Solar water heating

Solar water heating (SWH) or **solar hot water** (SHW) systems comprise several innovations and many mature renewable energytechnologies that have been well established for many years. SWH has been widely used in Australia, Austria, China, Cyprus, Greece, India, Japan, Jordan, Spain and Turkey.

In a "close-coupled" SWH system the storage tank is horizontally mounted immediately above the solar collectors on the roof. No pumping is required as the hot water naturally rises into the tank through thermosiphon flow. In a "pump-circulated" system the storage tank is ground- or floor-mounted and is below the level of the collectors; a circulating pump moves water or heat transfer fluid between the tank and the collectors.

SWH systems are designed to deliver hot water for most of the year. However, in winter there sometimes may not be sufficient solar heat gain to deliver sufficient hot water. In this case a gas or electric booster is used to heat the water.

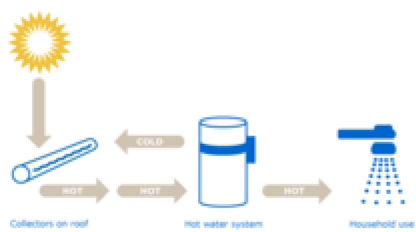
Overview[edit]

Water heated by the sun is used in many ways. While perhaps best known in a residential setting to provide domestic hot water, solar hot water also has industrial applications, e.g. to generate electricity.[1] Designs suitable for hot climates can be much simpler and cheaper, and can be considered an appropriate technology for these places. The global solar thermal market is dominated by China, Europe, Japan and India.

A solar water heater installed on a house in Belgium

In order to heat water using solar energy, a collector, often fastened to a roof or a wall facing the sun, heats working fluid that is either pumped (active system) or driven by natural convection (passive system) through it.[٢] The collector could be made of a simple glass-topped insulated box with a flat solar absorber made of sheet metal, attached to copper heat exchanger pipes and dark-colored, or a set of metal tubes surrounded by an evacuated (near vacuum) glass cylinder. In industrial cases a parabolic mirror can concentrate sunlight on the tube. Heat is stored in a hot water storage tank. The volume of this tank needs to be larger with solar heating systems in order to allow for bad weather[clarification needed], and because the optimum final temperature for the solar collector[clarification needed] is lower than a typical immersion or combustion heater. The heat transfer fluid (HTF) for the absorber may be the hot water from the tank, but more commonly (at least in active systems) is a separate loop of fluid containing anti-freeze and a corrosion inhibitor which delivers heat to the tank through aheat exchanger (commonly a coil of copper heat exchanger tubing within the tank). Copper is an important component in solar thermal heating and cooling systems because of its high heat conductivity, resistance to atmospheric and water corrosion, sealing and joining by soldering, and mechanical strength. Copper is used both in receivers and primary circuits (pipes and heat exchangers for water tanks).[٣]

Another lower-maintenance concept is the 'drain-back': no anti-freeze is required; instead, all the piping is sloped to cause water to drain back to the tank. The tank is not pressurized and is open to atmospheric pressure. As soon as the pump shuts off, flow reverses and the pipes are empty before freezing could occur.

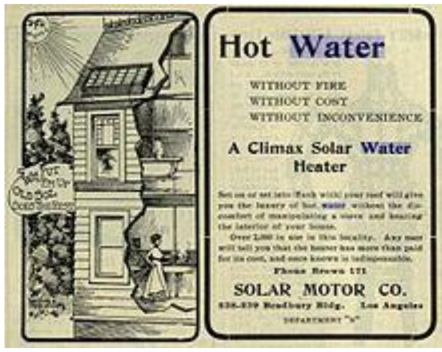


How a Solar Hot Water system works

Residential solar thermal installations fall into two groups: passive (sometimes called "compact") and active (sometimes called "pumped") systems. Both typically include an auxiliary energy source (electric heating element or connection to a gas or fuel oil central heating system) which is activated when the water in the tank falls below a minimum temperature setting such as ٥٥ °C. Hence, hot water is always available. The combination of solar water heating and using the back-up heat from a wood stove chimney to heat water[٤] can enable a hot water system to work all year round in cooler climates, without the supplemental heat requirement of a solar water heating system being met with fossil fuels or electricity.

When a solar water heating and hot-water central heating system are used in conjunction, solar heat will either be concentrated in a pre-heating tank that feeds into the tank heated by the central heating, or the solar heat exchanger will replace the lower heating element and the upper element will remain in place to provide for any heating that solar cannot provide. However, the primary need for central heating is at night and in winter when solar gain is lower. Therefore, solar water heating for washing and bathing is often a better application than central heating because supply and demand are better matched. In many climates, a solar hot water system can provide up to ٨٥٪ of domestic hot water energy. This can include domestic non-electric concentrating solar thermal systems. In many northern European countries, combined hot water and space heating systems (solar combisystems) are used to provide ١٥ to ٢٥٪ of home heating energy.

