Certification is to provide an independent review of system design and installation specifications to help assureproper function and consumer protection. Companies who sell packaged SWH systems—typically collector or tank manufacturers—submit system specifications to SRCC or IAPMO, which performs a review process to determine whether the design meets the *SRCC OG 300 Operating Guidelines and Minimum Standards for Solar Water Heating Systems.* If the design meets these requirements, the system is modeled in TRNSYS, a computer program that estimates system performance. These estimates are based on a specific set of design conditions for selected cities in the United States—the actual system performance may vary somewhat from the OG-300estimates. Procedures for obtaining system-specific estimates are discussed in Section 6. The *SRCC OG 300 Operating Guidelines and Minimum Standards for Solar Water Heating Systems*, which is a primary reference for the NABCEP Solar Heating Installer Exam, and ratings for OG-300 Certified systems are available at www.solar-rating.org.

Certification and Rating of Solar Heating Equipment

During the decade between 1975 and 1985 the U.S. Government, as well as numerous individual states, implemented financial incentive programs for solar heating products, including tax credits and grants. Nearly all of these programs had no associated requirement for product testing or performance rating. As a result, many products entered the market without the benefit of third-party quality assurance assessment.

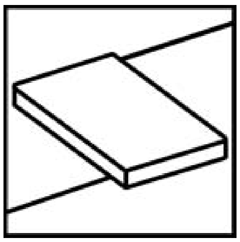
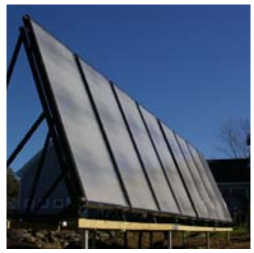
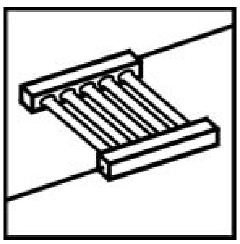
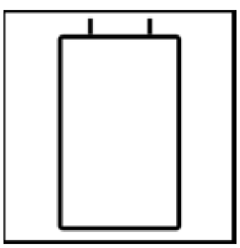
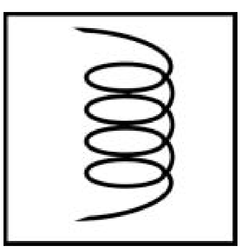
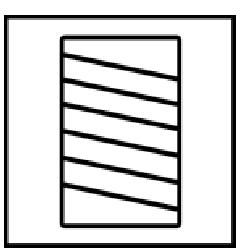
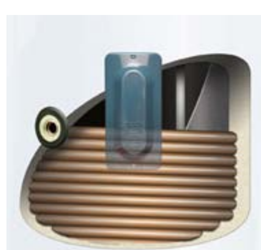
Today, solar heating incentive programs in the U.S. have product quality and performance requirements intended to help assure that installed products function and perform as designed. The Solar Rating & Certification Corporation (SRCC) has developed several standards for testing solar collectors, and certifies collectors that have been tested according to those standards by independent laboratories.

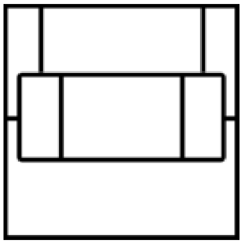
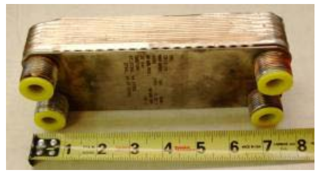
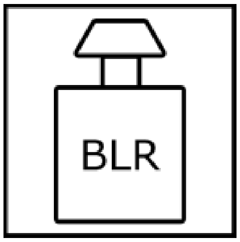
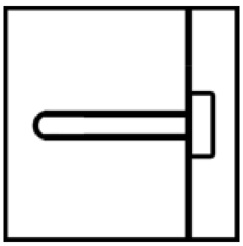
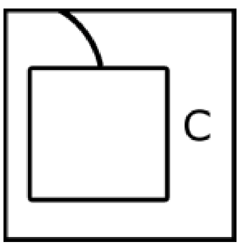
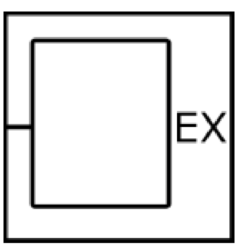
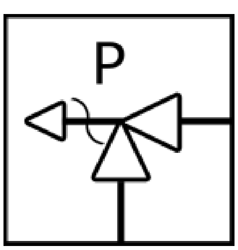
The International Association of Plumbing & Mechanical Officials (IAPMO) also certifies solar collectors, as well as solar storage tanks, conventional back-up water heaters, and a wide variety of plumbing components. In addition, IAPMO developed and maintains the Uniform Solar Energy Code and the Uniform Plumbing Code, which is used as the basis of state and local plumbing codes around the country. In some areas of the country, IAPMO product certification is required by state or local building officials before construction permits may be issued.

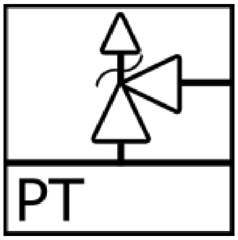
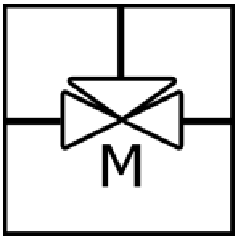
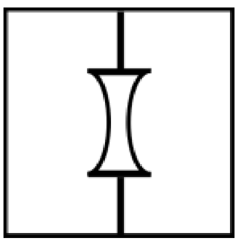
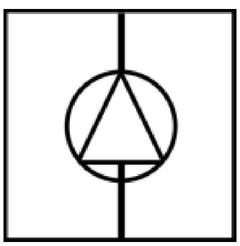
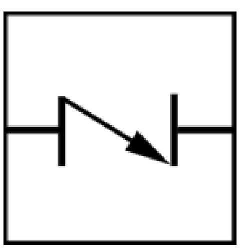
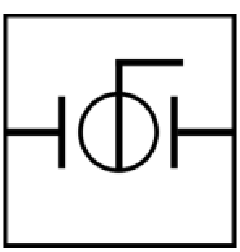
Both IAPMO and SRCC also certify complete solar water heating systems, performing a design review and generating an annual performance prediction via computer modeling.

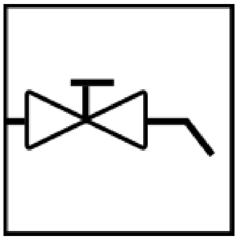
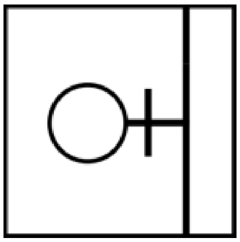
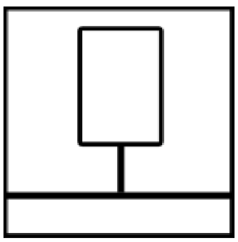
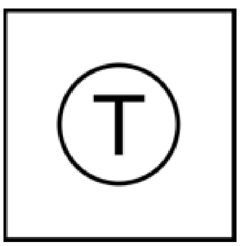
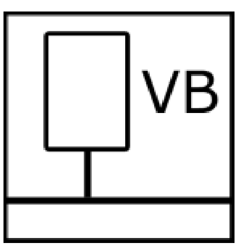
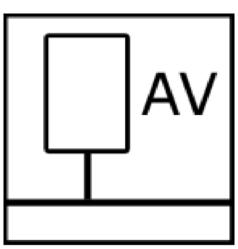
- Les Nelson

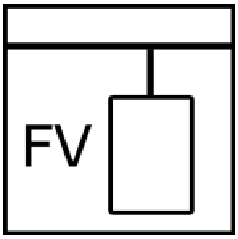
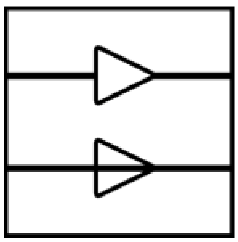
In addition to certifying and rating SWH systems, the SRCC publishes mechanical plans with details on specific system designs. These system schematics use standardized symbols for the components of SWH systems that are derived from the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). These symbols are often used in engineered drawings as well. Descriptions of the symbols, the components they represent and the purpose of these components are detailed below.

	Symbol	Photo	Purpose	Systems
Flatplate collector			Collects sun's radiation to produce heat	All
Evacuated tube collector			Collects sun's radiation to produce heat	All
Storage tank			Stores the energy collected by the system for future use	All
Immersed heat exchanger			Transfers heat from collector loop to potable water	Indirect systems
Wraparound heat exchanger			Transfers heat from collector loop to potable water	Indirect systems

	Symbol	Photo	Purpose	Systems
External heat exchanger			Transfers heat from collector loop to potable water	Indirect systems
Boiler			Provides auxiliary heat for SWH	All (possible)
Electric element			Provides auxiliary heat for SWH	All
Controller			Provides power to pumps and other outputs	All forced circulation systems
Expansion tank			Buffers closed systems from excessive pressure	Collector loop of IFC Antifreeze systems; potable piping of all systems (possible)
Pressure relief valve			Protects collector loop from excessive pressure	All

	Symbol	Photo	Purpose	Systems
Pressure & temperature relief			Protects storage tank from excessive pressure and temperature	All
Mixing valve			Tempers hot water from storage tank to protect hot water consumers	All
Flow meter			Indicates flow rate in collector loop	All forced circulation systems
Pump/circulator			Lifts fluid to collectors in drainback systems; circulates fluid in other forced circulation systems	All forced circulation systems
Check valve			Permits fluid flow in one direction only	DFC and IFC Antifreeze systems
Ball valve			An on/off valve used to isolate portions of the system	All

	Symbol	Photo	Purpose	Systems
Drain			Allows access to the system usually for draining and or filling	All
Pressure gauge			Indicates system pressure	IFC Antifreeze systems
Thermometer			Indicates system temperature	All
Temperature sensor			Measures system temperature for controller functionality	All forced circulation systems
Vacuum breaker			Permits entrance of air into system when under negative pressure	IFC Drainback systems
Air vent			Permits elimination of air from system	IFC Antifreeze systems

	Symbol	Photo	Purpose	Systems
Freeze valve			Releases fluid from collector loop to allow circulation of warmer water from storage tank	DFC systems
Direction of flow		NA	Indicates direction of fluid flow	All

4.2.1 Integral Collector Storage (ICS)

Integral Collector Storage (ICS) systems are manufactured with the collector and storage tank as a single unit. They are available as batch heaters or thermosyphon systems. Batch-type units use either a one large tank or multiple tubes for hot water storage.

ICS systems are considered passive solar water heaters because they do not require a separate electro/mechanical device like a pump to operate. The systems are only appropriate for year-round use in those areas of the contiguous U.S. and Hawaii where freezing conditions occur infrequently during winter months.

4.2.1a Batch heaters

Batch water heaters are the simplest of all solar water heaters. They utilize a cylindrical tank that is painted black and placed inside an insulated hot box. To provide added insulation on the glass face of the collector, most batch heaters are manufactured with two pieces of glass, similar to double-glazed windows. The tank is filled with domestic potable water from the building that it serves. The operation is simple—the sunlight shines through the glass, hits the black tank and heats it and the water within. Batch water heaters use tanks between 30 U.S. gallons (113 L) and 66 U.S. gallons (250 L). The tank enclosure is insulated by 1″–2″ of high temperature foam insulation. Batch solar water heaters are very effective in mild climates and the tropics. Since the only thing between the hot tank and the cold outside air is two layers of glass, during winter evenings in harsher climates the tank tends to lose most of the energy gained during the day. Batch water heaters are simple, reliable, easy to install, and are typically inexpensive. They can provide 50%–90% of hot water needs depending on usage and climate.In moderate climates, the tank in the water heater has too much mass to freeze, but the piping to and from the heater is susceptible to bursting in freezing conditions. Even a well-insulated ¾″ pipe will freeze at or slightly below 0°F if the temperature is sustained for a few hours.

Progressive tube is another style of batch water heater. Instead of a single large tank, the water is contained in several 4″ diameter copper tubes. The tubes are piped in series—the cold water enters at the bottom of the collector and is heated in the tubes before exiting at the top. The progressive tube design allows the water to stratify more than tank type models by eliminating the ability of the incoming cold water to mix with the exiting hot water. Both the tank type and progressive tube batch heaters are classified as ICS units.

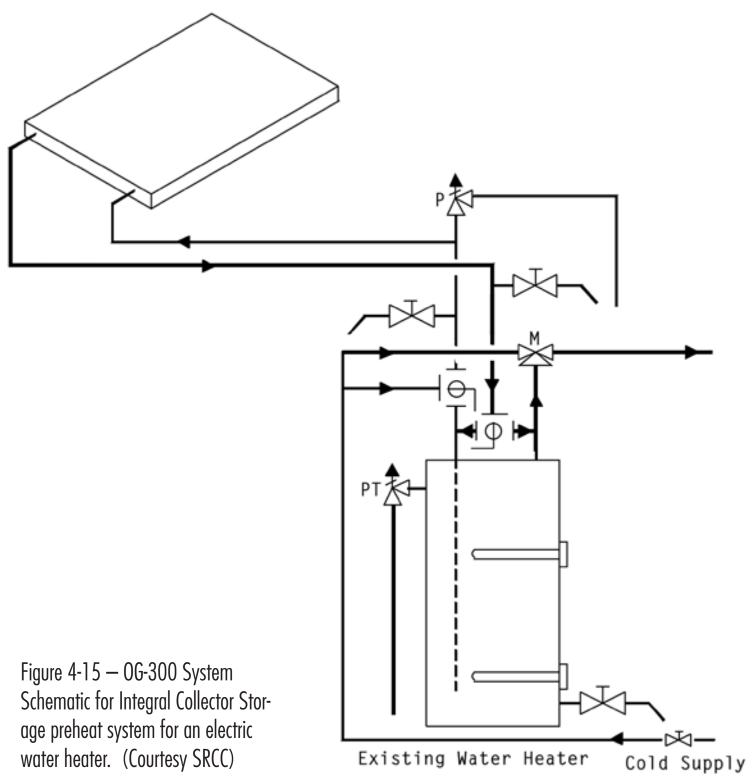


Figure 4-15 – OG-300 System Schematic for Integral Collector Storage preheat system for an electric water heater. (Courtesy SRCC)

4.2.1b Thermosyphon Systems

Thermosyphon systems that are manufactured with the tank and the collector as a single unit are classified as ICS systems. Thermosyphon systems use the natural convection of liquids to circulate the fluid through the collectors and storage tank. With proper design, the system can achieve adequate flow rates without the use of a pump. Thermosyphon systems must be configured with the storage tank above the collectors to work effectively. A direct thermosyphon system uses potable water as the medium of heat transfer, and the flat plate and evacuated tube collectors used are similar to those in active systems. In these systems the tank is oriented horizontally. As the water in the collector is heated by the sun, it rises through piping to the top of the storage tank due to natural convection. The colder water in the bottom of the tank flows to the bottom inlet of the collector. As long as there is sufficient solar energy, there is continuous circulation of the water through the collector and tank.

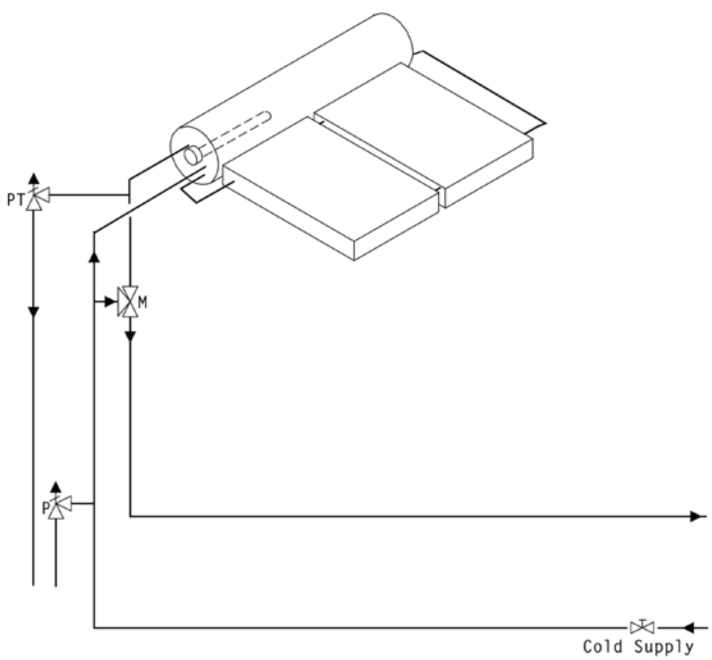


Figure 4-16 – OG-300 System Schematic for Direct Thermosyphon System with an electric backup. (Courtesy SRCC)

This system type does not require a control and will not cycle backwards at night if the tank is mounted at an adequate height above the collector. Systems with less height use a passive check valve in the system to prevent reverse thermosyphoning at night. This allows the tank to be just slightly above the collector, thereby facilitating a lower profile appearance.

Unpressurized thermosyphon systems that utilize evacuated tubes are widely used in some countries. Each tube is inserted into a port at the bottom of an insulated stainless steel tank. The ports have the same diameter as the outside of the evacuated tube. When the tank is filled with water, the fluid also fills the inner tube. As the sun heats the fluid in the tubes, the water inside naturally rises to the storage tank. The evacuated tube thermosyphon system has a freeze tolerance advantage over flat plate thermosyphon systems due to the high insulation value of the vacuum.

Split Thermosyphon Systems

Thermosyphon systems are sometimes designed with separate components that are assembled on site. These split thermosyphonsystems consist of standard flat plate or evacuated tube collectors and a standard storage tank mounted separately and can be installed as either direct or indirect systems.

Direct split thermosyphon systems with flat plate collectors were first introduced commercially in 1909 by William Bailey. Bailey's initial "Day and Night" solar water heaters were popular in California until widespread freezing events led to massive system failures. These systems utilized small riser tubes in the collector, making them particularly susceptible in the event of periodic freezing winter temperatures.

Figure 4-17 – Indirect Thermosyphon System.

Figure 4-18 – Unpressurized Thermosyphon evacuated tube system.

4.2.2 Indirect Thermosyphon Systems

The failures of the Day and Night led Bailey to develop the indirect storage tank and modify his system to an indirect split thermosyphon system. This modification alleviated the freeze issues of his initial model. While these systems can still be used effectively today, they are somewhat rare due to the necessity of either mounting the collectors low or installing solar storage tanks in attics.

These systems use a heat exchanger between the glycol solution in the collector loop and the tank. As the glycol solution is heated, it moves by natural convection to the heat exchanger and transfers the energy to the water in the storage tank. The colder, heavier glycol solution in the heat exchanger flows to the bottom inlet of the collector. Like direct thermosyphon systems, indirect thermosyphon systems require the tank to be elevated adequately to allow natural convection of the fluid.

Passive systems do not require temperature controls, and many installations include either a tempering or an anti-scald valve in the design. The ports on these valves are labeled *hot, cold* and *mix*, and utilize a bimetal spring assembly to ensure the delivered water temperature is no hotter than the dial setting on the valve. Anti-scald valves are specified or required in many system designs since they are more accurate than tempering valves and have a fail-safe design that delivers only cold water upon valve malfunction. Anti-scald valves are about twice the cost of the less accurate tempering or mixing valves.

Figure 4-19 – Example of a standard anti-scald valve used in SWH systems.

A few notes about thermosyphon systems:

- In all thermosyphon systems, the tank is well-insulated to help keep the water hot overnight. By reducing thermal losses, these systems tend to be more effective than batch systems.
- As with any direct system that utilizes flat plate collectors, thermosyphon systems installed in areas with hard water require periodic maintenance. Provisions should be made upon installation to be able to circulate a mild acidic solution through the collector to remove the mineral buildup on the inside of the riser tubes. More detail on this is given in Section 8.
- Careful consideration must be made regarding the placement of storage tanks due the filled weight of the equipment and other hazards of locating equipment in attics and other elevated locations. Water weighs 8.3 pounds per U.S. gallon (2.2 lb/L). As a result, a full 80-gallon (300 L) tank will often exceed 750 pounds. Placing this amount of weight on roofs or in attics requires attention to roof design, as well as to the potential damage that could occur due to leaking equipment.

4.2.3 Direct Forced Circulation Systems

Direct forced circulation (DFC) systems are popular in locations like Hawaii and the southern quarter of Florida, where freezing conditions are rarely or never experienced. These systems are called direct, or open loop, because the collectors heat the potable water directly. The main components of a DFC system are the collector(s), storage tank, pump, and an electronic control to energize the pump when there is enough sunshine to provide usable heat to the storage tank.

DFC systems are simple, efficient and reliable when properly installed in a suitable climate. A single low-head pump circulates the storage tank water through the solar collector(s). The coolest water is circulated from the bottom of the tank to the inlet at the bottom of the collector. The heated water exits the top of the collector and is circulated back to the middle of the storage tank. The pump is controlled by a differential controller, which constantly monitors the tank and collector temperatures using two sensors. When the collector is 10°F (5°C)–20°F (11°C) higher than the water in the bottom of the tank, the controller sends power to the pump. When the collector is only a few degrees warmer than the tank the controller shuts the pump off, providing complete automatic operation.

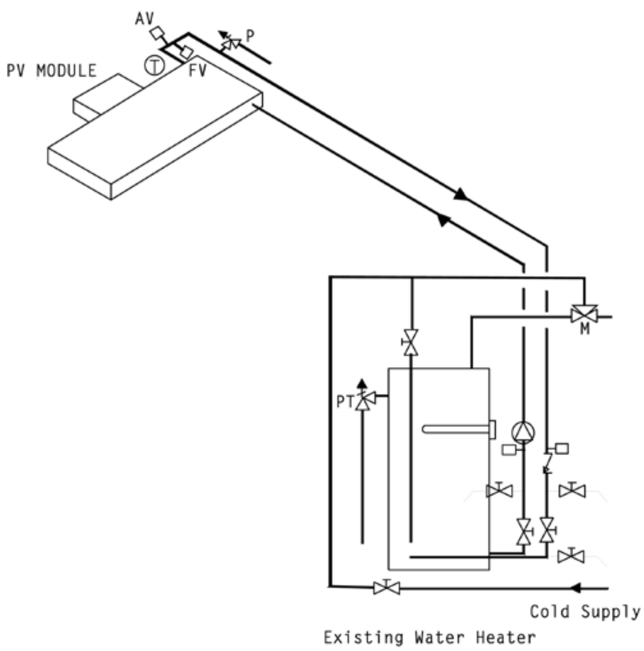


Figure 4-20 – OG-300 System Schematic for Direct Forced Circulation with PV control. (Courtesy of SRCC)

Of all SWH system types, DFC systems have the least dependable freeze protection mechanism. As a result, these systems should only be installed in areas where freezing is nonexistent. California has opted to exclude DFC systems from their current incentive program due to past widespread system failures in the state.

Direct current (DC) systems are controlled with a photovoltaic (PV) panel that provides power to the pump when there is enough solar energy to produce adequate electrical power. If the pump and PV panel are correctly sized, a differential controller is not required. PV panels should be sized based on the pump manufacturer's specifications. The module must be large enough to run the pump when there is enough solar energy available for the collector to heat the tank. PV-powered DC pumped systems are known to have small inefficiencies due to the pump being energized too early or too late in the afternoon. DC differential controls are available and can be used to make PV-powered systems more efficient.

DFC systems require a check valve that allows the fluid to travel in just one direction. The check valve prevents nighttime heat loss caused by hot water in the tank thermosyphoning through the colder collectors and back to the tank.

Periodic maintenance is required if hard water with high mineral content is circulated through the collectors. More detail on the effect of hard water in SWH systems is given in Section 10.

Freeze Tolerance

After decades of sporadic freezing failures, most of the solar heating industry agrees that direct systems should only be installed in the mildest of climates. While there are numerous benefits of direct systems, including cost and productivity, freeze failures are catastrophic. There are a number of solutions that offer freeze protection for direct systems, but these measures have their limitations. Freeze valves that induce a small flow in the collectors during freezing weather are susceptible to failure in areas with hard water. DFC systems that use differential controller functions to circulate the storage tank water through the collectors during freezing conditions are ineffectual during power interruptions or if failure occurs in a pump, controller, or sensor during freezing weather. Reliably protecting solar collectors from damage due to freezing is the reason for the complexity and cost of the freeze-protected indirect systems. The Solar Rating & Certification Corporation (SRCC) publishes the freeze tolerance limit of systems that are certified under SRCC Operating Guidelines 300 (OG-300).

In direct systems, collector tubing will burst with a hard freeze. The conditions that will cause a pipe to burst include the magnitude and duration of the freezing temperatures, as well as the size and type of tubing. While it is common practice to install direct systems in locales that have never had a record low temperature below freezing, an installer must recognize that an extreme weather event could cause a freeze and lead to major system failure.

The least freeze-tolerant systems are DFC and direct thermosyphon systems that utilize flat plate collectors. The relatively small riser tubes in the collectors make these systems susceptible to freeze damage at temperatures around 20°F (-7°C). Any system with an integrated tank outside the heated space (ICS batch and thermosyphons) will have 3/4″ potable water lines piped outside to and from the tank subject to freezing. Pipe insulation can be a factor for short, moderate freezes. Progressive tube ICS systems are less tolerant and will freeze at higher temperatures (about 10°F–20°F) due to uninsulated 3/4″ tubes inside the collectors that connect the 4″ tubes.

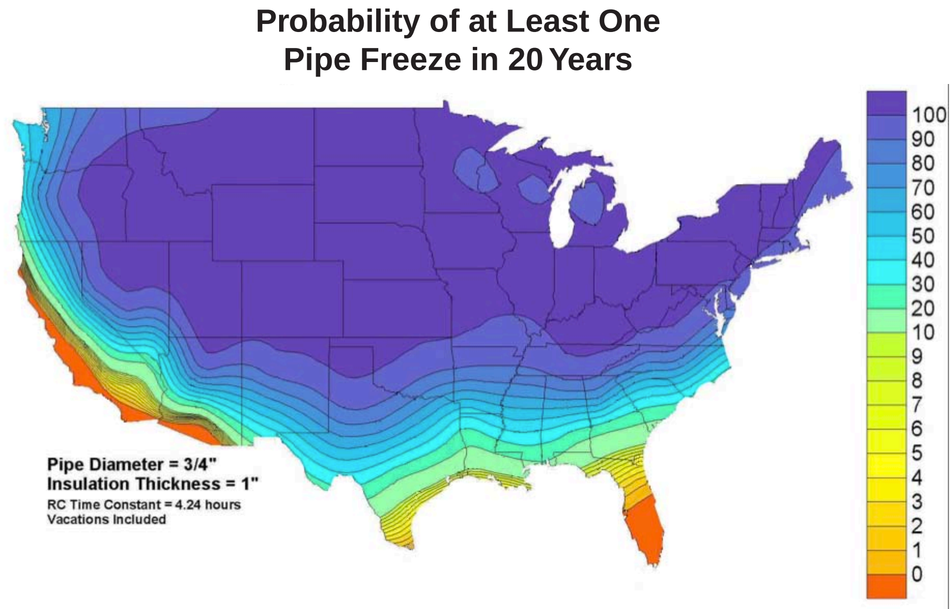


Figure 4-21 – Freeze map for the continental United States for ¾″ copper tubing with 1″ insulation. As is illustrated, there are very few locations in the country where direct systems with exposed piping (including in the collector) are appropriate. Though freeze protection measures such as forced circulation of warm or hot water or the use of freeze valves are included in many direct systems, they can be unreliable due to interruption in power or valve failure. (Courtesy of the National Renewable Energy Laboratory)

4.2.4 Indirect Forced Circulation Systems

Indirect Forced Circulation (IFC) systems are the most reliable systems in areas that experience recurrent freezes. IFC systems are classified into two types—drainback (DB) and antifreeze (AF). A Drainback system provides freeze protection by allowing the water to drain from the collectors when the pump(s) is/are not energized. Antifreeze systems utilize a nontoxic antifreeze, such as propylene glycol, to eliminate freezing in the collector loop.

4.2.4a Drainback Systems

The freeze protection in Drainback systems is not as fail-safe as Antifreeze systems but is sufficient when the system is designed and installed properly. Freeze protection depends on the water in the collector loop draining back to a drainback reservoir when the pump(s) turns off—leaving the collectors and piping filled with air. Drainback reservoirs, also referred to as drainback tanks, are unpressurized tanks located above the pump on its suction side to allow the pump to pull fluid from the tank to fill the collector(s). When the controller activates the pump, the air above the drainback tank is forced into the drainback tank by the fluid filling the collectors. This air returns to the collectors when the pump turns off. The drainback tank may be separate from the solar storage tank, or an unpressurized solar storage tank may function as the drainback reservoir.

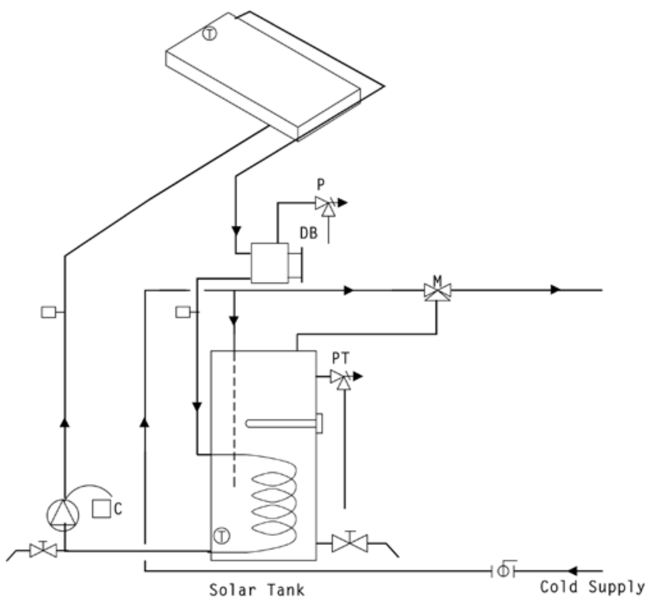


Figure 4-22 – OG-300 System Schematic for a single-pump Drainback system. (Courtesy of SRCC)

Drainback systems are unforgiving—the collectors and all piping must slope a minimum of ¼" per foot (2cm per meter) to the drainback tank to assure draining of the collectors and piping when the pump is de-energized. Otherwise, fluid will remain in the collector and burst the piping under freezing conditions. In addition, accommodations must be made to ensure that the air can return to the collectors to allow the fluid to drain. This is typically accomplished by means of a weep hole in the dip tube of the drainback reservoir. The hole must be above the fluid level of the reservoir for proper operation. A sight glass is frequently provided, allowing for the fluid fill level to be checked during installation. Inadequate or excessive heat transfer fluid in a Drainback system can lead to operational problems and possible system damage.

Drainback systems can be designed as a single-pump or a double-pump system. A single-pump system uses a storage tank with an integrated heat exchanger. The integrated exchanger is a coil of suitable tubing wrapped around or immersed in the tank. The pump must have sufficient head, or pumping power, to pump the collector loop fluid from the initial system fill level to the top of the collector array with enough velocity to create a siphon and flood the system piping. As the system is filled following pump start-up, the fluid flow rate decreases until the siphon closes. Once the siphon closes, the flow rate increases due to the elimination of static head, which is the pressure that the pump must overcome due to the vertical height of the system. At this point, the pump only needs to overcome the resistance resulting from the friction between the fluid and the fittings, obstructions, and pipe walls in the loop. This resistance is referred to as the dynamic head or frictional head.

A double-pump Drainback system utilizes an external heat exchanger and two pumps. The heat exchanger may be inside the drainback reservoir or external to both the storage tank and reservoir. One option is a stainless steel flat plate heat exchanger. A flat plate heat exchanger features channels between mechanically connected plates. The fluid from the collector loop passes through alternate channels of the heat exchanger. Potable water passes through the adjacent channels. This design assures very efficient heat transfer due to the high wetted surface area between the two fluids and the turbidity of flow through the channels. Flat plate heat exchangers are manufactured in single- and double-wall models.

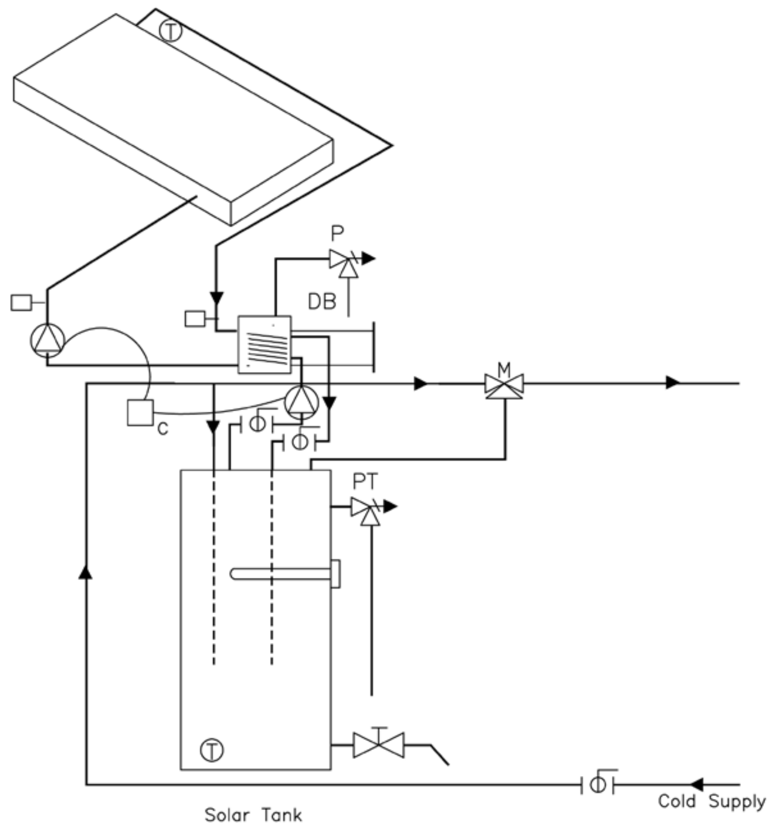


Figure 4-23 – Double-pumped Drainback system. (Courtesy of SRCC)

Drainback designs are adaptable to both large and small systems and are favored when overheating is a concern. Smaller, one- to three-collector SWH systems are frequently available as a pre-engineered package. Larger systems are not typically available in a packaged form, meaning many aspects of the system design will need to be engineered based on specific site and system parameters.

Most differential controls have an adjustable high limit feature that will shut off the pump(s) when a desired storage tank temperature is reached. The collectors are not harmed and the system will not experience excessive pressure since the water will have drained into the drainback reservoir leaving the collectors filled only with air. The drainback tank configuration also prevents nighttime thermosyphoning.

Drainback systems are usually not powered with a PV panel, since reliable DC pumps capable of overcoming large static head are difficult, if not impossible, to find.

In the past, vacuum breakers were used in Drainback systems to break the vacuum at the top of the collectors. This is problematic in areas with hard water as the vacuum breakers will scale up and clog shut. Reliable solar energy system freeze protection should never depend on valves or the presence of electrical energy.

Closed-loop heating systems typically require a pressure relief valve and expansion tank to accommodate the expansion of fluid that occurs with temperature increases. This is not necessarily true in Drainback systems. An expansion tank is not required in a closed-loop Drainback system—the air in the system absorbs any expansion due to temperature increases. Because the system is closed, it requires a pressure relief valve in case system pressures exceed the pressure ratings of various components.

4.2.4b Antifreeze Systems

Antifreeze (AF) systems utilize propylene glycol as a heat transfer fluid to ensure freeze protection. Propylene glycol, like other antifreeze solutions, has a low freezing point. Unlike ethylene glycol, which is typically used as automotive antifreeze, propylene glycol is nontoxic. Ethylene glycol should never be used in SWH systems. Due to this lack of toxicity and its chemical stability at the temperatures common to SWH systems, propylene glycol solutions are the standard for SWH systems in freezing climates. A 50% glycol and water solution is used in most of North America and a 30% glycol solution is common in mild climates. In extremely harsh climates, such as parts of Canada and Alaska, many installers prefer a solution of 60% propylene glycol and water. Providers of propylene glycol solutions for solar systems typically use nontoxic additives, which enhance the fluid's ability to withstand the high operating temperatures of solar systems.

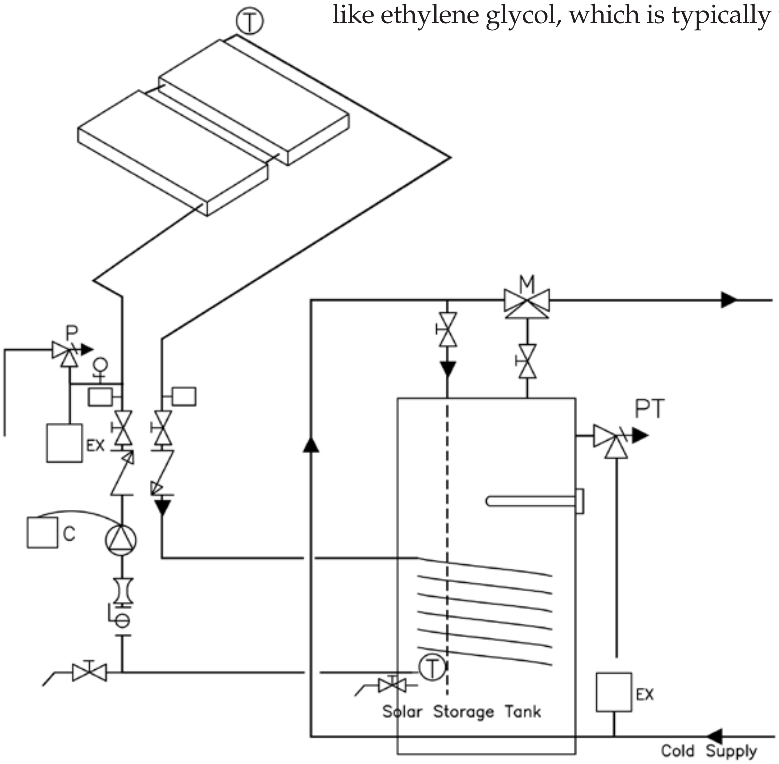


Figure 4-24 – OG-300 System Schematic for a single-pump Antifreeze system. (Courtesy of SRCC)

The type of propylene glycol used in Antifreeze systems is critical to system performance. Glycol includes inhibitors to maintain the fluid's integrity over time. Propylene glycols used in Antifreeze systems must use inhibitors that maintain fluid stability above temperatures of 300°F. If the glycol is not rated for such conditions, the inhibitors will acidify and deteriorate components in the collector loop. High quality propylene glycol solutions that are not subjected to extensive overheating can last for years, even decades, but should be checked for pH (acidity) and freeze protection level every few years.

Single and double-pump designs are also options in Antifreeze systems. The systems require only low to mediumhead pumps and consume less electricity than the highhead pumps used in Drainback systems. This is because the pumps in Antifreeze systems must overcome frictional head only, unlike pumps in Drainback systems which must overcome both static and frictional head. A single-pump system uses a tank with an integrated heat exchanger. Double-pump Antifreeze systems use an external heat exchanger, such as a flat plate heat exchanger.

Antifreeze Systems and Stagnation

Antifreeze systems are susceptible to stagnation, a phenomenon that occurs when the collector array is subjected to high levels of solar insolation and the heat transfer fluid is not circulating. This may occur due to a power outage, a pump failure, or a controller malfunction, for example. It may also occur intentionally; once the solar storage tank

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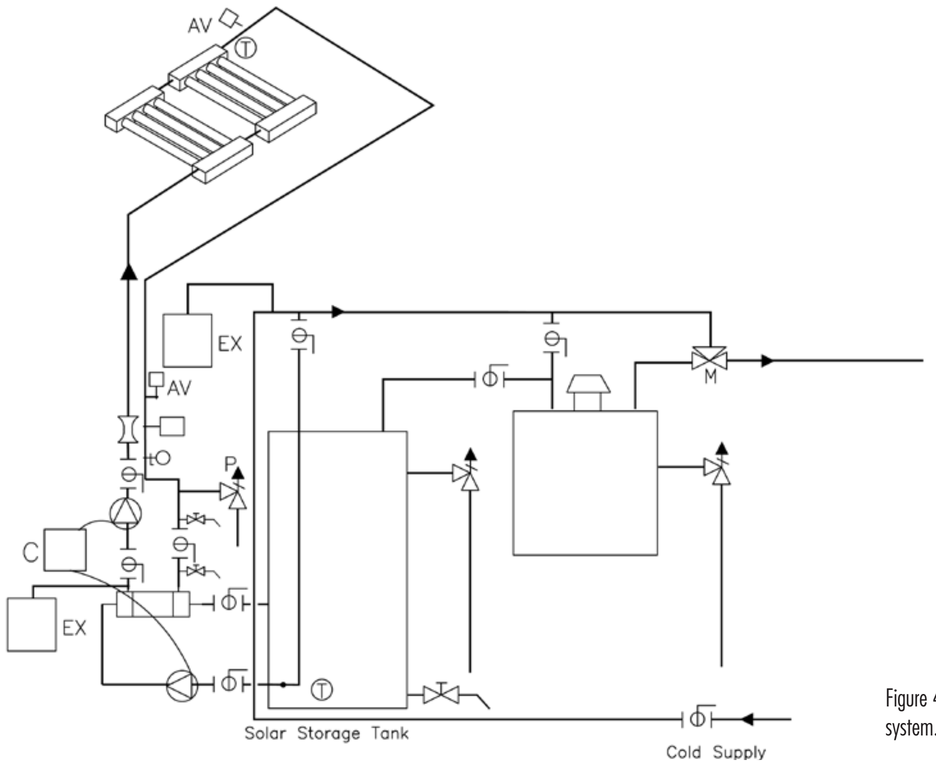


Figure 4-25 – Double-pumped Antifreeze system. (Courtesy of SRCC)

Dealing with Stagnation

Stagnation may occur due to system failures, such as a power interruption, broken pump, shaded sensor, or controller error. Stagnation may also occur by design. Most differential controls include a feature that will deactivate the solar pump if the solar storage tank temperature exceeds a setpoint. The purpose of this setting is to protect the integrity of the tank and to prevent steam formation.

Stagnation is an issue in Antifreeze systems because it can lead to depressurization. It can also cause acidification of the glycol inhibitors, which can cause deterioration of system components.

While measures can be taken to avoid stagnation, it is nearly impossible to eliminate the threat. Protection measures such as battery or generator backup can maintain system operation during a power outage, but these are also not immune to component failures. Powered heat dumping strategies or the inclusion of redundant pumps are only effective if the power is uninterrupted and all components are functioning properly. An experienced solar designer evaluates stagnation risks and determines an appropriate strategy.

Some designers have recognized the probability of stagnation and have designed their systems to minimize the effects of stagnation rather than try to avoid them. These methods include:

- Sufficiently sizing the expansion tank to accept the expansion caused by steam formation in the collectors. This method aims to keep the system pressures below the relief valve rating to allow for steam formation and continued system operation. Once the heat dissipates from the collectors and the heat transfer fluid condenses, the system returns to normal operation.
- Sufficiently sizing the expansion tank and using a high-rated pressure relief valve—typically 150psi—to prevent steam formation. As pressures increase, so does the boiling point of the glycol solution. If the increases in pressure and temperature correspond with one another properly, steam formation can be prevented. This is a balancing act—if the temperature rises too fast, the solution will steam; if the pressure rises too fast, it can cause the relief valve to open.
- Inclusion of a reservoir that acts in a manner similar to the antifreeze reservoir in an automobile. If pressures are excessive, some of the glycol solution is expelled into the reservoir. When the pressure drops, the glycol is drawn back into the solar loop.

has reached its maximum temperature, many controllers are designed to turn off the pump to protect the tank from overheating. Prolonged stagnation can result in collector temperatures that exceed 400°F (205°C). These temperatures increase system pressure and can cause release of the pressure relief valve, which leads to system depressurization.

