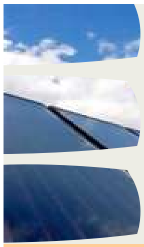


Solar Thermal

Terms & Definitions

Active System: Uses a mechanical device (e.g. pump) to move the transport medium and operate any end-use heat exchange.

Azimuth Angle: the angle clockwise from true north of the direction that the PV array faces. Due south = 180°.

Bypass Valves: Solar bypass is a series of three valves that allow you to bypass the existing water heater to manually force the solar system to do all of the work. Used with solar batch heaters. (See figures next page)

BOS: Balance of System—typically denoting all components other than the solar themal collectors. (e.g. controllers, tank, piping)

Closed Loop System: A heat transfer fluid is circulated through a heat exchanger in line with the storage tank to heat the storage water. These systems are preferable in areas prone to frost and freezing.

Controllers: Automatically regulate the temperature of the water in the storage tank. There are two main types—***time trigger controllers*** and ***minimum temperature controllers***. Newer controllers are set up to incorporate both functions.

Evacuated Tube Collector: This collector typically includes a heat exchanger at it's higher end and a transfer fluid, which rises in thetubes and heats the water in theheat exchanger. Highest efficiency collectors but also come at higher cost.

Flat Plate Collector: Consists of a flat sheet absorber or envelope of specially blackened material which absorbs the sunlight and transfers the heat produced into the water, or transfer fluid, flowing through the collector.

Frost Protection: Solar collectors in colder climates need freeze protection to avoid damage in cold weather. Protection is achieved in a number of ways:

- ***Closed Loop Systems***—heat transfer fluid in the panels, such as glycol, has anti-freeze properties.
- ***Open Loop Systems—***Temperature sensors turn the pump on to run water from the bottom of the storage tank through the panel before it freezes. Frost valves can also be installed to let water flow through the panel when the temperature is close to freezing.
- ***Frost Tubes--***Frost tubes may also enable the water in the panels to freeze without damaging them.

FSEC: Florida Solar Energy Center, the leading US solar equipment testing and technical installation training center.

Insolation: Radiant solar energy reaching an area (kWh/m^2/day)

Irradiance: Radiant power per unit area from the sun (Watts/m^2)

kW: kilowatt. Unit of turbine capacity.

kWh: kilowatt-hour. Unit of energy.

Terms & Definitions (cont.)

Magnetic Declination: Difference in degrees from magnetic north and true north. Adjustment needed to estimated energy generation potential of thermal collector.

MW: megawatt. Unit of turbine capacity.

MWh: Megawatt-hour. Unit of energy.

Minimum Temperature Controllers: Trigger the supplementary heating whenever the water tank temperature drops below a minimum pre-defined temperature.

OG-100—SRCC Document #OG-100 is the "Operating Guidelines for Certifying Solar Collectors." Often panel performance is depicted as OG-100 Certified.

Open Loop System: Water from the storage tank is circulated through the solar collector and heated directly.

Orientation: Position of SHW panels with respect to true south. Differs by state/location.

Passive System: Relies on thermal gradients to move energy.

Peak Irradiance: Standard peak sunlight condition (1000 W/m^2)

Peak Sun Hours: 9am – 3pm

Pressure Temperature Relief Valve (PTRV): Installed at the hot water outlet of batch heater systems in case temperatures or pressures become excessive.

Solar Collector: An element that absorbs solar energy and transmits it to a medium that can be used to convey the energy to where it is used. There are two main types—***flat plate collector panels*** and ***evacuated tubes***.

SRCC: Solar Rating & Certification Corporation—Housed at FSEC, providing independent certification of solar water heating collectors & systems.

SHW: Acronym used for Solar Hot Water system.

Standard Test Conditions (STC): the standard reference environment for PV cell operation is an environment of 1000 W/m^2 irradiance, 1.5 air mass, and cell temperature of 20°C.