History[edit]



An advertisement for a **Solar Water Heater** dating to ١٩٠٢

There are records of solar collectors in the United States dating back to before ١٩٠٠,[٥] comprising a black-painted tank mounted on a roof. In ١٨٩٦ Clarence Kemp of Baltimore, USA enclosed a tank in a wooden box, thus creating the first 'batch water heater' as they are known today. Although flat-plate collectors for solar water heating were used in Florida and Southern California in the ١٩٢٠s there was a surge of interest in solar heating in North America after ١٩٦٠, but especially after the ١٩٧٣ oil crisis.

See Appendix ١ at the bottom of this article for a number of country-specific statistics on the "Use of solar water heating worldwide". Wikipedia also has country-specific articles about solar energy use (thermal as well as photovoltaic) in Australia, Canada, China, Germany,India, Japan, Portugal, Romania, Spain, the United Kingdom and the United States.

Mediterranean[edit]

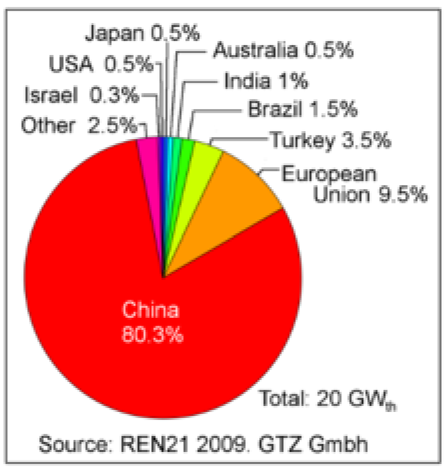
Passive (thermosiphon) solar water heaters on a rooftop in Jerusalem

Israel and Cyprus are the *per capita* leaders in the use of solar water heating systems with over ٣٠٪–٤٠٪ of homes using them.[٦]

Flat plate solar systems were perfected and used on a very large scale in Israel. In the ١٩٥٠s there was a fuel shortage in the new Israeli state, and the government forbade heating water between ١٠ pm and ٦ am. Levi Yissar built the first prototype Israeli solar water heater and in ١٩٥٣ he launched the NerYah Company, Israel's first commercial manufacturer of solar water heating.[٧] Despite the abundance of sunlight in Israel, solar water heaters were used by only ٢٠٪ of the population by ١٩٦٧. Following the energy crisis in the ١٩٧٠s, in ١٩٨٠ the Israeli Knesset passed a law requiring the installation of solar water heaters in all new homes (except high towers with insufficient roof area).[٨] As a result, Israel is now the world leader in the use of solar energy *per capita* with ٨٥٪ of the households today using solar thermal systems (٣٪ of the primary national energy consumption),[٩] estimated to save the country ٢ million barrels (٣٢٠،٠٠٠ m³) of oil a year, the highest per capita use of solar energy in the world.[١٠]

In ٢٠٠٥, Spain became the first country in the world to require the installation of photovoltaic electricity generation in new buildings, and the second (after Israel) to require the installation of solar water heating systems in ٢٠٠٦.[١١]

Asia-Pacific[edit]



New solar hot water installations during ٢٠٠٧, worldwide.

The world saw a rapid growth of the use of solar warm water after ١٩٦٠, with systems being marketed in Japan and Australia.[٥] Technical innovation has improved performance, life expectancy and ease of use of these systems. Installation of solar water heating has become the norm in countries with an abundance of solar radiation, like the Mediterranean,[١٢] Japan, and Australia.

Colombia developed a local solar water heating industry thanks to the designs of Las Gaviotas, directed by Paolo Lugari. Driven by a desire to reduce costs in social housing, the team of Gaviotas studied the best systems from Israel and made adaptations as to meet the specifications set by the Banco Central

Hipotecario (BCH) which prescribed that the system must be operational in cities like Bogotá where there are more than ٢٠٠ days overcast. The ultimate designs were so successful that Las Gaviotas offered a ٢٥-year warranty on any of its installations in ١٩٨٤. Over ٤٠،٠٠٠ were installed and still function a quarter of a century later.

Australia has a variety of incentives (national and state) and regulations (state) for solar thermal introduced starting with MRET in ١٩٩٧.[١٣][١٤][١٥]

Solar water heating systems have become popular in China, where basic models start at around ١،٥٠٠ yuan (US$٢٣٥), much cheaper than in Western countries (around ٨٠٪ cheaper for a given size of collector). It is said that at least ٣٠ million Chinese households now have one and that the popularity is due to the efficient evacuated tubes which allow the heaters to function even under gray skies and at temperatures well below freezing.[١٦]

System design requirements[edit]

The type, complexity, and size of a solar water heating system is mostly determined by:

- Changes in ambient temperature and solar radiation between summer and winter.
- The changes in ambient temperature during the day-night cycle.
- The possibility of the potable water or collector fluid overheating.
- The possibility of the potable water or collector fluid freezing.