These pressures also create complications as it relates to the use of heat exchangers. In jurisdictions that have adopted the Uniform Plumbing Code, the rating of the pressure relief valve is limited to 30psi when using a single-wall heat exchanger. If the system is engineered, the pressure relief valve rating may be increased as long as it does not exceed the normal operating pressure of the potable water system. This requirement is in place to protect the potable water from being contaminated by the propylene glycol solution if a leak occurs in the heat exchanger. Alternately, a doublewalled heat exchanger with leak detection can be used without limiting the pressure relief valve rating to the pressure of the potable system.

In jurisdictions with a strict interpretation of the code, singlewalled heat exchangers are impractical due to the difficulties of maintaining Antifreeze systems below 30psi. Without the ability to exceed 30psi, it is difficult for an installer to purge the air from the collector loop when the system is initially filled with antifreeze. Additionally, a relatively large expansion tank is required to prevent an Antifreeze system from exceeding 30psi under stagnation conditions.

Antifreeze systems require an expansion tank to alleviate variations in system pressures. Expansion tanks are sized based on the maximum system temperature, the volume of the system, and the pressure difference between the initial system pressure and the relief valve rating. If the expansion tank is designed to allow the system to stagnate without exceeding the pressure rating of the relief valve, it must be capable of accepting normal system expansion and the expansion that occurs due to steam generation in the collectors.

Antifreeze systems require more components than DFC and Drainback systems. As in DFC systems, Antifreeze systems require a check valve in the collector loop piping to prevent reverse thermosyphoning, as well as fill/drain valves, an expansion tank and a pressure gauge. A number of manufacturers assemble these components along with the pump(s) and controls into a pump station package. Pump stations and individual components are explained in detail in Section 8.

Antifreeze systems can be PV-powered since low to medium head DC pumps are readily available.

What's the best IFC system?

Different installers have their preferences and history offers some guidance. Antifreeze systems have less chance of collector damage due to freezing. Over-temperature issues can be better addressed with Drainback systems. Drainback systems have little tolerance for installation errors while Antifreeze systems tend to be more forgiving. Antifreeze systems can easily accommodate PV powered pumps. Installers in regions with mild to moderate climates tend to prefer Drainback systems because of the inherent overheating protection feature—the harsher the winter, the more installers prefer Antifreeze systems.

What's best? Some installers have combined the systems by adding propylene glycol to a Drainback tank. With the right mixture of antifreeze, the collectors will never freeze and still have Drainback system overheat protection. This works but the fluid must be monitored if the system stagnates frequently from a high limit setting. Antifreeze solutions don't drain from collectors as cleanly as water. Small amounts of the glycol solution stick to the riser tubes and this residue is blackened from the high collector temperature. Antifreeze solutions that overheat can turn acidic and harm copper tubing. Glycol/drainback systems are known for the antifreeze solution turning black and blackening the entire interior of the collectors, Drainback tank, heat exchanger, pump(s) and piping. The pH of the heat transfer fluid in these systems should be checked every 1–2 years. This procedure is detailed in Section 10 along with procedures for flushing and refilling the system.

4.2.5 Solar Pool Heating Systems

Solar pool heating (SPH) systems are considered low-temperature systems due to their typical operating temperature range of 75°F (24°C)–85°F (29°C). Systems used for heating outdoor pools differ considerably from those used for indoor pools in freezing climates. The components of the collector loop used in an indoor pool system often resemble the components of IFC systems. Outdoor systems are typically seasonal and do not require freeze protection, thus they are less complex and do not require the use of high-temperature components. In freezing climates, pool systems must be designed and installed to drain completely.

Outdoor pool systems

A standard residential, open-air SPH system utilizes pool collectors and the existing pool pump. The collector loop is constructed of PVC pipe, fittings and valves. Because the system is open-loop and operates at low temperatures, components do not need to be rated to the pressures and temperatures required of components in closedloop SWH systems.

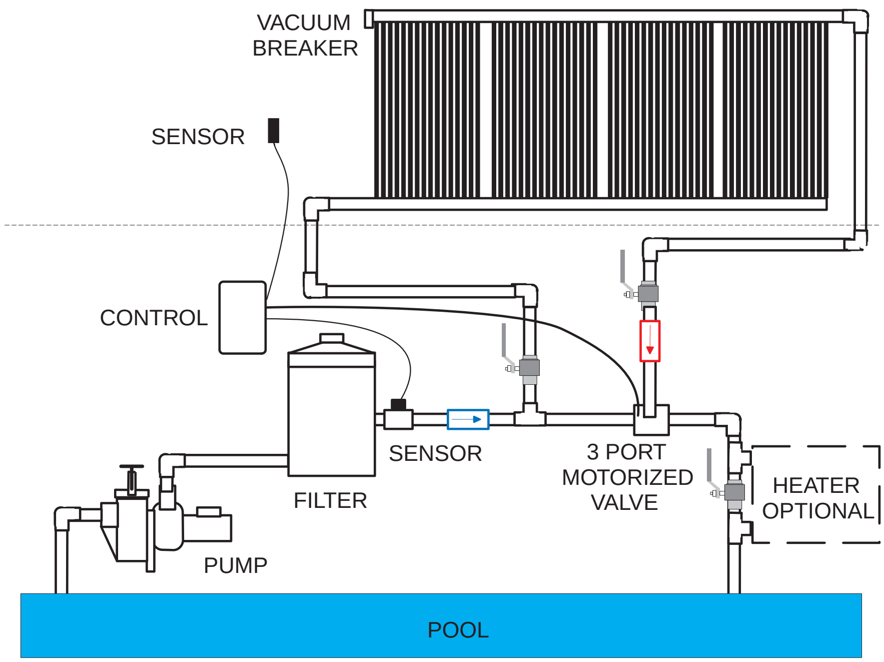


Figure 4-26 – System diagram for standard outdoor solar pool heating system.

The PVC pipe and fittings are typically glued together using PVC cement, and rubber couplings secured with hose clamps are used to join individual collectors. Larger pools and some residential pools may require a booster pump in the collector loop to ensure adequate flow through the collectors. Public pools will almost always require a solar system booster pump because of health regulations requiring adequate filter flow to maintain water quality.

Collectors are usually installed on an adjacent roof or trellis, but they can also be mounted on ground racks. Most pool collectors require full support by the roof or rack because they are not made with an integral frame. The panels are strapped to the mounting structure in a manner that will allow for the expansion and contraction of the solar collectors that occurs due to temperature fluctuations. Failure to allow for expansion/contraction can cause premature failure of the panels.

Systems using polymer panels are usually configured similarly to Drainback systems. The system is controlled with a differential control that operates at a low temperature differential—typically 5°F (3°C) or less. The control is used to energize a three-port motorized valve that diverts the pool water to the collectors. Sensors measure the temperature of the

SPH systems for indoor pools resemble IFC systems.

They can function similarly to Drainback or Antifreeze systems using an external heat exchanger. These heat exchangers must be stainless steel or titanium, depending upon the chemical composition of the pool water. Due to the high flow rates produced by the pump on the pool side of the heat exchanger, special consideration must be given to the frictional head loss, or pressure drop, caused by the heat exchanger. Shell-and-tube heat exchangers are commonly used for this reason. The collector loop side of the heat exchanger is designed similarly to other large IFC systems.

Another difference between SPH systems for indoor pools and open-air pools is consideration of the natatorium—the building that houses an indoor pool. The systems within a natatorium are complex due to the need to maintain indoor air quality and temperature. Mechanical systems often include heaters, air conditioners, dehumidifiers, and ventilation. In open-air SPH systems, an increase in water temperature above the pool's set temperature only impacts comfort. In an indoor pool heating system, an increase in pool temperature may increase evaporation of the pool water and affect the ancillary mechanical systems in the natatorium. SPH systems for indoor pools should be engineered by qualified professionals familiar with the conditioning of natatoriums.

collectors and the temperature of the pool water. Whenever there is enough heat in the collectors to add heat to the pool, the valve is actuated. When the sun is not shining, the valve directs the flow only through the pool's standard piping.

Many residential pools are heated only with solar. SPH systems may also be used in conjunction with an auxiliary heater when the sun's energy is insufficient. A properly sized system will maintain a swimming pool temperature of 75°F (24°C)–85°F (29°C) through the swimming season.

Indoor pool heating

While PVC and polypropylene are advantageous due to cost, these materials are also necessary due to the corrosivity of standard pool chemicals. Standard plumbing materials such as copper and iron will affect pool water quality due to a chemical interaction with chlorine and will eventually fail.

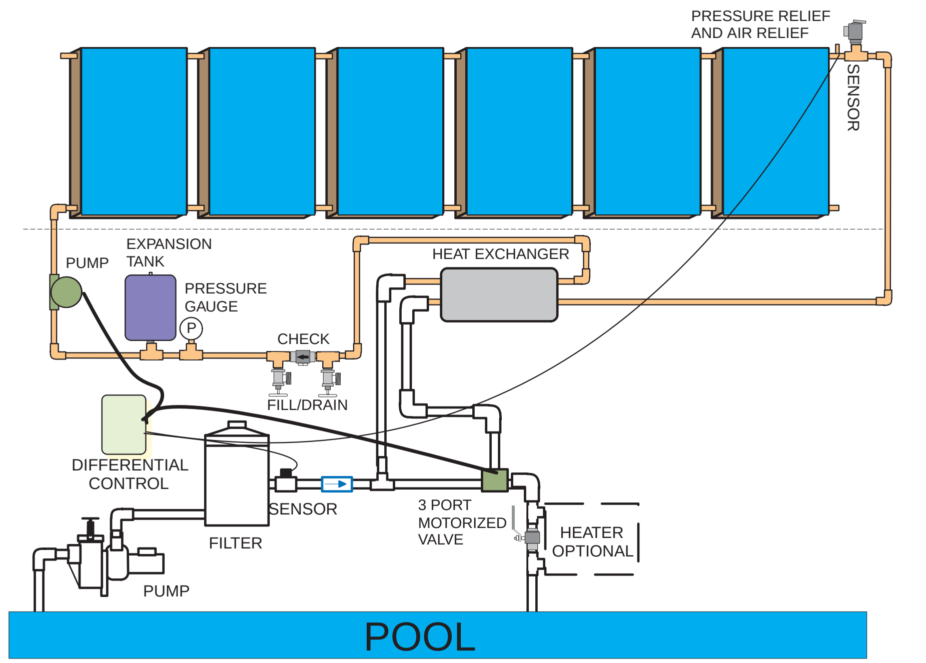


Figure 4-27 – Indoor solar pool heating system.

Corrosion considerations are more significant in SPH systems for indoor pools than for outdoor pools due to the common practice of using medium temperature collectors to improve year-round solar heat collection.

Pool water in residential indoor pools is often maintained at or slightly above a pH of 7. Under these conditions, the SPH system can be designed as a Drainback system using the pool as the Drainback reservoir. Care must taken when using the PVC piping in these systems—if an electrical power interruption occurs when the sun is shining, the collector temperatures can exceed 300°F (150°C). PVC pipe begins to soften at 140°F (60°C).

The pH scale measures the acidity or alkalinity of a solution. A solution with a pH of 7 is neutral. Acidic solutions have a pH of less than 7 while alkaline, or basic, solutions have a pH greater than 7. In solar heating systems, pH is used to monitor the acidity of pool water, glycol solutions, and water in unpressurized storage tanks.

5 Prepare for Project

The successful installation of a solar heating system is dependent upon proper planning. Experience is a critical asset in this process. An experienced installer is familiar with standard construction plans and is able to use these plans to assemble the materials, tools, and safety equipment needed for the job.

5.1 Review the construction plans

Construction plans may be required by the Authority Having Jurisdiction (AHJ) for permit approval. The AHJ may be the Building Department of a town, city, or county, or in some cases a state. Regardless of whether they are required by the AHJ, construction plans should be provided for all SWH systems. Plans may serve several purposes, including:

- Providing details for bidding purposes
- Serving as a working document between the designer and the installer
- Allowing the installer to assemble a parts list
- Providing details to the installer for proper installation
- Detailing system design and operation for the owner after system installation

Depending upon the application and jurisdiction, construction plans may be produced by a mechanical engineer, the system manufacturer, or the installation firm. Engineers will most likely be involved in larger commercial, industrial, and municipal systems. Smaller systems, such as residential domestic water heating systems, are more likely to be based on OG-300 or manufacturer-provided designs. Design requirements vary by jurisdiction and must be verified by the installer.

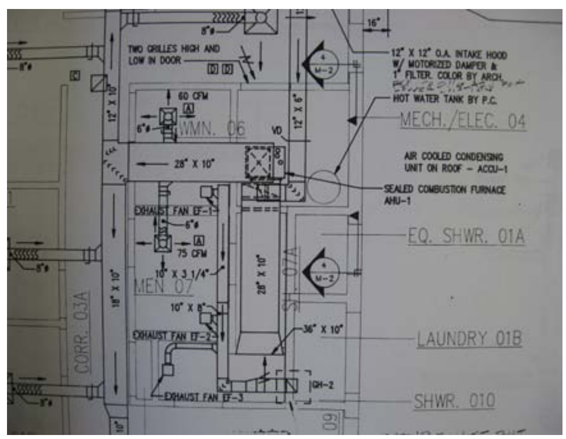


Figure 5-1 – Mechanical plans.

A qualified installer must be able to interpret construction drawings to determine the functionality of the system, identify potential issues with the design, ensure code compliance, compile a list of required equipment and tools, and properly install the system. All details on the construction plans should be verified prior to installation.

Construction plans may consist of various types, including:

- *Architectural plans* illustrate the dimensions and appearance of a structure through the use of floor plans, profile views, details, and sections. They can often be used to determine roof pitch, utility room layout, and the location of collector loop piping.
- *Structural plans* lay out the location and size of load-carrying members in a building. These can be used to determine appropriate attachment points for collector racking.

- *Mechanical and plumbing plans* give specific details on the location and type of tanks, valves, piping, etc. In engineered systems, these plans are the blueprint for the SWH system installation.

Construction plans are used to visualize the project before it is installed. Specifications often accompany these plans and describe the exact equipment and procedures required for the installation. Plans and specifications must be reviewed prior to the installation to assure that the system can be installed as designed and will perform effectively as designed.

Prior to installation, the installer should review the system design to verify the following:

- The system is suitable for the specific application.
- All critical components are included.
- The components are sized appropriately.
- The system is properly integrated with the auxiliary heating system(s).
- The system meets national and/or local code requirements.

Any discrepancies or questions should be addressed immediately with the system designer or manufacturer.

5.1.2 Create a materials list

Construction plans assist the installer with creating a list of materials and equipment needed for the installation. Some designs will specify the manufacturer and model of each major component in the system, while others will identify the type of component to be used (e.g., circulator, collector, air vent) and leave the component selection to the installer.

While an OG-300 certified system utilizes specific collectors for each design, an engineered design may specify the style of collector (flat plate or evacuated tube) and the required output of the collector array under appropriate conditions.

When the installer is selecting other components that have not been specified, s/he must consider the operating conditions of the system. The components must be rated for the appropriate maximum temperature and pressure and must be constructed of materials that are compatible with the fluid(s) used in the system. Failure to recognize the design conditions for particular systems can lead to premature failure of system components, may threaten the health of building occupants, and/or may affect the operation of the system. For example:

- An automatic air vent used in a standard boiler application will not be rated for the stagnation temperatures in an AF system.
- A cast iron pump used in a DFC system will corrode.
- A standard hydronic expansion tank rated to 100psi (7 bar) is not acceptable in a system with a 150psi (10.3 bar) relief valve.
- Any components that are used in the potable piping system must be constructed of materials that do not exceed the lead content limits of the local plumbing code.

Example

Specifications for the collectors on a small commercial installation read as follows:

Collectors: Solar collectors shall be flat-plate style with a single layer of low-iron tempered glass. The array output shall be 150,000 BTU/day (44 kW/day) based on SRCC OG-100 Category C, Mildly Cloudy conditions.

In this scenario, the installer must determine the type and quantity of collectors required to fulfill the project specifications. Besides considering the output requirements, the installer must also consider limitations relating to the available roof area for the collector array. The output ratings and collector area are found on the SRCC OG-100 Collector Thermal Performance Rating—available at www.solar-rating.org—and the collector dimensions are available from the manufacturer.

Suppose the installer plans to utilize a collector with the following ratings:

COLLECTOR THERMAL PERFORMANCE RATING							
Kilowatt-hours (thermal) Per Panel Per Day				**Thousands of BTU Per Panel Per Day**			
Climate → CATEGORY (Ti-Ta)	High Solar Radiation (6.3 kWh / m^2.day)	Medium Solar Radiation (4.7 kWh / m^2.day)	Low Solar Radiation (3.1 kWh / m^2.day)	Climate → CATEGORY (Ti-Ta)	High Solar Radiation (2000 Btu / ft^2.day)	Medium Solar Radiation (1500 Btu / ft^2.day)	Low Solar Radiation (1000 Btu / ft^2.day)
A (-5 °C)	12.5	9.4	6.4	A (-9 °F)	42.6	32.2	21.8
B (5 °C)	11.4	8.3	5.3	B (9 °F)	38.8	28.3	18.0
C (20 °C)	9.5	6.5	3.6	C (36 °F)	32.5	22.3	12.1
D (50 °C)	5.7	3.0	0.7	D (90 °F)	19.5	10.3	2.3
E (80 °C)	2.2	0.3	0.0	E (144 °F)	7.6	1.1	0.0

A–- Pool Heating (Warm Climate) **B–-** Pool Heating (Cool Climate) **C–-** Water Heating (Warm Climate)
D–- Water Heating (Cool Climate) **E–-** Commercial Hot Water & Cooling

Figure 5-2 — SRCC OG-100 Collector Rating. (Courtesy of SRCC)

For Category C, Mildly Cloudy conditions, this collector has a rating of 22,300 BTU/day (6.5 kWh/day). To determine the number of collectors required to satisfy the design specifications, the installer must divide the specified output of the array by the rating of each collector:

Number of collectors = Total array output ÷ Collector output

Number of collectors = 150,000 BTU/day ÷ 22,300 BTU/day

Number of collectors = 6.7

In this example, the installer would need to use 7 collectors.

Other considerations for component selection may include: availability, cost, quality, and the length and type of warranty. Prior to purchase, the installer must review the manufacturer's specifications and instructions to ensure that the equipment is appropriate for the system and to ensure proper installation.

5.1.3 Identify safety equipment needed

The Occupational Safety and Health Administration (OSHA) requires that employers implement appropriate safety training and safety protection for their employees. Regulations for the solar industry are contained in 29 CFR 1926—General Construction. While the employer is responsible for the oversight of company safety programming, it is the installer's responsibility to assess job risks and work with his/her employer to provide appropriate protection.

During the construction plan review or the site evaluation (see Section 6), the installer must determine how the installation will be completed *safely*. Particular attention should be paid to roof and attic work, areas where work needs to be performed from ladders, scaffolding, or man-lifts, and situations where heavy equipment, such as storage tanks, must be transported through the work area.

Figure 5-3 – Fall protection equipment.

Upon review of the construction plans and during the site evaluation, the installer should determine a specific plan for providing fall protection while working on the roof. The plan should identify measures for providing appropriate attachment points and safety hardware

Solar installer falls three stories to his death

On April 7, 2010, a solar installer in California was working on the roof of a three-story multi-unit apartment building. The roof had a slope of 9:12 or 37°. The installer was working without a personal fall arrest system and there were no other fall protection measures installed.

The 30-year-old installer was verifying the alignment of solar brackets that had been mounted on the roof. The installer observed the mounting hardware from near the gable end of the structure and likely stepped backward off the roof. He fell 45 feet (15 m) onto a concrete sidewalk. He was pronounced dead at the hospital following an airlift.

The largest number of deaths in the construction industry is due to falls. Because collectors are often installed on roofs, solar heating installers incur significant risk. When an individual opts not to follow common safety practices, s/he could be risking his/her life.

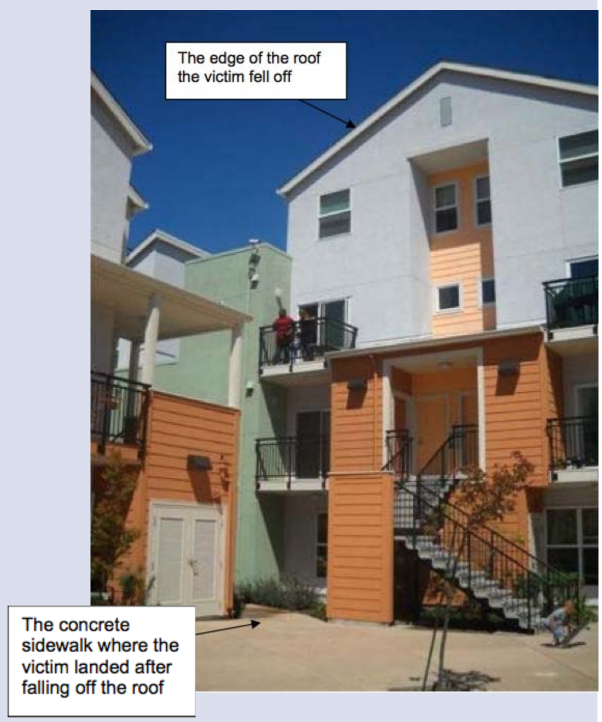


Figure 5-4 — Accident site. (Courtesy of NIOSH FACE Reports) for attaching work harnesses when working on steep roofs (slope greater than 4:12). On low-slope roofs, the safety plan may include work harnesses, warning lines, guardrails, or other OSHA-approved techniques. See 29 CFR 1926 Subpart E (Personal Protective and Life Saving Equipment) and Subpart M (Fall Protection) for more details.

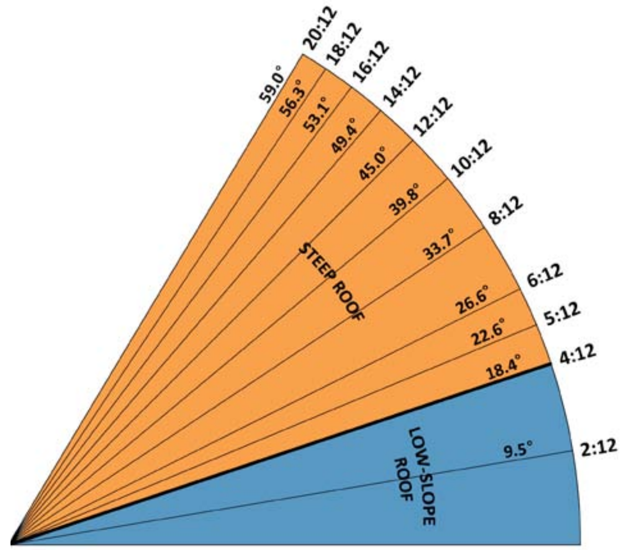


Figure 5-5 – Common roof slopes.

Attics present unique hazards. Whenever work needs to be performed in an attic, attention must be paid to preparing a safe means for accessing the attic; providing a safe workspace in the attic; and the use of skin, eye, and respiratory protection when working around insulation.

The installer should also determine what type and size of ladders and/or scaffolding should be used to access roofs or complete overhead work. The safety plan must utilize methods in accordance with 29 CFR 1926 Subpart L (Scaffolding) and Subpart X (Ladders).

The safety plan may also include minimizing risk by utilizing hoists, man lifts, pallet jacks, lift gates, or other equipment that assists with lifting, accessing roofs, or moving heavy equipment. If machinery is used to mitigate risks associated with lifting heavy objects or providing access to elevated work areas, the equipment must be operated by properly trained personnel.

Ladder duty ratings

OSHA requires portable ladders to be designed for at least four times the maximum intended load with the exception of extra-heavy-duty type ladders, which must be designed for at least 3.3 times the maximum intended load. The American National Standards Institute (ANSI) requires manufacturers to label ladders based on a standard duty rating system. The weight of the installer and any tools or equipment that s/he uses while on the ladder must not exceed the duty rating of the ladder. Duty ratings are as follows:

Ladder Type	Duty Rating	Application
Type IAA	375 lb	Extra heavy duty industrial
Type IA	300 lb	Extra heavy duty industrial
Type I	250 lb	Heavy duty
Type II	225 lb	Medium duty
Type III	200 lb	Light duty

Type II and Type III are not allowed on construction worksites.

Figure 5-6 – Ladder stabilization device. (Courtesy of Safe-T-Climb)

5.1.4 Prepare project schedule

Effective project scheduling requires the installer to be knowledgeable of the tasks required to complete the installation; to be able to adapt to schedule changes that result from weather, equipment availability, or other unforeseen events, and to be an effective communicator.

Project scheduling is often unique to the project, the client, and the installation company, thus it is difficult to provide a concise discussion of the topic that is both thorough and universally applicable. Instead, the following sections provide general guidelines and considerations to assist installers with effectively scheduling SWH installations.

Based on the scope of the project, an experienced installer is able to estimate the size of the crew and the number of work hours required to complete the project. S/he may be responsible for, or assist with, scheduling crews for the installation. While some projects may have flexibility in the order of tasks—e.g. it may not matter if the collectors are installed before or after the solar storage tank—the installer must ensure that sufficient equipment and labor are available when needed. For example, if a lift is rented to transport collectors to the roof, the proper fall protection and work crew will need to be on-site to coincide with the availability of the lift.

Portions of the installation may require licensed technicians, such as hardwiring the controller, replacing a combustion appliance, or connecting to the potable water supply. Other tasks may require other construction specialists, such as roofers and carpenters. Scheduling considerations are critical when subcontractors and other specialized personnel are involved.

During installation, it is the installer's responsibility to follow the plan and adapt as needed. Because SWH projects require outdoor work, weather has a significant impact on project scheduling. Additionally, equipment delays and scheduling overruns on other projects may affect the initial installation timeline. Delays are inherent to contracting. An effective contractor recognizes the importance of maintaining effective communication with the client, with vendors, and with other personnel to minimize the difficulties that can arise due to such delays.

Figure 5-7 – Copper tubing with standard fittings.

5.2 Assemble materials

Supply chains for SWH equipment vary by region. Some installers have the luxury of close proximity to local supply houses that carry solar equipment in inventory. Others may have to special order solar equipment or stock specific equipment in inventory to minimize supply chain delays. An experienced installer is familiar with time frames for receiving standard equipment and is aware that certain equipment is less- frequently used and may require more lead- time to obtain.

Once the appropriate equipment has been purchased and received, the installer should inspect and verify that the components are the correct model and are operational. For installations in remote locations, it may be necessary to test equipment prior to loading it on the work truck. It is often advantageous to carry extra quantities of standard components, such as controllers, sensors, pumps, and fittings, in case a part is defective or is damaged during installation.

Job site efficiency starts prior to setting foot on the site. A well-organized work vehicle minimizes time spent searching for misplaced tools and equipment. Attention to detail will also minimize trips to the supply house, which increases profitability and demonstrates professionalism to the client.

Site access must be coordinated with the client prior to installation. If large equipment, such as tanks and collectors, will be delivered directly to the site, the installer must ensure that proper personnel are there to receive the shipment. It is in an installer's best interests to inspect all delivered equipment and ensure it was not damaged during shipping. Many shipping companies will only consider a damage claim if it is made at the time of delivery. Some freight companies require that the recipient reject delivery if the equipment is damaged in order to make a claim. If damaged equipment is presented for delivery, the installer should review the freight company's policy prior to accepting the shipment. At the very least, any discrepancies in the shipment should be noted on the delivery paperwork and the delivery person should be asked to initial.

Because installation may require access into the living space and/or interruption of the water supply, it is important for the installer to verify

Fitting notation

Fittings for copper tubing come in a variety of sizes and styles. The table below lists and describes the common industry abbreviations used to describe standard styles of joints. Each fitting will have at least two joint notations.

Abbreviation	Name	Description	Type of fitting(s)	Example
FTG	fitting	end of the fitting is the same diameter as the tubing	couplings	1"x¾" FTGxC (reducer)
			adapters	½" FTGxF
			elbows	¾" FTGxC 45°
C	cup	tubing fits inside this end of the fitting	couplings	½" CxC
			adapters	1" CxM
			elbows	¾" CxC 90°
			tees	¾"x¾"x½" CxCxC
M	male	end has male thread	adapters	1" CxM (see above)
F	female	end has female thread	adapters	½" FTGxC (see above)
			brass tees	¾" CxCxF

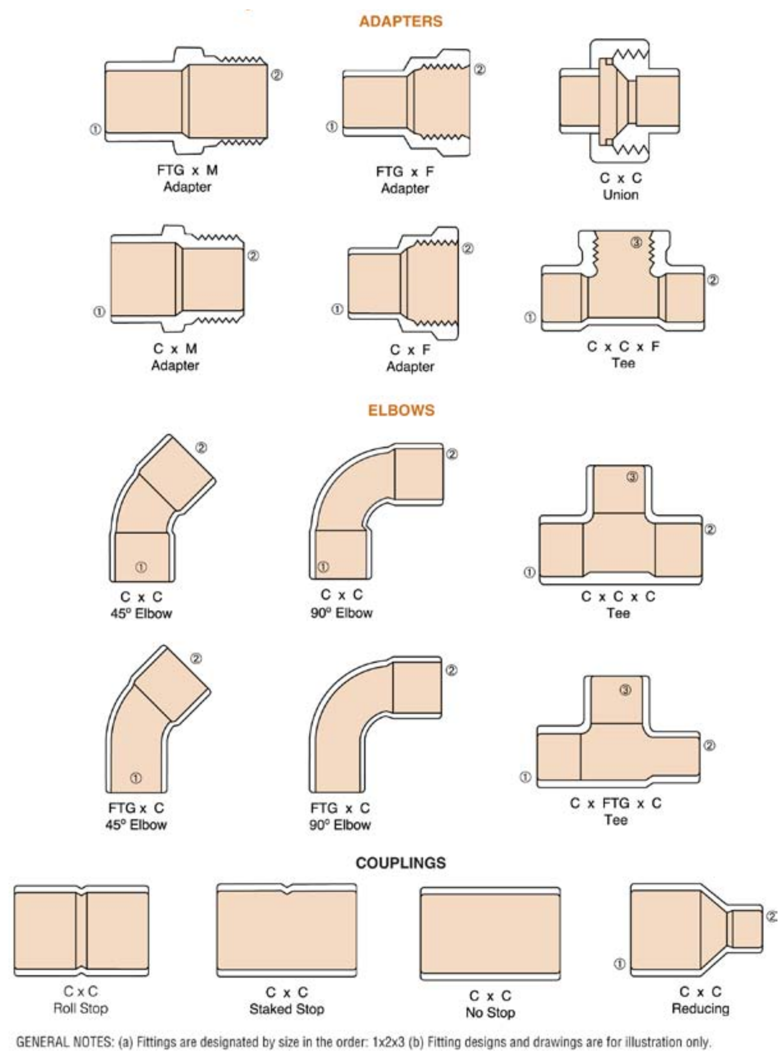


Figure 5-8 – Standard copper fittings with their designated notations.
(Courtesy of Copper Development Association, Inc. in New York, New York)

appropriate times to install the system. Scheduling may be more difficult in new construction, where the timeline will likely depend upon the general contractor's schedule. At times, these projects require the installer to respond quickly to the schedule of the roofing, drywall, and heating contractors.

5.3 Assemble and inspect safety protection equipment

All safety equipment should be laid out at the shop and inspected. This includes fire extinguishers, ropes, harnesses, ladders, ventilators, masks, gloves, hearing protection devices, and other hardware associated with this equipment. Visual observation should determine the status of the equipment. In some cases, stress testing (pulling or tearing movements) are required to fully assess equipment like harnesses or ropes. Safety equipment found unserviceable for its purpose should be discarded and replaced.

5.4 Assemble tools

An experienced installer has a thorough collection of tools needed for a standard SWH installation (see below). These tools should be well organized in work bags, tool boxes, and bins. Often these tools are stored in work vans, in truck boxes, or in a utility trailer. Best practice is to have fixed locations for tools so that they are readily accessible. This minimizes the chance of forgetting critical tools and helps to support a clean, organized, and safe work site.

Figure 5-9 — Soldering kit.

Figure 5-10 – Adjustable wrenches.

Figure 5-11 – Pipe wrench.

Soldering kit:
Flux brushes – for applying acid flux to tubing and fittings
Wire brushes – for cleaning fittings; one required for each size of tubing used
Tubing cutter(s) – for cutting tubing to length
Deburring tool – for smoothing out tubing after it is cut
Emory cloth or sand cloth – for cleaning tubing
Torch – used with propane or MAPP gas to heat fittings during the soldering process
Rags – for wiping joints after soldering
Inspection mirror – for inspecting joints
Torpedo level – for checking plumb and level of piping
* Acetylene torch – for brazing joints

Wrenches:
Allen wrench set – for adjusting mixing valves, removing pump cartridge housing, etc.
Adjustable wrenches – for tightening screwed joints, bolts, etc.
Pipe wrenches – for tightening screwed joints
Open-end wrenches – for tightening flange bolts, collector rack hardware, etc.
Socket wrench set – for tightening flange bolts, collector rack hardware, etc.

Power tools:
Cordless drill – for drilling pilot holes and making roof and wall penetrations
Cordless impact driver – for installing screws
Reciprocating saw – for general construction
Circular circular saw – for general construction
Corded drill – for drilling holes for piping

Bits:
Hole saw kit – for drilling roof and wall penetrations
Spade or auger bits – for drilling penetrations in framing members
Assorted bits – for drilling pilot holes, etc.
Driver bits – for installing screws
Extension bit – for extending drill bits when drilling through wall and floor assemblies
Installer bit – long pilot bit for drilling holes and feeding sensors wires

Electrical:
Extension cord
Multimeter – for testing sensors, diagnosing circuits, etc.
Wire strippers – for preparing wiring
Circuit tester – for quickly identifying if a circuit is live
Precision screwdriver set – for installing the controller
Fish tape – for running wires in walls

Figure 5-12 – Cordless drill.

Figure 5-13 – Cordless reciprocating saw.

Figure 5-14 – Wire strippers.

Figure 5-15 – Multimeter. (Courtesy of Home Power)

Figure 5-16 – Antifreeze filling station.


Figure 5-17 – Drill pump and washing machine hose.

Hand tools:
Chalk line – for collector layout
Caulk gun – for sealing penetrations
Hacksaw – for cutting all-thread and insulation
Hammer – for general carpentry, installing hangers, etc.
Inclinometer – for measuring collector tilt and roof pitch
Utility knife – for opening boxes, cutting shingles, etc.
Level – for checking slope of collectors, tanks, and piping
Pliers – for general construction and wiring
Spring clamps – to hold back pipe insulation while soldering; for securing hoses in bucket
Screwdriver set – various sizes of standard and Phillips-head screwdrivers for general work
Tin snips – for cutting flashing
Flat pry bar – for lifting shingles
Hand truck – for transporting tanks and other large equipment

Miscellaneous tools:
5-gallon buckets – to collect drained fluids; to hold heat transfer fluid during filling process
Compass – to verify true south and the collector azimuth
Flashlight – for work in dark areas
Drop light – for work in dark areas
Compressor – for filling expansion tanks and pressure testing piping
Washing machine hoses – for filling and draining the system
Garden hose – for draining tanks
Refractometer or hydrometer – for testing glycol concentration
Tire gauge – for measuring the expansion tank air bladder pressure
Lighter – for testing sensors

Tools should be inspected prior to and after use to ensure they are in proper operating condition. Tools that are not functioning properly should be removed from inventory until they have been repaired or replaced. Good tools help perform good work; bad tools can lead to injuries and poor craftsmanship. Tool inspection may include:

- Visually inspecting cords on power tools
- Checking the sharpness of tube cutters, saws, and drill bits
- Verifying inventory of consumables such as torch gas, solder, acid flux, emory cloth, and pipe thread compound
- Charging batteries for cordless tools
- Visually inspecting tool handles for wood or fiberglass splinters

When specialty tools are needed, the installer should arrange for purchase or rental. These tools may include hammer drills, core drills, excavators, concrete saws, conduit benders, and pipe clamping tools. Tool availability may have an impact on project scheduling.

6 Evaluate the Site

Upon his/her first trip to the site, an experienced installer will perform a site assessment to determine the details and tasks required to install a SWH system. During a site evaluation, the installer will envision all facets of the installation, including the equipment that will be needed; the layout of this equipment; and the labor, tools, and safety measures that will be required. When done well, the site evaluation lays the foundation for a successful project by providing appropriate expectations for the client, assuring the system meets the client's particular needs, and providing the planning information needed to run an efficient and profitable installation.

The scope of a site evaluation will depend upon the installer's specific responsibilities and the type of SWH system being installed. Purposes of the site evaluation may include:

- determining the heating loads for the system
- measuring the amount of available solar insolation
- determining appropriate layout for the system, including collector and storage tank locations, piping locations, and integration with the auxiliary heating system
- assessing the labor required for the installation
- determining the specific equipment and tools required
- preparing a safety plan for the project
- assessing the suitability of the system design for the specific site
- marketing the installation company to a potential client

6.1 Compare design to site

Any type of heating system is site-specific. For instance, a natural gas boiler is only appropriate in an area where there is an infrastructure for delivering natural gas to the site. Likewise, a responsible heating contractor wouldn't put a 50,000 BTU/hr furnace in a building with a heating demand of 150,000 BTU/hr. The same fundamentals hold true for SWH systems. Significant attention needs to be paid to the availability of energy and the demands on the system. While solar heating technologies can be efficient and cost-effective in many applications, there are situations in which a system isn't suitable for the particular site.

Figure 6-1 – Possible roof location for solar collector.

Qualified installers must understand the principles of system sizing and selection in order to effectively serve their clientele. For small residential systems, the installer may be responsible for ensuring the proper installation of a predesigned SWH package, such as an SRCC OG-300 Certified™ system. For larger residential systems and commercial applications, the installer may be responsible for installing a system that has been

Figure 6-2 – An existing water heater.

Figure 6-3 – The proposed layout for the system should be verified by the installer to ensure that the collectors are oriented properly and that shading will not be a significant issue.

If the site evaluation is performed to assist with bidding or the development of a proposal, it may be necessary to estimate the number of hours required for the installation. An experienced installer should be able to provide an accurate estimate upon completion of the site evaluation. Some installation companies may have a formula they use to assist in estimating projects that are large in scope or pose unique installation challenges.

designed by an engineer to meet the specific needs of the site. In either situation, the installer must be aware of the solar access at the site, the magnitude of water heating demands for the facility, and understand how the system will integrate with the auxiliary heating system and building structure. A quality site evaluation is fundamental to this process.

6.1.1 Verify system type is appropriate for site

An installer must be knowledgeable about the types of systems that are appropriate for the climate(s) within the company's service range. The predominate system types used in North America are DFC and IFC systems. DFC and ICS systems are very limited in their applicability and should not be used in climates that might be susceptible to freeze. IFC systems are appropriate across the entirety of North America. Drainback (DB) systems may have limitations due to the inability to properly slope piping in some buildings and in far northern climates due to severe cold weather. Antifreeze (AF) systems are less preferable in hot climates where system overheating may be common. See Section 4 for a more detailed discussion of system types and their appropriateness for particular climates.

Appropriate system selection also relies upon an accurate understanding of the water heating demands of the site during the life-cycle of the system. Many standard SWH systems are designed to last for at least twenty years. Consequently, the system size will depend upon current and future heating demands. Clients with teenagers in the home may have a drastic change in water heating demands once the children move out of the house, while a childless couple may have increased demands as their family grows. In many locales, it is important to consider the size of residence due to the turnover of the real estate market. A four-bedroom home owned by a retired couple could be sold to a family of five.

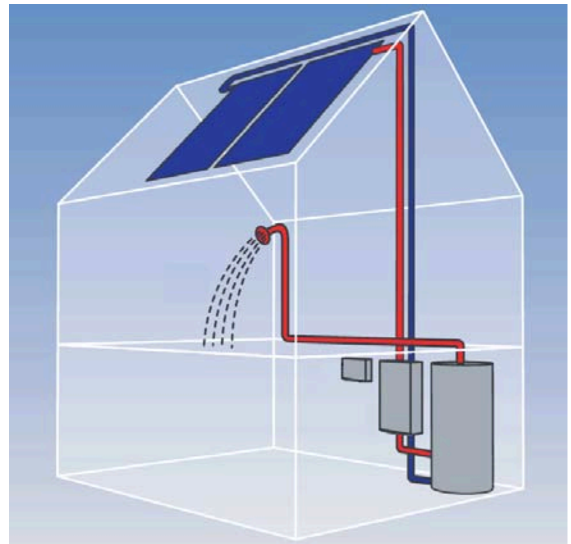


Figure 6-4 – During a site evaluation, the installer will need to inspect most of the building to identify the location of collectors, mechanical equipment, and the solar piping. (Courtesy of Schüco)

There are a number of methods for estimating the water heating loads of a residence:

Household size estimates

For systems based upon occupancy size, general estimates can be made based upon average hot water use for the household size. Below are estimates based upon household size from two sources: *Residential Energy*, a text used for training energy auditors, and *RETSCREEN*, an energy modeling software.

Household size	Residential Energy estimate (gal/day)	*RETSCREEN* estimate (gal/day)
1	25	16
2	40	32
3	50	48
4	65	63
5	75	79
6	85	95

These are rough estimates and do not account for households that are thrifty and use energy-saving measures, nor for others that may use excessive quantities of hot water due to long showers or the use of a large bathtub.

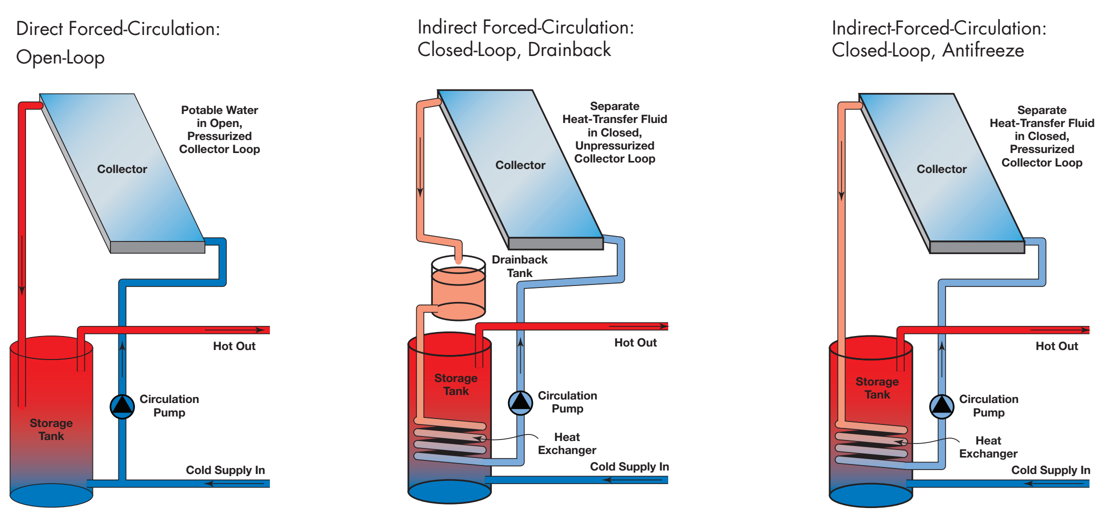


Figure 6-5a,b,c – Generalized schematics of the three most commonly installed systems in North America. (Courtesy of homepower.com)

These estimates are similar to the daily hot water use estimated by the Department of Energy and used for SRCC OG-300 performance models. The SRCC OG-300 annual performance estimates are based upon a four-person household with an average hot water use of 64.3 US gallons per day. This is a key consideration when using an SRCC OG-300 Certified™ system performance estimates to select a system for a specific site.