Storage: A means of smoothing out fluctuations in solar supply (e.g. insulated water tank.

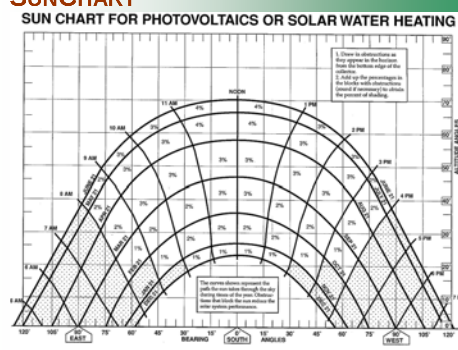
Tilt Angle: The tilt angle is the angle from horizontal of the inclination of the PV array (0° = horizontal, 90° = vertical).

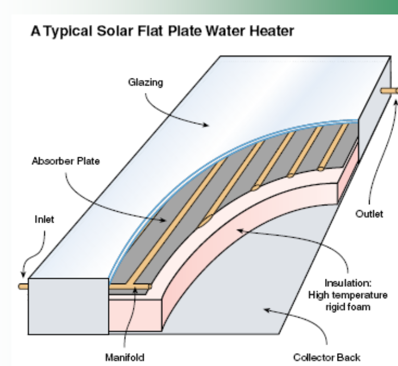
Time Trigger Controllers: Used to keep the booster heating turned off during the day, to ensure you're not paying for electricity or gas to heat your water when the sun could be doing the job for free. The timer can be set to turn on the supplementary heating before periods of high water use. Both features increase the system's efficiency.

Transport Medium: A fluid or gas that transfers the heat from the solar collector to the end use site (e.g. hot water heater).

Annual Sun Position

SunChart





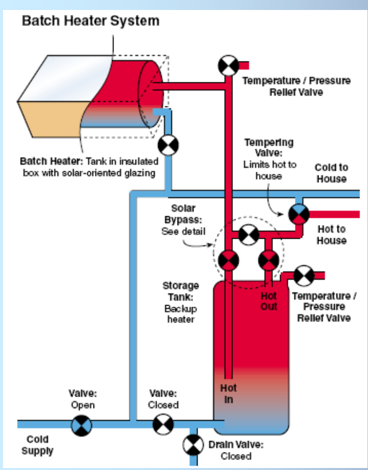
Thermomax Evacuated Tube Collector

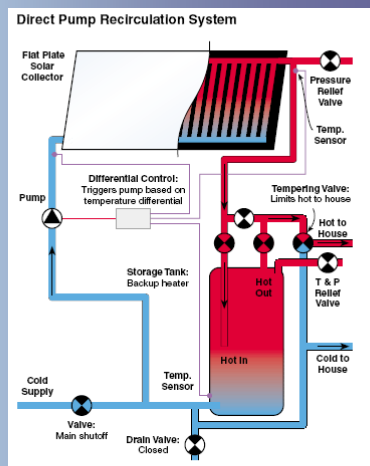
Solar Electric System Overview

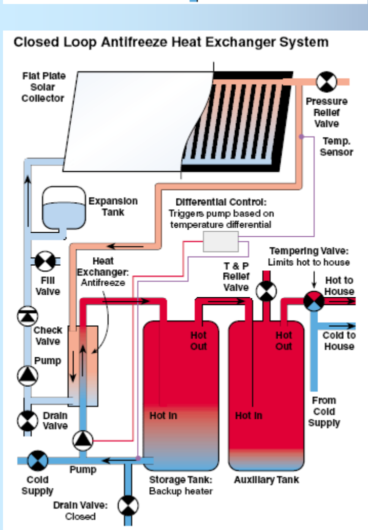
Solar Thermal Collector Output—Depends on four main criteria:

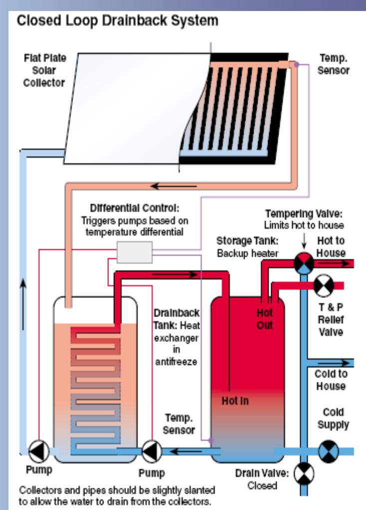
- Size, type, and construction materials of the collector;
- Solar energy available at the site;
- Difference between the collector inlet temperature (T_i) and the ambient air temperature (T_a);
- The application of the collector.

System Layouts









Solar Hot Water System Types: Advantages & Disadvantages

System Type	Characteristic & Use	Advantages	Disadvantages
Solar Batch Water Heater	Open loop; Integrated collector & storage; Freeze protection generally limited to infrequent or light freeze climates	Simple; No moving parts	Freeze protection typically poor; Inefficient in cold climates; Small systems only
Thermosiphon	Typically open loop; May be closed loop with heat exchanger & antifreeze	Simple; Requires no electricity for operation	Collector must be located below tank; Inappropriate for use with hard water (open loop system)
Direct Pump System	Open loop; Freeze-free climates	Flexible placement of tank & collector; can be powered by PV	No freeze protection; Inappropriate for use with hard water
Direct Pump Recirculation System	Open loop; Climates where freezing is an unexpected occasion	Simple; can be powered by PV	Freeze protection is limited to infrequent & light freezes; Inappropriate for use with hard water
Draindown	Open loop; Designed to drain water when near freezing	Can be powered by PV	Freeze protection is vulnerable to numerous problems; Collectors & piping must have adequate slope to drain; Inappropriate for use with hard water
Closed Loop Heat Exchanger	Closed loop; Cold climates	Very good freeze protection; Basic principles well understood by conventional plumbing trades; No problems with hard water; can be powered by PV	Most complex of all systems, with many parts; Heat exchanger & antifreeze reduce efficiency; Fluid may break down at high stagnation temperatures
Drainback	Closed loop; Cold climates	Very good freeze protection if used with antifreeze; No problems with hard water; Simplest of reliable freeze protection systems; Fluid not subject to stagnation temperatures; Simple to homebrew; can be powered by PV	Heat exchanger & antifreeze reduce efficiency; Collectors & piping must have adequate slope to drain; Requires larger pump to lift

Rules of Thumb

Energy Replacement—Standard systems can replace 75% of a households water heating demand in summer and 25-45% in the winter. Similar rations exist for properly sized commercial systems. Systems sized to supply 100% of the annual load will produce over-heated water in summer which is unnecessary & potentially problematic.

Efficiency First—Before installing a SWH system, insulate pipes and tanks, install efficient faucets & showerheads, lower water heater thermostat.

Roof Structural Loading—Roof loading is typically not an issue. Panels weight about 100# each. Passive systems with roof storage tanks may require additional structural bracing. Architectural signoff required for these systems.

Materials Selection:

- Don't use dissimilar materials
- Use only sunlight resistant materials
- Structural materials:
  - o Corrosion resistant aluminum 6061 or 6063
  - o Hot dip galvanized steel per ASTM A123
  - o Stainless steel

Waterproofing—Require builder/roofer signoff on mounting for roof mounted systems to prevent leaking at connection points.

Solar Collector Output Decreases As:

- (T_i - T_a) the collector temperature delta grows
- The available solar energy decreases

Sizing Estimates:
Rough estimates for 100% of summer demand and 40% of year round demand.

- In the Sunbelt—1 square foot of collector per 2 gallons of tank capacity (daily hot water demand)
- In the SE & Mountain States—1 square foot of collector per 1.5 gallons of tank capacity.
- In the Midwest & Atlantic States—1 square foot of collector per 1 gallon of tank capacity.
- In New England & the NW—1 square foot of collector per 0.75 gallon of tank capacity.