The minimum requirements of the system are typically determined by the amount or temperature of hot water required during winter, when a system's output and incoming water temperature are typically at their lowest. The maximum output of the system is determined by the need to prevent the water in the system from becoming too hot.

Freeze protection[edit]

Freeze protection measures prevent damage to the system due to the expansion of freezing transfer fluid. Drainback systems drain the transfer fluid from the system when the pump stops. Many indirect systems use antifreeze (e.g. Propylene glycol) in the heat transfer fluid.

In some direct systems, the collectors can be manually drained when freezing is expected. This approach is common in climates where freezing temperatures do not occur often, but is somewhat unreliable since the operator can forget to drain the system. Other direct systems use freeze-tolerant collectors made with flexible polymers such as silicone rubber.

A third type of freeze protection is freeze-tolerance, where low pressure polymer water channels made of silicone rubber simply expands on freezing. One such collector now has European Solar Keymark accreditation, following extra durability testing.

Overheat protection[edit]

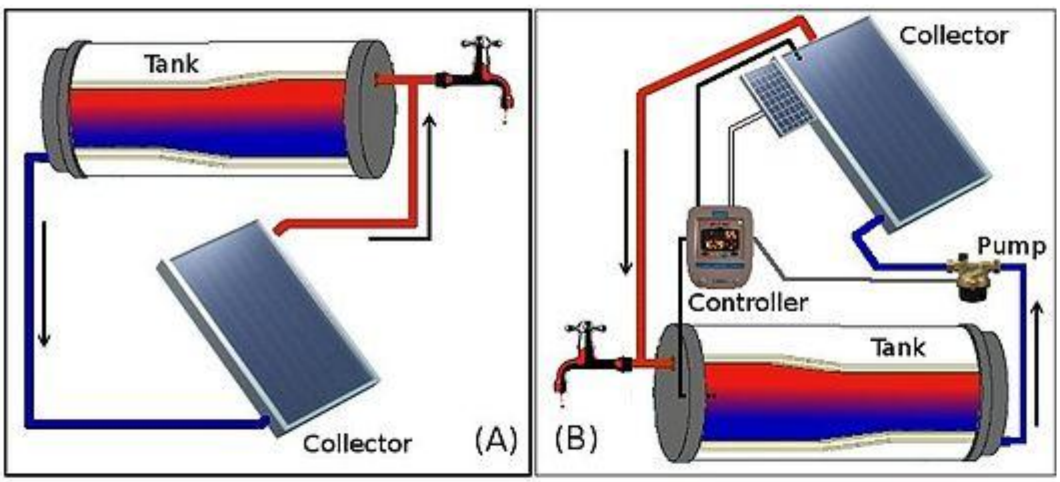
When no hot water has been used for a day or two, the fluid in the collectors and storage can reach very high temperatures in all systems except for those of the drainback variety. When the storage tank in a drainback system reaches its desired temperature, the pumps are shut off, putting an end to the heating process and thus preventing the storage tank from overheating.

One method of providing over heat protection is to dump the heat into a hot tub[*further explanation needed*].