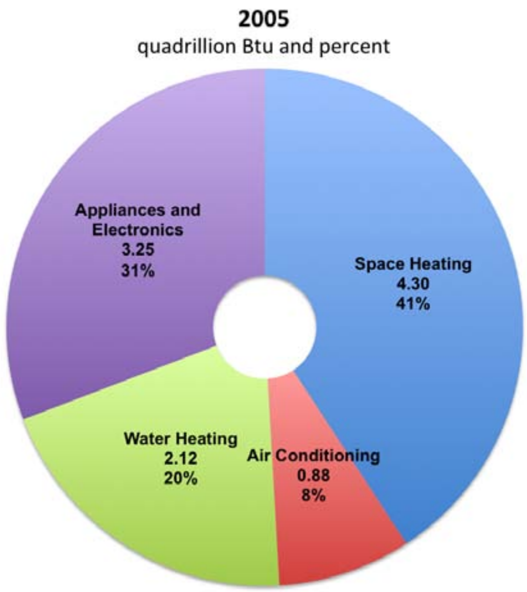


Figure 6-6 – Average U.S. household energy use for 2005.

Estimates for specific households

A designer or installer may use more complex methods to estimate hot water use, such as the technique presented in *Modeling Patterns of Hot Water Use in Households* by Lutz, et al., that account for the age of the occupants, the types of appliances in the home that use hot water, whether occupants are home during the day, and a variety of other factors.

Daily hot water use can also be estimated based on the specific behavior of the occupants. A thorough site evaluation includes a hot water use survey to assist with estimates. The Department of Energy recommends using the following average values to for such estimates:

- shower, 8 minutes = 10 U.S. gallons of hot water
- clothes washer, one load = 7 U.S. gallons of hot water
- dishwasher, one load = 6 U.S. gallons of hot water
- kitchen faucet flow = 2 U.S. gallons per minute
- bathroom faucet flow = 0.5 U.S. gallons per minute

More information about the Department of Energy's method for estimating residential hot water use can be found at http://www1.eere.energy.gov/femp/technologies/eep_waterheaters_calc.html.

Care should be taken in households that utilize modern energy efficient washing machines and low-flow fixtures, as well as in homes where the occupants minimize hot water use by taking short showers and use the cold cycles on their washing appliances. The aforementioned estimating models are often based on household data that predates efficiency advances and represents average household hot water use.

Metering

In some instances, an in-line water meter can be installed or an ultrasonic flow meter can be placed on the inlet piping to the existing water heater to get a more accurate estimate of hot water use. This method is used infrequently in residential applications due to cost and the level of accuracy that is necessary for sizing residential systems but is common in large commercial systems where hot water use is difficult to estimate by standard models.

The accuracy of water heating estimates needed for a particular project is heavily dependent upon the application. In residential systems, the standardization of collector and tank sizes establishes the level of accuracy necessary. If the initial estimate of residential hot water use is off by 20%, there will be limited impact on system overheating and system efficiency. In large commercial systems, a 20% difference in facility hot water use could have much larger impacts on the performance and cost-effectiveness of the system.

While it is the system designer's responsibility to ensure that the system is sized appropriately, a qualified installer must be aware of these issues to ensure that the system is appropriate for the site.

6.1.2 Confirm collector location, tilt, and azimuth

The amount of solar energy available to a collector array is dependent upon a variety of factors, including:

- weather and climate
- orientation of the collectors
- the site's latitude
- the presence of shading obstructions at the site

The potential effects of latitude and orientation are considered during a site evaluation as an installer assesses appropriate collector locations. A majority of SWH systems are roof-mounted, but wall- and ground-mounts may be more appropriate if the building structure is oriented unfavorably, the distance between the roof and the mechanical room would cause severe inefficiencies, or if roof-mounting would cause structural or aesthetic issues. During the site evaluation, these issues are considered by documenting the building orientation, the roof pitch, the location of the piping between the collectors and the storage tank, and any other factors that might affect collector location.

For most residential installations, the collector azimuth and tilt are driven by the properties of the building structure. Roof-mounted collectors are often mounted at the same angle as the slope of the roof and in-line with the existing structure for aesthetics.

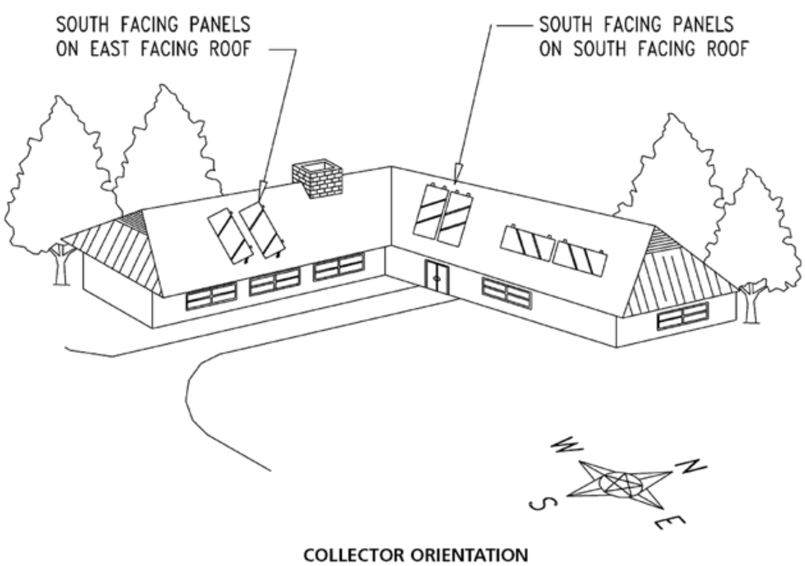


Figure 6-7a – Standard roof mounting configurations of an antifreeze system. (Courtesy of SunEarth)

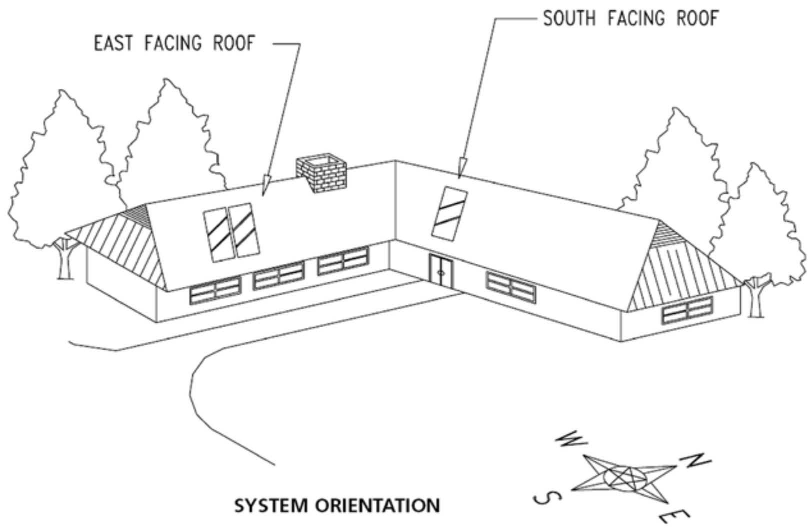


Figure 6-7b – Standard roof mounting configurations of a drainback system—note the lack of a landscape recommendation. (Courtesy of SunEarth)

Figure 6-8 – Solmetric SunEye shade analysis tool. (Courtesy of Solmetric)

6.1.3 Evaluate present and future collector shading

During a site evaluation, it is critical to determine whether trees, buildings, chimneys, dormers, or other rows of collectors will cause shading of the array and assess the impact of any such shading on the system's performance. The effect of existing obstructions can be measured using a variety of solar shade tools. These include, but are not limited to:

- Solar Pathfinder – www.solarpathfinder.com
- Solmetric SunEye – www.solmetric.com
- Wiley ASSET – www.we-llc.com
- Solmetric iPV application for iPhone and iPod – www.solmetric.com

Each of these tools uses a trace of the obstructions at a site and superimposes this shading on an appropriate sun path diagram to determine the monthly effects of shading. Solar Pathfinder also offers its Solar Pathfinder Assistant software with Thermal Plug-In, which utilizes the shade analysis results to estimate system production. With the other tools, the shading analysis results must be imported into third-party design simulation software specific to SWH applications. Installers should be familiar with these tools and their proper operation. Instruction manuals for each tool are available at the websites listed above.

Figure 6-9 – Solar Pathfinder shade analysis tool.

In order to assess shading at sites that have yet to be built or that are impractical to access for planning purposes, the SunEye can be used with an extension pole and the Pathfinder Assistant software allows the installer to take a shading measurement from the ground and adjust the results for the collector height.

On systems that require multiple rows of collectors, care must be taken to avoid or account for the effects of inter-row shading. This occurs when insufficient spacing between collector rows causes one collector bank to shade the other.

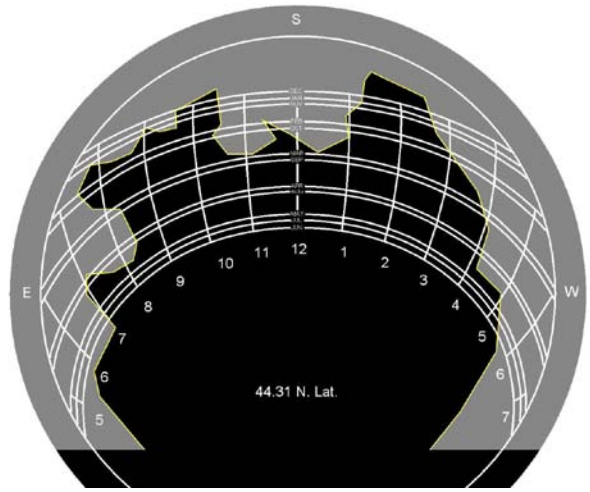


Figure 6-10 – Output from Solar Pathfinder Assistant software.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends that the minimum row spacing for commercial SWH systems should be based upon the sun's altitude angle at 10am on December 21. This spacing guarantees that the front row(s) will not shade the collectors from 10am to 2pm on winter solstice. The minimum row spacing is dependent upon the following factors:

- the length of the collectors
- the collector tilt angle
- the azimuth of the array
- the site's latitude
- the slope of the mounting surface

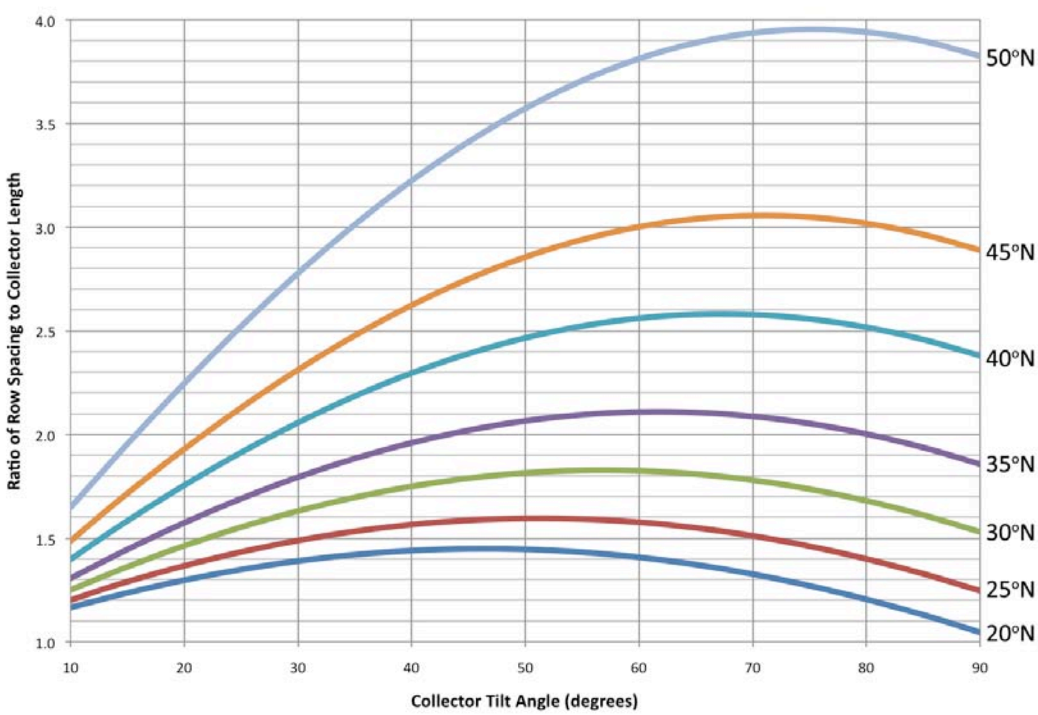


Figure 6-11 – The ratio of the required spacing between collector rows and the length of the collector can be determined using the chart to the left for collectors mounted due south at the same elevation. For a collector array with collectors mounted at a tilt angle of 40°at a site with a latitude of 35N, this ratio would be approximately 1.95. If 4'x8' collectors were mounted in portrait orientation, there would need to be approximately 15.6' of spacing between the collector rows to meet ASHRAE's recommendations for inter-row spacing.

Figure 6-11 illustrates the minimum row spacing for specific latitudes based on ASHRAE recommendations. These figures are based upon collectors that are oriented on a flat surface and oriented due south. For installations that are not oriented due south or are on a sloped surface, trigonometry or drafting software can be used to eliminate inter-row shading or to account for its effects.

6.1.4 Verify balance-of-system equipment suitability

In addition to siting the collector array, the installer should also determine the layout of the balance of the system. This includes the collector support, the solar loop piping, the storage tank, and the interconnection to the existing—or future—water heating equipment.

Solar loop piping

During the site evaluation, the installer must identify an appropriate layout for the solar loop piping in order to determine the type and length of piping and pipe insulation required, identify flashing and other methods for sealing penetrations, and determine

District Energy Solar Thermal Project

While reducing or eliminating inter-row shading is often desirable, there are instances in which it is more preferable to install collector rows closer together than ASHRAE's minimum recommendations.

One example is the District Energy Solar Thermal Project in Saint Paul, MN. This project utilizes 144 flat plate collectors that are each approximately 19.5′ (6.0m) wide and 7.5′ (2.3m) tall. The collectors were installed at a tilt angle of 45°degrees and were aligned with the roof of the Saint Paul RiverCentre, which has an azimuth of 186°. Engineers had 32′ of roof depth available for installing the collector array.

Based on ASHRAE guidelines, the system would have required a row spacing of approximately 24′ to eliminate inter-row shading for a four-hour window on December 21st. To meet these guidelines, only two rows of collectors could have been installed on the roof.
Since the system serves a district water heating system that provides heat and hot water to a majority of buildings in downtown Saint Paul,

Figure 6-12 – View of collector array for the solar thermal District Energy project. (Courtesy of District Energy St. Paul)

there is significant demand for hot water year-round. The decision was made to install three rows of collectors to maximize solar production in the available roof space. As a result, the system could utilize 50% more collector area while inter-row shading would reduce annual system production by approximately 3–4% when compared to optimal row spacing.

While the size and scope of the District Energy Solar Thermal Project is unique, their approach to dealing with shading issues is not. In residential systems, it is not uncommon to increase the size of the array or accept decreases in system performance during the winter as a result of collector shading.

More information on the District Energy Solar Thermal Project is available at www.solarsaintpaul.com.

whether chases will need to be built to conceal piping. If piping needs to be run through structural members, such as trusses or joists, the installer may need to consult the building code to avoid compromising the integrity of the structure.

Collector racking

When installing a system on an existing structure, the roofing should be inspected to verify its integrity. Since the SWH system is designed to last for decades and re-roofing often requires the removal of collectors, it is typically most economical to replace the roofing under the array prior to installation if it will require replacement during the life of the SWH system. Of course, this work must be priced into the system installation and care should be taken to avoid compromising the existing roof surrounding the collectors. Installers must be vigilant when inspecting the integrity of the roof in the vicinity of the proposed collector array; if any problems arise with the integrity of the roofing, the occupants will likely assign blame to the solar installation.

Additionally, the installer must determine how the collector will be attached to the structure (spanners, J-hooks, lag bolts) and assess the integrity of the roof structure for roof-mounted arrays. For older roofs or systems that require collectors to be installed at steep angles, this may require analysis by a structural engineer. If structural reinforcement is required, this should be noted during the site evaluation.

For ground-mount systems, the installer must consider the soil conditions on the site. Shallow bedrock and clay present unique opportunities for installing stable foundations.

Storage tank

Allocating an appropriate location for storage tanks can be difficult in both residential and commercial SWH systems due to space restrictions. These restrictions may include floor space, height clearance, and the width of access doors to the installation site. The installer must verify these clearances to ensure the system can be installed as specified or to assist with proper tank selection.

Interconnection to auxiliary heating equipment

Proper integration between the SWH system and the auxiliary heater(s) is needed to ensure that the SWH system produces as much usable energy as possible and to minimize the energy requirements of auxiliary heating equipment. Poor integration of the systems can make even the most robust SWH system ineffectual. A qualified installer must be knowledgeable of conventional water heating systems and have the ability to interpret construction plans and evaluate as-built heating systems to determine the appropriate means for connecting the SWH system. During a site evaluation, an existing schematic should be verified or a new one should be developed if not already available.

Installing Solar on Commercial Roofs

When evaluating a commercial roof for a large solar system, the quality of the existing roof becomes a more significant issue. In some cases, if the building owner is not interested in repairing the roof (roof repair costs are not eligible for state or federal solar incentives), it may be necessary for the contractor to walk away from a project. In some circumstances, the existing roof quality may be so poor that the mere act of carrying heavy solar collectors onto the roof surface may damage the roof beyond repair. This will almost certainly become the responsibility of the contractor, unless the building owner is willing to sign a legal waiver exempting the contractor from responsibility. In most, if not all cases with larger systems on commercial roofs, it is advisable to secure the services of a professional roofing contractor to ensure that all of the roof penetrations and attachment points are properly flashed and sealed. In this way, the roofing subcontractor assumes responsibility for the roof integrity, rather than the installing contractor.

- Ed Murray, Aztec Solar

6.2 Inspect and document existing site conditions

Another purpose of the site evaluation is to perform a risk assessment. These risks may include:

- deficiencies with existing equipment or building structure. If an installer notices that existing hot water piping is uninsulated, that the auxiliary heater or roofing will need to be replaced in the near-term, or that the roof is structurally unsound, it should be documented and communicated to the owner.
- safety hazards that were not identified during the initial construction plan review. Hazards such as overhead power lines, the presence of vehicular or pedestrian traffic adjacent to the worksite, or unstable ground where ladders or scaffolding might be used should be noted and discussed with other installers during daily safety meetings.
- liability risks, such as equipment or structural damage in areas where installation tasks will be performed. Such damage should be documented and reported in accordance with company policy.
- additional work that is outside of the contract scope. If piping will need to be concealed in a chase or an electrician will be needed to relocate or install a service box to power the controller, this should be noted and resolved.

6.3 Ensure code compliance

The lawful installation of SWH systems is governed by building codes and local requirements for installer credentialing. These regulations have little uniformity across the United States. This is in contrast to Canada, which utilizes fairly standardized national codes that may have some local variance.

6.3.1 Codes

Local codes relevant to SWH installations may include the following:

- *Building codes* address the structural considerations of SWH systems, including: attachment to the building structure, the substructure of ground mounts, and appropriate piping penetrations. The major building codes in the United States are the *International Building Code* (IBC) and the *Uniform Building Code* (UBC). In Canada, many provinces have their own building codes; most are based on the *National Building Code*.
- *Plumbing codes* are requirements for the portion of a SWH installation that impacts a facility's potable water system. The purpose of the code is to eliminate hazards associated with temperature and pressure, to ensure system durability, and to protect the potable water system from contamination by foreign substances. The two dominant plumbing codes in the U.S. are the *Uniform Plumbing Code* (UPC), developed by the International Association of Plumbing and Mechanical Officials (IAPMO), and the *International Plumbing Code* (IPC), by the International Code Council (ICC). Figure 6-13 illustrates the plumbing codes used by jurisdictions in the United States. Most provinces in Canada model their plumbing codes on the *National Plumbing Code* (NPC), published by the National Research Council of Canada.

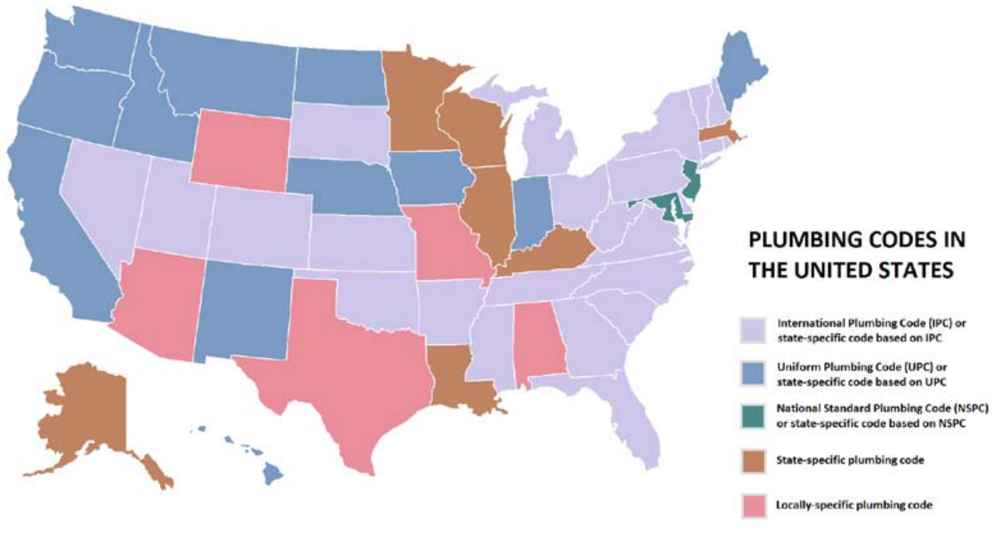


Figure 6-13– Plumbing code adoption in the U.S. (Courtesy of NYSERDA)

- *Mechanical codes* typically relate to the collector loop side of the heat exchanger in indirect systems. Like plumbing codes, mechanical codes address hazards associated with temperature and pressure, the integrity and durability of the mechanical installation, and the protection of the potable water system. Additionally, these codes may address requirements pertaining to the installation of solar collectors. IAPMO's *Uniform Mechanical Code* (UMC) and ICC's *International Mechanical Code* (IMC) are the two dominant mechanical codes in the United States. Additionally, IAPMO has produced the *Uniform Solar Energy Cod*e (USEC), which specifies the mechanical and plumbing requirements of SWH systems. USEC is one of the primary references for the NABCEP Solar Heating Installer Exam. In Canada, The Canadian Standards Association has an installation code for packaged SWH systems: CSA *Installation Standard F383*. F383 applies to the installation of pre-packaged systems that meet the CSA F379 Manufacturing Standard. The F383 Standard is similar to the SRCC Operating Guidelines 300 (OG300) in the United States.

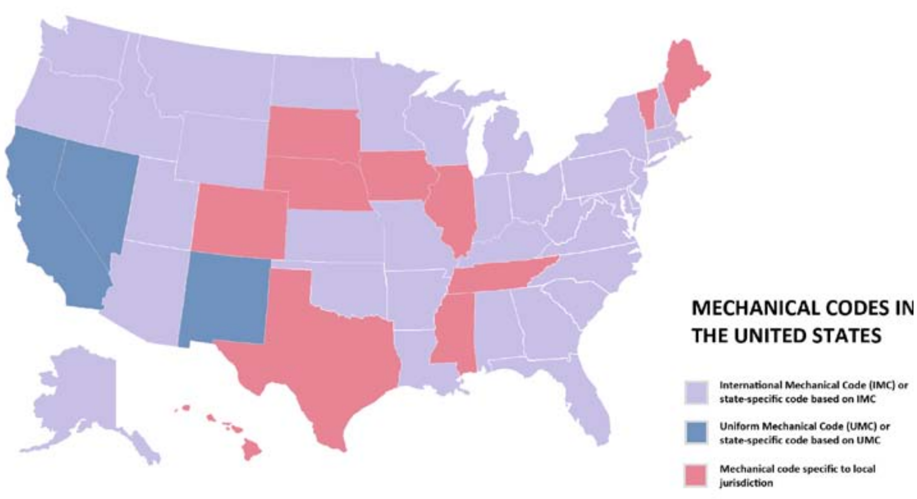


Figure 6-14 – Mechanical code adoption in the U.S.

- *Electrical codes* address the wiring of photovoltaic modules, controls, pumps, and motorized valves in the system. The predominate electrical code in the U.S. is the *National Electrical Code* (NEC) by the National Fire Protection Association (NFPA). The *Canadian Electrical Code* (CEC), published by the Canadian Standards Association (CSA), is commonly used in Canada. The CEC is also referred to as CSA Standard C22.1.
- *Energy codes* are requirements for addressing the efficiency of a SWH system. These codes often address insulation levels for piping and storage tanks, proper sealing of penetrations, heat traps, and the set temperature for mixing valves and auxiliary water heating equipment. The dominant energy code in the United States is the *International Energy Conservation Code* (IECC) by ICC.

Figure 6-15 – Plumbing, mechanical, electrical, conservation and solar code books used in the U.S.

It is critical that the installer identifies the Authority Having Jurisdiction (AHJ) and has a thorough knowledge of the applicable codes while preparing for the project. Requirements may vary greatly by jurisdiction; a system that is code-compliant in one town may have major infractions in a neighboring jurisdiction. For example, in jurisdictions that have adopted the IPC, it is perfectly acceptable to install an indirect system with a single-wall heat exchanger and a pressure relief valve rated at 87psi (6 bar). The same system installed in a jurisdiction governed by the UPC would require the use of a double-wall heat exchanger or a pressure relief valve that is rated at 30psi maximum.

Another resource for understanding the particular requirements of certain jurisdictions is the New York State Energy and Research Development Authority's (NYSERDA) *Field Inspection Manual for Solar Heating Systems*. While this document is specific to building codes in New York State, these codes are based upon the International Codes and NEC and are therefore applicable to many other jurisdictions in the United States.

6.3.2 Permitting

Like codes, permitting and licensure requirements vary greatly by jurisdiction. All new SWH systems that heat domestic water usually require a plumbing permit for installing the potable tie-in. Some jurisdictions may require building, mechanical, and/or electrical permits depending upon the application. It is important that the installer obtains all required permits prior to the installation of the system.

6.3.3 Homeowner Association approval

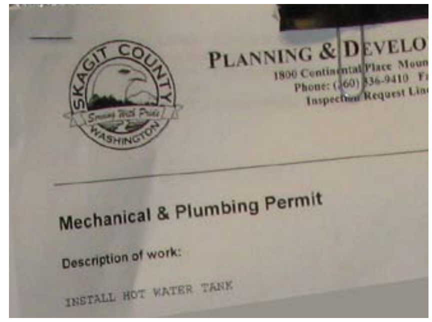


Figure 6-16 – Permits are usually required for SWH installations.

Increasingly, additional approval for a SWH system is required when the system is installed in a community governed by a Homeowner Association (HOA). HOAs are sometimes established during the creation of new residential housing developments. When a home is sold within the jurisdiction of a HOA, development is subject to certain conditions, covenants, and restrictions (CC&Rs).

Some HOAs adopt restrictive covenants that apply to the installation of solar systems. In these jurisdictions an application for the installation may be required by the HOA, sometimes through the Architectural Committee. It is in the installer's best interest to submit all requested diagrams, pictures, product information etc., so the HOA cannot reject the application on the grounds that it is incomplete. The HOA will evaluate the submittal and may suggest reasonable changes to that original submittal.

Prior approval is critical. If the installer does not seek and receive approval prior to installation, the Homeowner Association may have the right to require that the system be removed at the expense of the installer or the homeowner. More information on this topic can be found in *Bringing Solar Energy to the Planned Community: A Handbook on Rooftop Solar Systems and Private Land Use Restrictions* available at http://www.consumerenergycenter.org/erprebate/documents/CC+Rs_and_solar_rights.pdf.

6.3.4 Licensure

The AHJ may require specific credentials, such as a plumbing or general contractor license, for obtaining the necessary permits. Additionally, local regulations will detail the requirements for individuals working on the plumbing, mechanical, and electrical portions of a system. All SWH installation work must satisfy licensure requirements.

Some incentive programs may require installer certification in order for an installation to qualify for a rebate or tax credit. Certification differs from licensure—while a license is a legal requirement to satisfy a government agency, a certification is typically a voluntary credential that proves a level of proficiency in a trade or profession. Often installer certification is not required to legally install a system, but rather to be eligible for local incentive programs.

6.4 Ensure OSHA compliance

There are several tasks involved in a SWH installation that may require larger work crews—namely transporting and installing collectors on a roof, and installing solar storage tanks. When possible, lifting equipment should be used to assist with these tasks. When used properly, lifts mitigate some of the risk inherent in transporting equipment that is heavy or must be lifted to roofs. All such installation requirements should be assessed during the site evaluation.

See Section 8 for more details regarding proper safety practices.

7 Plan System Installation

Positioning of the collector array, the system piping, and the storage tank(s) are important considerations that must be determined during the site evaluation and design process to ensure that the system can be installed as proposed. Site limitations, such as a confined mechanical room, limited roof space, narrow door widths, or the need to construct mechanical chases for concealing system piping may have significant impacts on component selection. For example, most solar storage tanks are too tall to be installed in a crawl space. The failure to pre-identify such limitations or to select appropriate locations for solar heating equipment prior to system installation can lead to construction delays and cost overruns.

Many of the details of the installation should be determined prior to arrival at the site. Once at the site, the lead installer must review these details and ensure that the system can be installed per design specifications. This process will often require the installer to resolve discrepancies between the construction plans and the site or to develop solutions for portions of the installation that are not specifically detailed in the plans. This is often the case in retrofit installations where concealed work is required. Frequently, the plans must be modified as the installation progresses.

Unpleasant surprises

The importance of a thorough site assessment is rarely more evident than when a crew arrives at a jobsite and discovers that major modifications will be needed or that the system can't be installed at all. Here are a few unpleasant discoveries that can be avoided with attention to detail:

- Roof is barely capable of holding itself up and the shingles are fifteen years old.
- Tall conifers are shading the collector location on a summer day and they're located on the neighbor's side of the property line.
- Piping runs cannot be sloped continuously for a drainback system.
- Storage tank won't fit through the front door.
- Existing water heater is in the attic or a bedroom closet.
- The only place to put the collectors is on a slate roof.
- Occupants are renting their home.
- Occupants have little or no taxable income.
- Client asks, "When can the gas/electric meter be taken out?"
- An uncovered pool in a room with northern glass and the ventilator is dumping air outside when it's below freezing.
- Existing, uninsulated hot water recirculation loop under the slab to a bathroom 50 feet away.
- Gated community with nothing on any other roofs.
- Homeowner's association was not contacted for approval.
- Customer was not told of the location of the panels and/or tank.
- Panels do not fit in the designated roof area.
- Valves do not work to shut off the water inlet.
- There is no electricity for the controls and pumps near the tank location.
- Customer was not told to have the work area cleared out.
- There is no attic access or there are vaulted ceilings.

7.1 Layout collector(s) installation

For roof-mounted arrays, the attachment points must be located and marked on the roof surface. Locating the centerline of roof rafters or trusses is important for maintaining the integrity of the roof and the collector attachment to the building. There are several methods for locating these attachment points:

- *Drilling from below* – When attaching directly to a rafter or truss, a quick and reliable method is to drill a 1/8" (3 mm) pilot hole up from the attic directly adjacent to the structural member. Consideration should be made to locate this pilot hole near the proposed location of the collector rack. It is advantageous to have an installer above the roof to help identify an appropriate drilling location and to mark the location of the structural member once the hole has been drilled. Care must be taken on metal roofs to ensure that the drilling location does not fall on a seam or rib.
- *Drilling from above* – If a spanner or blocking is used to connect to the structure, the pilot hole can be drilled from above the roof surface. As with drilling from below, it is helpful to have one person on either side of the roof during this process. Once the pilot hole has been drilled, the installer below the roof can position the spanner or blocking at the appropriate location.
- *Using reference objects* – Plumbing vents, chimneys, or other objects that penetrate the roof surface can be used to identify structural members, as well. By measuring the offset distance between a roof rafter and a plumbing vent, an installer can identify the rafter from above the roof. In buildings with cathedral ceilings or inaccessible attic spaces, locating nails at the eaves where the fascia boards are fastened to the ends of rafters and the use of stud finders on the interior ceiling may assist with locating structural members.
- *Other methods* – Roof structural members can sometimes be located using technological means such as specialized stud finders or infrared cameras. Some installers are proficient at finding trusses and rafters by tapping a hammer on the rooftop and listening for changes in the roof vibration. A qualified installer uses careful consideration when locating structural members since any hole in the roof surface threatens the integrity of the entire roof.

Figure 7-1 – Drilling a pilot hole from below to locate roof rafters.

When installing collectors on shingled roofs, pilot holes can be drilled underneath the upper course of shingles to verify the location of structural members. Any pilot hole that misses a structural member should be filled and sealed in accordance with the roofing manufacturer's recommendations.

Once the roof attachment locations have been identified, the mounting hardware should be installed. The sealant, hardware, and tools should be loaded on the roof and secured in canvas buckets, work bags, or other suitable containers that will help prevent equipment and tools from sliding or rolling off the roof.

Structural modifications are not within the scope of work for a solar installer unless a qualified person is performing or supervising the work. Trusses, rafters, and joists should not be modified unless approved by an engineer or the local building inspector. General building regulations and rules may exist even for minor structural modifications, such as drilling holes for wiring and piping. Spanners and blocking as described in Section 8 are structural additions, not modifications.

7.2 Plan solar loop piping

To maximize system efficiency, it is preferable to locate the collector loop piping in a direct line between the collectors and the location of the solar storage tank. In practice, this can be difficult due to the layout of the building. Horizontal piping runs located inside of the structure are typically routed through unfinished spaces such as attics or basements or above drop ceilings. Vertical runs are often run through closets or in the corner of rooms, where they can later be concealed in a chase. In new construction, piping may be concealed within wall or floor cavities.

Building penetrations are necessary to pipe the collectors to the storage tank and/or other mechanical equipment. This often involves drilling and cutting into concealed spaces where existing wiring and piping may be present. A small light and mirror can assist an installer in determining if a location is suitable for a larger penetration. Boroscopes, which utilize a camera probe with an inspection display, are valuable in detecting concealed obstructions. The probes can be inserted in roofs and walls through drilled holes as small as ½" inch (13mm).

Figure 7-2 – A camera-type boroscope and a higher-end stud finder can help with installation planning.

Residential flat roof installations require special consideration. Penetrations are typically made into a concealed space between the roof joists. Joists will often change directions in flat roof construction and this may not be detectable from the roof or the ceiling below. Where roof joists can be identified from below, an installer can often measure the distance from existing plumbing and mechanical vents to the joists on the underside of the roof in order to locate the joists from the roof surface. A goal with all installations is to place the collectors as close as possible to the tank location—this is particularly true for flat roof installations. Otherwise, long piping runs may be required on the roof.

Piping layout is critical and unforgiving with Drainback systems. Some building layouts are unsuitable for drainback systems due to the inability to route piping in such a way that a continuous piping slope of at least ¼" per foot (2 mm per meter) can be maintained. Minimizing the length of piping and the number of fittings in all active systems can help minimize pumping energy by limiting frictional head loss.

Figure 7-3 – It is often beneficial to locate the pump station and controls near the storage tank.

7.3 Plan mechanical room/area

When installing a solar preheat system that utilizes a separate solar storage tank, the solar preheat tank should be installed as close as possible to the auxiliary water heater to minimize the piping required between the two tanks. In these systems cold water is plumbed into the solar storage tank, and the hot outlet of the storage tank is then directed to the cold inlet of the auxiliary heater. Piping between the two tanks reduces system efficiency, as water in that piping will lose heat between the solar storage tank and the auxiliary heater during times of no flow.

In a single tank system, the solar storage tank is plumbed like any traditional tank-type water heater. In a retrofit situation, the hot, cold, and relief piping may need to be modified to accommodate the new solar tank, which is often larger than the existing heater. If the new tank replaces a combustion appliance, the existing venting should be terminated in accordance with local regulations. Dampers or vents that were required for providing makeup air for the removed combustion appliance may be sealed or removed if they do not supply another combustion appliance in the room.

The tie-in to the potable water system will require a temporary interruption of the hot water service. It may also require shutting off the entire building's cold water supply if a shutoff valve is missing or is leaking. The occupant(s) of the building should be informed of any interruption and given an approximate time and duration of the inconvenience.

The positioning of the balance of system (BOS) components, such as pumps, valves, gauges, and controls, is typically adjacent to the solar storage tank location. Wall space in garages and utility/mechanical rooms are often used for these components. The location of piping to and from the collector array and the tank location should dictate the logical placement of the other components.

8 Install System

System installation must be carried out in accordance with specifications. For residential and small commercial SRCC OG-300 Certified™ solar water heating systems, these specifications are provided by the system manufacturer. For small systems that are not SRCC OG-300 Certified and larger systems that are outside the scope of the SRCC OG-300 Certification program, specifications are often provided by an engineer or designer. It is critical to ensure that all components are installed per manufacturer's specifications. Specifications and installation instructions are typically included with each component.

The size of the work crew required for the installation of an SWH system will depend upon the size and scope of the project. Small residential systems are a job for a crew of two or more. While many facets of a residential installation can be completed by a single installer, two or more people are often needed for transporting collectors to the roof, moving storage tanks, and minimizing installation time. Commercial, industrial, and municipal systems may require larger crews due to the scale of work and tighter work schedules.

Though a single person can handle evacuated tube and pool collectors, care must be taken to ensure that the installation is performed safely. OSHA requires that installers "use at least one hand to grasp the ladder when progressing up and/or down the ladder" (29 CFR 1926.1053(b)(21)). It is often most practical to have at least two installers involved in transporting collectors to the roof in order to adhere to these safety regulations. Collector arrays mounted near the ground, including ground-mounted or some wall-mounted arrays, may provide more flexibility in work crew size due to easier accessibility.

Other work areas will include mechanical rooms, attics, occupied rooms, garages, and basements. The specific work areas and safety risks associated with working in these areas should be identified during the initial project risk assessment. Once on site, the installer must review the safety plan and the site to verify proper adherence to OSHA regulations.

Note: This section includes all of the tasks given in Part D of the Solar Heating Installer Job Task Analysis, however the material in this guide is not necessarily presented in the same order. The task and subtask ordering in this guide reflects the order that work most often progresses on a jobsite.

Figure 8-1 – Roof fall protection kit in a bucket.

8.1 Implement site safety plan

Site safety plans should be implemented on arrival at any jobsite. All workers should be able to:

- demonstrate safe and accepted practices and the use of proper safety equipment
- identify appropriate codes and standards concerning installation, operation, and maintenance of solar heating systems and equipment
- identify physical personnel safety hazards associated with solar heating installations (roof work, attic temperature, electrical work, heavy lifting, etc.)

- identify environmental hazards associated with solar heating installations through demonstrated awareness of pertinent Material Safety Data Sheets and other appropriate documents
- determine components that require identification tags and/or labels (per system certification guidelines)

8.1.1 OSHA regulations

The site safety plan should ensure that all work is done in accordance with construction standards established by the Occupational Safety and Health Administration (OSHA). These regulations are covered in Chapter 29 of the U.S. Code of Federal Regulations, Part 1926 (29 CFR 1926) – Safety and Health Regulations for Construction. These federal regulations detail the minimum safety standards for employees engaged in construction activities. OSHA standards are adopted and enforced on a state-by-state basis. To ensure compliance and to protect workers from injuries or death, employers and installers must be familiar with the specific requirements of the jurisdiction within which work is performed.

8.1.2 OSHA 10 and 30 cards

OSHA has two basic safety certifications for workers and supervisors. The programs are directed at different segments of industry—solar installers will benefit most from the onsite construction courses. OSHA construction industry courses provide training for workers and employers on the recognition, avoidance, and prevention of safety and health hazards in workplaces. The courses also provide information regarding workers' rights, employer responsibilities, and how to file a complaint. Workers can attend 10-hour or 30-hour classes delivered by OSHA-authorized trainers (available online). The 10-hour class is intended for entry-level workers, while the 30-hour class is directed more at supervisors or workers with some safety responsibility. The program is voluntary, but is customarily required for many government and commercial jobs and worker certification programs.

8.1.3 Identify unsafe practices

Working safely with SWH systems requires a fundamental understanding of plumbing and mechanical systems, as well as common sense. The following basic concepts are fundamental to workplace safety:

- When the workplace is cluttered with tools and equipment, the possibility of tripping over something is significantly increased.
- If that work space is a roof, the possibility of falling off the roof is significantly increased.
- When tools are left lying out on a roof, the chance of them falling off the roof and injuring someone below is increased.
- Tools and equipment should be used for the purpose for which they were designed.
- When working on a rooftop in bright sunshine, the chance of sunburn is increased. The use of sunscreen and proper hydration is appropriate.
- Jobsite accidents are more likely when an installer is rushing to perform a task or is not focused on the work at hand.

While careful adherence to State and Federal Safety Regulations is the law, another important factor comes into play with safety: contractor liability insurance. Virtually all insurers will require the insured to strictly observe workplace safety procedures as a condition of coverage. Liability insurance is expensive—by adhering to a strict regimen of workplace safety policies and procedures, insurers will be able to offer the best possible policy pricing. And should a workplace injury occur, follow-up investigation by the insurance company will focus directly on the presence or absence of workplace safety measures. The price of noncompliance will likely be a legacy of higher insurance premiums, or worse, harder-to-find insurance.

- Les Nelson

Figure 8-2 – Contents of a roof fall protection kit, including a lanyard, rope grab, and safety rope; a safety harness and a ridge anchor are typically included and not shown.

Figure 8-3 – Solar installers wearing proper fall protection, including safety harnesses, lanyards, rope grabs, and safety ropes. (Courtesy of Shawn Schreiner)

Figure 8-4 – Temporary guardrail system for low-slope roof installations. (Courtesy of ToolUp)

Unsafe work practices put people at risk, and it is the responsibility of an installer to follow the company's safety plan and ensure other co-workers do the same. A colleague who works on a roof without proper fall protection not only risks his/her own life, but may also injure others and put the company at risk. A responsible installer ensures that his/her entire work crew adheres to appropriate safety practices.

More common hazards exist as well. These include nicks, cuts, and burns from sharp or hot components. Gloves should be used when handling anything that might be sharp, hot, or rough, or that might splinter. There is always the possibility of dropping tools or materials on others or on sensitive equipment or materials. The use of torches for soldering and brazing creates hazards for fire or severe burns. When an SWH system is being assembled or serviced, personnel also face the risk of thermal burns from high-temperature fluids or steam.