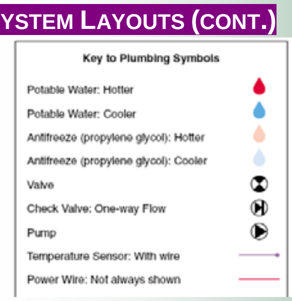
Freeze Protection—Systems which use liquites as heat-transfer fluids need protection from freezing in climates where temperatures fall below 42^{o}F.

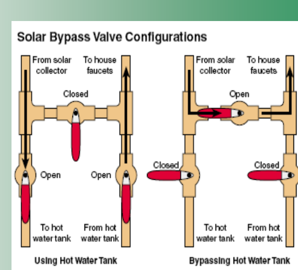
Factors Affecting Well Designed SWH Systems—The major factors affecting the performance of properly sited and installed SWH systems are scaling (in liquid or hydronic-based systems) and corrosion (in hydronic and air systems).

- Avoid scaling by using water softeners or by circulating a mild acidic solution (e.g. vinegar) through the system every 3-5 years, and cleaning in-tank heat exchanges w/ sandpaper.
- Avoid corrosion by avoiding dissimilar metals and by using the proper materials for components to prevent rust in an open loop system due to oxygen.

Characteristic	Batch	Thermosyphon	Open-Loop Direct	Glycol	Drainback
Low profile—unobtrusive in appearance			✔	✔	✔
Lightweight			✔	✔	✔
Freeze tolerant				✔	✔
Easy installation & infrequent service	✔	✔	✔		
Passive operation—no pumps or controls	✔	✔			
Space saving—storage tank unnecessary	✔	✔			

System Layouts (cont.)





Calculations/Engineering Review

Load & Collector Sizing Calculations

1. **Calculate daily water heating load—**Measuring water temperature and timing the length of use will allow you to calculate energy consumed. For example, a 10-minute shower at 110°F (heated from a 50°F supply) with a flow rate of 1.5 gpm in Des Moines, Iowa, would result in an energy consumption of:

   Volume (gallons) X Temperature Rise(oF) X 8.33 Btu/gal (specific heat) = Btu
   1.5 gpm X 10 min X 60°F X 8.33 = 7,497 Btu for the 10 minutes
   = 44, 982 Btu/hr
   = 13.2 Watts

2. **Determine sites average daily insulation and equivalent SRCC "Sky Type**—Use NREL data (PVWatts) and convert the kWh/m^2/day to Btu/ft^2/day

   4.83 kWh/m^2/day X 317.1 Btu/ft^2/day = 1,531.6 Btu/ft^2/day
   This available solar resource most closely matches the SRCC's "Mildly Cloudy" (1,500 Btu/ft^2/day) sky-type category

3. **Categorize your climate—**For all but the coldest locations in the US, using the "C" category will give you a reasonable estimate

*Example Collector Data**

Category (T_i–T_a)	Thousands of Btu/Sq. Ft./Day: Clear (2,000 Btu/ ft.^{2} per day)	Mildly Cloudy (1,500 Btu/ ft.^{2} per day)	Cloudy (1,000 Btu/ ft.^{2} per day)
A (-9°F)	43	32	21
B (9°F)	39	28	18
C (36°F)	33	24	13
D (90°F)	23	13	4
E (144°F)	13	4	negligible

*Black chrome, flat-plate collector, 32 sq. ft. nominal

4. **Obtain collector performance output data from the SRCC Web Site**—Use SRCC ratings for location & equipment manufacturer. (See reference section for web link.)

5. **Size system (no. of collectors) according to demand**—50-70% of load covered by SWH

Design Considerations

Backup Heating: Systems require a backup water heating method (e.g. standard water heater or instantaneous water heating) to "boost" the water temperature when there isn't enough solar energy to heat the water.