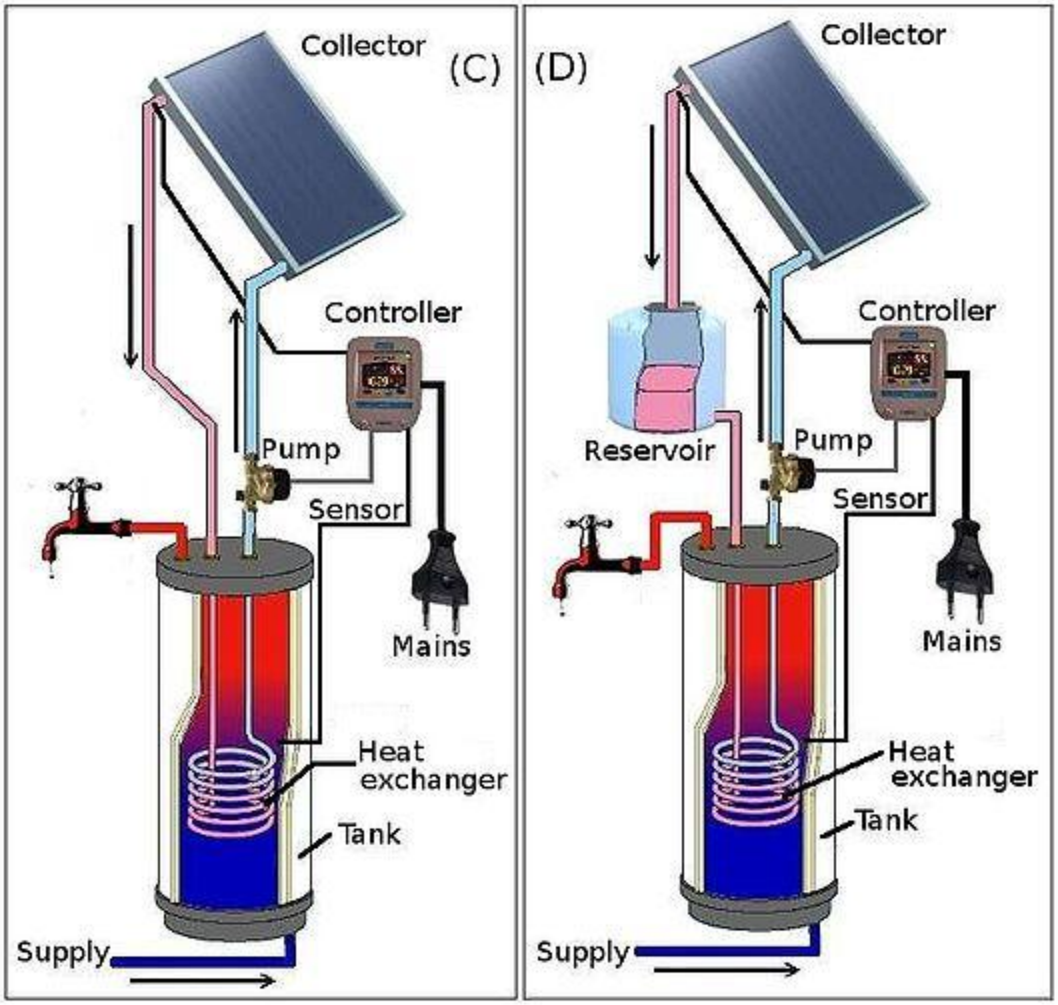
Some active systems deliberately cool the water in the storage tank by circulating hot water through the collector at times when there is little sunlight or at night, causing increased heat loss. This is most effective in direct or thermal store plumbing and is virtually ineffective in systems that use evacuated tube collectors, due to their superior insulation. No matter the collector type, however, they may still overheat. High pressured sealed solar thermal systems versions ultimately rely on the operation of temperature and pressure relief valves. Low pressure, open vented ones have simpler, more reliable safety controls, typically an open vent.

Types of solar water heating systems[edit]

Direct and indirect systems[edit]



Direct systems: (A) Passive CHS system with tank above collector. (B) Active system with pump and controller driven by a photovoltaic panel



Indirect active systems: (C) Indirect system with heat exchanger in tank; (D) Drainback system with drainback reservoir. In these schematics the controller and pump are driven by mains electricity

Direct or **open loop** systems circulate potable water through the collectors. They are relatively cheap but can have the following drawbacks:

- They offer little or no overheat protection unless they have a heat export pump.
- They offer little or no freeze protection, unless the collectors are freeze-tolerant.
- Collectors accumulate scale in hard water areas, unless an ion-exchange softener is used.

Until the advent of freeze-tolerant solar collectors, they were not considered suitable for cold climates since, in the event of the collector being damaged by a freeze, pressurized water lines will force water to gush from the freeze-damaged collector until the problem is noticed and rectified.

Indirect or **closed loop** systems use a heat exchanger that separates the potable water from the fluid, known as the "heat-transfer fluid" (HTF), that circulates through the collector. The two most common

HTFs are water and an antifreeze/water mix that typically uses non-toxic propylene glycol. After being heated in the panels, the HTF travels to the heat exchanger, where its heat is transferred to the potable water. Though slightly more expensive, indirect systems offer freeze protection and typically offer overheat protection as well.

Passive and active systems[edit]

Passive systems rely on heat-driven convection or heat pipes to circulate water or heating fluid in the system. Passive solar water heating systems cost less and have extremely low or no maintenance, but the efficiency of a passive system is significantly lower than that of an active system. Overheating and freezing are major concerns.

Active systems use one or more pumps to circulate water and/or heating fluid in the system.

Though slightly more expensive, active systems offer several advantages:

- The storage tank can be situated lower than the collectors, allowing increased freedom in system design and allowing pre-existing storage tanks to be used.
- The storage tank can be hidden from view.
- The storage tank can be placed in conditioned or semi-conditioned space, reducing heat loss.
- Drainback tanks can be used.
- Superior efficiency.
- Increased control over the system.

Modern active solar water systems have electronic controllers that offer a wide range of functionality, such as the modification of settings that control the system, interaction with a backup electric or gas-driven water heater, calculation and logging of the energy saved by a SWH system, safety functions, remote access, and informative displays, such as temperature readings.