Unexpected situations on the jobsite cannot be overlooked. When working in a potentially dangerous location, it is wise to keep a conversation going so workers know exactly where everyone is located. Good communication can alleviate surprises, such as bumping into another worker on the roof, which can cause a loss of balance and result in a serious fall.

8.1.4 Safety in attics

Solar heating installations often involve work in attic spaces, which may require the use of a breathing mask, eye protection, and clothing that will protect skin from insulation.

Knowledge of attic floor construction will help identify locations where it is safe to support the weight of a person without risk of falling through the ceiling. It is essential when traversing an attic to support one's weight by stepping only on the ceiling joists or trusses; the ceiling material itself will not support the weight of a worker. 1" x 2" furring strips for holding rock lath or plaster board may be present, but these will not support the full weight of a worker. Note that these strips may be confused with joists or trusses when they are covered with insulation. In many cases, planking or boards may be laid on top of the joists temporarily to support the weight of workers, allowing for easier movement around the attic space.

Because attics can often be dark, confined spaces, it is important to be properly prepared prior to attic work. It is important to plan an exit route in case of a fire or other emergency. Droplights may be needed for adequate lighting. Finally, before entering an attic one should be sure to drink adequate water for personal hydration, particularly if the attic is hot and if it is expected that the attic work will take more than fifteen minutes.

While working in the attic, an installer must take care with tools and surrounding hazards. To avoid damaging the ceiling below the attic, care should be taken not to drop or lay heavy tools onto the ceiling material. Care should be exercised when climbing around wires, piping, air conditioning ductwork, and any other projections, such as recessed lighting fixtures, which may be hot. Wires, pipes, etc., present a tripping or choking hazard to the worker. Special care must be made to avoid crushing air conditioning ductwork or damaging existing electrical wiring. Additionally, the installer must exercise caution to avoid lacerations or puncture wounds from nails protruding from the underside of the roofing surface.

8.2 Install solar collectors

Solar collectors for domestic water heating (DWH) are commonly mounted on roofs, but may also be wall- or ground-mounted. Roofs are usually less susceptible to shading from trees and buildings and provide a support structure for the collector array. In the case of wall-mounted collectors, the walls themselves are used for structural support; these installations may have limitations due to the wall orientation, the presence of obstructions that may shade the array, or aesthetic concerns. Ground-mounted arrays can be effective in specific applications but can be cost-prohibitive due to the need for construction of a separate support structure for the collectors, as well as the challenges associated with trenching and burying the collector loop piping and insulation.

The system type may have an impact on appropriate collector location. Roof-mounted arrays are usually the best option for Drainback systems due to the need for piping to be sloped towards the storage tank. This is often difficult to accomplish with ground-mounted arrays. Large systems may require ground-mounting if there isn't sufficient area on the roof for the collector array. Wall-mounted collectors may be appropriate for buildings with steep, sloped roofs that face east and west.

Fire extinguishers

A proper fire extinguisher should be included with any soldering bucket or kit. Fire extinguishers are rated for the type of fire they are designed to extinguish. There are four classes of fire as defined by the National Fire Prevention Association (NFPA).

Fire extinguisher models are available for single classes, or may be capable of use on multiple classes. Because the biggest fire risks during installation of a SWH system are the ignition of ordinary building materials and electrical fires, installers should use a fire extinguisher that is rated for Class A and Class C fires.

Fire class	Symbol	Picture	Description
Class A	A		Ordinary combustibles including wood, paper, cloth, and other ordinary materials
Class B	B		Flammable liquids and gases
Class C	C		Electrical equipment
Class D	D		Combustible metals
Class K	none		Cooking fires

Collectors may be installed with tilt rack sets to improve collector orientation. These kits may be supplied by the collector manufacturer or can be assembled on site with commonly available materials.

8.2.1 Install safety equipment

In the United States, falls are the leading cause of workplace fatalities, with 150–200 workers killed each year and nearly 10,000 injured. Installers must remain vigilant when working from ladders and elevated surfaces to minimize the risk associated with such work.

Prior to any roof work, all appropriate fall protection must be installed. OSHA requires fall protection for any work performed more than six (6) feet above an adjacent level. Standard fall protection systems used when installing collectors on steep roofs include personal fall arrest systems, which are comprised of an appropriate roof anchor and safety harness, and guardrail systems. OSHA defines a "steep roof" as any roof with a slope greater than 4 in 12 (approximately 18°–20°). Work on "low-slope roofs" (roofs with a slope of 4 in 12 or less) may include warning line systems, safety net systems, guardrail systems, or personal fall arrest systems. Specific regulations relating to appropriate fall protection are contained in 29 CFR 1926.502.

Care must also be taken to assure that ladders are used properly. Extension ladders should be secured at top and bottom and must extend above the roof surface by a minimum distance of thirty-six inches. If the ladder is not long enough to meet this extension requirement, the top of the ladder must be secured and a grab line must be installed to provide a safe transition for workers getting onto or off of the ladder. The ladder must have the appropriate duty rating for the work being performed and must be angled at a slope of 4:1 (roughly 75°).

Like all safety equipment, ladders should be inspected for defects prior to use. If any signs of damage or defects are present, such as a missing rung, damaged side rail, or broken foot, the ladder must be marked as defective and removed from service immediately.

In addition to fall protection practices, it is important to ensure that tools and equipment are secured on the roof. If an object is dropped from overhead, anyone below is subject to injury. Typical means for securing tools and equipment include the use of roof workbags and buckets that are either tied off or supported by staging. The use of these organizers can also minimize cluttering the roof, which leads to an unsafe worksite.

Other safety equipment may include scaffolding, hard hats, and other personal protective equipment (PPE).

8.2.2 Install mounting hardware

Mounting hardware will vary based on the roof type and the orientation, location, and type of collectors. Much of this equipment will be provided by the manufacturer, but

Figure 8-5 – Proprietary flat plate collector mounting rack. (Courtesy of Heliodyne)

there are a number of details that are the responsibility of the installer. Proper collector mounting requires significant knowledge about general building construction and common roofing practices.

Figure 8-6 – Another style of flat plate collector mounting hardware. (Courtesy of Solar Skies, LLC)

8.2.2a Roof-mounted installation

Factory mount sets for roof installations typically come in two types: flush- or rack-mounted. Flush-mounting refers to collectors that are installed at the same tilt angle as the pitch of the roof. The most common method of flush-mounting is to use standoffs, which elevate the collector above the surface of the roof. Another style of flush-mounting utilizes collectors that are specifically designed to be installed on the roof sheathing and flashed into the roof surface. When collectors are installed at an angle steeper than the roof surface, a rack-mount is used. For flat plate collectors, these racks typically incorporate cut-to-length or adjustable legs that attach either directly to the collector frame or to an extruded channel support that attaches to the collector frame. The attachment devices for flat plate collectors are commonly provided by the collector manufacturer specifically for their own products—they may consist of a proprietary clamp that attaches to a groove in the collector casing, self-tapping screws that attach to the collector frame, or another specially-designed fastener system. When using self-tapping screws, structural loads must be considered and care should be taken that the screw does not penetrate any farther than necessary to avoid contact with collector piping or glass. Evacuated tube collectors commonly utilize stainless steel racks. Unlike flat plate collectors, evacuated tube collectors are not self-supporting and require a racking frame for both flush-mount and rack-mount installations.

Most collector manufacturers offer proprietary racking systems that are specifically designed for use with their collectors. These racks have been engineered to support the collector under specific design conditions, including severe wind loading and exposure to the elements. An installer must ensure that the collector racking is installed in accordance

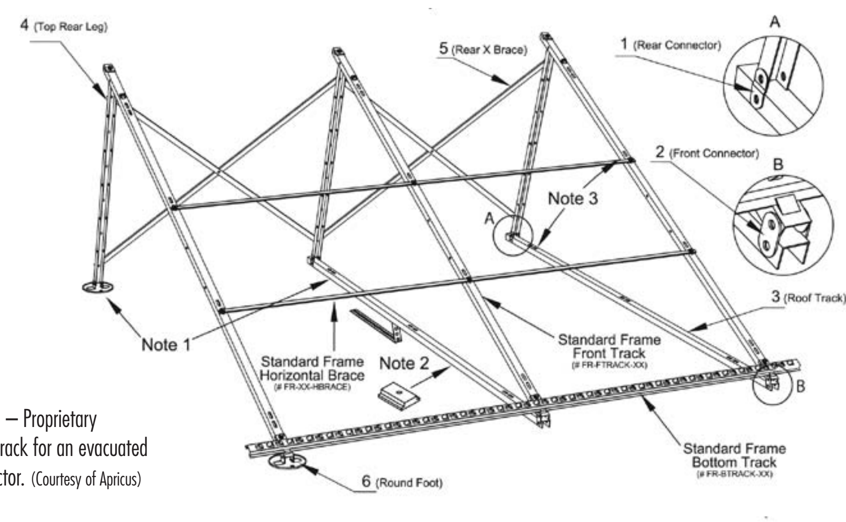


Figure 8-7 – Proprietary mounting rack for an evacuated tube collector. (Courtesy of Apricus)

with the manufacturer's specifications and is appropriate for the application. Modifying manufactured racks or building custom collector racks increases an installer's liability and should be done in collaboration with qualified personnel, such as an engineer. In certain jurisdictions, building inspectors may require wind loading data from an engineer or collector manufacturer in the permitting process.

Racking materials are selected based on their strength and corrosion resistance. Most racks are constructed from stainless steel or aluminum. While designs vary by manufacturer, standard kits often utilize sections of channel, angle, or tubing (square or round) that are joined together with stainless steel hardware. Aluminum and stainless steel are compatible with one another, unlike other dissimilar metals that may cause galvanic corrosion when in contact with one another. When using other materials, the installer must be aware of galvanic compatibility and the material's ability to withstand corrosion due to the surrounding climate. Installers in humid, rainy, or coastal areas must be especially vigilant. In desert climates with low humidity, painted angle iron can be used for collector racking.

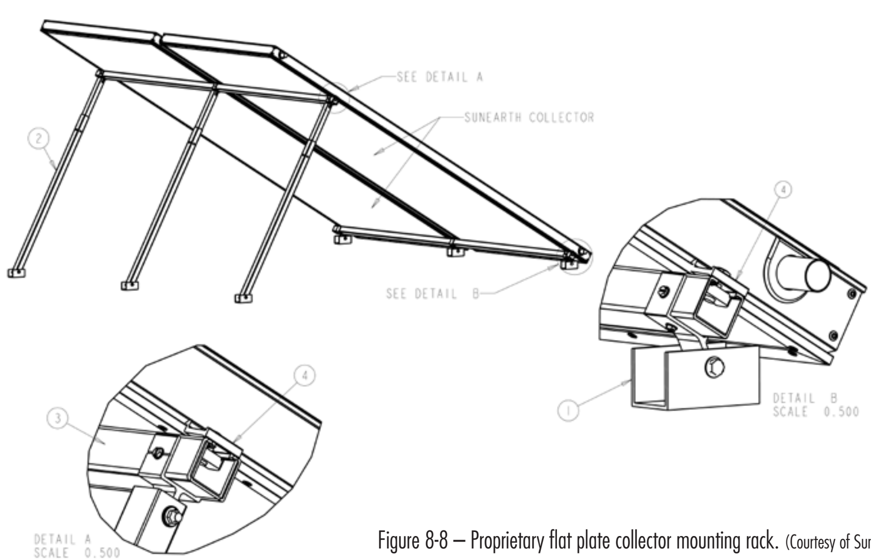


Figure 8-8 – Proprietary flat plate collector mounting rack. (Courtesy of SunEarth)

Securing SWH collectors requires attaching the racks to structural members of the roof—the joists, rafters, or trusses. Racks fastened solely to the roof decking will not withstand heavy winds. Some local codes require that collectors are connected to the structural members with a J-bolt or spanner. A J-bolt wraps around the structural member, penetrates the roof, and is bolted to the mount set. Spanners are constructed of dimensional lumber or structural metal that are attached beneath or between two structural members in the attic. Long bolts or all-thread rod are run through the spanner and the roof and bolted to the mounts. Spanners are especially useful when the collector rack does not align with the roof structural members.

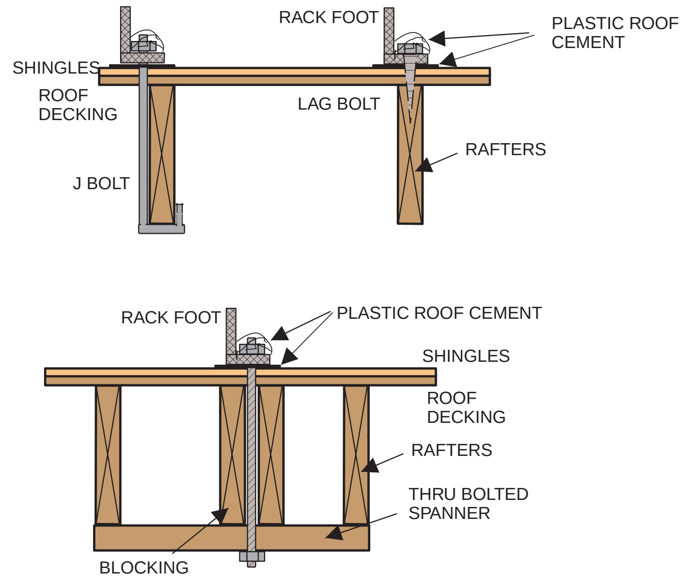


Figure 8-9 – Details for spanner, lag screw, and J-bolt mounting.

Lag screws are commonly used for connecting the collector rack to the roof structure. The lag screws should be placed in the center of the structural member to ensure proper attachment and to keep the structural member from splitting. Splitting can also be alleviated by drilling a pilot hole that is 50–75% of the screw diameter. The quantity and size of lag screws required at each attachment point depends upon the loads on the collector and the geometry of the collector rack. For most tilt rack configurations, uplift forces from wind will cause the most critical loads to occur at the rear feet of the rack. The collector manufacturer can often provide assistance in determining these loads. An engineer may be required by the AHJ depending upon the size and scope of the installation. For redundancy, a minimum of two lag screws should be used at each foot of a tilt rack; this protects the foot from prying action and provides an additional factor of safety.

Wind loads will subject lag screws to withdrawal, which is the tendency for the screw to be pulled out of the structural member. The threads of the lag screw must be embedded sufficiently to withstand this force. The required embedment depth depends upon the size of the screw and the species of wood into which it is screwed. Figure 8-11 illustrates a standard table for determining the minimum embedment depth.

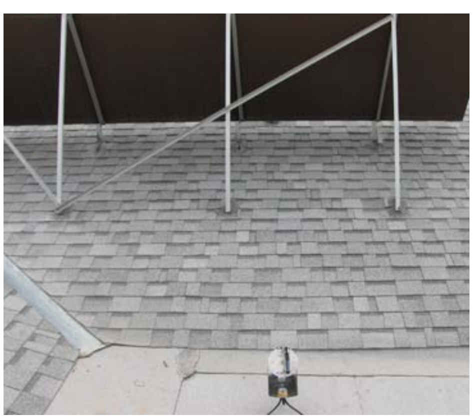


Figure 8-10 – Climate plays a significant role in the suitability of materials. The image on the left is a painted steel rack supporting aluminum-framed collectors in the southwestern United States. After ten years there is no sign of corrosion. A similar installation in the northeastern U.S. creates significant galvanic corrosion between dissimilar metals, as can be seen on the right. (Courtesy of NYSERDA)

Minimum embedment depth example

An installer is mounting collectors at an angle of 40° on a 4:12 roof. The manufacturer determines that each rear foot must withstand a withdrawal force of 650 pounds (295 kg). Because the installer is unsure of the type of wood used for the roof rafters, *Spruce*, *Pine*, or *Fir* is selected to be conservative since it is one of the least dense woods commonly used in construction. For a 3/16" (5mm) lag screw, the withdrawal strength is 205 pounds (93 kg) for each inch of thread embedded in the rafter. The minimum thread depth required can be determined by dividing the maximum withdrawal force by the withdrawal strength:

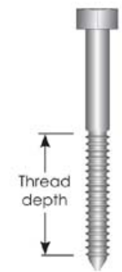
d_{min}= (650lb)/(205lb/in) = 3.17in

Since two lag screws should be used per foot, the minimum thread embedment depth per screw is 1.59in (40mm).

The installer must select a lag screw that will have slightly more than 1½" (40mm) of thread embedded in the rafter. For proper lag screw selection, the installer must consider the thickness of the roofing, the roof sheathing, and the attachment hardware, as well as the length of thread on the screw itself.

Lag pull-out (withdrawal) capacities (lbs) in typical roof lumber (ASD)

		Lag screw specifications
	Specific gravity	*5/16" shaft,* per inch thread depth*
Douglas Fir, Larch	0.50	266
Douglas Fir, South	0.46	235
Engelmann Spruce, Lodgepole Pine (MSR 1650 f & higher)	0.46	235
Hem, Fir, Redwood (close grain)	0.43	212
Hem, Fir (North)	0.46	235
Southern Pine	0.55	307
Spruce, Pine, Fir	0.42	205
Spruce, Pine, Fir (E of 2 million psi and higher grades of MSR and MEL)	0.50	266



Sources: American Wood Council, NDS 2005, Table 11.2A, 11.3.2A.

Notes: (1) Thread must be embedded in the side grain of a rafter or other structural member integral with the building structure.

(2) Lag bolts must be located in the middle third of the structural member.

(3) These values are not valid for wet service.

(4) This table does not include shear capacities. If necessary, contact a local engineer to specifiy lag bolt size with regard to shear forces.

(5) Install lag bolts with head and washer flush to surface (no gap). Do not over-torque.

(6) Withdrawal design values for lag screw connections shall be multiplied by applicable adjustment factors if necessary. See Table 10.3.1 in the American Wood Council NDS for Wood Construction.

**Use flat washers with lag screws. Flat washers are not necessary with concealor screws.*

Figure 8-11 – Withdrawal capacity for lag screws in various wood species. (Courtesy of Unirac)

When installing collectors on flat roofs, standoffs and a separate substructure for the collector racks may be installed to minimize roof penetrations. Alternately, curbs may be installed beneath the roof membrane and attached to the roof structure. Collector racking is then attached to the curb using methods approved by the roofing manufacturer. When curbs are installed, considerations must be made to ensure that the curbs do not impact roof drainage. Any work performed on a warrantied roof should be done in conjunction with the original roof manufacturer and/or roofing contractor to ensure compliance with roof warranties.

8.2.2b Ground-mounted installation

Ground-mounted systems eliminate the safety hazards associated with roof mounts. Ladders and scaffolding are used occasionally, but exposure to fall hazards is lessened relative to a typical roof-mounted array. Specific hazards associated with ground-mounted collectors include working near open trenches that may be required for collector piping and near foundation holes required for ground-mount footings.

The classic ground-mount installation uses concrete piers to support the collectors. Precast piers can be used, or footings can be constructed using a post-hole digger and ready-to-mix concrete. Small installations of one to three collectors will require at least four piers, the bases of which must be below the frost depth in freezing climates. The AHJ will often specify the minimum footing depth. Care must be taken to ensure proper drainage below the pier; this is typically accomplished with a layer of gravel or crushed stone. The presence of bedrock or clay requires special consideration and may require consultation with an experienced foundation contractor. The installations are seldom completed in a day regardless of crew size since the concrete structures require cure time.

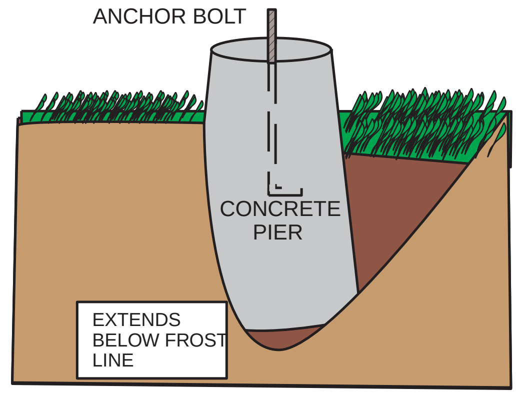


Figure 8-12 – Site preparation for installation of a cast-in-place pier.

When using concrete piers, an anchor bolt should be embedded into the concrete. This is used to fasten the collector mounts. A string level or laser level tool should be used to level the top of the piers and anchor bolts. Cast-in-place piers can be installed efficiently and attractively using commonly available pre-manufactured cylindrical cardboard forms. Certain jurisdictions may have requirements for concrete piers that stipulate the need for embedded rebar or a minimum height that the pier must extend above ground. The Uniform Solar Energy Code (USEC) stipulates a minimum 6" (15 cm) clearance above ground while the Florida Solar Energy Center (FSEC) Solar Water and Pool Heating Manual recommends a minimum 12" (30cm) above grade. In areas where snow is prevalent, these clearances will be greater.

Another option for ground mounts are helical piles. These systems utilize galvanized steel pipes with an auger welded to the end of the pipe. The pile design is proprietary and many companies offer a multi-year guarantee against settling or heaving. In areas subjected to frost, plastic sleeves are used on the piles to allow the frost to move the sleeve up and down without displacing the pile.

Piping integrity and the potential for excessive pipe lengths require careful consideration with ground-mounted installations. Long piping runs may require increasing the pipe diameter and/or the size of the pump. The distance that piping is buried below grade is rarely specified by the Authority Having Jurisdiction (AHJ). Several inches of backfill will protect the piping; in cold climates, consideration should be made to ensure that frost heaving does not expose the piping. The piping should be insulated with a minimum ¾" (19mm) of closed cell piping insulation or comply with local requirements. Underground piping and insulation should be encased in a suitable PVC pipe to prevent the earth from crushing the insulation. Buried sensor wires should also be installed in suitable conduit.

8.2.2c Wall-mounted installation

Mounting hardware is easily adapted for mounting collectors to the side of a building. Wall-mounting is an appropriate solution if a structure is oriented with a suitable unshaded southern wall. Wall installations eliminate the liability of sealing roof penetrations and the uncertainty of installing a ground-mount foundation. On many two-story homes there is enough space on a second story gable-end wall to install a collector or two without conflict with any windows. The mounts can sometimes be lag-screwed or bolted directly to structural members, such as wall studs or concrete walls. Buildings with brick facades or

Ground-mounted arrays

Ground-mounted arrays can provide complexity to an installation due to the variability of soil conditions, the possibility of differential settling, and the presence of underground utilities. When performing foundation work for large projects, it is common for contractors to investigate soil conditions prior to construction. If clay or bedrock is encountered during installation, the complexity and cost of installing a stable foundation can increase dramatically. An installer also needs to consider the presence of underground utilities before excavating to ensure safety and avoid interruption of services to the building. Additionally, consideration needs to be made for the potential of differential settling. Differential settling occurs when one portion of the system remains fairly rigid while another portion of the system settles or heaves. For example, if only one pier supporting a collector array heaves, it will place undue stress on the collectors and racking.

Figure 8-13 – Wall-mounted evacuated tube collector. (Courtesy of Liquid Solar Systems)

concrete block walls will require lag shields or lead anchors. Adobe walls will usually require that rack components are thru-bolted to the interior of the structure.

8.2.3 Unglazed collector installation

Most unglazed collectors do not have frames and are flush-mounted to a roof or other surface. The primary design consideration for pool collectors is uplift due to wind. Strapping material is typically used to hold unglazed collectors to the roof. Additional hardware attaches the top and bottom headers to the roof and allows expansion and contraction of the panels. The factory-supplied hardware is usually screwed into the roof decking unless local codes require otherwise.

8.2.4 Seal and flash mount penetrations

Roof penetrations must be sealed and flashed appropriately to maintain a weathertight barrier and to isolate dissimilar metals that could corrode. Sealing can be accomplished by using roof cement on the mounting screws or bolts and on the surface of the mount that is directly in contact with the roof surface. Contractor's silicone caulking is good for metal-to-metal or other nonporous surfaces. Plastic roof cement—also known as pookie—is a rubberized, asphalt-based black sealant that has been the standard for sealing roof penetrations of all kinds for over forty years. It is difficult to remove from tools, skin, and clothing. As a result, the top of the mounts and fasteners should be sealed as the last step of an installation to avoid a messy jobsite and the need for excessive cleanup. Newer polystyrene and other plastic based products are available, but none have been used long enough to compare their longevity with plastic roof cement. If lag screws are used for fasteners, they should be dipped into the sealant prior to securing them.

Some manufacturers utilize a neoprene or EPDM (Ethylene Propylene Diene Monomer) gasket that is installed between the mounting foot and the roof surface. These can also be custom-made using rubber roofing. While these gaskets are sometimes used on shingled roofs, they are critical on metal roofs to isolate the dissimilar metals of the collector rack and the metal roofing. Without this isolation, the reaction between the metals can lead to galvanic corrosion.

Figure 8-14 – Mechanical flashing for structural attachment points. (Courtesy of EcoFasten Solar)

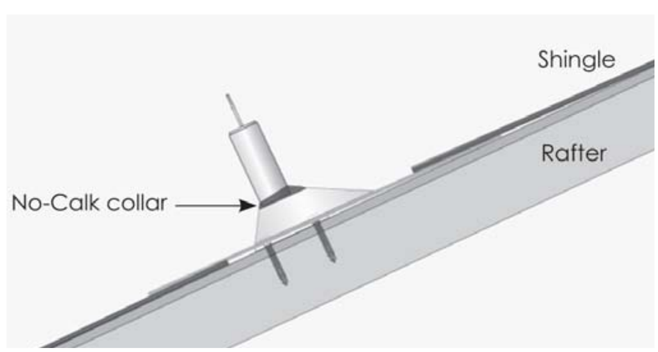


Figure 8-15 – Flashing detail for a cylindrical standoff with boot flashing. (Courtesy of Unirac)

Additionally, there are a number of mechanical flashing systems used for weatherproofing roof penetrations. When using cylindrical standoffs, roof vent flashing boots are often used. The flashing boot consists of a flat surface that slides beneath an upper course of shingles and a conical rubber boot with a round hole that slides down over the standoff. Other proprietary flashing systems utilize gasketed flashing plates that are sealed to the roof's surface by the mounting lag screws.

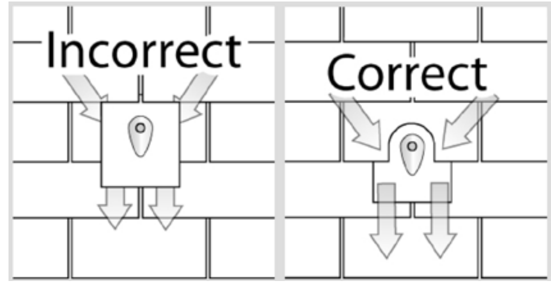


Figure 8-16 – Roof boot flashing detail. (Courtesy of Professional Solar Products)

8.2.5 Place panels on roof

Staging solar collectors on the roof requires significant attention to detail. Flat plate collectors will require several workers due to their size and weight, while the modular design of evacuated tube collectors allows piece-by-piece lifting. In large installations with either type of collector, it is beneficial to utilize small cranes or other lifts to minimize the time, lifting-related injuries and exposure to fall hazards associated with making multiple trips to the roof. With careful preparation and the proper equipment, collector arrays can be assembled on the ground and lifted into position for installation. For installations on single-story roofs, work trucks can be used to facilitate lifting collectors directly onto a roof.

Sealant should be applied to the top of the collector mount penetrations and roof jacks, as necessary. While this can be accomplished immediately after installing the collector mounts, applying exposed sealant prior to collector installation increases the risk that the sealant will be tracked on the roof, then on the ladder, and then on the white carpet in the home. This should be one of the last tasks completed on the roof. The sealant can be painted with spray paint to the approximate color of the roof for a professional finish. For best appearance, metal roof installations are best sealed with clear silicone.

On steep, shingled roofs, shingle brackets with planks can be installed temporarily to provide level work surfaces for improved footing during collector installation. Steep metal roofs may require working from manlifts or the installation of specialized work platforms designed specifically for standing seam metal roofs.

Of all collector types, ICS systems can be the most difficult to place and attach due to the weight of the unit. In addition, the size of the systems is often cumbersome. Many installers use small cranes to lift and place ICS systems. In lieu of a crane, it can require four or more people to safely lift a heavy ICS system to a roof.

Safety is a critical consideration when transporting collectors to the roof. All individuals involved in the process must ensure they utilize appropriate fall protection. Because lifting collectors onto a roof typically requires installers to work at the edge of a roof, fall arrest systems must be adjusted to ensure that extension of the lanyard will not allow the worker to fall over the edge. Gloves and eye protection should be worn when handling solar collectors. Collectors should be carried and lifted using their frames; lifting collectors by their manifolds

Figure 8-17 – Using a crane to transport pre-mounted collectors to the roof.

Figure 8-18 – Installation of an ICS thermosyphon system.

can bend the piping, which may damage the collector or cause alignment issues when plumbing multiple collectors in an array.

8.2.6 Attach panels to mounting hardware

Attaching the collectors to the mounting hardware is usually a simple mechanical task using hand and power tools. When using racks supplied by a manufacturer, follow their instructions. When flat plate collectors are tilted up from the roof surface, a lower profile can be achieved by mounting the collectors in a *landscape* orientation. This is accomplished by rotating the collectors so that the long side is parallel to the ridgeline of the roof. However, most flat plate collectors are manufactured with the intention that the small riser tubes will be installed in a vertical orientation. Mounting the collectors in landscape orientation can pose a problem in Drainback systems due to the sagging of these small riser tubes over time. This can cause a water trap in the tubing, which can hold water that would otherwise have drained out and cause a freeze break in the tube(s). Although the flow through the collectors is not a problem in landscape, the tendency for the risers to sag may limit the use of landscape-mounted collectors to Antifreeze or DFC systems. Some manufacturers specifically discourage landscape mounting of their collectors.

Figure 8-19 – Landscape rack for a flat plate collector. (Courtesy of SunEarth)

Evacuated tube collectors with heat pipes should always be mounted with the manifold housing at the top of the collector to allow proper phase change in the heat pipe. Additionally, installers must follow the manufacturer's instructions regarding minimum and maximum tilt angles—usually a minimum of about 15°–30° and a maximum of 75° is recommended to ensure the efficient operation of the heat pipe.

8.2.7 Plumbing collectors

The heat transfer fluid must travel from the coolest portion of the collector array to the hottest part for efficient heat transfer. This flow path differs for the different type of collectors. In a harp-style collector, the HTF should enter the collector at the bottom header and exit from the top header at the opposite corner of the collector. While this flow path may be similar for certain serpentine collectors, some models are designed to have both the collector inlet and outlet at the top of the collector or on the same side.

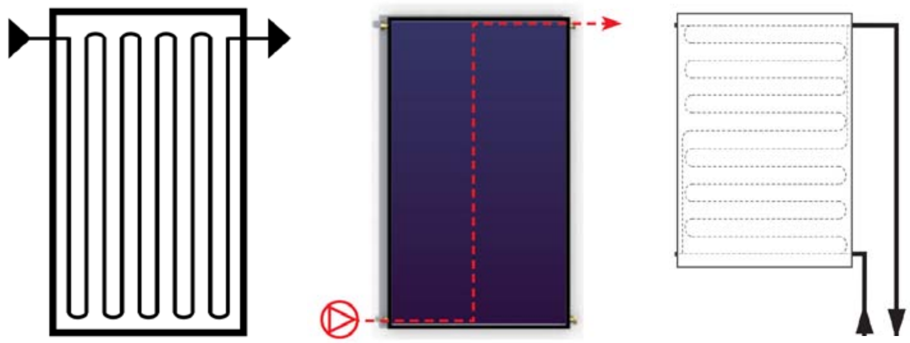


Figure 8-20 – Flow path through various styles of flat plate collectors. (Courtesy of Schüco, Heliodyne, Bosch Thermotechnology)

Most evacuated tube collectors have a continuous manifold that permits flow from one end to the other. With this configuration, the inlet can be installed at either end and the outlet is installed at the opposite end.

Figure 8-21 – Harp-style flat plate collectors plumbed in parallel. (Courtesy of AET)

When multiple flat plate collectors are used in an array, they should be plumbed in parallel. Plumbing collectors in parallel splits the system flow equally through the collectors, which provides equivalent temperatures in each collector. If collectors are installed in series, the heat transfer fluid travels through one collector before entering subsequent collectors. This provides equal flow through the collectors, but the temperatures in the last collector will be hotter than in the first collector. This increases thermal losses and decreases the efficiency of the hottest collectors in the array; flat plate collectors should not be plumbed this way unless specified by the manufacturer.

Figure 8-22 – Flat plate collectors plumbed in series. (Courtesy of NYSERDA)

Figure 8-23 – Plumbing harp-style flat plate collectors in parallel when oriented landscape requires extra external piping. (Courtesy of NYSERDA)

The method for connecting flat plate collectors in parallel varies by style. Harp-style collectors are connected in parallel by joining the manifolds together as shown in Figure 8-21. By installing caps on the unused ends of the headers, this configuration provides balanced flow through the individual risers. Serpentine flat plate collector manufacturers often utilize unique absorber designs; therefore, the proper method for connecting serpentine collectors in parallel must be considered on a case-by-case basis.

Flat plate collector manufacturers will often limit the number of collectors that can be plumbed together in a single bank.

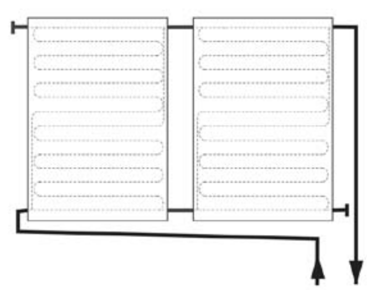


Figure 8-24 – Serpentine collectors plumbed in parallel. (Courtesy of Bosch Thermotechnology)

Figure 8-25 – Evacuated tubes plumbed in series. (Courtesy of NYSERDA)

Large banks may experience high frictional head loss and excessive fluid velocities due to the flow rates required for efficient heat transfer. Additionally, flow does not always balance properly through the risers in large flat plate arrays.

Piping harp-style flat plate collectors in parallel requires external piping when the collectors are oriented horizontally, e.g. landscape (Figure 8-23).

Due to lower thermal losses of evacuated tube collectors, many manufacturers will recommend plumbing these collectors in series by directly connecting the manifold headers to one another. Connecting too many evacuated tube collectors in series may cause unacceptable thermal losses and high fluid velocities, and may lead to excessive stagnation temperatures. Manufacturers often limit the number of evacuated tube collectors that can be connected in series. If more collectors are required, the array must be divided into multiple collector banks.

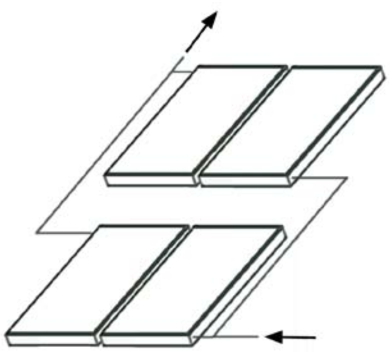


Figure 8-26 – Parallel collector banks plumbed reverse return. (Courtesy of NYSERDA)

When an array is divided into multiple banks of collectors, each bank should be connected in parallel and the flow through each bank should be balanced. There are three primary ways to accomplish this:

- **Reverse return** – Reverse return refers to a configuration in which the fluid path is split between two or more banks and the fluid that travels through the nearest collector bank must travel through addition piping on the outlet to ensure that the flow doesn't favor the nearest collector bank and limit flow through subsequent banks of collectors (Figure 8-26).

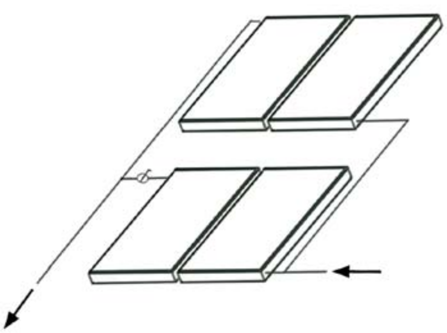


Figure 8-27 – Parallel collector banks plumbed direct return. (Courtesy of NYSERDA)

- **Direct return with balancing valves** – Direct return refers to a configuration in which the fluid path is split between two banks, and the fluid that travels through the nearest collector bank is the first fluid to return to the storage tank or pool. This causes unbalanced flow through collector banks, as the flow rate through the nearest bank will be higher than the flow through subsequent banks. To ensure that the subsequent banks are effective for generating heat, valves must be used to restrict flow through the nearest bank. If a ball valve can be used for this purpose, thermometers or flow meters are required to verify that the flow is properly balanced. Alternately, special balancing valves can be used that are set to the desired flow rate.
- **Separate pumps for each array** – Some differential controllers allow the heat from separate collector banks to be transferred via separate pumps to a common storage tank. In this configuration, a collector sensor is required for each bank and each pump operates off the differential between the storage tank and the corresponding collector bank.

Expansion of copper tubing

Copper tubing expands and contracts with changes in temperature. In typical residential SWH systems, tube expansion needs to be considered at roof penetrations and pipe supports. In large systems, custom solutions may be required to account for the significant variations in pipe length that can occur.

The magnitude of expansion (and contraction) for copper tubing can be determined using the following formula:

$\Delta L = e \cdot L \cdot \Delta T$
ΔL = change in length of copper, ft
e = expansion coefficient of copper = 0.0000094 ft/ft · F
L = length of copper, ft
ΔT = change in temperature, °F

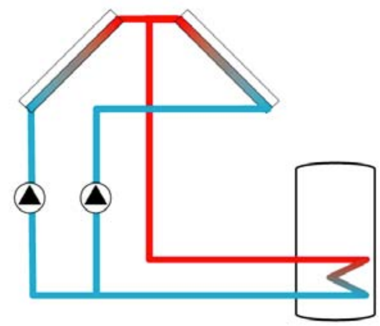


Figure 8-28 – Balancing flow through collector banks through the use of controls. (Courtesy of Resol)

For a collector array with two (2) 4'x8' flat plate collectors, the header is approximately 8'-6" long. If the stagnation temperature of the collector is 360°F and the collector was installed when the collectors were approximately 80°F, the maximum header expansion would be:

$\Delta L = e \cdot L \cdot \Delta T$
ΔL = (0.0000094 ft/ft · F)(8.5')(280°F)
ΔL = 0.0224ft = 0.27in

This expansion is minimal and can be accommodated by installing an offset between the collector header and the pipe penetration when flush mounting the collector.

Suppose instead that a large commercial job required 300' of piping to be buried in a straight trench between the collector array and the utility room. The following expansion might be expected:

$\Delta L = e \cdot L \cdot \Delta T$
ΔL = (0.0000094 ft/ft · F)(300')(180°F)
ΔL = 0.5076ft = 6.1in
If expansion is not accounted for in this system, significant stress would be placed upon components.

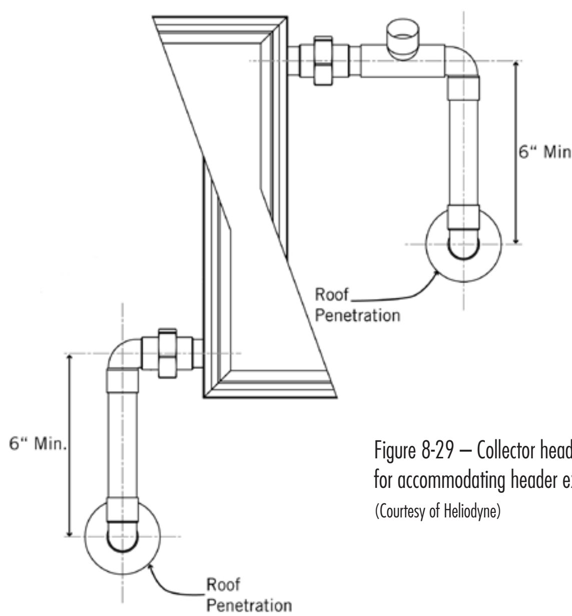


Figure 8-29 – Collector header offsets for accommodating header expansion. (Courtesy of Heliodyne)

8.3 Install solar loop

The solar loop provides the connection between the collector(s) and the storage tank or other heat distribution equipment. The size and type of tubing used can have a dramatic impact on the performance of a SWH system. An experienced installer recognizes these impacts and is proficient in joining various types of tubing, adequately supporting and insulating the solar loop, and sealing piping penetrations.

8.3.1 Piping considerations

There is a direct relationship between system piping and the amount of pump pressure required to achieve the desired system flow rates. Dynamic—or frictional—head refers to the resistance that the piping has on the flow of a fluid. This resistance, also referred to as pressure drop, can be reduced by using larger diameter piping, reducing the system flow rate, and minimizing the number of fittings in the system. The relationship between the system flow rate and pressure drop is exponential—if the flow rate is doubled, the pressure drop approximately triples.

Collector manufacturers specify optimal flow rates through a collector to maximize collector efficiency. If the pressure drop is too high, a selected pump may not be able to achieve the desired flow rate. An experienced installer must be able to determine the pressure drop through system piping and interpret pump curves to assure that the desired flow rates can be achieved. More information on determining the pressure drop is contained later in this section.

Maximum fluid velocities in copper tubing

The Copper Tube Handbook specifies a maximum fluid velocity of 5 feet per second (1.5 m/s) for copper tube that is used in hot water systems. Flow exceeding velocities of 5 feet per second (1.5 m/s) may cause pipe erosion and cause excessive noise in the system.

8.3.2 Seal and flash pipe penetrations

Any location where system piping penetrates a building's weathertight membrane or passes through a surface that separates the conditioned portion of a building from unconditioned space must be sealed. Piping for roof-mounted systems will commonly penetrate the roof, but may also penetrate a wall. Wall-mounted and ground-mounted systems will penetrate through a wall or rim joist.

Figure 8-30 – Flashing of pipe penetration and cylindrical standoff. (Courtesy of Liquid Solar Systems)

Roof or wall piping penetrations can be sized either to the piping or to the diameter of the piping plus its insulation. Roof penetrations should be drilled slightly larger than the piping, so that contact between the pipe and building structure can be avoided. Some installers use plastic roof insulators to isolate the pipe from the building sheathing or structural member.

Flashing is required for all pipe penetrations. Best practice is to flash the piping, not the pipe insulation. Flashing directly to the pipe produces a more dependable seal. Standard pipe flashings utilize an EPDM, silicone, or copper collar. Consideration must be made for temperature—EPDM is typically rated to intermittent temperatures of 275°F (135°C), which is adequate for most systems, while silicone has a 435°F (225°C) continuous rating.

Flashing is available for single pipes, or in some cases two pipes can utilize the same flashing. Flashing individual pipes is often easier and more effective and can minimize the amount of exterior piping on the roof.

On shingled roofs, the hole in the roof should be placed so the flat part of the pipe flashing can be slid under an upper course of shingles. The flashing is sealed with plastic roofing cement on both the underside and top of the flat portion of the flashing and should be nailed or screwed to the roof decking only where covered by a shingle from above to shed water. When using copper flashing, the cap should be soldered to the piping but not to the collar to allow for expansion and contraction of the piping without affecting the integrity of the seal (See Figure 8-31).

When penetrating a metal roof, pipe flashing should be provided by the roof manufacturer, if available, and sealed with silicone sealant. With all EPDM and silicone boots, the manufacturer's instructions for sealing between the piping and the boot should be followed. Some manufacturers require the use of a stainless steel hose clamp and sealant. Built-up tar roofing and EPDM surfaces are commonly used on flat roofs. As with any work on these types of roofs, the company that installed the roof should be consulted to assure compliance with the manufacturer's warranty.