System Sizing—Systems are usually sized to provide enough hot water to supply the average daily demand. In the USA 30 gallon/person/day is reasonable for design. Typical household (family of four) use is 120 gal/day. Systems will produce twice as much in summer as winter.

Storage Tanks
- Sizing dependant upon no. of collectors and climate at the site.
- Generally, larger storage = lower collector operating temp = higher performance
- Storage tank for solar should be separate from the backup system storage.
- Backup system storage should accommodate 100% if load.

Closed Loop vs. Open Loop—Closed loop systems are preferable in areas prone to frost and freezing.

Orientation Factor: Combined affects of SWH panel's tilt & orientation from true south. SHW systems oriented within 45° east or west of true south will not see significant decreases in performance. A tilt equal to the local Latitude is ideal

Shading: Use of a suncharting tool is critical to estimating shading impacts to system performance. Both manual and software versions are available for use. See Reference section for suncharting tool links.

Collector Rating—Manufacturer ratings are in Btu/ft^2/day energy saved. Will need converted to W/m^2.

Solar Resource—Usable solar radiation = average value from solar insulation table X 96%. Approximately 4% of annual solar energy is not captured due to low irradiance conditions.

Maximizing Efficiency—Heat losses typically occur through the plumbing and the storage tank walls. Properly insulation can reduce these losses to less than 5% per day. Use ¾" thick closed cell foam pipe insulation and wrap tanks with insulating blankets. Select solar storage tanks with insulation levels greater than R-15, or with more than 2' of foam insulation.

Engineering Review

Review Steps

- Check commercial availability of key system components (vendor specification sheets must be supplied)
- Verify total system generation capacity (gallons/day)
- Confirm solar radiation value based upon location, tilt & orientation (kWh/m^2/day). Use NREL data.
- Check shading correction factor
- Verify the system design contains all key components and that they are adequately sized for the hot water demand (Solar collectors/panels, storage tanks, components like pumps and controllers to circulate the heated water through the system and control the backup system, safety signage)
- Verify energy demand & hot water production calculations.
- Review system installation and mounting methods.
- Confirm adequacy of O&M and decommissioning procedures.
- Confirm system installed cost ($/m^2) is within a reasonable range.
- Calculate simple payback using stated utility rate, system costs minus any stated incentives/tax rebates, and calculated energy savings.

Conversion Values

1 Watt	=	3.412 Btu/hr
Specific Heat of Water	=	8.33 Btu/gallon
1 kWh/m^2/day	=	317.1 Btu/ft^2/day

References

PV Watts
Performance calculator to determine site W/m^2.
http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/

Magnetic Declination
http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp

SRCC Collector Performance Ratings
Solar radiation data for panel & evacuated tube collectors and systems compiled by SRCC, organized by manufacturer and by state.
http://www.solar-rating.org/ratings/ratings.htm

Sunrise & Sunset Times
You can obtain the times of sunrise, sunset at:
http://aa.usno.navy.mil/data/docs/RS_OneDay.php

Costs/Financials

CostBreakdown

Installation	=	30% of cost
Panels	=	50% of cost
BOS	=	15% of cost
Engineering	=	5% of cost
O&M	=	5-10% of system cost every 3-5 years. Electrical component replacement each 10 years.

Life Cycle
20-30 years

System Cost Range
Flat Plate collector systems--$6-8/ ft^2
Evacuated tube systems--$8-12/ ft^2

Simple Payback

$$\frac{\text{(Total Installed System cost + Lifetime O\&M)}}{\text{(Annual SWH System kWh savings) X (Utility Rate \$/kWh)}}$$

Other

Critical Factors
Verification of shading, energy demand & supply calculations.

Environmental Issues
No adverse environmental issues.

Market Status
Commercially available solar thermal panel or tube assembly systems. Refer to the Florida Solar Energy Center's website for a list of certified panels
http://www.fsec.ucf.edu/en/industry/testing/STcollectors/hot_water_ratings/index.htm