A typical programmable differential controller

The most popular pump controller is a **differential controller** that senses temperature differences between water leaving the solar collector and the water in the storage tank near the heat exchanger. In a typical active system, the controller turns the pump on when the water in the collector is about ٨–١٠ °C warmer than the water in the tank, and it turns the pump off when the temperature difference approaches ٣–٥ °C. This ensures the water always gains heat from the collector when the pump operates and prevents the pump from cycling on and off too often. (In direct systems this "on differential" can be reduced to around ٤ °C because there is no heat exchanger impediment.)

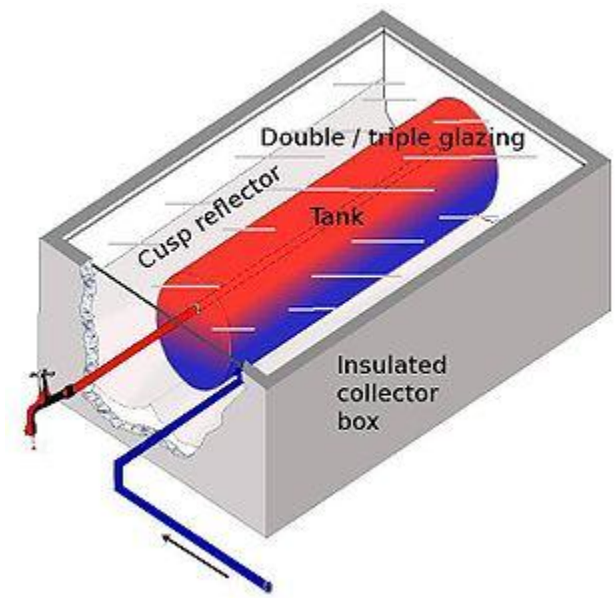
Some active SWH systems use energy obtained by a small photovoltaic (PV) panel to power one or more variable-speed DC pump(s). To ensure proper performance and longevity of the pump(s), the DC-pump and PV panel must be suitably matched. Some PV pumped solar thermal systems are of the antifreeze variety and some use freeze-tolerant solar collectors. The solar collectors will almost always be hot when the pump(s) are operating (i.e., when the sun is bright), and some do not use solar controllers. Sometimes, however, a differential controller (that can also be powered by the DC output of a PV panel) is used to prevent the operation of the pumps when there is sunlight to power the pump but the collectors are still cooler than the water in storage. One advantage of a PV-driven system is that solar hot water can still be collected during a power outage if the sun is shining. Another advantage is that the operational carbon clawback of using mains pumped solar thermal (which typically negates up to ٢٣٪ of its carbon savings) is completely avoided.

The bubble separator of a bubble-pump system

An active solar water heating system can be equipped with a bubble pump (also known as geyser pump) instead of an electric pump. A bubble pump circulates the heat transfer fluid (HTF) between collector and storage tank using solar power, without any external energy source, and is suitable for flat panel as well as vacuum tube systems. In a bubble pump system, the closed HTF circuit is under reduced pressure, which causes the liquid to boil at low temperature as it is heated by the sun. The steam bubbles form a geyser pump, causing an upward flow. The system is designed such that the bubbles are separated from the hot fluid and condensed at the highest point in the circuit, after which the fluid flows downward toward the heat exchanger caused by the difference in fluid levels.[١٧][١٨][١٩] The HTF typically arrives at the heat exchanger at ٧٠ °C and returns to the circulating pump at ٥٠ °C. In frost-prone climates the HTF is water with propylene glycol anti-freeze added, usually in the ratio of ٦٠ to ٤٠.

Pumping typically starts at about ٥٠ °C and increases as the sun rises until equilibrium is reached, which depends on the efficiency of the heat exchanger, the temperature of the water being heated, and the total solar energy available.

Passive direct systems[edit]



An integrated collector storage (ICS) system

An **integrated collector storage** (ICS or Batch Heater) system uses a tank that acts as both storage and solar collector. Batch heaters are basically thin rectilinear tanks with a glass side facing the position of the sun at noon. They are simple and less costly than plate and tube collectors, but they sometimes require extra bracing if installed on a roof (since they are heavy when filled with water [٤٠٠–٧٠٠ lbs],) suffer from significant heat loss at night since the side facing the sun is largely uninsulated, and are only suitable in moderate climates.

A **convection heat storage unit** (CHS) system is similar to an ICS system, except the storage tank and collector are physically separated and transfer between the two is driven by convection. CHS systems typically use standard flat-plate type or evacuated tube collectors, and the storage tank must be located above the collectors for convection to work properly. The main benefit of a CHS systems over an ICS system is that heat loss is largely avoided since (١) the storage tank can be better insulated, and (٢) since the panels are located below the storage tank, heat loss in the panels will not cause convection, as the cold water will prefer to stay at the lowest part of the system.