Figure 8-31 – Copper pipe flashing with gooseneck for sensor wire. A collar is soldered to the copper plate flashing and concealed under the copper cap in this photo. The copper cap is soldered to the copper tubing. There is no connection between the collar and the cap or the collar and the piping; this allows the tubing to expand and contract without affecting the integrity of the copper flashing plate.

Wires for the collector sensor(s) can be flashed with the pipe penetration, separately through gooseneck flashing, or an extra penetration can be made for conduit that is sealed with a standard flashing boot. When sensor wire is run alongside the hot return pipe from the collectors, attention must be paid to ensure the sensor wire sheathing is rated above the maximum piping temperature.

Sealing roof penetrations correctly is an ongoing process during roof work. The pipe flashing and each and every mounting screw or bolt must be sealed. Any pilot holes used for locating structural members must also be sealed. Tiny holes are easily overlooked and should be sealed immediately or conspicuously marked and filled prior to the day's departure from the site.

8.3.3 Install pipe

Copper tubing is the favored material for SWH system piping. Copper will withstand the hottest temperatures a SWH system can produce. High Density Cross Linked Polyethylene (PEX) tubing that is used in some domestic water and radiant floor heating systems is only appropriate for use in select solar collector loops. Closed loop systems can exceed the temperature and/or pressure limitations of PEX. Other types of polymer piping with high temperature limits in the 200°F (90°C) range are also unsuitable for closed loop systems. The exceptions are silicone and Teflon® tubing, however both of these products have limitations due to expense and the availability of specialized connections. CPVC piping has a temperature limit of 180°F (80°C), which is unsuitable for SWH system piping. Black steel pipe is an option for the collector loop of large Antifreeze systems, but is inappropriate in open loop and Drainback systems. Galvanized steel can be used in closed loop systems that utilize water, but is inappropriate for glycol systems—the zinc will react with the glycol inhibitors to create sludge. Both black iron and galvanized steel pipe are less expensive than copper but are more labor-intensive.

The use of PEX in SRCC OG-300 Certified Systems

In 2010, the SRCC approved the use of PEX tubing in drainback systems under very specific conditions. The requirements are as follows:

- The PEX cannot be exposed to UV radiation.
- The Drainback system must be unpressurized or open to the atmosphere.
- There must be a minimum of three feet of uninsulated 3/4" (or greater) copper piping between the PEX and the collector inlet and outlet, unless the collector stagnation temperature is below 210°F (99°C).
- All PEX fittings must be rated for potable water applications and approved by the PEX manufacturer.
- The system must have a pressure relief valve at the drainback tank that is rated between 25–50 psi.

The collector supply pipe is always connected from the pump to the cold inlet of the collector. The return pipe runs from the hot outlet of the collector(s) to the pump equipment area, where the return pipe is plumbed to the heat exchanger in an indirect system and to an inlet in the storage tank in a direct system.

The proper installation of piping in Drainback systems is critical and unforgiving. Sloping the piping at a minimum of ¼″ per foot (2cm per meter) will protect from water being trapped and then freezing in the piping. Collectors should also be sloped to the same minimum specifications. Collectors used in DFC and Drainback systems need to be sloped towards the inlet at a minimum of ¼″ per foot (2cm per meter) so that they will drain via gravity. For a four-foot by eight-foot collector mounted with the long dimension vertical (portrait orientation), this equates to one inch (25 mm) per collector. Piping should also be sloped to the same minimum specifications. The hot return pipe must be a minimum size of 3/4″ (19mm) and should be installed as vertically as possible. This allows air in the Drainback tank to quickly rise to the top of the collector and break the vacuum that will otherwise hold the water in the collector piping.

8.3.4 Soldering copper tubing

Copper tubing is typically joined by soldering or brazing—the two methods are differentiated by the materials used to join the tubing and the temperatures required for the process. Soldering takes place at temperatures below 630°F (330°C); brazing requires

Corrugated stainless steel tubing

A number of manufacturers offer rolls of corrugated stainless steel tubing that is rated for SWH applications. The tubing connects to copper tubing at the collectors and the pump station with the use of proprietary unions that typically utilize a compression fitting to seal the flexible stainless steel tubing. Corrugated stainless steel tubing is available in uninsulated rolls or as two runs of tubing encased in high temperature pipe insulation. The two runs of tubing can be separated from one another by cutting the insulation. The insulation may also contain a sensor wire.

The benefit of these products is that they can lessen labor costs by reducing the number of fittings required in the system and the labor associated with insulating piping. They also have some disadvantages. Due to the corrugations of the tubing, this product has approximately twice the frictional head as equivalently-sized copper tubing, which increases pumping requirements. The corrugations can also trap fluid and may make air elimination during start-up more difficult. Consideration must also be paid to physical support of the tubing and to the integrity of the unions.

Figure 8-32 – Pre-insulated stainless steel flex line with sensor wiring.

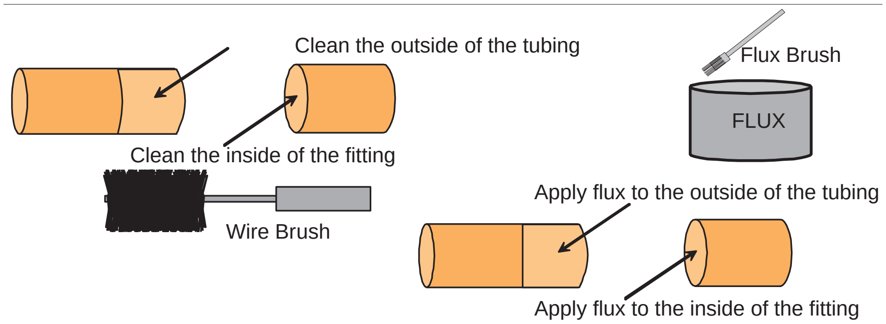


Figure 8-33 – Cleaning copper tubing and fittings.

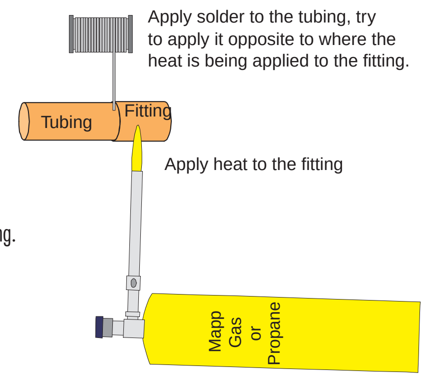


Figure 8-34 – Soldering a copper fitting.

Types of Copper

There are six standard types of copper tubing: Type K, Type L, Type M, DWV (drain, waste, and vent), medical gas, and ACR (air conditioning and refrigeration). The two types of copper tubing most common to SWH systems are Type L and Type M.

Type L and Type M copper are available in ASTM standard nominal sizes. The outside diameter of each is 1/8" greater than the nominal tube size. For example, 3/4" Type L and Type M copper have an actual outside diameter of 7/8". Due to their equivalent outside diameter, these types of pipe utilize the same fittings, pipe supports, and pipe insulation.

Type M copper has the thinnest wall of all of the six types of copper except DWV. It is only available in straight lengths and is appropriate for potable piping and collector loop piping, unless otherwise specified or restricted by code. Type M copper is rated well above the temperatures and pressures common to SWH systems. Type M copper is marked with red labels to differentiate it from other types.

Type L copper is available in straight, drawn lengths and in 60-foot and 100-foot rolls. Type L rolls are made of annealed copper, which makes the tubing more flexible. Annealed Type L copper is required by most jurisdictions for tubing that is buried. It can also be used to make custom heat exchangers for unpressurized storage tanks. Type L copper is marked with blue labeling.
The Copper Tube Handbook is a valuable resource for specifications of copper tubing and related fittings and can be downloaded at www.copper.org.

temperatures exceeding 1205°F (650°C). For collector loop piping, soldering is the standard method used.

Copper must be properly prepared prior to soldering. Successful, leak-free soldering is accomplished by following a few simple rules in order. Failure to follow these steps can result in a leak.

- **Cut the tubing to length –** The tubing can be cut to length with a manual tubing cutter, which is available in fixed or adjustable sizes, or with a motorized tool
- **Deburr the inside of the tubing –** Deburring tools, or reamers, are typically attached to a tubing cutter or can be purchased as a separate tool. They are used to create a smooth inner edge of the piping to prevent an uneven surface that impedes flow.
- **Clean the tubing and fitting –** A wire brush or sand cloth can be used to remove oxidation on the pipe. The copper should be cleaned until it has a bright finish.
- **Apply flux to the cleaned surfaces –** Acid flux is used to protect the metals from oxidizing. An acid brush is used to apply flux to the inside of the fitting and the outside of the tubing.
- **Apply heat to the fitting –** Solder is drawn into the fitting through capillary action. In order for this to occur, the fitting and piping adjacent to the fitting must be hotter than the surrounding metal.
- **Apply solder to the tubing –** Once the fitting and adjacent copper tubing exceeds the melting point of the solder, the solder should be applied around the edge of the fitting. Heating the fitting evenly ensures that the solder will be distributed around the entire fitting. Care must be taken to remove heat from the joint before it smokes. The smoke results from burning of the flux.
- **Allow the solder to cool –** The joint should remain undisturbed until the solder hardens. Flexing or rotation of the joint could affect the integrity of the connection.
- **Wipe the joint –** A wet rag should be used to wipe the join while it is hot to remove any excess flux. Failure to wipe the joint will cause green corrosion on the tubing over time.

When soldering a fitting or a valve on a water line that is leaking due to an old, faulty valve that cannot be stopped, a piece of bread can be used to absorb the water. Even a pipe that is barely dripping cannot be soldered because the vaporization of the water from the torch keeps the temperature of the tubing below the melting point of the solder. Cheap, white bread is best. After the joint is prepared and fluxed, the bread is pushed up the tubing and it acts like a sponge to soak up the water. This gives the installer enough time to solder the joint. The bread dissolves in the water. Another handy soldering tool is a small piece of galvanized tin about a foot square. This can be used to protect finished walls when soldering close to them. The tin will reflect the heat off the wall and protect the finish.

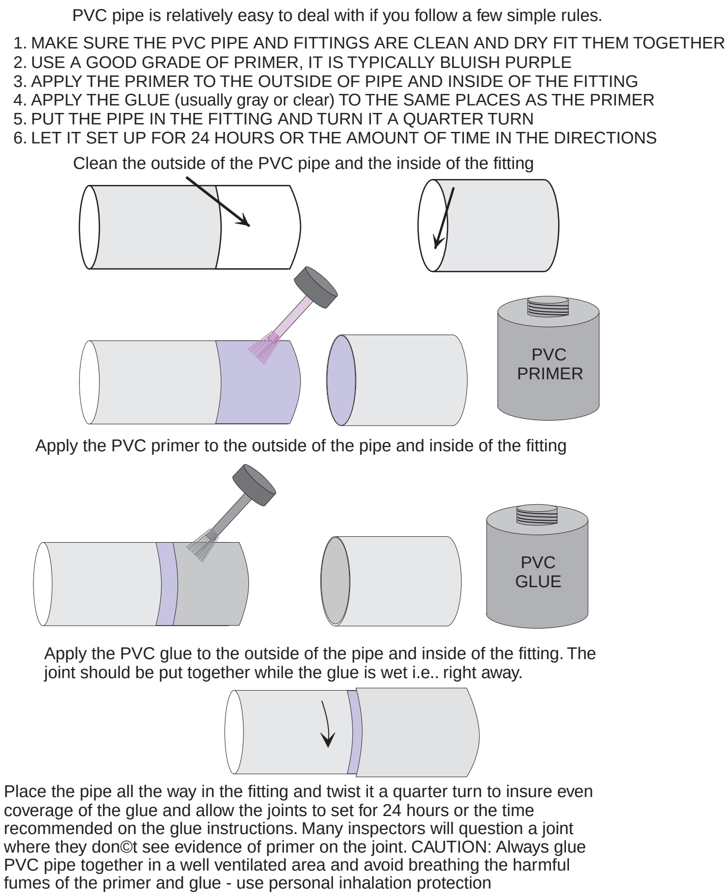


Figure 8-35 – Gluing PVC pipe.

Other methods for joining copper

While soldering is the standard method for joining copper, a number of other methods are available that are considered less labor-intensive.

One method utilizes a pressing tool to crimp a specially-designed fitting to the copper tubing. Press fittings include a seal that is compressed between the copper of the fitting and the copper tubing.

Another style of fitting that does not require heat is a push fitting. Push fittings utilize an o-ring to make a seal between the fitting and the tubing. A grab ring holds the tubing in place by preventing the tubing from being pulled out of the fitting.

If these types of fittings are used in SWH systems, the installer must verify that the seals and o-rings are compatible with system temperatures and type of heat transfer fluid. In some press fittings, special seals may be required. In Antifreeze systems, press or push fittings used near the collector array must be rated for stagnation temperatures.

Figure 8-36 – Pressing tool used to crimp specialized fitting; the raised ring on the fitting houses an o-ring that seals between the fitting and the tubing.
(Courtesy of SunWater Solar)

8.3.5 Install pipe supports

To protect the integrity of system piping, the tubing must be supported at regular intervals by appropriate hangers. The hangers must able to support the weight of the pipe, allow for expansion, and protect the tubing from significant displacement. Also, the hanger material must be compatible with or isolated from the tubing to avoid galvanic corrosion.

Support requirements may vary by jurisdiction. For instance, the International Plumbing Code stipulates that copper tubing with a nominal diameter of 1¼″ or less must be supported every six feet on horizontal runs and at ten feet intervals for tubing larger than 1½″. The Uniform Plumbing Code requires support at every six feet for copper tube up to 1½″ and ten feet for tubing that is 2″ and above. Both codes stipulate 10′ for vertical runs of all sizes of tubing with the Uniform Plumbing Code requiring additional support at each story when the ceiling height is less than ten feet. Both codes list support requirements for other piping materials and should be consulted depending upon the code adopted by the AHJ. In some cases, state and local rules may be more stringent for pipe supports and installers must be familiar with these regulations.

PVC piping is used for pool system installations. Both codes require support at a minimum of 4′ for all sizes of PVC pipe on horizontal runs and 10′ on vertical piping. Additionally, mid-story guides shall be used on all vertical piping.

8.3.6 Pressure test collector loop

Mechanical codes require that installers pressure test the collector loop with air from a compressor to ensure that the system will not leak during normal operation. Requirements differ by jurisdiction. For example, the Uniform Solar Energy Code requires that the pressure test for the collector loop on closed loop systems is one and one-half times the maximum system pressure. The maximum pressure typically equates to the rating on the pressure relief valve installed on the collector loop. The International Mechanical Code has the same requirement, but also stipulates that the minimum test pressure must be 100psi.

Figure 8-37 – Filling the system with compressed air.

Pressure testing requires a compressor fitting that can attach to a fill valve. For indirect systems, it is usually most effective to pressure test the entire collector loop once the pump station has been installed since it will contain a pressure gauge and fill valve(s). In new construction, it may be necessary to pressure test the collector loop in stages. For example, if piping will be concealed in a wall cavity, it is critical to test the system for leaks before the drywall is installed.

Pressure testing of a solar collector loop requires attention to detail and introduces some challenges. The minimum time of the test is fifteen minutes, but it may be greater in some jurisdictions. If any air vents are present in the system, they should be isolated to avoid air leaks. If the system loses pressure during the test, the installer must determine the source of the leak. Leaks at soldered joints will oftentimes be audible. At threaded and gasketed fittings, leak detection fluid should be used to determine whether a leak exists.

Some codes do not allow for pressure testing of PVC. Therefore, outdoor pool systems are tested when the system is commissioned.

8.4 Install balance-of-system

The balance-of-system (BOS) components include the valves, pumps, pressure relief devices, controls, expansion tank(s), and heat exchanger(s). The selection and location of these components within the system are critical for proper system operation. All components must be installed per the system schematic and in accordance with manufacturer's specifications.

8.4.1 Install valves

For SPH systems, component selection is standardized. PVC check valves are often used on the collector return piping when a motorized three-port valve is used to divert pool water to the array. Vacuum breakers are installed at the high point in the system to allow the pool water to drain from the collectors. Installers should follow the solar collector manufacturer's instruction manual to ensure proper installation.

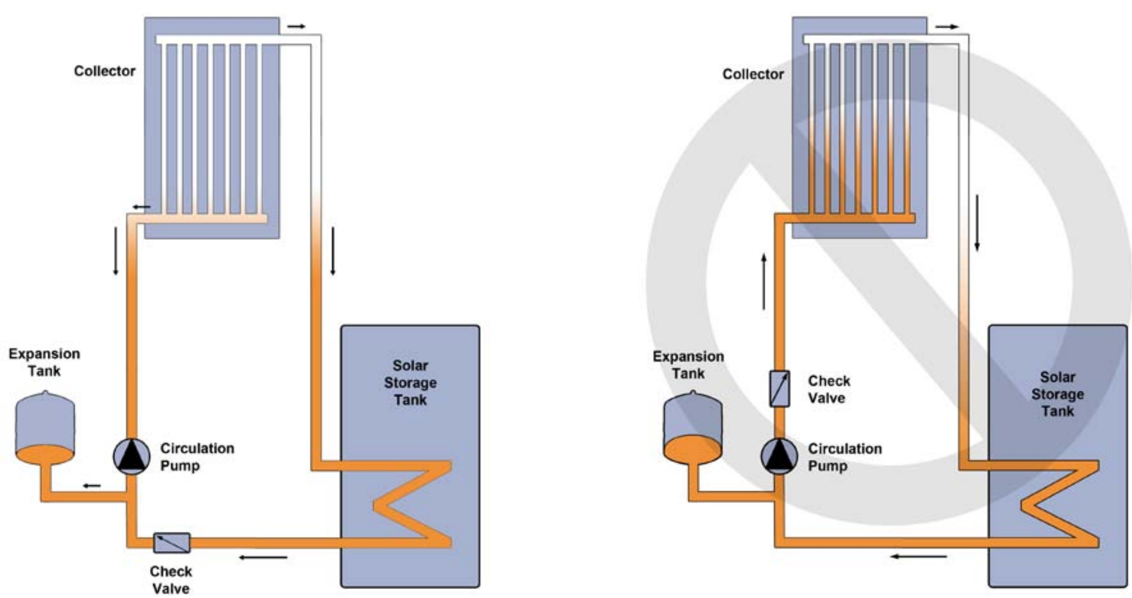


Figure 8-38 – Proper and improper check valve location in an AF system.

Check valves need to be installed in DFC and Antifreeze systems to prevent thermosyphoning at night. A malfunctioning or missing check valve can allow the cold fluid in the collectors to sink to the solar storage tank at night. The hotter fluid will then rise to the collectors and dissipate the tank's stored heat to the cold sky. In very cold climates, this phenomenon can cause freeze breaks in external heat exchangers. The proper installation and operation of a check valve eliminates reverse thermosyphoning by allowing the collector fluid to flow only in one direction.

For Antifreeze systems, a check valve installed between the two boiler drain valves that are used for purging and filling the system can serve a diagnostic purpose in the future. Using this configuration, the system is filled from the boiler drain on the downstream side of the valve. If the fluid immediately flows out the discharge drain valve on the upstream side of the check valve instead of filling the system, the check valve is defective or stuck in the open position. The complete fill procedure is addressed later in this section.

If the expansion tank is installed with the pipe fitting down (tank upside down), the tank will continue to function in the event the internal bladder fails. An expansion tank placed with the fitting horizontal will still hold some air with a bladder failure and might continue to function. A tank placed with the fitting up, upon failure, will introduce all the air in the tank to the collector loop piping. This can be a cause of system failure in older systems. Expansion tank manufacturers often recommend the tank be installed with the fitting up.

Expansion tanks are required in Antifreeze systems to prevent excessive pressure. Fluids physically expand when heated and contract when cooled. An expansion tank utilizes a rubber diaphragm and an air cushion to buffer the system from major fluctuations in pressure. As the heat transfer fluid expands, the air in the expansion tank compresses. The expansion tank represents the point of no pressure change in the system. If the expansion tank is located on the discharge side of the pump in large systems, it can cause negative pressures on the suction side of the pump. This can cause pump cavitation and make air elimination difficult. However, many small pre-packaged pump stations locate the expansion tank on the discharge side of the pump without incident.

The location of the expansion tank also impacts the location of the check valve in Antifreeze systems. During stagnation, steam formed in the collector array should be able to force fluid out of the array through both the outlet and the inlet. If the check valve is located between the expansion tank and the collector inlet, fluid will not be able to be expelled down the collector feed piping. This configuration will increase steam formation, force superheated fluid through the collector piping, and increase system pressures. Most pre-packaged pump stations account for this and *locate the expansion tank between the check valve and collector inlet*. When an installer builds a custom pump station for an Antifreeze system, the check valve should be placed appropriately. If the expansion tank is placed on the suction side of a pump with an integrated flow check valve in the housing, the check valve should be removed and a separate check valve should be installed upstream from the expansion tank.

An air vent may be located anywhere that an air pocket is likely to form within the piping. Air will always move to the top of a piping loop absent any traps. The SRCC requires either a manual air vent, such as a coin vent, or an automatic air vent at the high point in the system for Antifreeze systems that are SRCC OG-300 Certified. DFC systems that are SRCC OG-300 Certified require an automatic high vent. Alternately, a system may utilize a form of air elimination at the pump station. ICS, Drainback, and direct thermosyphon systems do not require high air vents.

Air elimination is important in DFC and Antifreeze systems; air that is trapped in a pump impeller housing or at the top of the system can prevent flow through the collectors.

If installing a two-tank system with an auxiliary water heater, a three-valve configuration is typically utilized for SRCC OG-300 Certified systems to isolate the solar tank and allow the auxiliary heater to remain in service when the solar tank undergoes maintenance or replacement (see Figure 8-39). For systems that are not SRCC OG-300 Certified, plumbing codes often require isolation valves on the inlet and outlet of water heaters. Installing a third bypass valve to achieve the three-valve configuration is best practice. A bypass valve can also be installed between the inlet and outlet piping of the auxiliary heater to bypass it during the summer or for servicing.

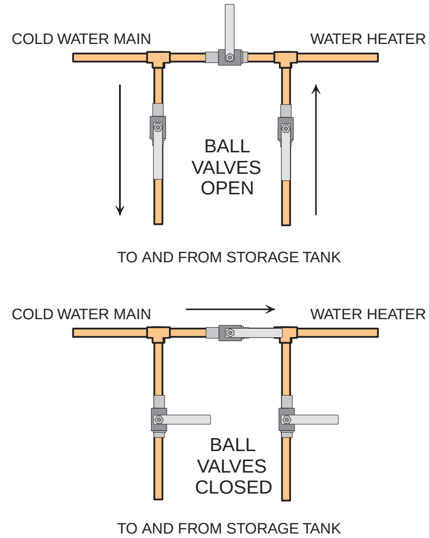


Figure 8-39 – Ball valve configuration for two-tank systems. The illustration on the top shows the valve configuration during normal operation. The illustration on the bottom shows the valve configuration when isolating the solar storage tank.

Pressure gauges are an important component in Antifreeze systems; they are used to monitor system pressure and serve as a service and repair diagnostic tool.

Other BOS components, including thermometers and sight glasses, are not necessary for system operation, but are useful for monitoring system operation. Well-type thermometers are often installed in the collector supply and return piping and in the hot piping from the storage tank. The thermometers can be used to monitor temperature differentials on either side of the collectors and the heat exchanger, if present. This information is useful in assessing system operation. Flow meters with sight glasses can be used in Drainback systems to monitor system fluid levels. Alternately, a sight glass can be installed on the drainback tank for the same purpose.

Figure 8-40 – Internal components of a high head circulator pump.

8.4.2 Install pumps

Pumps used in active SWH systems are called circulators. They are rated for 240°F (115°C) and have no suction lift, so they cannot draw water from below the pump—they must have liquid in the impeller housing to move any fluid. The impeller in circulator pumps is not in contact with the inside of the impeller housing. The impeller circulates fluids by propelling them out of the housing, much like a squirrel-cage blower does with air. Because of their design, circulators can last for a decade or more if installed and used according to manufacturer's specifications.

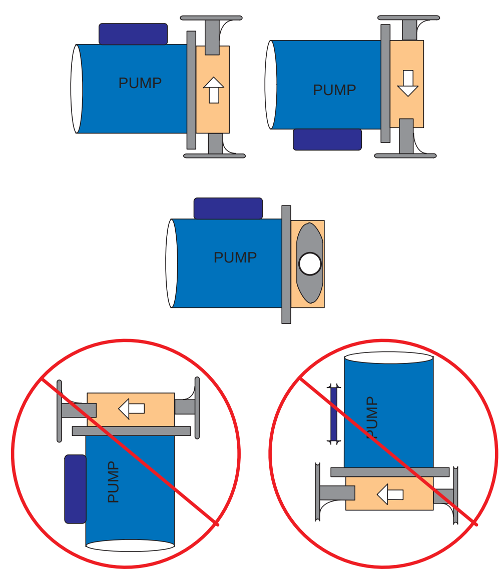


Figure 8-41 – Correct pump orientation: The pump shaft should always be horizontal; when the shaft is vertical, gravity adds to the wear on the shaft bearings and causes premature pump failure.

Considerations must be made regarding the orientation and location of the pump in a system. Circulator pumps should always be mounted so that the impeller shaft is horizontal. Mounting a pump with the shaft vertical will cause too much pressure on the shaft bearings and could lead to premature failure. If possible, the circulator(s) should pump upwards; this prevents air from getting trapped in the pump impeller housing, or volute. Also, circulators should be positioned where they will pump the coldest fluid in the system. The fluid is coldest after it has passed through the heat exchanger and transferred most of its heat to the storage tank. If using an external heat exchanger, or in the case of a DFC system, the coldest water is at the bottom of the tank. In Drainback systems, the pump must be located below the drainback tank and must be able to pull fluid from the drainback tank to ensure that the pump is always filled with liquid.

8.4.2a Pump materials

Circulators used in fluid pumping applications can be classified according to the material used for the volute, or pump body. Cast iron pumps are used in closed loop systems, such as an Antifreeze system or some Drainback systems. Open loop systems require a bronze or stainless steel pump due to the dissolved oxygen present in potable water; a cast iron pump used for this application will corrode within a few months. As a result, bronze and stainless steel pumps are required in DFC systems and on the potable water loop when using an external heat exchanger in Drainback and Antifreeze systems. Bronze and stainless steel pumps can also be used with glycol, but they are substantially more expensive than cast iron pumps.

8.4.2b Pump head

A pump's performance is often described as a relationship between head and flow. The height a pump can move a liquid is called the gravity, or static, head and is usually expressed as a unit of pressure (in pounds per square inch, psi) or a unit of height (in feet or meters of water column). The pressure at the bottom of 2.31 feet of water column

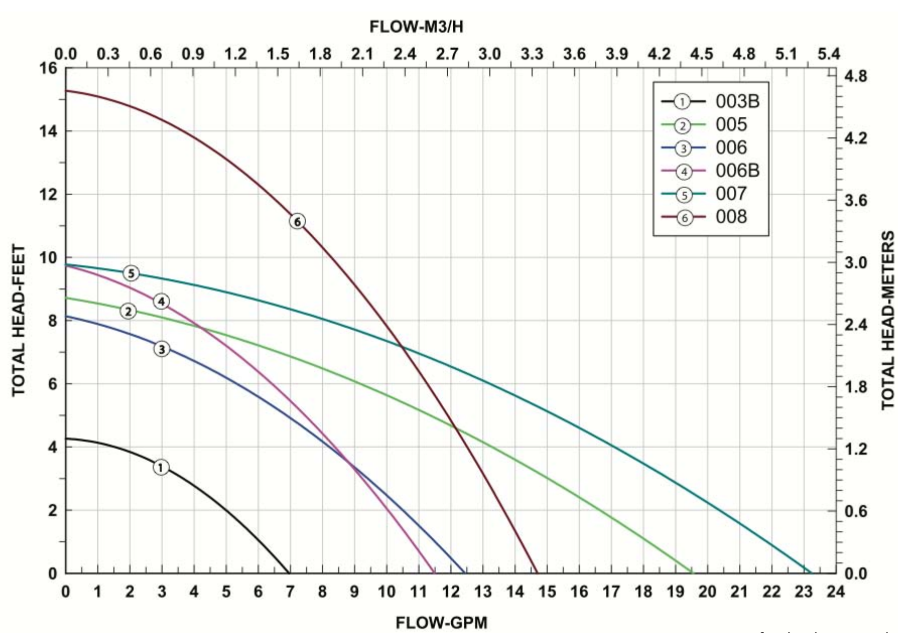


Figure 8-42 – Pump curves for the three speed settings on a standard solar circulator. (Courtesy of Taco)

Determining frictional head loss

The following information is needed by a designer to determine the proper pump for an application:

- The type of fluid being pumped
- The type and size of piping being used
- The length of tubing in the system
- An estimate of the number and types of fittings
- The head loss characteristics of the collectors
- The head loss characteristics of the heat exchanger, for indirect systems
- The maximum system flow rate

Pump sizing is a somewhat inexact science, but the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) has a detailed method for approximating the head loss that will occur in a system based in the system flow rates. This procedure involves finding the head loss for water through the tubing and fittings at the given flow rate and adding it to the head loss in the collectors and heat exchanger. If an antifreeze solution is used for the heat transfer fluid, the head loss for water must be increased by up to 23% to adjust for the increased viscosity.

Since many small residential SWH systems will be similar in their head loss characteristics, experienced installers typically use three-speed circulators that can be adjusted on the jobsite to achieve the desired flow rate. For larger systems, the pump must be sized more precisely. Designers may perform pump selection calculations manually or use a computer program to help determine the expected frictional head loss for the system piping (see http://www.engineeringtoolbox.com/hazen-williams-water-d_797.html). Information about head loss in the collectors and heat exchanger must be obtained from the manufacturers.

When sizing drainback pumps, the gravity head also needs to be considered.

is equal to 1psi. The standard measures of flow are either gallons per minute (gpm), liters per minute (Lpm), gallons per hour (gph) or liters per hour (Lph). As the amount of head a pump must overcome is increased, the flow decreases. The head and flow relationship is represented by a pump curve, which is commonly presented in a graph or table. When the height of a pump's maximum, or "cut off" head is reached, flow is zero. When a pump is used in an application with minimal head, such as through short lengths of horizontal pipe, it approaches its maximum flow rate.

The static head is a critical measurement in Drainback systems, but does not have an impact on pump performance in DFC and Antifreeze systems. This is due to the system being completely filled—because the weight of the fluid at the top of the system exerts pressure on the fluid at the bottom of the system, the pump must only overcome the dynamic, or frictional, head that occurs between the fluid and the piping and various fittings in the system.

The magnitude of frictional head is dependent upon the system flow rate. As with air resistance to a car on a roadway, frictional head loss is much less significant at low fluid velocities or flow rates. Therefore, frictional head is a much greater consideration in large systems than in small residential SWH installations. Collector manufacturers will typically provide optimal system flow rates depending upon the size of the collector array. SRCC OG-300 Certified system designs will specify the pumps that are acceptable in their systems. For large systems where frictional head loss can be a substantial design consideration, engineers typically select and specify the pumps concurrently with the piping system.

In the solar industry, pumps for smaller systems are usually classified as low-, medium- or high-head. A low-head pump is capable of overcoming about ten feet of head or less, medium-head pumps can overcome about ten to twenty feet of head, and a high-head pump is rated at more than twenty feet. Low-head and medium-head pumps are typically used in residential closed-loop systems. Residential drainback systems often require high-head pumps.

Drainback systems that start when collectors have been stagnating may experience significant noise in the return pipe for a few minutes as steam is forced into the drainback tank. The noise is a normal result of hot DB startup.

The differential controller can be set to prevent this occurrence, though if it is set improperly, the pump may remain off during times when solar collection is possible due to the collector temperature exceeding the controller's maximum setting.

If the heat transfer fluid contains glycol, this steam event can cause the formation of residue in the collectors and can lead to degradation of the glycol inhibitors.

A high-head pump is usually required for Drainback systems. The size of the pump depends on the height and flow rate of the system. The pump must be capable of lifting the fluid from the drainback tank liquid level to the top of the collector. As the pump pushes the liquid up through the piping system, the air is forced down into the top of the drainback tank. All Drainback systems will have a noticeable sound of "gurgling" upon start-up as the air and some liquid return to the Drainback tank. Once the pump forces all of the air from the collector loop piping into the drainback tank, the system will form a natural syphon, where fluid falling into the drainback tank from the collector return piping will pull fluid behind it up into the collectors from below. Once the syphon has formed, the pump must only overcome frictional head loss in the system. As a result, the system flow rate will increase once the syphon has formed.

Small hot water circulator pumps suitable for Drainback collector loops usually have head limits of approximately thirty feet. This head limitation may be exceeded in some situations, such as a two-story home with the drainback tank located in a basement. Many higher-head pumps are available for these situations, however they are expensive and require significant amounts of electricity. To alleviate this, two identical pumps in series can be used to double the head capacity. Installing two pumps in series to overcome high-head situations in a Drainback system requires careful consideration. In the event of failure, both pumps are highly unlikely to fail at the same time. If one circulator remains functional, the water may only partially fill the collectors or only rise to the attic level. In cold climates, the partial filling of the system may result in a frozen and burst pipe, which could cause damage in the collectors or lead to water damage in the building structure.

Another alternative for overcoming gravity head in a Drainback system is to raise the drainback tank. By elevating the tank, an installer also raises the water level. This reduces the height required for pumping. In some circumstances, raising the drainback tank to a shelf location in a heated upper story room can allow for use of a medium-head pump.

Two identical pumps can be piped in parallel to double the flow. This is not useful in Drainback systems, but may be considered in DFC or Antifreeze systems. In large Antifreeze systems, this configuration allows continued circulation of the antifreeze solution if one of the pumps fails, facilitates simple replacement of the failed pump, and eliminates stagnation issues that would arise in a single-pump system when the pump fails.

8.4.2c DC pumps

Direct Current (DC) pumps are normally powered directly by PV panels. PV-powered pumps for residential SWH systems are available with a nominal DC voltage of 12V or 24V. Manufacturers that supply DC pumps to the industry have recommended PV module sizes to use with each pump; modules of this size or slightly larger should be used. One drawback of PV-powered pumps is that modules often produce enough electricity in the afternoon to energize the pump when a solar heating collector cannot supply usable heat to the already hot storage tank. To alleviate this inefficiency, differential controls are available for PV-powered SWH systems that will activate the pump only when the collector is able to add heat to the storage tank.

DC pumps are not as versatile as AC-driven pumps. Reliable DC hot water circulators with heads higher than about fifteen feet are difficult to find, thus PV-powered pumps are rarely used in drainback systems. A few small bubbles that are easily evacuated with a higher powered AC pump can stop the circulation with some small DC pumps.

Brush-type DC circulators are able to vary their speed with the power produced by the PV modules. This means that the system flow rate will start out low and increase as the amount of solar radiation increases. A linear current booster may be required to ensure that the pump starts when morning sun has heated the collectors sufficiently.

The PV module can be mounted either next to or near the SWH collectors. Wherever the module is located, it should be mounted at the same tilt angle as the collectors. It is critical for system operation that the PV module is completely unshaded—PV modules have much less tolerance for shade than SH collectors. In northern climates, PV modules may be unable to shed snow as readily as solar collectors. This may result in stagnation in the collectors due to the inability for the pump to receive power.

8.4.2d Pump stations

Pump stations have been manufactured for almost three decades, mostly for small Antifreeze systems. These stations incorporate many of the valves, gauges, pumps, and controls necessary for a SWH system in a pre-designed package. Pump station packages may be contained in a molded, insulated case and may include expansion tanks and/or heat exchangers. The alternative to manufactured pump stations are field-built or shop-built versions that are designed and assembled by the installer. Custom-made or manufactured pump stations can save significant time at the jobsite.

8.4.2e Pool system pumps

Small pool systems are usually designed to use the existing pool filter pump to provide flow through the collectors. Residential pool pumps vary in size from 1–2 ½ horsepower and are used primarily to circulate water for filtration and conventional pool heating—solar heating is usually an add-on application. As a result, the pool pump may not be powerful enough to achieve adequate flow through the additional solar collector loop or to maintain sufficient flow through the filter to maintain pool water quality. When this occurs, a larger pump should be installed or a booster pump can be added to the pool collector loop. Pool collector manufacturers can assist with system designs when boosters are needed.

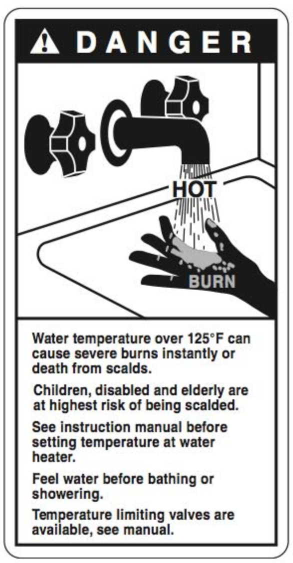
8.4.3 Install system safety devices

Temperature and pressure relief (T&P) valves are required on all water heaters. The standard valve will release fluid, or *pop off*, at 210°F (99°C) and/or 150psi. T&P valves should be installed per manufacturers' instructions and in compliance with local codes.

Pressure (only) relief valves (PRV) are installed on collector loops. PRVs used in SWH systems are typically rated from 30psi to 150psi. These valves protect system components from damage or failure due to excessive pressure. A suitable PRV must be rated below the pressure rating of each component in the system. PRVs can be installed indoors if the appropriate termination of the relief piping adheres to national and local codes.

T&P and pressure relief valves must adhere to a set of strict rules regarding the drain piping from the valve to its termination point. Typical requirements for relief valve piping include:

- Restrictions on reducing the diameter of relief drain piping
- Appropriate termination locations
- The distance the piping must terminate above a designated surface (concrete, drain, etc.)
- Restrictions on installing traps in the piping



Time/Temperature Relationship in Scalds

Temperature	Time To Produce a Serious Burn
120°F	More than 5 minutes
125°F	1½ to 2 minutes
130°F	About 30 seconds
135°F	About 10 seconds
140°F	Less than 5 seconds
145°F	Less than 3 seconds
150°F	About 1½ seconds
155°F	About 1 second

Table courtesy of Shriners Burn Institute

The chart shown above may be used as a guide in determining the proper water temperature for your home.

⚠DANGER: Households with small children, disabled, or elderly persons may require a 120°F or lower thermostat setting to prevent contact with "HOT" water.

NOTICE: Mixing valves should be installed to reduce the point of use water temperature by mixing hot and cold water in branch water lines. Contact a licensed installer or the local plumbing authority for further information.

Figure 8-43 – Tank manufacturers typically include information on scalding temperatures and mixing valve requirements in installation manuals. (Courtesy of Rheem)

In many jurisdictions, pressure relief valves installed at the collector outlet are exempt from termination rules.

In Antifreeze systems, the rating of the PRV has significant bearing on the size of the expansion tank. An expansion tank is sized to maintain system pressures between the normal operating pressure and the pressure rating of the PRV. If the expansion tank is too small, the PRV will release glycol from the system, requiring servicing of the system. When the PRV rating is close to the normal operating pressure of the SWH system, the expansion tank will need to be large enough to accommodate the thermal expansion caused by heated glycol and possibly steam.

The International Plumbing Code (IPC) and the Uniform Plumbing Code (UPC) have significantly different requirements for the rating of PRVs in Antifreeze systems. The IPC allows the use of single-wall heat exchangers regardless of the PRV rating. The UPC limits the PRV rating to 30psi when using single wall heat exchangers. If the system is engineered, the UPC allows a slightly higher PRV rating.

Anti-scald and tempering, or mixing, valves are three-port valves that are used to limit the temperature of water delivers to the hot water fixtures. Two of the ports on the valve are connected to the cold water supply and the hot water supply from the storage tank or water heater. The third port is the outlet, or mix, port; its temperature is controlled by the valve.

Storage tank volume and weight

For a standard cylindrical solar storage tank, the storage volume can be determined using the following formula:

$$V = \pi r^2 h$$

where: V = the volume of the vessel

$\pi \approx 3.14$

r = the radius of the vessel

h = the height of the vessel

When determining a tank vessel's volume, it is important that the dimensions account only for the storage area and exclude insulation, jacketing, etc. For example, a tank with an outside diameter of 26″ and a height of 64″ is surrounded by 2″of foam insulation and tank jacket. The approximate volume of this tank is:

$$r = d/2 = (26''\text{-}4'')/2 = 11''$$

$$h = 64''\text{-}4'' = 60''$$

$$V = 3.14 \cdot (11'')^2 \cdot 60''$$

$$V = 22{,}796\text{in}^3$$

To convert from cubic inches to cubic feet, divide by 1724. Alternately, the dimensions could be converted to feet before calculating the volume.

$$V = 22{,}796\text{in}^3 \div 1724\ \text{in}^3/\text{ft}^3$$

$$V = 13.22\text{ft}^3$$

There are approximately 7.5 U.S. gallons in one cubic foot, thus the tank volume in gallons is:

$$V = 13.22\text{ft}^3 \cdot 7.5\ \text{U.S. gal}/\text{ft}^3$$

$$V = 99\ \text{U.S. gallons}$$

To determine the weight of this water, the volume is multiplied by the density of the water, 8.3 pounds per gallon:

$$W = (99\ \text{U.S. gal}) \cdot (8.3\ \text{lb/U.S. gal})$$

$$W = 823\text{lbs}$$

Anti-scald valves are more precise and more expensive than tempering valves, although they perform similar functions. The difference between the valves is safety: if an anti-scald valve fails, it will limit the hot water supply to protect occupants from scalding water.

Anti-scald valves should be installed on the outlet of the auxiliary tank in two-tank systems to ensure that a failed valve can be identified. If the valve is installed on the hot outlet of the solar storage tank in these systems, a valve that has failed or is set too low will be difficult to identify because the auxiliary heater will feed a constant temperature to the fixtures.

8.4.4 Place storage tanks

Storage tanks used in SWH applications may be pressurized or nonpressurized. Pressurized solar storage tanks are similar in construction to standard tank-type water heaters. Nonpressurized tanks are uncommon in conventional water heating applications, but are sometimes used in custom-designed systems that require large quantities of thermal storage, such as buffer tanks for wood boilers and large SWH systems.

Pressurized storage tanks suitable for residential SWH systems range from 30 U.S. gallons (110 L) to 120 U.S. gallons (450 L). Pressurized tanks that are larger than 120 U.S. gallons (450 L) often require ASME-certification, which significantly increases costs. Often, multiple tanks are used when large volumes of pressurized storage are required.

Stratification

Stratification is the phenomenon in which water will remain layered by temperature in solar storage tanks, with the hottest layers remaining at the top of the tank and cooler layers towards the bottom. The layering occurs due to the difference in density of water at different temperatures.

Effective stratification improves system efficiency. For example, a one-tank system relies upon stratification to minimize the auxiliary heat required. These systems utilize an electric element or a coil from a fossil fuel boiler in the top portion of the tank; solar energy is used to heat the bottom portion of the tank. If all of the solar heat has been exhausted from the tank and the tank maintains good stratification, the bottom of the tank can be the temperature of the incoming cold water supply and the water at the top of the tank will be at the setpoint temperature for the auxiliary heat source. This allows the solar collectors to operate towards their highest efficiency. In essence, stratification allows a one-tank system to function as two tanks stacked upon one another. Since heat will only migrate upwards in a solar storage tank, the solar collectors can add heat to the top of the tank, but the auxiliary heat source cannot add heat to the bottom of the tank.

Stratification is a function of a tank's geometry and inlet piping. Stratification is more pronounced in tall, narrow tanks and in tanks that minimize water disturbance. The inlet piping should keep mixing to a minimum when new water is supplied to the tank in order to preserve thermal layering. Some unpressurized storage tanks are marketed as stratification tanks. Because the water in these tanks remains stagnant and heat is added and drawn from the tank with a series of heat exchangers, these tanks are able to eliminate mixing.

A tank with pronounced stratification can be used to increase distribution efficiency, as well. The hottest water in the top of the tank can be used to supply domestic hot water while heat in the middle of the tank can be used to assist with space heating in high-mass distribution systems, such as in-floor radiant tubing.

Larger pressure vessels can be custom made, but they are typically expensive and require a few weeks to build and deliver.

Non-pressurized, or atmospheric, tanks are available from several manufacturers or can be constructed on-site. Standard non-pressurized tanks incorporate an insulated frame and a liner. These tanks hold a fixed quantity of water that acts only as a heat transfer medium. Heat is transferred to and from the heat transfer medium using either removable, internal heat exchangers or by pumping the heat transfer medium through an external heat exchanger. Similar tanks can be constructed on-site using standard building materials and a liner made from EPDM or other materials rated for the appropriate temperature. Fiberglass or stainless steel tanks can also be modified as non-pressurized storage tanks.

Other nonpressurized tanks include European stratification tanks and Chinese thermosyphon tanks. Stratification tanks utilize the natural thermal layering of water and multiple heat exchangers to draw usable heat for various purposes, such as domestic hot water and space heating. The Chinese evacuated tube thermosyphon incorporates a 20 U.S. gallon (75 L) to 30 U.S. gallon (110 L) tank constructed of very thin stainless steel that will only withstand very small pressures. These tanks are considered nonpressurized since almost all municipal and private well systems in the U.S. have a minimum pressure of 20psi to 40psi.

The choice between a single-tank or double-tank system depends upon several factors. Single-tank systems take up less space, which is a critical factor for some installations. They also have less standby heat loss than double-tank systems. Double-tank systems can be more efficient than a single-tank system depending on the tank insulation levels and the water usage patterns of the household. Depending on tank sizes, heavy morning usage can actuate the backup element in a single-tank more often than a double-tank system. Installers may prefer one type of system to the other, but ultimately the system selection should depend upon the specific requirements of the installation.

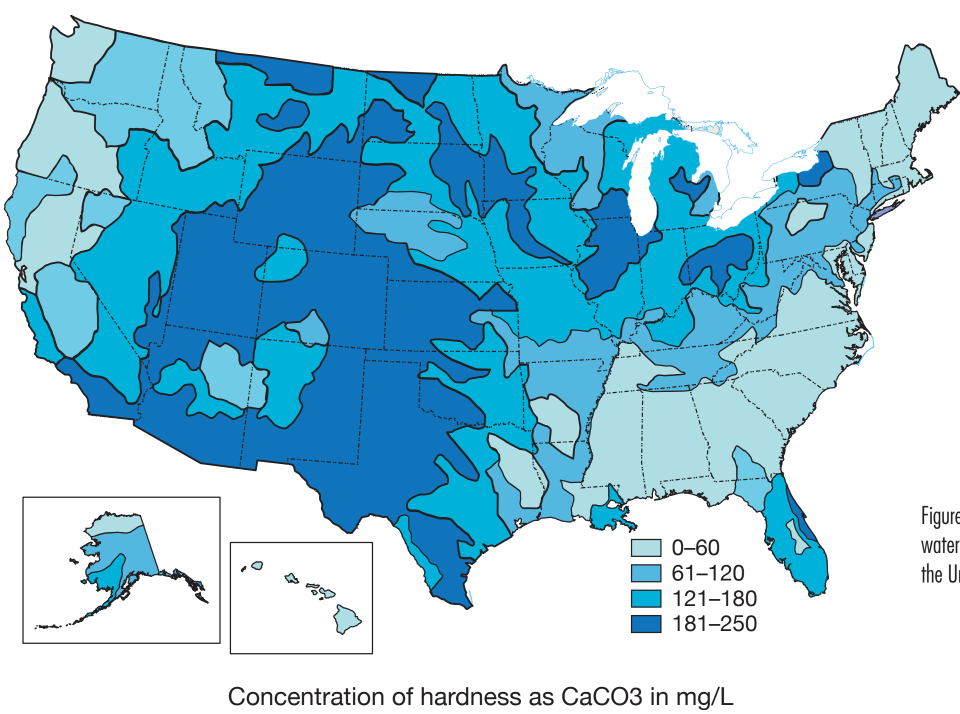


Figure 8-44 – Map of standard water hardness for locations in the United States. (Courtesy of USGS)

Standard residential SWH systems are configured as single-tank or double-tank designs. Single-tank systems incorporate either a single electric backup element or a coil from a boiler in the upper portion of the storage tank to heat the DHW on cloudy days or during times of unusually high hot water usage. In systems with two tanks, the solar collectors

Figure 8-45 – Earthquake strap for a standard water heater.

are the only source of heat for the solar storage tank, which acts as a preheat tank for an auxiliary (backup) water heater. The auxiliary heater, which typically uses natural gas, electricity, propane, or oil, heats the water when the solar energy is not adequate for the load. Where solar is installed in conjunction with a natural gas-fired tank-type water heater, a double-tank configuration is used, since the gas-fired tank is heated from the bottom and unable to stratify.

Tankless water heaters sometimes serve as a backup heater. When integrating a tankless water heater with a SWH system care must be taken to ensure that the tankless heater is designed to work efficiently with preheated water. Tankless models that are used with SWH systems must modulate based on the incoming temperature and produce a fixed outlet temperature. Models that are flow dependent provide a fixed amount of heat regardless of the incoming temperature and are inappropriate for use with preheated water.

Tankless heaters often have higher installation costs than tank water heaters, especially if electrical, flue pipe, combustion air, and/or gas pipe upgrades are required. Tankless heaters with copper heat exchangers are not compatible with hard water. In areas with hard water, the heat exchanger can accumulate scale and become clogged. Hard water is defined as tap water with a high mineral content, and the degree of hardness can vary significantly over distances of less than twenty miles in some areas.

Pressurized storage tanks are available as thermal storage tanks without a heat exchanger or as indirect tanks with an internal heat exchanger(s) or a wraparound heat exchanger. Mild steel tanks with a glass lining are the most common pressure tanks in SWH systems. Stainless steel, fiberglass-lined, and polybutylene-lined tanks are also available.

When thermal storage tanks are used in IFC systems, an external heat exchanger is required. Two pumps are often required to transfer heat through the heat exchanger—the solar pump and a bronze or stainless steel pump that circulates potable water. This configuration requires an additional pump, increases labor costs, and increases the parasitic power required to run the additional pump. The advantage of using a two-pump external heat exchange design is that it can increase the heat exchange efficiency and permit the use of a less expensive storage tank.

The installer must consider several factors when placing a storage tank. Storage tanks should be installed as near as practicable to the existing water heater in double-tank systems. In areas subject to earthquakes, tanks must be located where they can be strapped to a wall or otherwise braced or anchored to resist lateral movement in accordance with state and local code requirements. The tank must be placed on a level surface that can adequately support the filled weight of the tank. Some plumbing codes require that the tank be elevated above the floor surface with feet, a concrete pad, or concrete blocks. If the tank is placed on a floor that can be damaged by leaking, such as a wood-framed floor, an approved water heater drain pan must be installed underneath the tank and be drained to an appropriate location. Additional code requirements may apply for tanks that are installed in garages or attics.

8.4.5 Water heater integration

Many jurisdictions require licensed personnel for the installation of storage tanks. A licensed plumber is often required by law to connect a SWH system to the potable water system. If a fossil fuel water heater is being replaced with a single solar storage tank with a backup element, an adequate electrical circuit must be provided. This usually requires a licensed electrician. Licensed professionals must consult and follow the manufacturer's instructions and national and local codes. In some locations, specialty solar contractor licenses are issued, allowing for all of the scopes of work required to install a solar heating system to be performed by the license holder.

Integration with the auxiliary water heater depends upon the configuration of the system. Single-tank systems are plumbed like a standard water heater. In double-tank systems, including most ICS systems, cold water will normally be piped to the solar storage tank first. The hot outlet pipe on the solar tank is then piped to the cold inlet on the auxiliary heater. This method of piping the tanks in series allows the cold water to be preheated by any available solar energy. Solar heated water produced in the preheat tank will be transferred to the backup heater whenever hot water is drawn from any tap. Solar heated water will reduce or eliminate the actuation of the auxiliary heater, whether it is a standard water heater or an appropriate tankless model.

Figure 8-46 – Drainback tank with a sight gauge and an internal heat exchanger.

8.4.6 Drainback tanks

Drainback tanks are integrated into a SWH system as a 5 U.S. gallon (20 L) to 10 U.S. gallon (40 L) reservoir in the collector loop piping or as a standalone solar storage tank for larger systems. Reservoir-only Drainback tanks are often installed next to the storage tank or on a shelf nearby. Larger drainback tanks can be utilized as standalone storage tanks. In these systems, the water in the large drainback tank is circulated through the collector and heat is transferred to the potable water or heating system through integrated or external heat exchangers.

A Drainback tank with an internal heat exchanger should be twice the volume of the collectors and piping in order to keep the exchanger immersed when the collector loop is filled with water.

8.4.7 Install heat exchangers

External heat exchangers require two pumps—one for the collector loop and one to circulate potable water. Stainless steel plate-type heat exchangers are preferred by most manufacturers and installers because of their high-efficiency heat transfer properties. The exchangers are able to maximize the heat transfer surface area through the use of multiple plates and have large wetted heat exchange surface areas due to the small fluid passages. External exchangers are also available in a tube-in-shell configuration. Smaller tube(s) immersed in a larger tube (shell) circulate the HTF, while potable water or pool water to be heated circulates in the shell. Exchangers that are not already incorporated into a pump station are usually secured to a wall near the storage tank. Mounting strut or similar hardware makes a good mounting interface for exchangers, pumps, expansion tanks and other small balance of systems components.

8.4.8 Install meters

Flow meters measure the system flow rate and are extremely helpful in optimizing system performance, especially if the system is commissioned when temperature differentials cannot be observed.

While thermometers, flow meters, and pressure gauges are most commonly installed as analog devices, electronic versions of these components can be connected to an appropriate controller, calorimeter, or datalogger for system monitoring. These devices are useful for determining whether the system is operating properly and can be used to estimate the amount of energy produced by the SWH system. Standard monitoring systems record the data on a secure digital (SD) memory card or are connected to networks where data can be recorded by a server or transmitted via the Internet. Several manufacturers offer controllers or controller accessories that allow for integrated performance monitoring. Other products are offered as add-on devices that utilize dedicated temperature sensors solely for monitoring purposes.

The information provided by monitoring systems is valuable only if the meters are installed properly. Some manufacturers recommend using shielded wire when connecting flow and pressure meters to the controls in order to reduce signal interference. Heat quantity calculation requires two reference temperatures and an instantaneous flow rate measurement. Flow rates vary based upon the fluid viscosity, which varies based on temperature. Flow rates will also vary based on pump speed variations for systems that incorporate such a function. If the energy monitoring system is installed on the potable water lines, flows will vary based on household water use. Some controls allow the installer to input an average flow rate to estimate the system production; this method has limited accuracy due to natural variations in flow rate as the temperature of the heat transfer fluid changes.

Once the appropriate components have been selected, consideration must be made for the location of reference sensors. If the quantity of energy delivered to the storage tank is desired, the reference temperatures should be located on either side of the heat exchanger in IFC systems or where the collector supply and return piping enters the storage tank in DFC systems. Measurements can also be made across the collector array to determine collector heat production or across the potable lines of the storage tank to determine solar heat delivery to the auxiliary tank or to fixtures. The placement of the sensors will determine what heat is being measured. Installing redundant analog devices is important when using electronic meters, as they allow the installer to evaluate the accuracy of the electronic devices.

8.5 Wire the system

Wiring in SWH systems is limited to the differential or PV controls in active systems and the electrical elements used for auxiliary heat. The wiring in SWH systems carry various voltages and currents and an installer should take steps to ensure that proper safety practices are followed and that wiring is installed in accordance with local codes. If a PV module is used to power the pump in a forced circulation system, the provisions of article 690 of the National Electrical Code must be followed. The photovoltaic wiring should be installed by a licensed electrician or other qualified individual as required by state or local regulations.

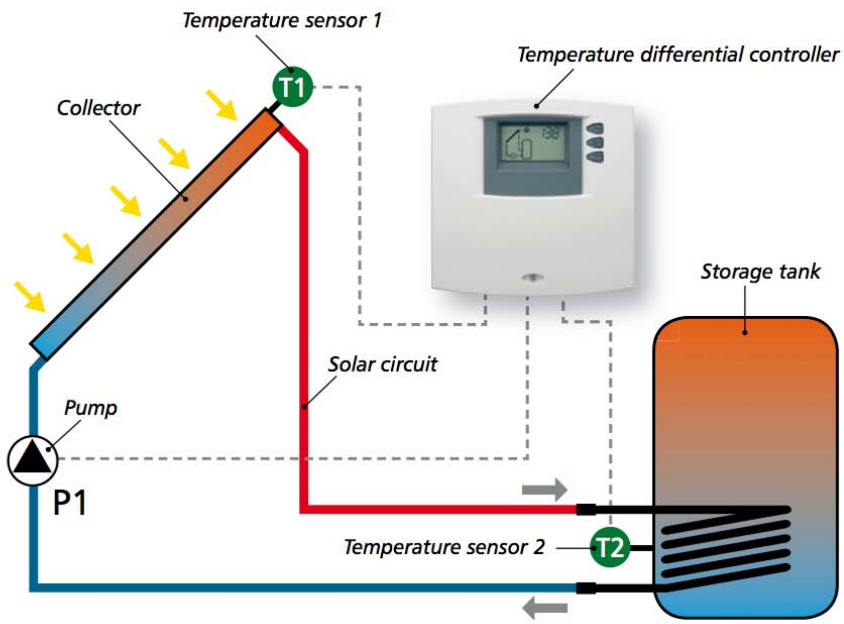


Figure 8-47 – Standard configuration of sensor placement for a differential controller.
(Image courtesy of SunEarth)

8.5.1 Install controller

Solar water heaters need a fairly sophisticated control to maximize the collection of available solar energy. The system controls need to accurately turn pumps on and off under a variety of conditions and water temperatures. Timers and set point controls are not accurate enough to control SWH systems efficiently. Solar energy is intermittent and therefore cannot be harvested on demand. In order to capture all available solar energy, the temperature of the HTF in the solar collector and the potable water in the storage tank need to be measured simultaneously. Differential controls constantly monitor system temperatures and turn pumps, and sometimes valves, on and off based on the temperatures of the sensors. When the temperature of the HTF in the solar collector is sufficiently warmer than the storage tank, the control energizes the primary solar pump to circulate the water. When the temperature difference is too small to generate usable heat, the differential thermostat turns the pump off. Differential controls may also incorporate digital displays and provide additional functions, such as a high limit setting for tank temperature control and a vacation mode setting.

An installer must determine an appropriate location for the controller. When possible, it is best to mount the controller near the storage tank and pump station. This limits the length of wire required and reduces installation time. Occasionally a client will want the controller installed in the living space for easier access. Where such placement would create a significant inconvenience, controllers with remote displays or wireless capability may be of benefit.

8.5.2 Connect sensors

Sensors are used to monitor system temperatures. An experienced installer is aware of the different types and styles of sensors used and of the importance of sensor placement for efficient system performance.

Figure 8-48 – Pool control and three-port valve.

8.5.2a Sensors

Two types of differential control sensors are common in SWH systems in North America—thermistors and resistance temperature detectors (RTDs). Both types of sensors undergo a change in resistance when their temperature changes. The most common type of thermistor used in SWH systems is a 10k inverse thermistor. The sensor has an electrical resistance of 10,000 ohms at 25°C (77°F). As the temperature rises, the resistance drops—hence the inverse designation. RTDs provide more precise measurements than thermistors, but their accuracy is dependent on the length, size, and type of wire used. The standard RTD used in SWH systems is a platinum, 1,000 ohm (Pt1000) sensor with positive coefficient—as the temperature increases, the resistance also increases. Pt1000 sensors have a resistance of 1,000 ohms at 0°C (32°F). Pt1000 and 10k sensors must be used with the appropriate controller and cannot be interchanged.

Manufacturers enclose temperature sensors in metal casings and use an epoxy-like substance to encapsulate the delicate electronics to protect them from water and the outdoor elements. The metal casings may be shaped like a cylindrical probe or may have a flat section for clamping to the outside of piping or screwing into a tank stud. If the sensor has a flat section suitable for clamping with a hose clamp it should be tightened securely. If the sensor is a probe, care should be taken to avoid crushing the sensor housing.

Pool controls

SPH controls are similar to SWH differential thermostats. Pool systems usually have a much higher flow rate than SWH systems and the on and off differentials are adjusted accordingly. The typical turn-on temperature differential of a pool control is about 5°F (3°C) and the turn-off differential is about 2°F (1°C). Pool differential thermostats normally control a three-port motorized valve that diverts the pool water to the collectors when the differential is achieved. The control also energizes booster pumps if they are required in the system. As long as the pool collectors can add heat to the pool, the control will keep the valve positioned to divert water to the collectors. When the solar resource cannot add heat to the pool, the valve moves to allow normal filtration and shuts off the booster pump, if used. Where solar pool heating systems are installed, pool pump timers are usually set to filter only in the daylight hours when the sun can heat the pool.

8.5.2b Sensor placement

Measurement of the fluid temperatures in a SWH system is the most important consideration for efficiently controlling pumps. Collector and tank sensors should be placed in locations that best represent the temperatures to be measured.

Collector sensors are typically installed in a thermal well, secured against the hot outlet pipe of the collector array, or attached to the absorber plate. In SRCC OG-300 Certified systems, the sensor location should be specified in the manufacturer's instruction manual. Some collector manufacturers include a thermal well kit that is installed in the hot outlet piping of the collector array. Other manufacturers have immersion wells that are in direct contact with the collector header. Some systems require that the collector sensor be secured to the hot return pipe of the collector array using a stainless steel hose clamp. When installed in this location, the collector output sensor should be placed within an inch of the collector, if possible, and particular attention must be made to properly insulate the sensor. If the insulation is damaged or is inadequate, the sensor readings will be inaccurate. If the sensor is attached to the absorber plate, the temperature differential on the control may need to be increased to ensure efficient operation.

Tank, or storage, sensors must be installed to measure the coldest temperatures at the bottom of the tank. Many solar storage tanks have immersion wells or ports where immersion wells can be installed. When possible, temperature sensors should be coated in thermal grease and immersed in these wells. Using silicone sealant to seal the well will isolate the sensor from the ambient air around the tank and provide the most accurate readings. Alternately, the tank sensor can be placed against the tank vessel and isolated from the ambient air temperature with the tank insulation. Some solar storage tanks have a threaded lug at the bottom of the tank where a sensor can be bolted to the tank.

8.5.3 Install sensor wires

Temperature sensors can typically be wired with 18-gage thermostat wire, unless the wire length exceeds 100 feet (30m) or the sensor wire could be subject to electrical noise. Electrical noise can occur when the sensor wire runs close to high voltage wire. If electrical interference affects sensor readings, shielded sensor wire should be used.

The collector sensor wire will normally be run with the hot collector loop return pipe. Plastic wire ties can be used to attach the wiring to the pipe insulation.

8.5.4 Wire the pump(s)

Cord-and-plug connections save time on installations and are NEC-approved disconnects for motors up to 1 HP. Wire should be sized in accordance with manufacturer's specifications and local code requirements. If a cord is not used between the controller and line voltage or between the controller and any pump(s) or motorized valve(s), wiring assemblies must be installed in conduit. Conduit attached to pump wiring should be flexible to allow for motor vibration.

8.5.5 Make final AC connections

With cord-and-plug connections, the controller simply needs to be plugged into a nearby outlet. In the case of hard-wired controls and pumps, they should be installed by a qualified professional. Most jurisdictions require a licensed electrician, who will be able to determine the best method of connecting the wiring to the existing electrical service.

Figure 8-49 – Pressurizing an expansion tank with compressed air.

8.5.6 Protect wires

All sensor wiring should be installed in accordance with the NEC or the electrical code adopted by the AHJ. Exterior sensor wiring must be protected from UV-degradation by using a wire with UV-protected insulation, by running the wire through UV-rated conduit, or by placing it on the outside of the pipe insulation between the insulation and the weather proofing.

8.6 Pressure test the system

It is most efficient to pressure test the entire collector loop upon completion. This is not always possible, as portions of the system may need to be tested intermediately if they are

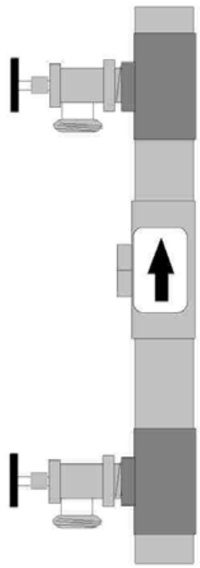


Figure 8-50 – Fill/drain assembly with check valve.

concealed in walls or chases. The requirements listed in Section 8.3.6 apply when the entire collector loop is tested. In order to satisfy code requirements, the pressure test needs to be performed prior to installation of the pressure relief valve. Any other components that are rated below the system test pressure must be isolated during the test.

8.6.1 Inspect for leaks

Solder leaks are almost always readily identified. A solution of soap and water can be used to detect very small leaks as soap bubbles will appear at the leaking joint(s). The pressure should be monitored for at least fifteen minutes to ensure piping integrity.

If leaks are found, the installer must fix them and repressurize the system. A solder leak requires depressurizing the system and resoldering the fitting. Threaded joints should be inspected carefully since they can have miniscule leaks that are almost undetectable. A leak at a threaded joint can sometimes be stopped with another quarter or half turn of the fitting if the piping permits. Malleable fittings, such as bronze, can sometimes leak directly through the fitting. The only remedy is to replace the fitting. Leaks can cost installers significant time on a job, so care must be made when joining piping.

8.6.2 Isolate the expansion tank

Prior to filling the system, the tank needs to be charged to the appropriate pressure. Expansion tanks are pre-charged by the manufacturer and the charge pressure can be adjusted by means of the Schrader valve opposite the pipe connection. Charge adjustments can only be made when the system is empty or before the expansion tank is installed; the expansion tank charge pressure cannot be accurately determined once the system has been filled. The tank should be charged to the collector loop system pressure. If the collector loop pressure will be 15psi, the air cushion in the tank should be 15psi. Significantly undercharging the expansion tank will result in a reduced volume for fluid expansion and larger pressure variations. A slight undercharge (2–3 psi) is preferred by installers in cold climates to accommodate contraction of fluid in the system and must be accounted for when the expansion tank is sized. An undersized tank can lead to high system pressure fluctuations when the HTF is hot and/or the pump is energized.

8.6.3 Flush system

Once the installer is confident that the system will not leak, the collectors and collector loop piping should be flushed. Flushing the system purges the residue from soldering and other small foreign objects from the piping and components. A system flush will also detect any gross flow restrictions in the loop. Flushing the system can be accomplished with a fill/drain valve assembly as shown in Figure 8-50.

If the collectors will be exposed to bright sunlight for more than a few minutes while filling, purging, or charging the system, they should be covered with a tarp or other suitable cover to prevent steam production when introducing fluid into the collectors.

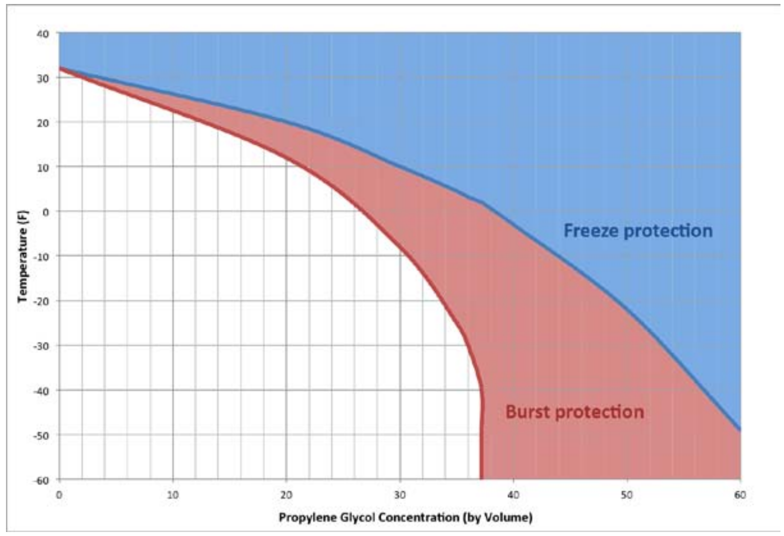


Figure 8-51 – Freeze and burst protection ratings for various concentrations of propylene glycol.

Some system manufacturers require that the system is initially flushed with a trisodium phosphate (TSP) solution, which acts as a degreaser and cleaning agent. An initial flush with TSP requires a charge pump and a container large enough to accommodate slightly more than the system fluid volume.

Boiler drain valves installed in the system piping allow hoses to be used for flushing and filling the system. Service water pressure can be used to flush the system and takes a few minutes. After the system is flushed, it should be drained completely for charging with heat transfer fluid. In some cases, the piping loop will not completely drain by gravity. Compressed air can be used to help force out trapped water. If water still remains, the installer must account for it when charging the system.

8.7 Fill the system

Once the installer is confident that the system is free of leaks and that all debris has been cleared from the piping, the collector loop can be filled with the heat transfer fluid. In direct systems, filling the system is as simple as opening an isolation valve to allow the water supply to flood the system. In indirect systems, the procedure is more complex.

8.7.1 Antifreeze systems

There are several options for filling an Antifreeze system, but the most common procedure involves the use of a charge pump. Experienced solar installers typically have a custom or manufactured filling station that they use for filling and pressurizing the system. The pump must be large enough to eliminate air in the collector loop and provide the head required to properly pressurize the system. The cost of a high head charge pump that can produce system pressures of 50psi to 75psi may be substantial, but the pump will pay for itself many times over in labor savings—in particular on service calls that require recharging Antifreeze systems.

Other options that are less common and less effective include filling the system from the roof, using drill-operated pumps, or using medium-duty pumps available at home centers that can develop about 15 psi of system pressure. Each of these methods is much more time consuming, far less effectual at removing air from the system, and should be left to the do-it-yourself homeowner or used as a backup if the charge pump malfunctions.

The most common antifreeze solution used in SWH systems is a mix of propylene glycol (PG) and water. The concentration of the PG in the solution is determined by the minimum ambient temperature at the site; it should be high enough to keep the solution from developing ice crystals. This is known as the fluid's freeze point. Generally, the higher the concentration of PG, the lower the freeze point. Propylene glycol reaches its useful limit at a concentration of approximately 60% PG; above this concentration, little additional freeze protection is gained. Manufacturers suggest a PG concentration that will prevent freezing at 5°F (3°C) less than the expected minimum ambient temperature. If the site falls below this temperature, the pump may not be able to circulate the slushy PG solution. The system may be damaged if the temperature drops below the burst point.

A variety of manufacturers offer propylene glycol-based antifreeze products advertised for use in SWH systems. These products are available in both pre-mixed and pure form. Antifreeze products designed for use in SWH systems must be formulated to be non-toxic. In addition, SWH system antifreeze must be able to withstand repeated episodes at high temperatures—stagnating solar collectors can easily reach 400°F (200°C) or higher. To address this likely occurrence, antifreeze providers add various chemicals that act as inhibitors, or buffers. The inhibitors allow the antifreeze to better withstand higher temperatures, while still preserving the nontoxic attributes that are mandatory.

In areas where extremely high summertime temperatures are expected, it is wise to use an antifreeze product that is rated for the highest possible temperature. Further, it is advisable to provide for a regular inspection regime for the system, in order to ensure that the antifreeze has maintained its original chemical composition and freeze tolerance. Refer to the antifreeze provider's instructions for more information about the selection and maintenance of antifreeze products.

Before filling the system, the installer must verify that all drains are closed and open the fill/drain valves. A feed hose is attached from the pump to the system fill valve. Another hose should be connected to the drain valve and routed to the glycol reservoir. The glycol reservoir may be a five-gallon bucket (or larger), a standard reservoir in a manufactured filling station, or another suitable, clean container. A third hose is connected to the suction side of the charge pump and draws the glycol solution from the reservoir.

Consideration must be made for the collector temperature. If an evacuated tube collector with heat pipes is installed, it is often advantageous to install the tubes after the system has been charged to avoid the challenge of charging a stagnated system. Alternately, a cover can be draped over the collectors if the sun is shining.

Glycol can be packaged in containers ranging from 1 U.S. gallon to 55 U.S. gallons, but is commonly transported to the jobsite in 5 U.S. gallon buckets. The container of pure glycol is poured into the glycol reservoir and then filled with the correct amount of water. If the water at the site contains significant mineral deposits or is heavily discolored, the installer should bring better quality water to the site to mix the solution.

At this point, the installer must estimate the volume of fluid required to fill the system. Large grid-style flat plate collectors require between 1 U.S. gallon (3.8L) and 1.5 U.S. gallons (5.7L) of the mixed solution. Serpentine flat plates and evacuated tube collectors may only need 0.2-0.5 U.S. gallons (0.8-1.1L) per collector. Each collector manufacturer's product documentation will contain this information. The fluid capacity of the piping can be determined using the piping volumes below:

Copper size	Type L	Type M
½"	1.21 gal (4.58 L)	1.32 gal (5.00 L)
¾"	2.51 gal (9.50 L)	2.69 gal (10.18 L)
1"	4.29 gal (16.24 L)	4.54 gal (17.19 L)
1¼"	6.55 gal (24.79 L)	6.81 gal (25.78 L)
1½"	9.25 gal (35.01 L)	9.51 gal (36.00 L)


Figure 8-52 – Checking propylene glycol concentration using a refractometer.

The size and type of heat exchanger also influences system volume. The fluid capacity of the heat exchanger must be obtained from the manufacturer.

Once the installer has estimated the system volume, the glycol should be mixed to the desired concentration. The freeze protection rating of the solution can be checked by using a glycol refractometer. It is always better to have extra glycol solution mixed prior to charging the system.

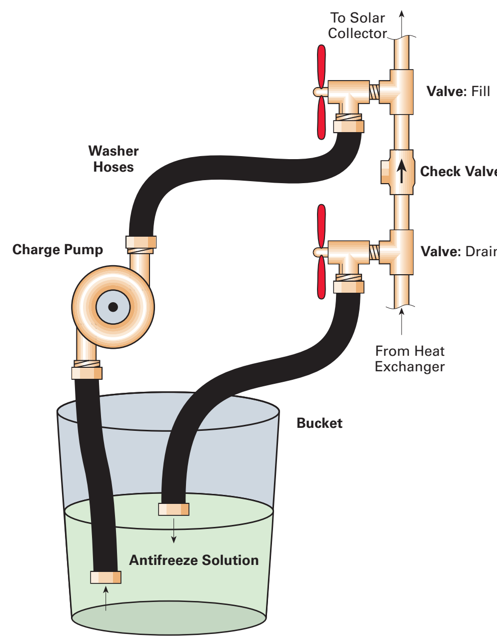


Figure 8-53 – Filling an antifreeze system with the check valve between the fill and drain valves.
(Courtesy of homepower.com)

The filling station should then be setup to fill the system. When using a five-gallon bucket as the glycol reservoir, a carpenter's spring clamp can be used to secure both hoses to the bucket to avoid spills. If needed, the bucket should be elevated so that both hoses can reach it. All extra containers of the premixed glycol solution should be staged near the filling station.

The installer must ensure that the system fill and drain valves are open all the way before starting the pump. If required, the pump should be primed with the glycol solution. Once the pump is on, the return hose will discharge a substantial amount of air, which is being forced out of the piping as the system is filled. The end of the return hose should be submerged in the reservoir to allow visual inspection of air bubbles. The glycol solution should circulate until the return hose fluid is flowing smoothly without air bubbles. This may require restricting flow from the drain valve to increase the system pressure in an effort to force trapped air from the loop. When the fluid is flowing without bubbles, the drain valve should be closed. The liquid system pressure should increase on the pressure gauge. The installer must monitor the gauge and shut the fill valve once the desired system pressure (see sidebar) is reached. Once the system is filled the pump can be shut off.

Figure 8-54 – Filling the charging station with a solution of propylene glycol and water.

Figure 8-55 – Connecting a glycol filling station to the pump station fill valve.

Once filled, the system should be tested and purged of any air in the piping or components. This can be accomplished using the solar circulator. The wiring of the control, sensors and pump(s) should have already been completed. The installer should set the controller to manually turn on the pump while leaving the filling station hoses connected to the fill and drain valves. The system may still have a small amount of air at the top of the system, which can be released via the air vent at the top of the system, if installed. Air is released from the air vent by unscrewing the setscrew in the coin vent or pushing in the valve stem of the automatic vent until only liquid appears. If the sun has come out during this process, the liquid expelled from the vent might be very hot.

If bleeding the air has caused any pressure drop on the gauge, the fill valve should be opened and the pump turned back on. Once the system pressure is reached, the pump should be turned off and the valve

Initial system pressure

In direct systems, the initial system pressure will be the pressure of the cold water supply. This pressure will vary over time. For systems connected to the public water supply, the pressure will typically be between 50–60psi. For systems connected to a well, the normal operating pressure may vary from 20–40 psi.

Drainback systems are often installed at atmospheric pressure. Atmospheric pressure is 14.7psi at mean sea level and varies by elevation. When a system is installed at atmospheric pressure near sea level, the absolute pressure is 14.7psia, but the gauge pressure is 0psig.

The initial pressure for antifreeze systems depends upon the height of the system. The pressure varies at various heights in the system. The initial pressure must be high enough to maintain pressure at all times in the top of the system. If the pressure at the top of the system drops to 0psig or less, there is potential for air to enter the system through fittings such as air vents.

The minimum pressure at the collectors is often based on the contraction of fluid during cold weather. For example, if a system in a cold, northern climate is initially pressurized on a hot summer day, the system pressure can drop significantly in the winter when the collectors are subjected to temperatures below freezing. In these conditions, an installer may choose to charge the system with a pressure in the collectors between 5psi and 10psi.

To determine the initial system pressure, the installer must determine the height that the collectors are above the pressure gauge, in feet. The minimum initial system pressure is calculated by adding 0.45psi per foot of height to the minimum desired pressure at the collectors.

For example, if the collectors are 20 feet above the pressure gauge at the pump station, the minimum initial gauge pressure would be 9psi greater than the desired minimum collector pressure.

Some manufacturers require very specific initial system pressures. Installers should consult these recommendations prior to filling the system.

closed. When the air is eliminated from the system and there are no leaks, the hoses are disconnected from the valves and the system is ready to be insulated and commissioned.

8.7.2 Filling a Drainback system

Best practice is to use distilled water when filling a Drainback system; in fact, many system manufacturers require that distilled water be used. Tap water can hinder quick draining of the system in the future and affect system performance. This occurs when the controller shuts the pump(s) off in times of high solar irradiance due to the system reaching the maximum solar storage tank temperature. Water in the risers will drain, and any water that is left will evaporate. This can cause dissolved solids to adhere to the inside of the tubes and cause the collector riser tubes to become partially scaled over years of operation. Reduced efficiency is one result of any deposits as they act as an insulator on the inside of the tubes or can be the cause of small riser tubes retaining a column of water within them after years of operation. If this happens, a freeze will likely burst the restricted tube. This phenomenon will not occur if distilled water is used.

A boiler fill/drain valve should be installed near—or at—the top of the Drainback tank, and a drain valve should be installed at the low point of the system. A funnel or drill pump can then be used to add distilled water to the system. The tank should be filled to the top but not above the fill valve. Some Drainback tanks have an interior dip tube in

Pipe insulation thickness

The minimum thickness of pipe insulation varies by jurisdiction; in some jurisdictions, the minimum thickness may not be specified.

- The International Energy Conservation and Construction Code specifies a minimum R-value of R-3 for any mechanical piping carrying fluids above 105F in residential systems. In commercial systems an R-value of approximately R-5.5 is specified for mechanical piping, but this requirement is only for systems that are heated primarily with fossil fuels or electricity.

- The Uniform Solar Energy Code requires a minimum R-value of R-2 for piping that is 1″ in diameter or less; 1½″ to 2″ piping requires an R-value of R-4.

Neither of these codes specifies the minimum thickness of pipe insulation used in outdoor applications. In the absence of code requirements, when using rubber pipe insulation, a minimum thickness of ½″ is recommended. Exterior rubber insulation should be a minimum of ¾″ in thickness for cold climates. Fiberglass insulation should have a minimum thickness of ¾″ and should only be used indoors.

The R-value for pipe insulation varies by type. USEC rates rubber at an R-value of approximately R-4.3 per inch and fiberglass at approximately R-3.0 per inch. Manufacturers' ratings may differ.

Manufacturers of SRCC OG-300 certified systems are required to specify insulation thickness in their installation manuals.

the hot return port of the tank. This will quiet the return water returning to the tank but is only suitable if there is a hole in the dip tube above the water level to allow air to travel up the pipe and break the vacuum. The installer should verify the presence of this weep hole prior to installation by removing the dip tube. If the pump is installed below the level of water in the Drainback tank, it will be primed and ready to start. The differential control can be used to cycle the pump(s) to ensure the system is free from leaks. A Drainback tank serves as an expansion tank and the design prevents thermosyphoning at night, which eliminates the need for a check valve.

8.8 Install insulation

Insulation can be installed either during the installation of the collector loop piping or once the system is filled and charged. There are benefits and challenges with each method. If the insulation is installed as the system is piped, leaks are difficult to detect and may require removal of insulation. If installed at the end of the project, slit insulation will be required, which also requires significantly more labor to install correctly. Slit insulation will tend lose its seal at the seams over time.

Piping can be insulated as it is installed by using spring clamps to compress the insulation and keep it away from any joints during the soldering process. It can then be slid over the joints to eliminate the need to cut and glue joints at pipe elbows. When pipe insulation is slid over elbows it is compressed, which reduces the effectiveness of the insulation. This is preferable to mitered joints, which are difficult to seal properly and can separate over time.

Pre-slit insulation is a time saver and is available with mastic on the edges to join the circumference. Ells and Tees should be mitered at 45° angles and the edges sealed with mastic. After the hot return pipe is insulated, the collector sensor wire can be attached to the outside of the insulation using plastic wire ties.

8.8.1 Types of insulation

SWH systems require the use of specific types of pipe insulation. Standard polyethylene pipe insulation is acceptable for domestic hot water piping, but will melt when exposed to the temperatures present in collector loops. Elastomeric, or closed cell rubber, pipe insulation is able to withstand collector loop temperatures and is commonly used in SWH systems. Fiberglass and mineral wool insulation materials are also appropriately rated for SWH applications, but should only be used for interior applications due to their tendency to absorb water. Insulation rated for solar applications can be procured at solar and insulation distributors, as well as large home improvement retailers.

Required labels and flow direction arrows can be applied to insulated piping.

Other components have unique insulation requirements. Pumps motors should never be insulated; many depend on air flow to dissipate heat. Tanks are insulated by the manufacturer, but insulated blankets can be added if the tank insulation does not meet

Figure 8-56 – Aluminum cladding used to protect pipe insulation from UV-degradation

local codes. Exterior heat exchangers must be insulated with closed cell insulation, which is available in sheets. Other components should be insulated based on the system manufacturer's instructions.

8.8.2 Exposed piping insulation

All pipe insulation exposed to sunlight needs to be protected from ultraviolet (UV) radiation for long-term durability. UV-resistant paint can last from five to ten years; manufacturers of high temperature closed-cell insulation will sometimes recommend a particular type of paint. A maintenance-free, lifetime covering for outdoor insulation is flat architectural grade aluminum used for camper shells and rain gutters. It is easily bent around the insulation and can be fastened with very short screws or bent to form a self-fastening clip similar to common snap lock stove pipe. Another option is PVC cladding, which is available in straight sections and in specially shaped joints for covering elbows and tees. The cladding is secured with adhesive and stainless steel tacks. Another solution is to wrap the pipe insulation with silicone tape.

Jobsite cleanup

Keeping a clean jobsite is important for safety and leaves a positive impression on the client. Having a wet/dry vacuum, a whiskbroom, and a dustpan on the work truck will assist with most cleanup.

It is beneficial to keep bins or boxes for trash and recyclables, such as copper scraps and cardboard, on the jobsite from the start of the project. This helps remove clutter from the work site and minimizes cleanup time at the end of the installation.

9 Commission the System

Almost all of the work required to install an SWH system will have been completed once the system is filled. The final step is to commission the system. While the commissioning of a system typically takes little time, an installer must be mindful during this process. An otherwise perfectly installed system can be ineffectual if the system is not commissioned properly.

9.1 Program the controllers

Proper system operation of a forced circulation system depends upon the appropriate configuration of the differential controller. A system installed following industry best practices will only function properly if the installer has a full understanding of solar heating controls.

The features of differential controls vary by model and manufacturer, thus the installer must review the manufacturer's instructions to ensure proper configuration. Though the selection of a particular controller is the responsibility of the system manufacturer or designer, an installer should have a well-rounded understanding of various control options to ensure that the controller selected for the installation is capable of controlling the pumps, motorized valves, and other outputs required for proper system operation.

All differential controllers require multiple sensors, or inputs. The controller monitors the resistances from these inputs to determine when to provide power via integrated relays. Each differential control requires two inputs for functionality—a tank sensor and a

Figure 9-1 – Programming a differential controller.

collector sensor—and operates the solar pump based on a difference in temperature (ΔT) readings between the sensors. The controller has adjustments for the *ΔT-on* setting that provides power to the pump and the *ΔT-off* setting that shuts off the pump. These settings are dependent upon a variety of factors, including the type of system, the climate, and the length of the run between the storage tank and the collectors. Additional inputs may be used as reference sensors. For instance, a third sensor may monitor the water temperature at the top of the storage tank. Additional sensors may also be used for additional controller functions, such as powering valves to direct heat to multiple storage tanks, providing power to auxiliary heating components, powering recirculation pumps, or diverting excess heat. The availability of advanced functions will depend upon the sophistication of the control. A differential control requires one output to run the solar pump. The complexity of the control increases as the number of outputs increases.

The method for configuring the controller will depend upon the user interface. There are three standard types of controller interfaces common to the market—analog, digital, and wireless. Analog controllers use switches and dials to adjust ΔT settings and use indicator lights to signal whether the controller and pump(s) are operating. Digital controllers use an LCD display and buttons to navigate through programming menus to adjust settings. Wireless controls have no direct interface at the controller, but instead require a computer or handheld device to observe system functionality and adjust controller settings.