Active indirect systems: drainback and antifreeze[edit]

Pressurized antifreeze or **pressurized glycol** systems use a mix of antifreeze (almost always non-toxic propylene glycol) and water mix for HTF in order to prevent freeze damage.

Though effective at preventing freeze damage, antifreeze systems have many drawbacks:

- If the HTF gets too hot (for example, when the homeowner is on vacation,) the glycol degrades into acid. After degradation, the glycol not only fails to provide freeze protection, but also begins to eat away at the solar loop's components: the collectors, the pipes, the pump, etc. Due to the acid and excessive heat, the longevity of parts within the solar loop is greatly reduced.
- Most do not feature drainback tanks, so the system must circulate the HTF – regardless of the temperature of the storage tank – in order to prevent the HTF from degrading. Excessive temperatures in the tank cause increased scale and sediment build-up, possible severe burns if a tempering valve is not installed, and, if a water heater is being used for storage, possible failure of the water heater's thermostat.
- The glycol/water HTF must be replaced every ٣–٨ years, depending on the temperatures it has experienced.
- Some jurisdictions require double-walled heat exchangers even though propylene glycol is non-toxic.
- Even though the HTF contains glycol to prevent freezing, it will still circulate hot water from the storage tank into the collectors at low temperatures (e.g. below ٤٠ °F (٤ °C)), causing substantial heat loss.

A **drainback** system is an indirect active system where the HTF (almost always pure water) circulates through the collector, being driven by a pump. The collector piping is not pressurized and includes an open drainback reservoir that is contained in conditioned or semi-conditioned space. If the pump is switched off, the HTF drains into the drainback reservoir and none remains in the collector. Since the system relies upon being able to drain properly, all piping above the drainback tank, including the collectors, must slope downward in the direction of the drainback tank. Installed properly, the collector cannot be damaged by freezing or overheating.[٢٠] Drainback systems require no maintenance other than the replacement of failed system components.

A rough comparison of solar hot water systems[edit]

Comparison of SWH systems[٢١]

Characteristic	ICS (Batch)	Thermosiphon	Active direct	Active indirect	Drainback	Bubble Pump
Low profile-unobtrusive			✓	✓	✓	✓
Lightweight collector			✓	✓	✓	✓
Survives freezing weather			✓	✓	✓	✓

Low maintenance	✓	✓	✓		✓	✓
Simple: no ancillary control	✓	✓				✓
Retrofit potential to existing store			✓	✓	✓	✓
Space saving: no extra storage tank	✓	✓				

Collectors used in modern domestic SWH systems[edit]

Main article: Solar thermal collector

Solar thermal collectors capture and retain heat from the sun and use it to heat a liquid.[٢٢] Two important physical principles govern the technology of solar thermal collectors:

- Any hot object ultimately returns to thermal equilibrium with its environment, due to heat loss from the hot object. The processes that result in this heat loss are conduction, convection and radiation.[٢٣] The efficiency of a solar thermal collector is directly related to heat losses from the collector surface (efficiency being defined as the proportion of heat energy that can be retained for a predefined period of time). Within the context of a solar collector, convection and radiation are the most important sources of heat loss. Thermal insulation is used to slow down heat loss from a hot object to its environment. This is actually a direct manifestation of the Second law of thermodynamics but we may term this the 'equilibrium effect'.

- Heat is lost more rapidly if the temperature difference between a hot object and its environment is larger. Heat loss is predominantly governed by the thermal gradient between the temperature of the collector surface and the ambient temperature. Conduction, convection, and radiation all occur more rapidly over large thermal gradients.[٢٣] We may term this the 'delta-*t* effect'.

The most simple approach to solar heating of water is to simply mount a metal tank filled with water in a sunny place. The heat from the sun would then heat the metal tank and the water inside. Indeed, this was how the very first SWH systems worked more than a century ago.[٥] However, this setup would be inefficient due to an oversight of the equilibrium effect, above: as soon as heating of the tank and water begins, the heat gained starts to be lost back into the environment, and this continues until the water in the tank reaches the ambient temperature. The challenge is therefore to limit the heat loss from the tank, thus delaying the time when thermal equilibrium is regained.

ICS or batch collectors reduce heat loss by placing the water tank in a thermally insulated box.[١][٢٤] This is achieved by encasing the water tank in a glass-topped box that allows heat from the sun to reach the water tank.[٢٥] However, the other walls of the box are thermally insulated, reducing convection as well as radiation to the environment.[٢٦] In addition, the box can also have a reflective surface on the inside.

This reflects heat lost from the tank back towards the tank. In a simple way one could consider an ICS solar water heater as a water tank that has been enclosed in a type of 'oven' that retains heat from the sun as well as heat of the water in the tank. Using a box does not eliminate heat loss from the tank to the environment, but it largely reduces this loss.

Standard ICS collectors have a characteristic that strongly limits the efficiency of the collector: a small surface-to-volume ratio.[۲۷] Since the amount of heat that a tank can absorb from the sun is largely dependent on the surface of the tank directly exposed to the sun, it follows that a small surface would limit the degree to which the water can be heated by the sun. Cylindrical objects such as the tank in an ICS collector inherently have a small surface-to-volume ratio and most modern collectors attempt to increase this ratio for efficient warming of the water in the tank. There are many variations on this basic design, with some ICS collectors comprising several smaller water containers and even including evacuated glass tube technology, a type of ICS system known as an **Evacuated Tube Batch (ETB) collector**.[۱]

Flat-plate solar thermal collector, viewed from roof-level

Flat plate collectors are an extension of the basic idea to place a collector in an 'oven'-like box with glass in the direction of the Sun.[۱]Most flat plate collectors have two horizontal pipes at the top and bottom, called headers, and many smaller vertical pipes connecting them, called risers. The risers are welded (or similarly connected) to thin absorber fins. Heat-transfer fluid (water or water/antifreeze mix) is pumped from the hot water storage tank (direct system) or heat exchanger (indirect system) into the collectors' bottom header, and it travels up the risers, collecting heat from the absorber fins, and then exits the collector out of the top header. Serpentine flat plate collectors differ slightly from this "harp" design, and instead use a single pipe that travels up and down the collector. However, since they cannot be properly drained of water, serpentine flat plate collectors cannot be used in drainback systems.

The type of glass used in flat plate collectors is almost always low-iron, tempered glass. Being tempered, the glass can withstand significant hail without breaking, which is one of the reasons that flat-plate collectors are considered the most durable collector type.

Unglazed or formed collectors are similar to flat-plate collectors, except they are not thermally insulated nor physically protected by a glass panel. Consequently these types of collectors are much less efficient for domestic water heating. For pool heating applications, however, the water being heated is often colder than the ambient roof temperature, at which point the lack of thermal insulation allows additional heat to be drawn from the surrounding environment.[۲۸]

Evacuated tube collectors (ETC) are a way in which heat loss to the environment,[۱] inherent in flat plates, has been reduced. Since heat loss due to convection cannot cross a vacuum, it forms an efficient isolation mechanism to keep heat inside the collector pipes.[۲۹] Since two flat sheets of glass are normally not strong enough to withstand a vacuum, the vacuum is rather created between two concentric tubes. Typically, the water piping in an ETC is therefore surrounded by two concentric tubes of glass with a vacuum in between that admits heat from the sun (to heat the pipe) but which limits heat loss back to the environment. The inner tube is coated with a thermal absorbent.[۳۰] Life of the vacuum varies from collector to collector, anywhere from ۵ years to ۱۵ years.

Flat plate collectors are generally more efficient than ETC in full sunshine conditions. However, the energy output of flat plate collectors is reduced slightly more than evacuated tube collectors in cloudy or extremely cold conditions.[۱] Most ETCs are made out of annealed glass, which is susceptible to hail, breaking in roughly golf ball -sized hail. ETCs made from "coke glass," which has a green tint, are stronger and less likely to lose their vacuum, but efficiency is slightly reduced due to reduced transparency.

Heating of swimming pools[edit]

Both pool covering systems floating atop the water and separate solar thermal collectors may be used for pool heating.

Pool covering systems, whether solid sheets or floating disks, act as insulation and reduce heat loss. Much of a pool's heat loss occurs through evaporation, and using a cover provides a barrier against evaporation. Using a pool cover will supplement the solar thermal collectors discussed below. See Swimming Pool Covers for a detailed discussion.

Solar thermal collectors for nonpotable pool water use are often made of plastic. Pool water, mildly corrosive due to chlorine, is circulated through the panels using the existing pool filter or supplemental pump. In mild environments, unglazed plastic collectors are more efficient as a direct system. In cold or windy environments evacuated tubes or flat plates in an indirect configuration do not have pool water pumped through them, they are used in conjunction with a heat exchanger that transfers the heat to pool water. This causes less corrosion. A fairly simple differential temperature controller is used to direct the water to the panels or heat exchanger either by turning a valve or operating the pump.[۳۱] Once the pool water has reached the required temperature, a diverter valve is used to return pool water directly to the pool without heating.[۳۲] Many systems are configured as drainback systems where the water drains into the pool when the water pump is switched off.