Properly configuring the ΔT settings is critical for optimal system efficiency. If the *ΔT-on* setting is too low, it will lead to pump short cycling. Short cycling occurs when the pump turns on and off because the solar radiation is not sufficient to maintain an operational temperature difference between the collector(s) and the tank. If the temperature difference drops below the *ΔT-off* setting, the controller will turn off power to the pump. The band between the *ΔT-on* and the *ΔT-off* is called the hysteresis. The hysteresis needs to be large enough to limit short cycling but not so large that is causes system inefficiency. These settings will depend upon the type of system and the climate.

Short cycling affects efficiency in two ways. First, it wastes the electricity used during short cycles because negligible usable heat is added to the storage tank. Second, the cooling down of fluid in the lines between the collector(s) and the storage tank will lead to cooling of the water in the storage tank. The latter issue is of significant concern in cold climates with a significant volume of heat transfer fluid in piping that is located outdoors or in unconditioned space. Short cycling can also increase wear on the pump.

During configuration of the controller, the installer must verify that the pump is energized by the controller relay and ensure proper functionality of the *ΔT-on* and *ΔT-off*. Most controllers have a manual override to power the pump regardless of the temperature differential. This should be activated to ensure the pump is operational. In digital and wireless systems with a graphical interface, the temperature readings for the sensors should be observed and verified. If there is a short-circuit or open-circuit, the controller will display a code to notify the installer of the error. With analog controllers, the sensor continuity and resistances should be checked using a multimeter. If there is not sufficient solar radiation to trigger the differential controller, heat can be applied to the collector sensor to observe system functionality. This typically requires a two-person work crew—one to place the sensor in the palm of his/her hand and the other to observe the readings at the controller. If higher temperatures are required, heat from a cigarette lighter can be applied to the collector sensor. Care should be made to ensure does not melt the protective sheathing on the wire.

While the solar pump is in operation, the flow rate for the system should be optimized. The installer must verify the design flow rate with the designer or manufacturer and adjust the pump speed, controller settings, and/or balancing valve accordingly. When utilizing speed control, the flow rate should be observed for several conditions to ensure that the minimum and maximum flow rates are appropriate. Some systems may not include flow meters; in such cases, the installer must verify the appropriate flow rate by observing the temperature differences in the collector loop. This approach requires the installer to be on site during normal system operation.

Figure 9-2 — Sensor for measuring instantaneous flow.

Other controller functions should also be verified during commissioning. This may involve activating other pumps and valves or simulating conditions that may lead to other functionality of the solar pump, such as nighttime heat dumping or high limit shutoff.

Most differential controllers have settings that will either turn the pump off or restrict it from turning on under high temperature conditions. These include the "collector maximum temperature" and the "storage tank maximum temperature." The purpose of these settings is to limit the formation of steam in the solar storage tank or collector loop and to maintain the integrity of the materials and components exposed to these high temperatures.

While the primary type of input is a temperature sensor, some controllers may utilize flow meters, pressure gauges, and irradiance sensors to monitor system operation and performance or to activate specific controller functions. The installer must verify proper operation of these inputs and ensure that they are compatible with the differential controller. In systems that utilize data logging or energy monitoring, the data collection settings must be configured according to the manufacturer's directions, and the installer must verify that the device is wired to a computer or network or that an appropriate memory storage medium, such as an SD card, has been installed.

9.2 Verify system operations

Once the differential controller has been configured, the PV control has been installed, or the thermosyphon system has been filled, the installer must ensure that the system operates as designed. This involves a walk-through visual inspection to ensure that there are no leaks in the system, listen for air in the system, bleed air vents as required, and monitor the system temperatures and pressure.

Hot water taps should be opened on all systems to verify the operation of the building DHW system. It is common for there to be air bubbles in the lines of newly-installed SWH systems, and they should be purged. There should be a difference in the temperature of the cold collector supply and hot collector return pipes if the collector has received any solar energy. If this isn't noticeable due to cloudy weather or nighttime job completion, any isolation and ball valves should be double-checked to ensure their correct settings. If an adjustable anti-scald or mixing valve is incorporated in the system, its setting should be checked and set to the desired temperature.

Don't forget to pick up the check!

As any supervisor can attest, picking up the payment check at the time of completion is VERY important, unless other arrangements have been made.

In more complex systems that feature multiple pumps, parallel loading of tanks, heat dumps, external heat exchangers, and bypasses, the installer must simulate the range of operational configurations that the system is expected to perform. This will include manually activating various components and manipulating sensors to ensure proper functionality.

9.3 Conduct customer walk-through

Once the installer has verified that the system is operating properly, s/he must provide documentation to the client and demonstrate proper system operation and monitoring. Documentation should include all appropriate installation manuals, component documentation, and the controller manual. These documents should be affixed in a conspicuous area for the client and/or future service technicians. Inserting the O&M manuals in a document protector and taping them to the solar storage tank adds a professional touch. In the case of an ICS system, the document protector can be attached to the backup water heater or the isolation/bypass valves.

A thorough walk-through is critical to the success of the system. If the client has a thorough understanding of the system, any servicing issues are likely to be identified in a timely manner. During the walk-through any routine maintenance, such as draining the solar storage tank or monitoring system pressure, must be explained.

9.4 Request final inspection

To ensure code compliance, the installer must notify the appropriate building code inspector(s) to arrange for inspection of the system. In some jurisdictions an inspection must be performed by a third-party agency to verify that the installation meets the requirements for local financial incentives. The installer must be aware of the procedure for inspection and ensure the proper documentation is available for the inspector(s). It saves significant time and trouble if the homeowner is made aware that someone will likely need to be present for an inspection to be completed.

10 Service and Maintain the System

The service and maintenance required for solar water heating systems is dependent on the type of system, the quality of the design and installation, the quality of components used in the installation, and various site-specific factors including water quality, power reliability at the site, and homeowner interaction with the system.

Service calls may be performed under an installation company's standard service plan overscheduled due to a component failure, an apparent decrease in system performance, or routine maintenance that is required by the manufacturer.

Under favorable site conditions, systems that are designed and installed properly can operate for 25–30 years with minimal attention, however all systems will require occasional servicing and maintenance. An experienced installer is well-versed in the issues and conditions that lead to service and maintenance calls and strives to minimize the potential for servicing through proper installation practices and education of the client on proper maintenance procedures.

10.1 Ensure OSHA compliance

System service and maintenance will require an installer to perform work similar to—or exactly the same as—the tasks required for system installation. As such, a site safety plan and personal protection equipment should be used in accordance with OSHA standards. Because maintenance and repair work is often performed by a single individual, extra precautions must be observed. The hazards associated with system maintenance include, but are not limited to: ladder use, roof work, working with hot fluids, working with pressurized fluids, electrical hazards, and soldering and brazing. See Section 8 for more details on proper safety practices.

10.2 Perform scheduled maintenance

SWH systems can often benefit from routine checkups. Many companies offer this service as part of an ongoing service contract or as a scheduled visit at routine maintenance intervals. The scope of the checkup will depend upon the type of system, its age, and issues discovered during an inspection. These visits also provide an opportunity for an installer to discuss possible upgrades in technology, such as controls and pumps that could increase system performance.

During a scheduled maintenance inspection, the entire SWH system should be checked for any visual indications of degradation. The service technician should also verify proper operation. This may require manual override of the controller to verify correct operation of the controller and the pump(s). Other standard inspection items may include determining flow rate, system pressure, pH, fluid levels, and operating temperatures. Exterior pipe insulation should also be inspected for signs of degradation.

10.2.1 ICS and Thermosyphon systems

The storage tank is the only component that has a shorter lifetime than the collectors in thermosyphon systems and in ICS systems that do not utilize copper progressive tubes.

Figure 10-1– Batch solar water heater.

Figure 10-2– The hot water heater breaker at the electrical panel must be shut off prior to any service work. Energizing a water heating element that is not submersed in water will immediately damage it.

Damage can necessitate repair of glass, insulation, and enclosures, but collectors have long service if not abused. The systems can suffer freeze damage but this is usually a case of being installed in an unsuitably harsh climate. Visual inspection and testing of the valves should be performed annually. Draining and flushing the tank is sometimes recommended by manufacturers; this is a simple but time-consuming task. If any tank with an electric element is to be drained, ensure the breaker supplying power to the tank is in the *off* position. Energizing an electric element not immersed in water will damage it beyond repair and require a replacement. Air needs to be introduced at the top of any tank in order for it to drain. T & P valves are often handy for this operation, however if a valve is manually actuated it may develop an unstoppable small leak.

Local water quality is probably the most significant factor affecting the lifetime of a glass-lined steel tank. In some locations, normal lifetimes are as little as ten years; in others the same tank can last at least twice as long. Anode rods are the reason manufacturers can offer extended tank warranties. Almost all glass-lined steel water heater and storage tanks have anode rods found in one of two locations: under a large hex plug labeled "Anode," or attached under the hot pipe nipple on top of the tank. Removing the large hex plug can be very difficult after a few years of tank service, and many seasoned installers leave it in place and install a new anode rod under the hot nipple. Stainless steel and polybutylene-lined tanks will probably not have an anode rod.

Figure 10-3 – A replacement electrical element.

10.2.2 DFC systems

An infrared thermometer can be used to quickly check any system indoors if the sun is shining. Once the installer verifies that the pump is running, the thermometer can be used to check the temperature of the supply and return pipes to the collectors (temporarily slide the insulation back if necessary). The return pipe from the collectors should be 10°F to 30°F (or 5°C to 15°C) warmer than the cold supply from the pump. If there is no difference in temperature, a flow problem exists. This could be a control malfunction, lack of electricity, pump failure, or, in rare instances, a blocked pipe. Possible causes and solutions are discussed later in this section.

Figure 10-4 – An infrared thermometer is handy for quick temperature readings.

DFC systems include the same ICS maintenance checks as well as visual inspections of the control and pump. Noisy pumps are often an indication of impending failure. This is particularly true if the noise is a high-pitched "squealing" sound that typically results from worn bearings. Extraordinarily hot pump bodies are also cause for concern. A pump's body that is near or slightly above the same temperature as the fluid is normal. Excessive pump body temperatures can indicate friction problems that will soon result in failure. The pump may have already failed if the body is extremely hot and a temperature check of the piping indicates a no-flow condition.

10.2.3 IFC systems

The heat exchanger and other components necessary for freeze protection in IFC systems make troubleshooting and repair more complex. Checking the collector loop piping for collector supply and return temperature differential can quickly provide a technician useful information. If the sun is shining and the system is functioning normally, the two pipes should have a noticeable temperature differential. If the system isn't too hot, many technicians prefer to check the pipes with their hands. The pipes should have a noticeable ΔT of up to 30°F (15°C) or more. If both pipes are cold and/or there is no difference in temperature, there is likely no flow to the collectors. If both pipes are hot but at the same temperature, this would indicate that the heat exchanger is not transferring heat. This symptom is associated with two two-pump Drainback and Antifreeze systems with a failed domestic hot water circulator pump.

Figure 10-5 – The flow meter on the left can be used as a sight glass in a drainback system when placed at the proper level.

Figure 10-6 - Glycol test equipment — Litmus litmus paper, propylene glycol freeze tolerance tester, and pH meter.

10.2.3a Drainback systems

In addition to the components in DFC systems, Drainback systems have the Drainback reservoir and a heat exchanger that should be inspected at least annually. Adequate water level is critical in Drainback systems. Adding water to a Drainback tank with a heat exchanger should be an annual maintenance task with smaller tanks. Low water level in the tank can result in a loss of efficiency from the exchanger coil not being completely immersed in the HTF. If the tank runs completely dry, the high head pump will fail from excessive heat since these pumps are lubricated by the pumped fluid. Checking the level is straightforward if the Drainback tank has a sight gauge or the supply piping has a transparent flow meter at the high tank water level. Some Drainback tanks are filled to a level of overflowing through a fitting plumbed for that purpose. Some have no provision to check the water level. A dipstick needs to be fashioned for systems without water level monitoring devices. The water level on larger atmospheric tanks can sometimes be visually observed. Collector loop piping can sag over time and should be inspected closely for any places that could trap water and lead to freezing. In particular, look for horizontal lengths of pipe being used as a clothes hanger, which will cause sagging.

10.2.3b Antifreeze systems

Antifreeze system maintenance includes inspection of storage tanks, pumps, heat exchangers, valves, controls, and the condition of the antifreeze solution. Antifreeze solutions can last for decades if maintained at correct operating temperatures. It is prudent to test the solution every few years to ensure that its freeze protection level and acidity are within design parameters. Chemical companies that make non-toxic propylene glycol add chemical buffers to the mixture to raise the pH. Seven is neutral on the pH scale and anything below it is acidic. The higher pH provided by the buffers gives the glycol a margin of safety from turning acidic. Anything below seven can be harmful to copper tubing, and solutions below a pH of 6.5 will start to corrode the tubing in solar collectors and their piping systems — first evidenced by pitting and then pinhole leaks. Temperatures above about 285°F (140°C) break down the buffers in most brands of propylene glycol, and fluid acidity is a probable result. Some solar-specific propylene glycols have a 325°F(160°C) buffer breakdown temperature.

Litmus paper and the color chart included in the test kit can easily be found with an Internet search engine (cost $8 to $12). A litmus test requires just a drop or two of the solution from the drain/fill valves that are installed with antifreeze systems. Carefully cracking the valve slightly can supply the test drops that are needed. The litmus paper will turn color and the paper is then compared with the chart to ascertain the solution's pH. This test is accurate to about two-tenths of a unit of pH.

An electronic pH meter is more expensive and also more accurate. A larger sample of antifreeze is needed to immerse the tip of the meter in the solution than with pH paper, however the test is simpler and quicker. The pH meter will provide a digital readout of the pH calibrated in tenths of each unit on the pH scale. Neglecting to test the pH of the solution in an antifreeze solar water heater has ruined many collectors. For each whole digit on the pH scale, the acidity rises or falls by a factor of ten. Any antifreeze system solution below a pH reading of seven should be changed.

The freeze level of the solution should also be checked. A propylene glycol hydrometer tester with tiny balls that float at various levels depending on the freeze point is the least expensive. These testers look exactly like the devices used to test car antifreeze (ethylene glycol) but are made specifically for propylene glycol. Refractometers produced specifically for propylene glycol may also be used to test freeze levels. These are more expensive and more accurate than hydrometer testers.

If testing indicates that the solution no longer provides the required level of freeze protection for a given climate, however the pH is still acceptable, some of the solution must be drained to accommodate more propylene glycol. A 30% solution (30% glycol, 70% water) is used in mild climates, a 50% solution is used in most of the United States, and extremely harsh climates require a 60% solution.

Propylene glycol antifreeze solutions have different freeze and burst points. The burst point is the temperature at which the solution will rupture copper pipe. A 50% solution gives freeze protection to -30°F (-34°C) and burst protection to below -60°F (-50°C). A 30% solution gives freeze protection to a few degrees above 0°F (-18°C) and burst protection to -20°F (-29°C).

Percent (volume) Glycol Concentration Required		
Temperature F	For Freeze Protection	For Burst Protection
20	18%	12%
10	29	20
0	36	24
-10	42	28
-20	46	30
-30	50	33
-40	54	35
-50	57	35

Figure 10.-7 – Freeze and burst protection ratings for various concentrations of propylene glycol and water solutions. (Courtesy of SunEarth)

SPH systems have few components that can fail and require little maintenance if installed correctly. SPH collectors can last over 20 twenty years. Most SPH collectors can be field-repaired. The most common valve failure is the vacuum relief valve, which is installed at the top of the collectors. In some circumstances, the valve may appear to fail, but the actual problem is a pool pump that is losing its pumping capability due to age. Visual inspection will detect any deterioration in the collectors, the mounting systems, piping, control, and valves. Adequate water flow through SPH collectors can usually be determined with an infrared thermometer or by placing a hand directly on the collector surface, in various locations around the collector array. All locations should be at about the same temperature, and should be relatively cool to the touch. If the SPH collectors are hot while the pump is operating, this means that there is inadequate water flow through the collectors.

10.3 Troubleshoot and repair system

The most valuable resource for an installer when troubleshooting systems is a thorough understanding of the system and its components. Often, it is valuable to keep an open mind and assume nothing about the system installation or operation in order to effectively diagnose problems.

Standard installation tools may be required if service issues are discovered during the inspection. For purposes of troubleshooting, the following items are often used:

- Multimeter
- Small screwdriver(s)
- An infrared thermometer
- Antifreeze test kit
- System schematic, if available

If the system has data logging capabilities, observation of trends in temperature, flow, and pressure can be valuable for diagnosing problems. Portable data logging equipment, which can be installed temporarily to monitor system trends, can help pinpoint difficult to identify issues.

The following list describes common maintenance issues that may arise in SWH systems and explains methods for identifying and solving these problems:

Anode rods

Figure 10-8 – The anode rod on the left will no longer protect the tank from corrosion and must be replaced by a new anode rod (right).

Glass-lined steel tanks typically have a sacrificial anode to protect the vessel from corrosion. This cathodic protection works by introducing another metal (the galvanic, or sacrificial anode) with a much more anodic surface, so that all the current will flow from the introduced anode and the metal to be protected becomes cathodic in comparison to the anode. This effectively stops the oxidation reactions on the metal surface by transferring them to the galvanic anode, which will be sacrificed instead of the metallic tank wall. Common metals associated with tank corrosion are copper, steel, aluminum, and magnesium. The four metals are listed in the order of resistance to corrosion in relation to the other metals in the group. The metal least subject to corrosion in the group, copper, will act as a cathode in relation to metals lower on the list; the more electrochemically active metal will be the sacrificial anode and corrode. Steel and copper together in a piping system will always create a situation where the steel is constantly undergoing deterioration. Aluminum and magnesium will corrode before the steel if present in the system. A magnesium rod immersed in a tank will act as a sacrificial anode by corroding in place of the steel.

Anode rods usually last five to seven years or more depending on the local water conditions. Salty water and heavily softened water accelerate the deterioration of anode rods. After the anode is completely corroded, the next metal present in the system on the list becomes the anode. In this case it will be the steel tank. Any flaw in the glass lining will be subject to deterioration. New anode rods are smooth cylinders about one-half inch in diameter. To facilitate installations where space above a water heater or storage tank is limited, replacement rods are available in a chain-like configuration (Figure 10-10). Aluminum anodes are used in some locations where the dissolved solids in the water are not compatible with magnesium. A symptom of anode rod incompatibility is a sulfurous, *rotten* egg smell.

Figure 10-9 – The anode rod may have a separate port on the top of the tank.


Figure 10-10 – Chain-style anodes can be used for locations where there is not sufficient clearance to replace an anode rod.


Figure 10-11 – Leaking pool collector (note the water on the riser tubes).

Collectors

Unglazed Flat Plates

Pool collectors can easily last more than twenty years when plumbed in such a way as all water drains from the collector when not in operation. After many years the collectors can develop leaks in individual riser tubes; these can be repaired with factory-supplied repair kits. Polypropylene products are thermally welded and normal sealants like silicone and epoxy are not suitable for collector repair since virtually nothing adheres to polypropylene. The factory repair plugs will fit tightly into a riser tube. The repair procedure requires cutting the leaking riser tube close to the bottom and top headers, leaving enough room for the plug. Plugs are inserted into the riser tube near both headers to seal off the leaking riser. A leaking riser in an older collector may indicate that the collector is nearing the end of its useful life. It is probably more economical to replace an older collector that has developed multiple leaks unless there is an identified reason for the leaks. When polypropylene panels are replaced, the mounting system must allow for expansion/contraction of the collector. The age of the panel can be verified through documentation or the stamped manufactured date on some panels to determine if the collector is still under warranty.

Glazed Flat Plates

A flat plate collector constructed by a reputable manufacturer should have a lifetime exceeding thirty years. Possible maintenance issues include:

- *Collector condensation* – Water leaking into the collector and gathering at the collector bottom can be a maintenance item in high humidity areas. Moisture that enters a

Figure 10-12 – This collector's frame is no longer holding the glazing in place and needs repair.

Figure 10-13 – Failure to promptly repair broken glass can cause absorber damage from the wind.

collector must be able to vent, thus efforts to seal them tight can cause perpetual condensation on the inside of the collector glass. A standard solution is to drill 1/8" weep holes in the bottom corners of the collector to allow drainage. Care must be taken to avoid breaking the glass or drilling into a header tube. Drilling near the back of the collector helps avoid these components and is more effective at draining water due to the tilt angle of the collectors.

- *Broken glazing* – Severe weather conditions, vandalism, or mishandling can lead to broken glass. Low-iron tempered glass is available from solar manufacturers and distributors, or by special order at specialty glass shops. Single sheets are difficult to ship. As a result, shipping charges are often more expensive than the glass itself. If the glass size required isn't available or economical, tempered glass can be used with a small loss of efficiency. Most large cities have a tempering facility that can furnish any size for collectors.

Glass cannot be cut once it has been tempered, so it is important to measure twice or more for replacement glass. A mismeasurement of a fraction of an inch can make a replacement glass unusable. All broken glass should be removed prior to replacement of the glazing. A powerful wet/dry vacuum cleaner with a narrow attachment is an effective tool for quick cleanup. A five-gallon bucket is handy to carry away the broken glass. The frame or trim will need to be taken apart in order to access the gasket holding the glass. It should be carefully removed, stored, and reused. Any deterioration to the absorber coating or insulation should be addressed while the glass is off. A spray can of flat, black, high high-temperature paint (engine or barbeque paint) can be used if the absorber coating has deteriorated to the extent that the absorber metal is visible in spots. Although the black paint will not have the superior properties of a selective surface, it is far superior to bare or nearly-bare metal.

- *Absorber repair and replacement* – Any absorber maintenance requires glass removal. Extreme care should be taken to avoid striking the edge of tempered glass, as it can easily shatter. Absorber repair may be required due to a freeze break or leaks at the joint between the header and riser. If a freeze break occurs on the back of a riser, the absorber plate will need to be removed. In this case, or if there are multiple breaks, it may be more economical to replace the entire absorber. Replacement absorbers are available from some manufacturers and distributors. Any repairs to collectors should be brazed or silver soldered, which is best accomplished with an oxyacetylene torch because of the temperatures required. Silver soldering is easier than regular soldering in many ways since cleaning and fluxing is not required. For repair of pinhole leaks in older collectors, radiator stop leak with dissolved copper granules may provide a short-term solution. Although this is not a best practice, it has been successful in giving a few more years of service life. If used, the stop leak must be applied using the manufacturer's repair procedure, the solution should be introduced into the system via the fill valves, and the system must have a double-wall heat exchanger.

Evacuated Tubes

Evacuated tubes are made from borosilicate or soda lime glass. The glass is not tempered and will break into shards, as opposed to tempered glass, which shatters into small pieces. Gloves should be worn when handling any glass, including intact evacuated tubes. Because evacuated tubes are not tempered, they are prone to breakage during shipping, handling, and operation.

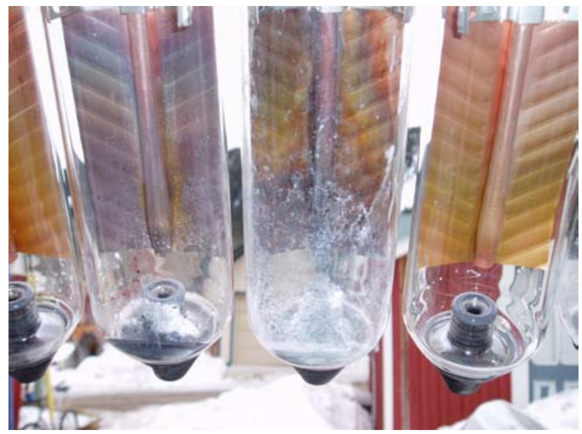


Figure 10-14 — Evacuated tube with failed vacuum.

(Courtesy of Jay Pozner, nunatakenergy.com)

Once the glass is broken or cracked, the vacuum that insulates the tube is lost and the tube should be replaced. Single-wall evacuated tubes require replacement of the entire tube, including the heat pipe. The glass in double-wall evacuated tubes can be replaced independently of the absorber and heat pipe. New tubes can be procured from the manufacturer or distributor. Vacuum loss is possible with any evacuated tube collector. Most manufacturers utilize a metallic barium coating inside the vacuum that turns white when the vacuum is lost to indicate when a tube needs to be replaced.

Figure 10-15 — Cutaway view of an evacuated tube collector manifold. The tube on the right is fully inserted into the dry socket of the manifold. The condenser bulb of the heat pipe on the left is visible prior to insertion into the dry socket.

An infrared thermometer can also assist in detecting vacuum loss. Under sunlight, a tube that has lost the vacuum will be hotter than an adjacent tube with an intact vacuum. Collector glass temperature is not an accurate indicator of collector performance, but is a valid method for determining the relative operating efficiencies of different tubes or collectors. A tube without a vacuum has virtually no insulation and exhibits significantly diminished performance.

The heat pipes in evacuated tubes are also susceptible to failure, which may occur if the heat pipe loses its vacuum or if the solution inside the heat pipe freezes. A heat pipe that has lost its integrity can no longer produce the vapor/condensation cycle essential for heat transfer, resulting in negligible heat production. Heat pipe failures can be diagnosed by removing individual tubes from the collector and measuring the temperature of the condenser bulb. Twenty minutes of direct sunlight should produce condenser bulb

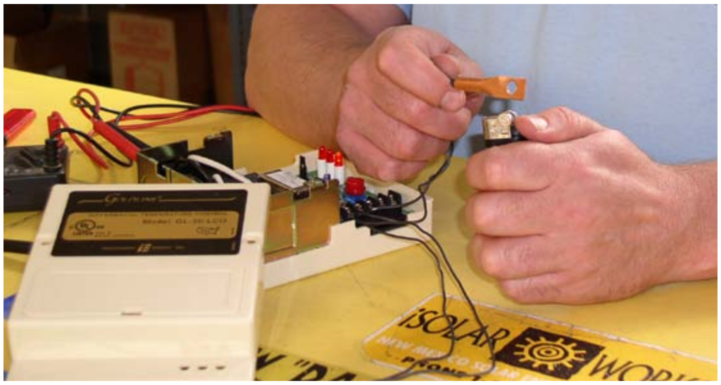


Figure 10-16 — Using a lighter to test the functionality of a sensor and controller.

Figure 10-17 — A differential controller with the face removed to check sensor and pump wiring.

temperatures approaching 300°F. When measuring the temperature with an infrared thermometer, silicone tape should be applied to the condenser bulb and the temperature of the tape should be measured. This alleviates the challenges of measuring the surface temperature of shiny materials such as copper that will reflect surrounding heat or cold and cause discrepancies in temperature readings.

Controls and sensors

When diagnosing control problems, care should be taken to minimize the risks of working with electricity. If the system is not functioning correctly, the power supply should be tested with a multimeter. For a PV-controlled system, the output of the module should be checked and compared to the requirements of the pump. For a differential controller, the supply voltage to the controller should be verified. If sufficient power is being provided, the internal fuse should be checked with a multimeter and replaced if it lacks continuity. If the controls are powered properly, the settings should be checked to ensure they are within the tolerances recommended by the manufacturer.

Care must be taken when diagnosing sensor errors due to the different styles of sensors used in SWH systems. RTD sensors have an *increase* in resistance with an increase in temperature; thermistors have a *decrease* in resistance with an increase in temperature. It is important to verify that the sensors used in the system correspond to the sensors required by the manufacturer.

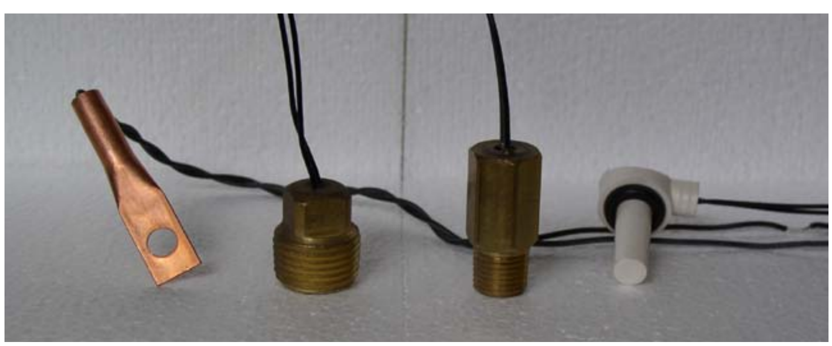


Figure 10-18 – Thermistors are available in various styles, including a typical 10 K sensor on the left, two immersion sensors with pipe threads, and a pool immersion sensor on the right with an O-ring seal.

Sensors can be tested by either observing the temperature readings on the controller display or checking the electrical resistance with a multimeter. A source of heat, such as a lighter, can be used to manipulate temperatures for testing sensors. The installation manual for the controller often includes a table of temperatures and the corresponding resistances for the particular sensor being used. A close approximate temperature of any sensor can be determined using an infrared thermometer. Open or shorted sensor wiring can also cause control failure and can be checked with an ohmmeter. Many modern controllers will indicate an open or shorted circuit on the display.

Excessive temperature and/or pressure

Chronic excessive temperature and/or pressure can result in repeated actuation of pressure relief valves, resulting in system maintenance. Expansion tank problems are one cause of excessive pressure but are easily diagnosed (see *Tanks* section below). Other causes of excessive pressure are an incorrect design or a flawed installation. Hot water load changes, caused by vacant homes, extended summer vacations, and reductions in family size, are also possible causes of excessive temperatures.

Systems that have too much collector surface area compared to the volume of storage often experience excessive temperature. This is particularly true if the collectors are installed at a low tilt angle that increases production under the intense summer sun. A system that develops too much heat in the summer can often be corrected with a steeper tilt angle favoring the winter sun. Space heating systems without a summer load can be installed vertically to mitigate the excessive summer heat production. Installers and designers usually favor Drainback designs for space heating systems because the collectors drain once the storage tank has reached its high limit. Where arrays are easily accessible, individual collectors can be covered in the summer as an alternative.

Flow diversions

Using any excess summer production for heating a swimming pool or hot tub can solve excessive temperature conditions. Should these useful loads not be available, a non-productive flow diversion, typically referred to as a *heat dump* or *shunt load*, can be considered. Examples of heat dumps include:

- *Fin tube emitters* – Finned tube baseboard radiators or similar proprietary designs can be used to emit heat to the outside or into areas where excess heat can be used or dissipated. These designs typically incorporate a three-port valve that is actuated by the controller, an aquastat, or a thermostatic actuator at the valve. The valve diverts the antifreeze solution through the fin tube emitter before returning to the collector array.

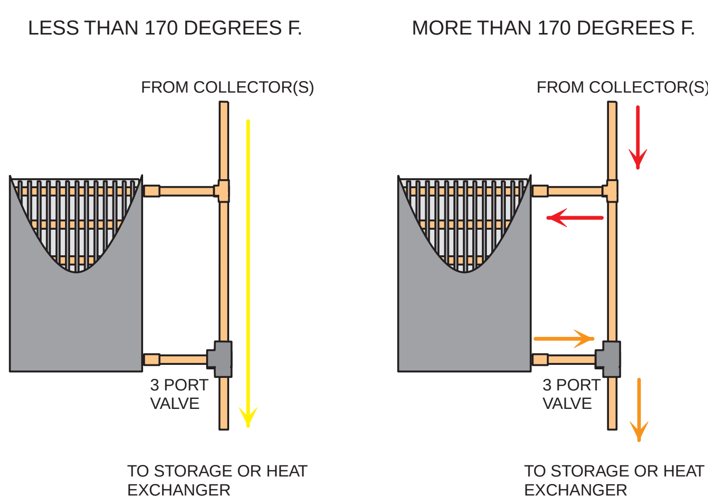


Figure 10-19 — Heat dissipator used to disperse excess heat.

- *Fan coils* – Alternately, a radiator-style heat exchanger with a fan can be used to dissipate heat. These units are able to dispel more heat per square foot of heat exchange surface area than fin tube emitters, but they require a significantly higher electrical draw to run the fan.
- *Nighttime cooling* – Home occupancy is reduced on occasion and can be a cause of excessive system temperatures. When using flat plate collectors, it is possible to radiate excess heat through the collectors to the night sky. Due to their minimal thermal losses, evacuated tube collectors are ineffective for this purpose. Nighttime cooling can be accomplished by installing a short pipe with a normally-closed ball valve parallel to the check valve. The valve is manually opened in the summer or whenever the system is subject to overheating. When open, the system will bypass the check valve and thermosyphon the hot fluid at night from the storage tank to the collectors, where the heat is radiated to the night sky. The valve must be closed after the period of low DHW use to prevent heat loss at night.
- This process can be automated through the use of the vacation mode feature that is available on select controllers. When set in this mode, the control monitors the storage tank temperature and will turn the pump on at night to move hot fluid to the collectors when the storage temperature is too high.
- *Overflow reservoir* – Another proprietary solution uses an automobile radiator cap to cool an Antifreeze system as it approaches excessive temperature. The unit is installed at the top of a collector and contains a capsule consisting of a finned tube radiator, a radiator cap, and an overflow reservoir. In case of excessive temperatures that would normally actuate a pressure relief valve on an Antifreeze system, the HTF flows into the unit. High-temperature fluid moves into the capsule and dissipates heat to the outside air. If the system pressure increases to 16 psi, the radiator cap actuates and allows fluid to flow to the small tank. The fluid and steam that enters the overflow reservoir returns to the system upon cooling at night. Installers should follow the manufacturer's instructions closely. The system operates at low normal pressure (2–3 psi) and expansion tanks need to be removed or isolated for the unit to operate correctly.

Figure 10-20 — Check valve bypass for nighttime cooling. Under normal operation the gate valve in this photo is closed. When opened, the valve allows reverse flow by thermosyphoning. Heat can be re-radiated to the colder sky if flat plate collectors are utilized.

Figure 10-21 — Differential controllers can also be used to dissipate heat at night by turning on the system pump when the tank is too hot. This feature is called vacation mode in some controls.

Figure 10-22 – Overflow reservoir used as a heat dump above an evacuated tube collector.

Flow problems

Correct flow in the collector loop and DHW loop, if present, is required for a SWH system to operate at peak efficiency. Too little flow will result in the collectors losing more heat to the outdoors than necessary; excessive flow rates will cause short cycling of the pump. Collector supply and return temperature differences will vary with solar irradiance, ambient temperature, and collector inlet temperature. The temperature differential in collector loops should be less than about 30°F under cloudless conditions. Higher temperature differences may indicate an undersized pump or high frictional head loss. In IFC systems, this could also be caused by an inefficient or undersized heat exchanger. A Drainback system may experience high temperature differences if the pump cannot completely fill the upper header of a collector. In this scenario, the water slowly trickles down the return pipe and the flow rate remains low because the fluid siphon in the collector loop cannot be created.

Figure 10-23 – Large systems may require that collector arrays are plumbed in multiple banks to limit frictional head loss.

High frictional head loss can be caused by too many collectors in a row, piping that is too small, or an undersized heat exchanger. Since frictional loss increases with flow, a larger pump will not necessarily create the required flow rates. If this is the case, large collector arrays may need to be re-piped into parallel banks or the surface area of the heat exchanger may need to be increased.

Hard water solutions

Water is considered *hard* when it has more than approximately 200 parts per million (ppm or milligrams per liter mg/L) of dissolved solids, which causes scaling on collectors, heat exchangers, tank interiors, tankless water heaters, and valves. Scaling reduces system

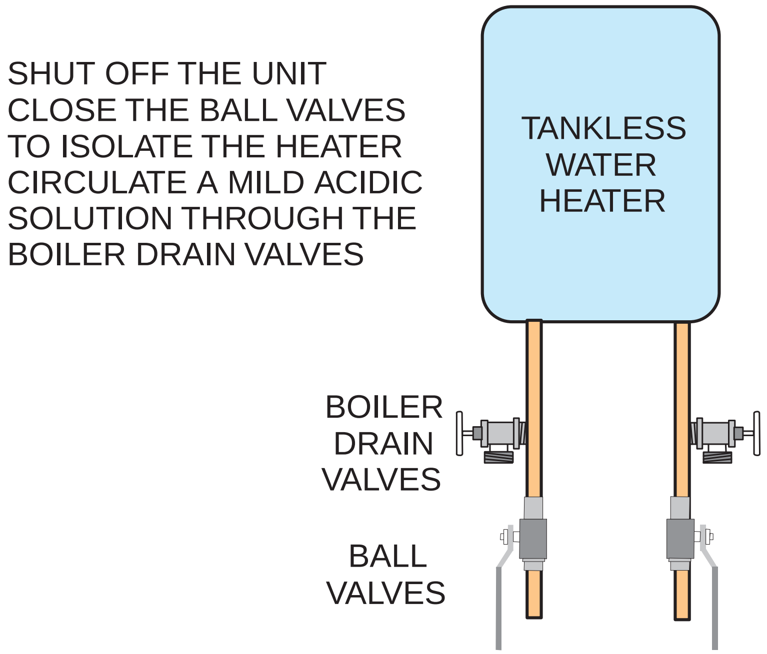


Figure 10-24 – A valve configuration for flushing a tankless water heater.

efficiency and can lead to component failures. Deep underground aquifers are one source of hard water. Figure 10-24 illustrates a piping configuration that can be used to isolate and clean expensive components without draining the system or removing the part.

Heat Exchangers

Heat exchanger effectiveness depends on the surface area of the exchanger, the ratio of surface area to volume of the fluid passages, flow rates, and the temperature difference between the two fluids. Higher flow rates and large temperature differentials result in more efficient heat exchange. Smaller fluid passages—including solar pool panel riser tubes—are also favorable for heat exchange because a larger portion of the fluid flowing through the passage is able to absorb heat from the tube or plate material.

Internal, or tank-integrated, exchangers are configured as coils. The coil can be constructed of copper or any other suitable metal. Copper coils are rarely used as internal heat exchangers in glass-lined steel storage tanks due to local water quality issues that result in premature tank failures. Glass-lined steel tanks are often fitted with porcelain-covered copper or cupronickel heat exchangers. Failures in coil-type exchangers are rare, however interior scaling from deposits of hard potable water can sometimes occur. When accessible, leaks in heat exchangers can be brazed and the scaling can sometimes be reduced or eliminated by circulating a mild acidic solution in the coil.

External liquid-to-liquid heat exchangers are manufactured in tube-in-tube, also known as *shell-and-tube*, and plate configurations. Copper tube-in-tube exchangers can develop scale in a manner similar to internal coil exchangers. These exchangers can be treated for scale removal in the same way as coils. Stainless steel plate-type heat exchangers are usually more efficient than the tube-in-tube type. The small fluid passages in the plate exchangers have substantial surface surface-to to-volume areas resulting in superior heat transfer efficiency. Copper plate exchangers are rarely used

Figure 10-25 – A copper heat exchanger and a stainless flat plate heat exchanger. The tube in the tube exchanger couldn't heat the indoor pool and was replaced with the smaller plate heat exchanger. The plate exchanger was more effective and heated the pool year-round with the same eight collectors due to the increased exchanger surface area and much higher surface-to-volume ratio.

since the small waterways will scale over in hard water areas. Stainless exchangers require little or no maintenance or repair.

Pumps

Most AC circulators are lubricated by the fluid they are pumping and use a capacitor to start the motor for better efficiency. Inoperable pumps are diagnosed by first connecting the pump directly to an appropriate AC electrical source. If the pump does not start once it is connected, either the pump windings/stator have failed or the capacitor is open.

Figure 10-26 – Corrosion in a copper tube heat exchanger.

Figure 10-27 – A bronze pump suitable for potable water with the volute separated from the motor. The capacitor is contained in the metal box with the label.

Capacitors have charge and discharge cycles and can be checked with an ohmmeter. Once the capacitor is removed from the housing and the wiring is disconnected, the two capacitor leads should be shorted to discharge the capacitor. The ohmmeter should be connected to the two leads on the capacitor. This charges and discharges the capacitor and a visible *bounce* will be observed in the needle on an analog meter. A digital meter will also show movement by displaying resistance for a very short time. The leads can be reversed and a good capacitor should again show movement. A capacitor that doesn't bounce the needle or display numbers momentarily should be discarded. Replacing the capacitor is sometimes the only repair needed on AC pumps.

If the capacitor is functional, the pump probably needs replacement. Some pumps only require replacement of the motor and impeller cartridge; others may require replacement of the entire pump. If the impeller housing on the new pump is bolted too tightly to the pump body, the pump may fail to start. Loosening the bolts slightly may be the repair solution as long as it does not cause the pump to leak.

AC circulators used in small SWH systems are often interchangeable with pumps available from other manufacturers if the pumps have a flange piping connection. When substituting pumps, consideration must be taken to assure that the replacement pump has equal or similar flow and head curves. Systems certified under OG-300 must specify allowable brand and model substitutions designated by the system manufacturer.

DC circulators are available in three types: brush motors, brushless motors, and static impeller- drive motors. Brush-type pumps require that the pump motor brushes are replaced periodically—normally every three to ten years depending on usage. Brush replacement is a simple procedure. Brushless and static impeller drive pumps require no maintenance.

Controllers

Some controllers allow for pump speed control, which can be used to improve system efficiency and limit pump cycling. This setting varies voltage to the pump based on the temperature difference between the collectors and the solar storage tank. As the temperature differential increases, the voltage output from the controller increases. This increases the flow rate in the system and maximizes the electrical energy consumed by the pump. As the differential begins to drop, the pump speed and corresponding flow rate decrease. By utilizing a target temperature differential that is above the "ΔT-*on*" setting, this strategy can minimize pump cycling by limiting the heat that is transferred from the collector during low sun conditions.

Solar Pool Systems

Solar pool heating systems have only a few components that may require repair or service, including the three-port valve and differential controller. Designs of the valves vary by manufacturer. The valves and controls are often supplied as a kit and the installer or service technician should consult the manufacturer for specific repair procedures. SPH systems usually include a vacuum breaker to allow the collectors and piping to drain. Vacuum breakers can develop leaks after years of service and are probably the easiest system component to replace. For outdoor pool systems installed in cold climates, the piping configuration should allow for complete draining of the collectors by gravity. When winterizing seasonal pool heating systems, care must be taken to completely drain pool collectors to protect them from freezing. After draining the collectors by gravity, a compressor or vacuum should be used to remove any residual pool water.

Tanks

Pressurized storage tanks do not lend themselves well to repair. Maintenance is limited to periodic tank flushing and anode replacement (see below). Electric elements used for auxiliary heat may require replacement, as well.

Fiberglass, polypropylene, metal, and bladder-lined unpressurized storage tanks can be repaired. Metal tanks are repaired with appropriate welding or brazing procedures. Polypropylene tanks require welding with a plastic welder and rod. Fiberglass tanks with poly liners can be repaired with common silicone. Leaking bladder tanks require bladder replacement. A common material for the bladder is EPDM rubber. EPDM is suitable for 212°F water storage. EPDM pond liners with a maximum service temperature in excess of 300°F are available from at least one supplier.

Drainback tanks are usually made from mild or stainless steel and can be repaired with welding or brazing.

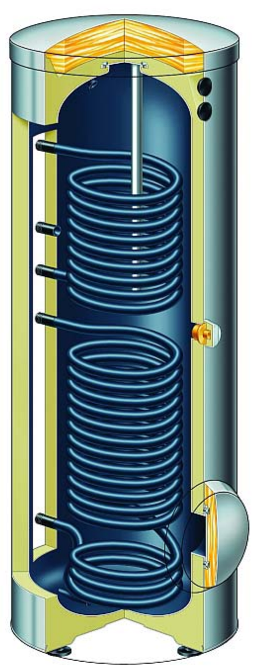


Figure 10-28a — Cutaway of a tank with two immersed coils. (Courtesy of Viessmann)

Figure 10-28b — Cutaway view of an indirect tank with a wraparound heat exchanger. (Courtesy of SunEarth)

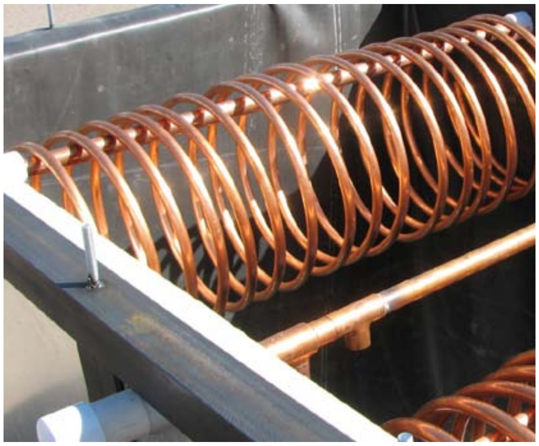


Figure 10-29a and b — Internal view of a bladder tank with heat exchangers and external view of a similar tank installed in a garage. The unpressurized atmospheric tanks are the least expensive method of storing large quantities (hundreds of gallons) of hot water for commercial systems or home space heating.

Expansion tanks

The failure of an expansion tank or the loss of air cushion pressure can be indicative of excessive system pressure, bladder failure, or Schrader valve failure. If the bladder has failed, air will likely have entered the system. The air can lock the pump impeller or gather at the highest point in the system. Prior to replacing an expansion tank, check the system pressure at the Schrader valve. If water sprays from the valve, the tank bladder has failed and the tank needs to be replaced. If no water is evident, the expansion tank should be isolated from the system and the pressure of the air cushion should be checked. Schrader valves on expansion tanks leak over time, just as they do on tires. A tire valve tool is needed to tighten the Schrader valve if it is leaking. After tightening, a compressor or bicycle pump should be used to pressurize the air cushion formed by the bladder to the same pressure as the solar loop when the system is cold.

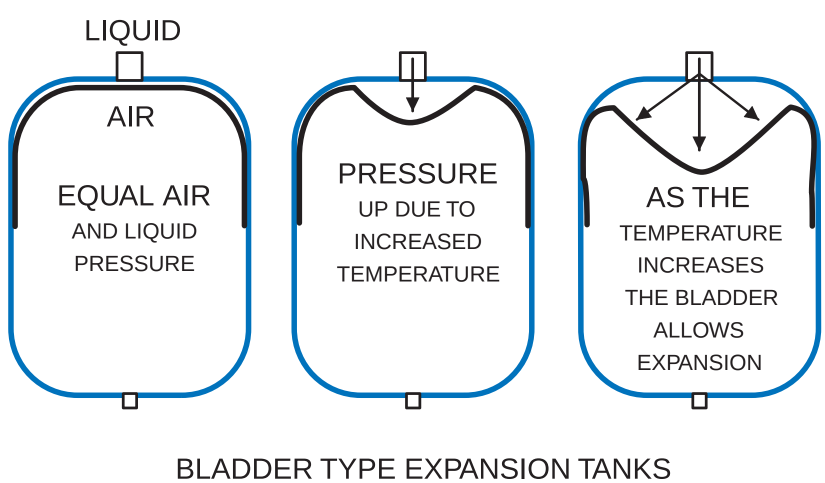


Figure 10-30 – Illustration of solar expansion tank during operation.

Valves

Often T&P valves will not re-seat and will leak continuously if actuated manually. Tapping on or manually actuating the valve a few times can sometimes stop the leak. Very small leaks, such as a drop every thirty or sixty seconds, will sometimes seal themselves in hard water areas.

Pressure relief valves often don't have a manual actuator and, if leaking, the only remedy is tapping on the valve or replacing it if the leak can't be stopped.

Automatic air vents can cause problems if located outdoors. On very cold winter nights, an automatic air vent can allow air into an antifreeze system as the system fluid contracts and system pressure decreases. Also, outdoor automatic air vents on antifreeze systems have been known to develop leaks prematurely. It is common practice to install a manual shutoff valve at the air vent to prevent these issues from occurring. Automatic air vents are specified on many SRCC OG-300 Certified™ systems and, unless an alternative such as a manual air vent is approved for substitution, the automatic air vent must be installed to comply with the certification. Manual air vents are often used to replace malfunctioning automatic vents.

Check valves prevent nighttime thermosyphoning and the resulting heat loss from the storage tank. Failed check valves in Antifreeze systems in harsh climates can cause the glycol to thermosyphon and freeze the potable water in an external heat exchanger, causing it to burst. Positioning the drain fill valves on either side of a check valve can aid in diagnosing a failure when filling the system after maintenance and repair.

Ball valves are usually reliable, although they may need replacement if leaking or frozen. One issue that may arise on ball valves is the packing nut at the top of the valve. If there is a leak at the packing nut, the handle can be removed and the packing nut tightened.

Gate valves have much higher failure rates than ball valves and are rarely used in modern SWH systems. The connection to the gate on the valve is a common source of failure. A failed gate valve usually results in the valve remaining closed or partially closed. Many installers replace gate valves with ball valves.

Boiler drain valves have a pipe thread at one port and a hose thread on the other port. The hose thread facilitates filling and draining the system with washing machine or garden hoses. A boiler drain that develops a very small leak can be stopped with a gasketed hose thread cap.

Anti-scald or tempering valves are subject to heavy scaling in hard water areas. Scaling will normally cause the valve to remain partially open, which permits cool to tepid water to flow to the hot water taps. The valves can sometimes be cleaned with a mild acidic solution.

Freeze protection valves are actuated by different passive mechanisms. They are designed to allow relatively warm water to flow through a collector to prevent the riser and header tubes from freezing during infrequent harsh weather in mild climates.

Type System	Maintenance Required
SPH Outdoor	Low
SPH Indoor	Moderate
ICS	Minimal
Thermosyphon	Minimal
DFC	Low
IFC DB	Moderate
IFC AF	Moderate
Any DB or AF system with space heating	High

The valves are also known as *dribble valves*. The valve actuators allow flow through the collectors when temperatures approach freezing. Standard models actuate at 35°F (2°C) and 45°F (7°C). Hard water can quickly compromise the reliability of these valves, particularly when installed in climates where they activate frequently. There are several other possible causes for freeze valve failures, including high summertime temperatures. Reliance on these valves for system freeze protection has resulted in many thousands of collector failures.

Maintenance and repair work on SWH and SPH systems requires the highest technical proficiency of installers or repair technicians. Troubleshooting is a logical, methodical problem-solving process that includes reviewing the symptoms of malfunction, evaluating potential solutions, and selecting and implementing the correct repair(s). Most older systems requiring repair will have little or no documentation on site available to the installer. The fact that OG-300 system certifications exist is evidence that solar manufacturers are cognizant of this flaw in prior practices. Modern guidelines require operation and maintenance manuals and appropriate system labeling.

Hall of Shame

These systems were NOT installed by NABCEP certified installers — spot any problems? If you do, can you cite a reference?

Figure 10-31 – Poorly secured collectors are victims of the wind.

Figure 10-32 – Antifreeze system — roof work.

Figure 10-33 – Same system above the storage tank.

Figure 10-34 – Smoke and Mirrors.

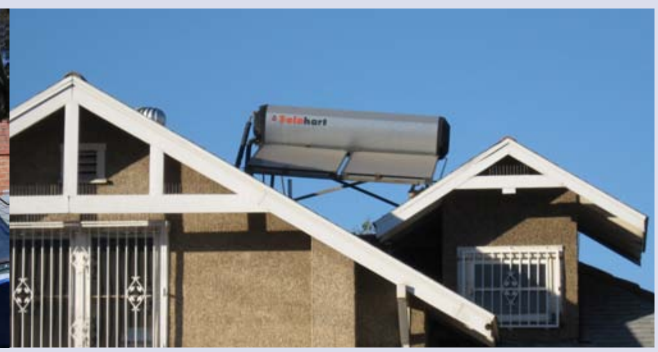


Figure 10-35 – Self-leveling ICS system.

Figure 10-36 – Right into the ground — know the rules.

Figure 10-37 – Insulation doesn't stay on piping without protection; will the collector stay on the roof?

Figure 10-38 – Stacking collectors with wood mounts?

Figure 10-39 – Pipe snake—what problems could this detail cause?

Figure 10-40 – Use factory supplied mounts.

Figure 10-41 – Two pipe snakes prior to mating?

Figure 10-42 – What happens when the wood rots?

Figure 10-43 – Know your ladder set up rules

Figure 10-44 – How long will this pump last?

Figure 10-45 – Maybe too steep without fall protection?

CASE STUDY A:
Solar Domestic Water Heating System

Project Description

A homeowner in Ingraham, NY would like to purchase a SWH system to offset oil used by an existing oil boiler. Two adults and two children, aged 6 and 9, live in the residence. During the site evaluation, the following information on the project was collected:

Existing Roof:

Slope: 8:12
Material: Architectural shingles
Age of roofing: 10 years
Usable area: 16′-0″ width x 16′-0″ height

Existing Water Heater:

Fuel type: Oil
Type of heater: Direct coil in 140,000 BTU high mass oil boiler
Age: 5 years

Hot Water Use:

Appliances: dishwasher, clothes washer
Frequency: 6 loads of laundry per week on warm cycle
Showers: Average of three per day, total

Shading Analysis:

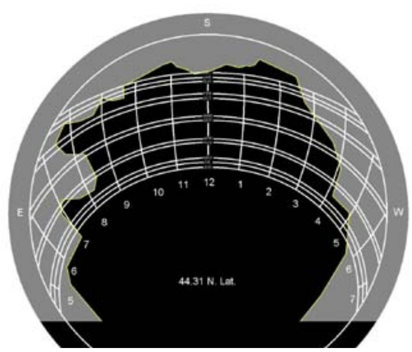


Figure A-1 – Shading profile of project site

Other notes:

Roof azimuth is 30°W of south
Piping run from proposed tank location to proposed collector location: 60′ one way

System design

Based on the site evaluation, the system designer estimated an average daily use of approximately 65 gallons/day. The existing hot water heater — an oil boiler required to stay above 160F all year to provide hot water — is extremely inefficient, so the designer opted to utilize a dual-coil tank. This design allows the solar collectors to heat the bottom of the tank and allows the boiler to provide auxiliary heat at the top of the tank through the installation of an additional heating zone in the distribution system. By using an indirect tank for the boiler, the boiler controls can be upgraded so that the boiler will only turn on during the non-heating season when the solar is unable to provide 100% of the hot water for the home.

The designer had previously decided to utilize an SRCC OG-300 Certified™ system. After researching SRCC OG-300 Certified™ systems on the SRCC website (www.solar-rating.org), the designer selected an antifreeze system that utilizes two (2) 4 foot x 10 foot collectors and a 110 US gallon dual coil indirect storage tank. Based on OG-300 ratings, this system should provide an annual savings of 5010 kWh, or 17,000,000 BTU under standard conditions. This represents 68% of the expected household hot water demand based on OG-300 conditions.

Since the roof slope is 8:12 (approximately 34 degrees) and the latitude is roughly 45 degrees, the designer chooses to flush-mount the collectors. This slightly favors summer production, which is suitable for the site since the auxiliary heating source — the oil boiler — has a lower combustion efficiency in the summer when the only heating load is for water heating.

Expected performance

Since OG-300 Ratings are estimates under standard conditions, the designer utilized the Solar Pathfinder Assistant software package to estimate the expected performance for this system at this particular site.

The shading results in a 15% decrease in annual system performance. Based on orientation, water heating loads, and other factors particular to the site, the estimated system production is approximately 10,500,000 BTU/yr, which equates to a solar fraction of 67%. The solar fraction is roughly 95% during the non-heating season.

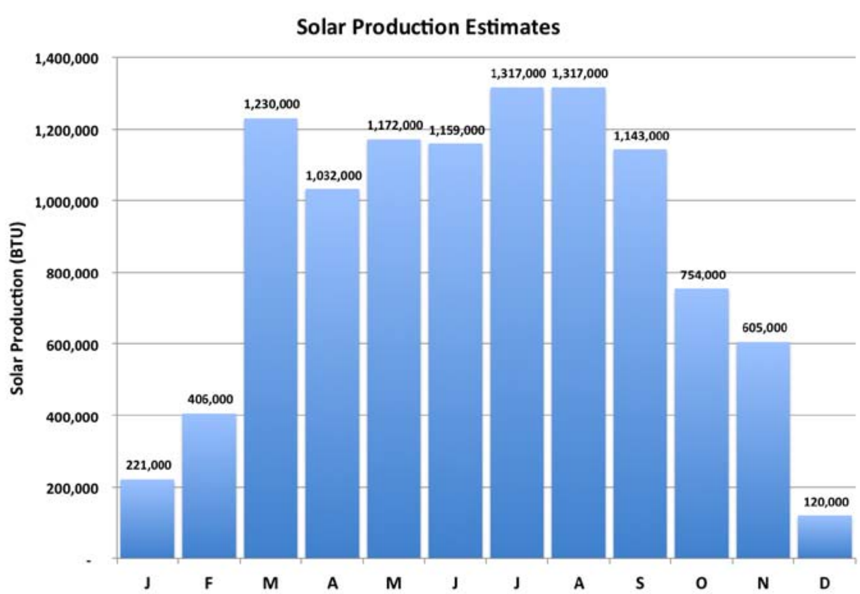


Figure A-2 – Monthly performance estimates for system based on Solar Pathfinder Assistant model

Pump and pipe sizing

The recommended flow rate for this system is 2.5 gallons per minute. The pump provided by the manufacturer is a three-speed model that has the following head loss characteristics:

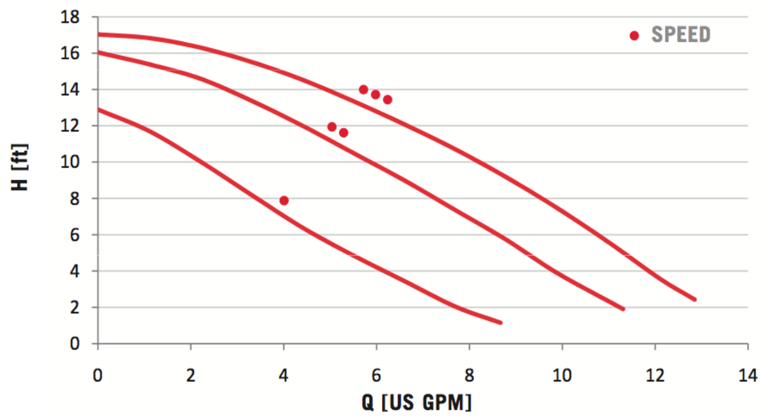
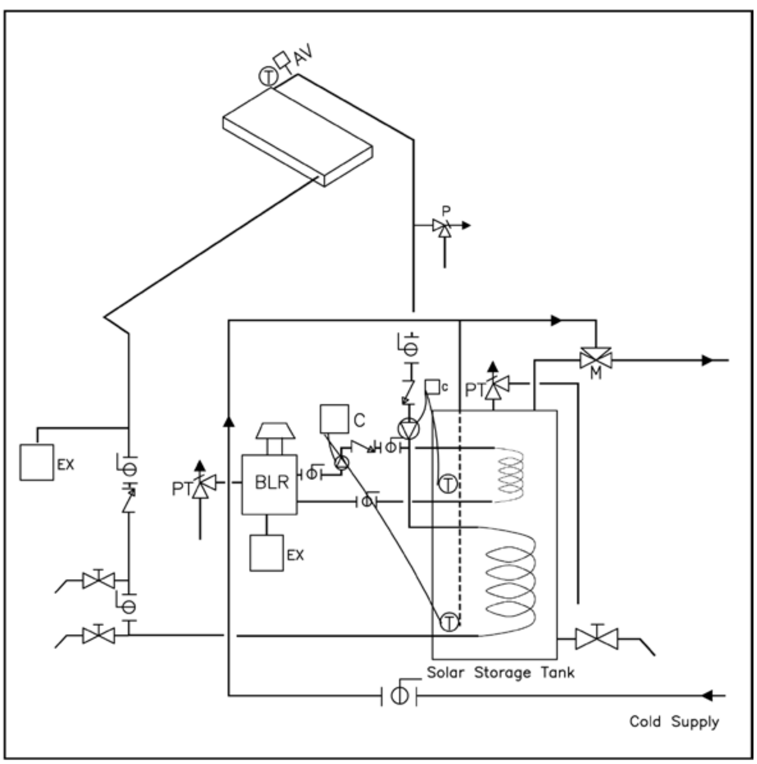


Figure A-3 – Performance curves for the three-speeds of the circulator pump in the pump station (Courtesy of Heliodyne)

At the recommended flow rate, the head loss in the various system components when using water as the heat transfer fluid is as follows:

Collectors: 0.3 ft of water column
Heat exchanger: 1.2 ft of water column
Piping, fittings, valves, etc.: 14.4 ft of water column in ½″ copper tubing–or– 2.8 ft of water column in ¾″ copper tubing



For ½″ copper, the total head loss would be 15.9 ft of water column when using water. Since glycol is more viscous, the designer increases the head loss by 23%; this results in an equivalent head loss of 19.6 ft of water column. The pump is unable to overcome this dynamic head, therefore ¾″ copper should be used. For ¾″ copper, the total head is 5.3 ft of water column after adjusting for the use of glycol as a heat transfer fluid. The pump supplied with the system can achieve the recommended flow rate in ¾″ tubing on Speed 1.

Figure A-4 – OG-300 diagram for system selected by the designer (Courtesy of SRCC)

CASE STUDY B:
Residential Solar Pool Heating System in California

Project Description

A family in Fontana, California has a backyard pool at their residence. The pool is unheated and has a pool cover. The pool is a 16′ x 32′ rectangle with an average depth of 5 feet. It is filtered with a one horsepower, 240-volt pump that is controlled with a timer. The pump and filter are located in a small shed adjacent to the back wall of the home. The owners would like to heat the pool with solar energy for about nine months a year.

The residence is a single-story ranch style home with a 4:12 pitched roof that faces 190 degrees on a compass. True south in Fontana is about 12 degrees east of magnetic south. Therefore, the roof faces very close to true south.

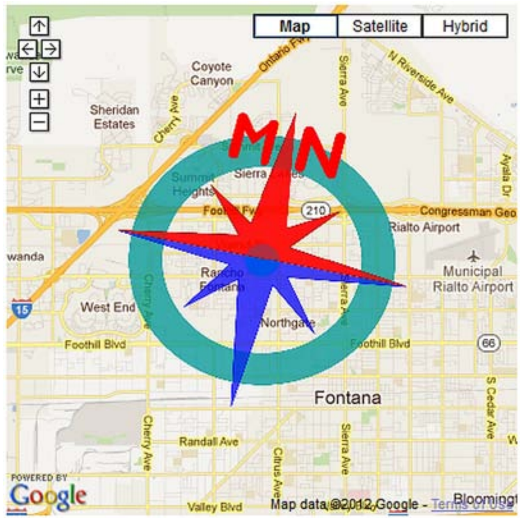


Figure B-1 – Magnetic and true south at Fontana, CA
(Courtesy of Google Maps and NOAA)

System sizing

Roughly 70% to 75% of a swimming pool's heat loss is due to evaporation. Residential solar pool heating systems are sized using a multiplier derived from the pool's surface area. The multiplier for the amount of collector surface area needed to heat a pool varies from about 0.5 in desert areas with intense solar radiation to 1.0 in colder areas. These ratios of collector area to pool surface area are designed to heat pools from 4-10 months of the year depending on the outdoor pool season. The multiplier of 1.0 is used to heat pools throughout the almost nonexistent winters in very mild climates. The multiplier often used in southern California for a long season is 0.7 for south facing collectors.

This system has a pool surface area of 512 square feet. To obtain a collector-to-pool surface area ration of 0.7, 358 square feet of pool collector area is

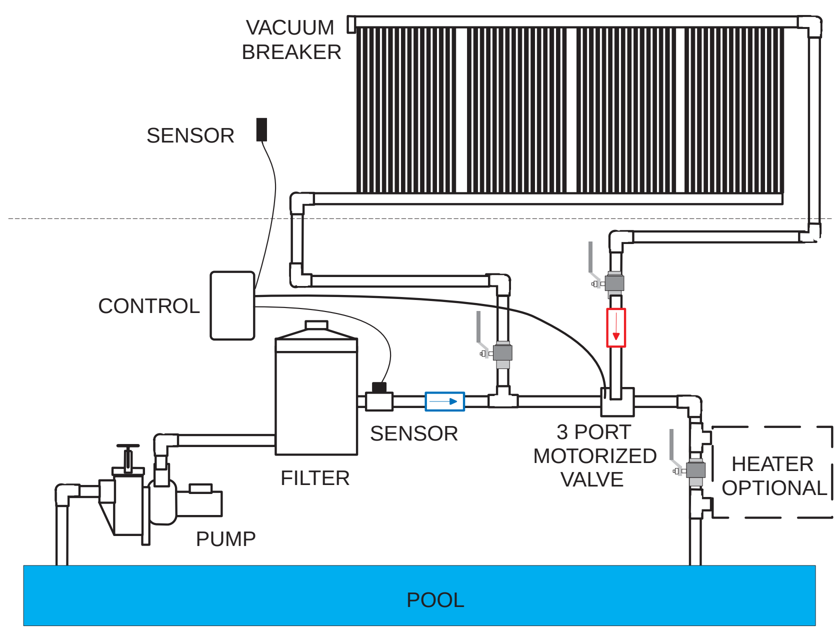


Figure B-2 – A typical pool heating system needed. This is the equivalent of nine (9) 4′ x 10′ pool panels. The system will be installed as given in Figure B-1.

System controls

The system will use a differential control specifically manufactured for SPH systems. The control will divert the pool water through the panels by energizing a valve when the collector sensor is five degrees warmer than the pool water as measured by a sensor immersed in the pool water piping. When the water is only two degrees warmer, the valve allows the water to flow directly back to the pool — in some cases through an auxiliary heater. The solar control does not regulate the operation of the pool pump — it is controlled by a clock timer set to operate during sunlight hours (typically 9 or 10 AM until 3 or 4 PM).

If the solar collectors are not configured to drain by gravity once the pool pump turns off, the system must be winterized each year to prevent water left in the solar collectors from freezing.

Figure B-3 – Differential control and 3-way valve

CASE STUDY C:
Residential Combination SWH and Space Heating System

Southern Oregon near the Oregon/Nevada border

The building

The main floor is 1800 sq ft, as is the unheated basement. There is also a 600 sq ft loft area. The main floor has 100% radiant heating divided into 2 heating zones. Most of the area is tile; the bedroom is carpeted.

The roof is metal over wood with 16″ insulation and an interior ceiling of 2x6 tongue and groove paneling. The pitch is 14/12 and the roof faces true south. There is some early morning shading, but the owner plans to remove some trees to the south of the house.

The elevation of the installation is 5000 feet. The closest station with solar and climate data is Reno, Nevada.

The utility room

There are no problems with floor space for hardware, including storage tanks. The home has a double-door access from outside into the walkout basement. All utilities are located in a utility area in the corner of the basement.

Existing heating system

The boiler and water heater are propane. The propane boiler is rated for 175,000 BTU/hour. The average propane usage in mid-winter is 9-10 gal/day. The boiler feeds a primary boiler manifold, which then feeds three (3) separate distribution loops. Each loop feeds one of the heating zones in the house (two radiant zones and a zone in the loft). Each zone has its own pump, thermostat, and zone valve; when the thermostat calls for heat, the zone valve opens and power is provided to the pump to allow flow through the distribution loop. The boiler controls also send power to the propane burner when any zone calls for heat.

The average load for the home during the heating season is approximately 600,000 BTU/day, which equates to a usage of 10 gallons of propane per day. This estimate is based on an average boiler efficiency of 65%, which is probably high for a 5000-foot elevation.

The domestic hot water load for the home is approximately 50 gallons per day.

Expected system performance

The solar energy system will displace approximately 70 to 75% of this load based on the solar and climate data for Reno, Nevada. At $3.00 per gallon of propane, the fuel displacement cost is on the order of $600 per month during the heating season. During the non-heating season, the system should provide 95 to 100% of the domestic hot water.

Space Heating Considerations

When installing a solar space heating system that is integrated into the building's auxiliary heating system, the system's effectiveness will depend heavily on the efficiency of the building envelope and the type of heating distribution used in the building.

The building envelope must limit infiltration and exfiltration, which is the leaking of air in and out of the building structure. If a solar heating system is installed in a leaky house, the heat produced by the system will quickly be lost. Sealing air leaks is fairly inexpensive and has significant economic payback. A professional energy auditor is able to identify locations that require particular attention by using a blower door, which is a device that uses a large fan to exaggerate air flow in and out of a building. Buildings should only be air-sealed to a point; homes that are too tight will have air quality issues and may require automated ventilation.

The building envelope should also be well-insulated. Basements and attics are fairly easy to address if there is a lack of sufficient insulation. Recommended insulation levels are available from Energy Star.

Air-sealing and increasing insulation levels are cost effective measures. Addressing deficiencies in the building envelope first will increase the portion of the heating load that can be provided by the solar heating system. If building envelope improvements are performed in conjunction with the installation of a solar space heating system, the energy savings will reflect favorably on the system and the installer.

The heating system distribution is also a critical consideration. Solar space heating integrates well with high-mass distribution systems that are able to operate at low temperatures. The best example of this type of system is in-floor radiant heating. Many of these systems can provide significant heat with floor supply temperatures of 95°F to 100°F (35°C to 40°C). This is in stark contrast to baseboard systems, which typically operate at temperatures of 160°F (70°C) and greater. Lower distribution temperatures allow the solar collectors to operate at lower temperatures, which increases efficiencies, and increases the heat storage capacity of the solar storage tank. In a space heating system, the tank can only contribute heat to the system if it is above the operating temperatures of the heating system. For example, if a system required 160°F supply temperatures, a 1000-gallon tank filled with 140°F water would be unable to contribute. Conversely, the same storage tank could provide significant heat to a radiant floor system that requires 95°F supply temperatures.

The installation of solar space heating systems requires significant knowledge of solar heating systems and traditional heating systems. Installers involved in this work often are involved in the traditional heating trades or collaborate with heating professionals.

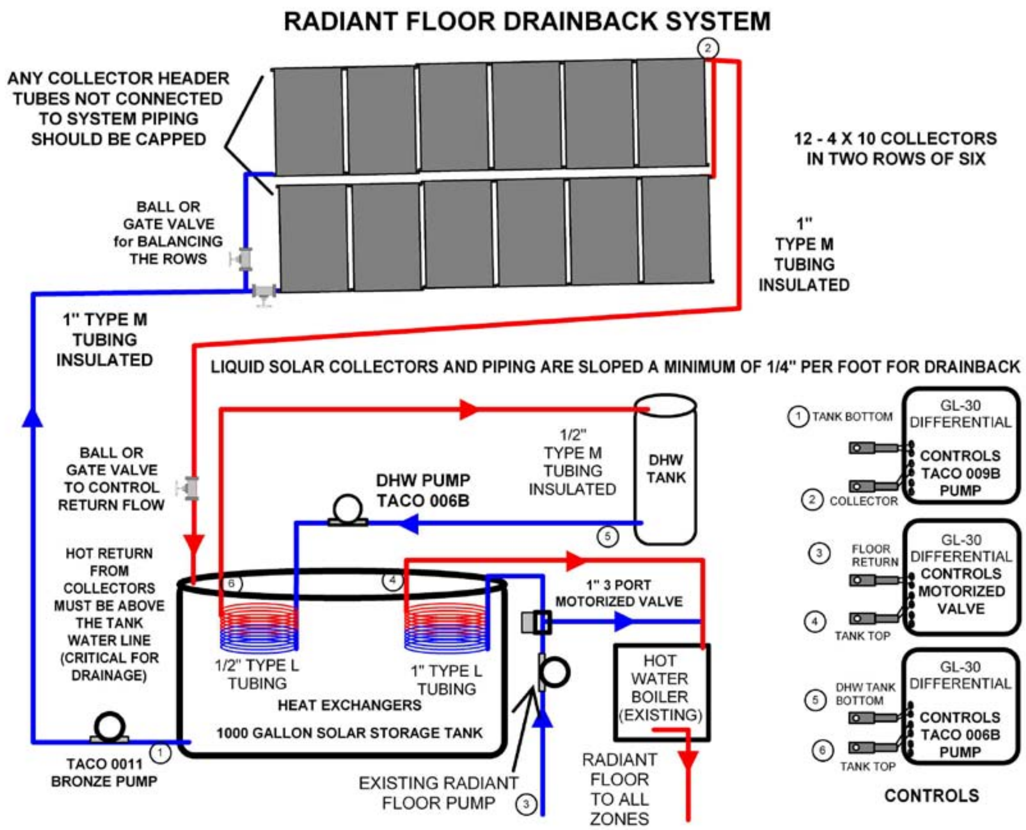


Figure C-1 – Radiant floor Drainback system

Retail equipment costs (2010 pricing)

12	4′x10′ Collectors	$1,195.00	$14,340.00
12	Mounts for collectors	$145.00	$1,740.00
1	DHW storage tank, 80 gallon	$682.50	$682.50
1	1000 gallon unpressurized tank	$2,250.00	$2,250.00
1	Bronze Taco 0011 high-head pump	$573.26	$273.26
3	GL-30 Differential controller	$129.00	$387.00
6	10 K sensors	$19.00	$114.00
1	Relays 120v coil DPDT	$26.00	$26.00
15	Inhibited Propylene glycol (gallons)	$29.40	$441.00
1	Flanges for solar pump - 1″ FIP	$18.50	$18.50
1	Bronze Taco 006 DHW pump - 3/4″ sweat	$187.00	$187.00
1	1″ Motorized valve	$221.90	$221.90
5	Thermometers - 1/2″ MIP	$16.00	$80.00
1	Expansion Tank	$60.80	$60.80
1	Drain, fill, check, pressure relief valve package	$58.00	$58.00
2	100 ft coiled 1″ copper heat exchangers	$942.00	$1,884.00
1	100 ft. coiled 1/2″ copper heat exchanger	$411.00	$411.00
	Freight Estimate		$800.00
		Materials total:	**$24,274.96**

CASE STUDY D:
Domestic Solar Water Heating System with Natural Gas Auxiliary Heat

Project Description

A family of four near Palo Alto, California lives in a single family home with a natural gas 50-gallon water heater located in their garage at the southeast corner of the house. The water heater location will permit a storage tank to be placed next to the gas water heater — this location is the preference of the owner. The home has a low-sloped roof with a 3 in 12 pitch. Due to tree shading, the only suitable location for the solar collectors will be on the extreme southwest roof, which faces due south. Calculations indicate there is not enough clearance in the attic to allow for the slope (1/4" per foot minimum) of a drain-back system. An antifreeze system is proposed and designed based on the estimated daily usage of the family.

System Design

Using standard estimates for household size, the expected hot water usage is approximately 65 gallons per day. The family would like to use a specific manufacturer recommended by a relative and also requests that the system pump is powered by photovoltaics.

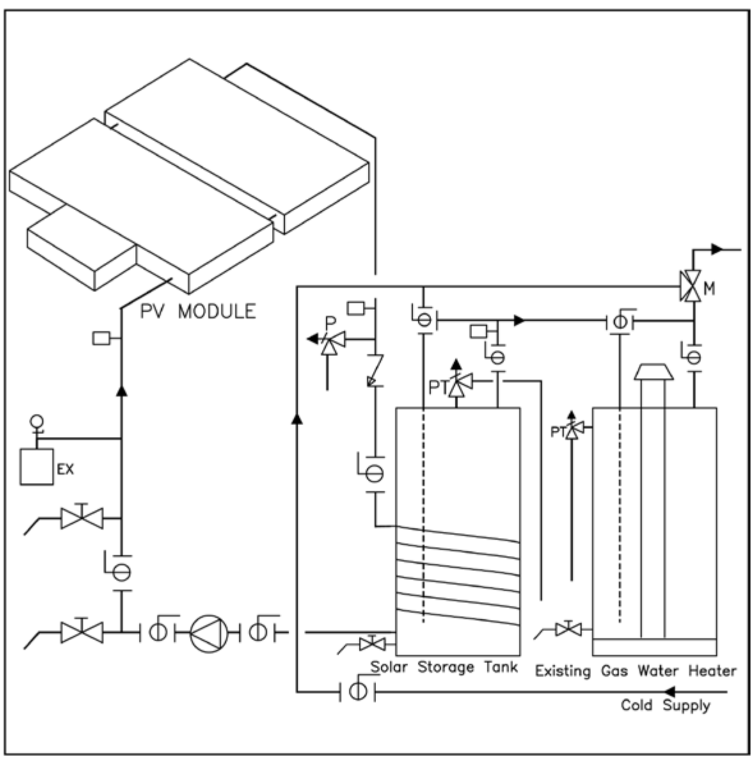


Figure D-1 – Drawing of the system (Courtesy of the SRCC)

Based on these requests, an SRCC OG-300 Certified™ system is selected. The minimum storage tank size available that meets the parameters listed above is 80 gallons, which is adequate for the estimated daily load. The selected system (SRCC number 2001003F, see Figure D-1) consists of two 32 square foot selective surface absorber flat plate collectors and a storage tank with a wraparound double wall heat exchanger. The pump is powered by a PV module. The manufacturer gives the system a freeze tolerance level at minus 60°F, which is more than adequate for Palo Alto.

System Performance

California is divided into 16 building climate zones as given in Figure D-2. Palo Alto is in zone 4; this information is utilized to estimate the performance of the system chosen for this project.

Based on SRCC OG-300 estimates, the system has an estimated savings potential of 166 therms per year with a solar fraction of 0.76. The solar fraction is an estimate of the percentage of energy supplied by the solar energy system — in this case the estimate is 76%. The system installation will comply with the drawing in Figure D-1 and all other requirements of the manufacturer including tags, labels and a copy of the operation and maintenance manual to be given to the system owner.

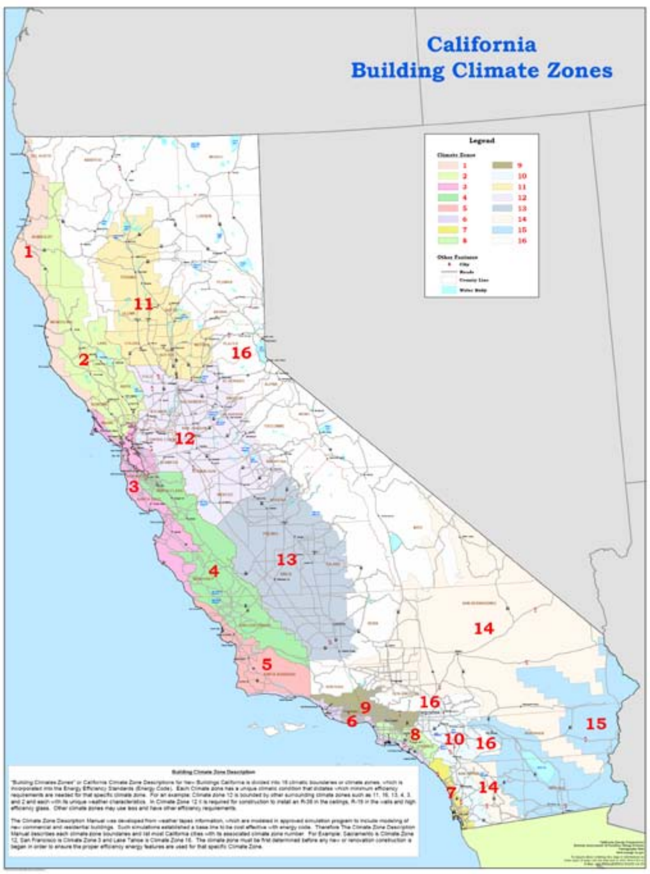


Figure D-2 — Building Climate Zones of California

12 Study Guide Review Questions

The content of the NABCEP Solar Heating Installer Exam is based upon the Solar Heating Installer Job Task Analysis (JTA) and the list of Primary References available at www.nabcep.org. The exam consists of 60 multiple-choice questions that cover the following content areas:

Exam Blueprint

The table below shows the blueprint (test specifications) for the NABCEP Certified Solar Heating Installer Examination. It is provided for candidates' and educators' use to determine which specific knowledge areas to focus on when preparing for the examination.

NABCEP Certified Solar Heating Installer Exam Blueprint

	% of exam	# of items
A. Prepare for project	12%	7
B. Evaluate the site	13%	8
C. Plan system installation	19%	11–12
D. Install the system	30%	18
E. Commission the system	14%	8–9
F. Service and maintain the system	12%	7
TOTAL	100%	60

An exam applicant should reference the JTA and this blueprint in preparation for the exam.

The exam questions have been prepared by a committee of Subject Matter Experts in collaboration with a psychometrician, who is responsible for ensuring that the exam items are clearly written, are properly constructed, and that each item has one definitive correct answer that can be defended based on content in one of the Primary References.

In order to maintain its relevance and integrity, the NABCEP Solar Heating Installer Exam is extremely rigorous. Applicants must be thoroughly versed in the requirements of various building codes and OSHA regulations, understand the details relating to the installation of systems used throughout North America, be able to competently troubleshoot and maintain these systems, and be well-versed in the factors that affect the performance and durability of solar water heating systems.

For those individuals who have limited experience with SWH systems and are not yet prepared to seek NABCEP Solar Heating Installer Certification, NABCEP offers a Solar Heating Entry Level Exam. It is not a certification program, but instead an acknowledgement that a successful candidate has demonstrated a basic understanding of SWH. The Entry Level program is based on the Solar Heating Entry Level Learning Objectives, available at www.nabcep.org.

Sample NABCEP Exam Questions

The following questions are indicative of the rigor and scope of items that may be encountered on the NABCEP Solar Heating Installer Exam. These questions are from previous versions of the Exam and have been retired. A discussion of the correct answers follows the sample questions.

Important note: These items do not represent the full content of the Exam. Their inclusion is for illustrative purposes only. Refer to the NABCEP Certified Solar Heating Installer Exam Blueprint and the NABCEP Solar Heating Installer JTA to determine the scope of the content that is included on the Exam.

1. Which classification of fire extinguisher should be used on flammable liquids, gas, and grease?

    A. Class A
    B. Class B
    C. Class C
    D. Class D

2. What is the water pressure at the base of a 65′ vertical column of type M copper?

    A. 10.6 psi
    B. 22.3 psi
    C. 28.2 psi
    D. 129.4 psi

3. 250′ of 1″ type M copper (0.0454 gallons/linear foot) is installed horizontally for a water distribution line, and the pipe weighs 0.843 lbs/foot. How much would the pipe and its contents weigh?

    A. 222 lbs.
    B. 305 lbs.
    C. 425 lbs.
    D. 1751 lbs.

4. When drilling a pilot hole in a rafter for a lag bolt, which is the MAXIMUM percentage of lag bolt diameter that the hole should be drilled?

    A. 25%
    B. 50%
    C. 85%
    D. 75%

5. Which of the following has the HIGHEST thermal conductivity?

   A. iron
   B. copper
   C. aluminum
   D. galvanized

6. An 80-gallon storage tank has a dry weight of 180 pounds. How much MORE will it weigh when it is full?

   A. 667 pounds
   B. 847 pounds
   C. 915 pounds
   D. 1020 pounds

7. Which type of pressure-rated copper pipe has the THINNEST wall?

   A. Air conditioning and refrigeration tubing (ACR)
   B. Type K
   C. Type L
   D. Type M

Answers:

1. B. Fire extinguishers are rated by OSHA for their ability to extinguish certain types of fires. Table F-1 in 29 CFR 1926.150(c)(1)(x) distinguishes these different classes and the types of fire extinguishers that are appropriate for each class of fire.

2. C. The pressure at the bottom of one foot of water column is 0.43psi. This means that for every 2.31 feet of water column, the pressure increases by 1psi. The size of the tubing is irrelevant.

3. B. One method for determining the answer to this question is to first determine the filled weight of the tubing per foot. This requires using the volumetric capacity of the tubing to determine the weight of the water in the tubing. Since water weighs 8.33 pounds per gallon, the weight of fluid in one foot of 1” Type M copper is 0.378 pounds per foot. This means that the filled weight of 1” Type M copper is 1.22 pounds per foot. This value is multiplied by the total length of tubing to determine the total filled weight.

4. D. In Section 3 of the Florida Solar Energy Center’s Solar Water and Pool Heating Manual, it states that the pilot hole should be 50-75% of the lag bolt’s diameter.

5. B. In *The Copper Tube Handbook*, it states that “Copper is the logical material for solar energy systems because… it has the best thermal conductivity of all engineering metals” (p. 15).

6. A. The total weight of water can be determined by multiplying the volume of water by the waters density, which is 8.33 pounds per gallon.

7. D. The wall thicknesses of the various types of copper tubing is given in the “Technical Data” section of *The Copper Tube Handbook*.

13 Additional Study Resources

PRIMARY REFERENCES:

The following reference list identifies training materials, reports, and codes and standards associated with the design and installation of solar heating systems. Studying these training materials will help prepare candidates for the Solar Heating Installer Certification exam. Please refer to the NABCEP Solar Heating Study Guide for additional direction on preparing for the NABCEP examination.

- *Active Solar Preheat Systems: Unified Facilities Criteria (UFC 3-440-01.pdf),* U.S. Department of Defense, www.wbdg.org
- *Code of Federal Regulations,* Chapter 29 Part 1926 – Safety and Health Regulations for Construction, Occupational Safety and Health Administration, www.osha.gov
- *The Copper Tube Handbook*, Copper Development Association, www.copper.org
- *Planning and Installing Solar Thermal Systems*: *A guide for installers, architects and engineers* (2nd Edition), 2010, by Deutsche Gesellschaft fur Sonnenenergie. ISBN 978-1-84407-760-1, James & James (Science Publishers) Ltd., www.earthscan.co.uk
- *Solar Water and Pool Heating Manual: Design and Installation & Repair and Maintenance*, January, 2006. Florida Solar Energy Center, www.fsec.ucf.edu
- *SRCC Document OG 300, Operating Guidelines and Minimum Standards for Certifying Solar Water Heating Systems*, May 2002, Solar Rating and Certification Corporation, www.solar-rating.org
- *Uniform Plumbing Code*, 2009. International Association of Plumbing & Mechanical Officials, http://www.iapmo.org
- *Uniform Solar Energy Code,* 2009. International Association of Plumbing & Mechanical Officials, http://www.iapmo.org

SUPPLEMENTAL REFERENCES:

- *Roofing Construction and Estimating*, 2006, by Daniel Atcheson. ISBN 1-57218-007-2, Craftsman Book Co., http://craftsman-book.com
- *Solar Domestic Water Heating*, 2010, by Chris Laughton. ISBN 978-1-84407-736-6, James & James (Science Publishers), Ltd., www.earthscan.co.uk
- *Solar Thermal Systems, Successful Planning and Construction*, 2002, by Felix A. Peuser, Karl-Heinz Remmers, Martin Schnauss. ISBN 1-902916-39-5, James & James (Science Publishers) Ltd., www.earthscan.co.uk
- *Solar Hot Water Systems Lessons Learned 1977 to Today, 2004*. Tom Lane Energy Conservation Services, www.ecs-solar.com/lessons_learned.htm
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