The collector panels are usually mounted on a nearby roof, or ground-mounted on a tilted rack. Due to the low temperature difference between the air and the water, the panels are often formed collectors or unglazed flat plate collectors. A simple rule-of-thumb for the required panel area needed is ۵۰٪ of the pool's surface area.[۳۲] This is for areas where pools are used in the summer season only, not year 'round. Adding solar collectors to a conventional outdoor pool, in a cold climate, can typically extend the pool's comfortable usage by some months or more if an insulating pool cover is also used.[۲۸] An active solar energy system analysis program may be used to optimize the solar pool heating system before it is built.

Economics, energy, environment, and system costs[edit]

A laundromat in California with panels on the roof providing hot washing water.

Energy production[edit]

The amount of heat delivered by a solar water heating system depends primarily on the amount of heat delivered by the sun at a particular place (the insolation). In tropical places the insolation can be relatively high, e.g. ۷ kW.h/m۲ per day, whereas the insolation can be much lower in temperate areas where the days are shorter in winter, e.g. ۳٫۲ kW.h/m۲ per day. Even at the same latitude the average insolation can vary a great deal from location to location due to differences in local weather patterns and the amount of overcast. Useful calculators for estimating insolation at a site can be found with the Joint Research Laboratory of the European Commission[۳۳] and the American National Renewable Energy Laboratory.[۳۴][۳۵]

Below is a table that gives a rough indication of the specifications and energy that could be expected from a solar water heating system involving some ۲ m۲ of absorber area of the collector, demonstrating two evacuated tube and three flat plate solar water heating systems. Certification information or figures calculated from those data are used. The bottom two rows give estimates for daily energy production (kW.h/day) for a tropical and a temperate scenario. These estimates are for heating water to ۵۰ °C above ambient temperature.

With most solar water heating systems, the energy output scales linearly with the surface area of the absorbers. Therefore, when comparing figures, take into account the absorber area of the collector because collectors with less absorber area yield less heat, even within the ۲ m۲ range. Specifications for many complete solar water heating systems and separate solar collectors can be found at Internet site of the SRCC.[۳۶]

Daily energy production (kW_{th}.h) of five solar thermal systems. The evac tube systems used below both have ۲۰ tubes

Technology	Flat plate	Flat plate	Flat plate	Evac tube	Evac tube
Configuration	Direct active	Thermosiphon	Indirect active	Indirect active	Direct active
Overall size ($m^٢$)	٢,٤٩	١,٩٨	١,٨٧	٢,٨٥	٢,٩٧
Absorber size ($m^٢$)	٢,٢١	١,٩٨	١,٧٢	٢,٨٥	٢,٩٦
Maximum efficiency	٠,٦٨	٠,٧٤	٠,٦١	٠,٥٧	٠,٤٦
Energy production (kW.h/day): *– Insolation ٣٫٢ kW.h/$m^٢$/day (temperate)* *– e.g. Zurich, Switzerland*	٥,٣	٣,٩	٣,٣	٤,٨	٤,٠
– Insolation ٦٫٥ kW.h/$m^٢$/day (tropical) *– e.g. Phoenix, USA*	١١,٢	٨,٨	٧,١	٩,٩	٨,٤

The figures are fairly similar between the above collectors, yielding some ٤ kW.h/day in a temperate climate and some ٨ kW.h/day in a more tropical climate when using a collector with an absorber area of about ٢$m^٢$ in size. In the temperate scenario this is sufficient to heat ٢٠٠ litres of water by some ١٧ °C. In the tropical scenario the equivalent heating would be by some ٣٣ °C. Many thermosiphon systems are quite efficient and have comparable energy output to equivalent active systems. The efficiency of evacuated tube collectors is somewhat lower than for flat plate collectors because the absorbers are narrower than the tubes and the tubes have space between them, resulting in a significantly larger percentage of inactive overall collector area. Some methods of comparison[٣٧] calculate the efficiency of evacuated tube collectors based on the actual absorber area and not on the 'roof area' of the system as has been done in the above table. The efficiency of the collectors becomes lower if one demands water with a very high temperature.

System cost[edit]

In sunny, warm locations, where freeze protection is not necessary, an ICS (batch type) solar water heater can be extremely cost effective.[٢٦] In higher latitudes, there are often additional design requirements for cold weather, which add to system complexity. This has the effect of increasing the *initial* cost (but not the life-cycle cost) of a solar water heating system, to a level much higher than a comparable water heater of the conventional type. The biggest single consideration is therefore the large initial financial outlay of solar water heating systems.[٣٨] Offsetting this expense can take several years[٣٩] and the payback period is longer in temperate environments where the insolation is less intense.[٤٠] When calculating the total cost to own and operate, a proper analysis will consider that solar energy is free, thus greatly reducing the operating costs, whereas other energy sources, such as gas and electricity, can be quite expensive over time. Thus, when the initial costs of a solar system are properly financed and compared with energy costs, then in many cases the total monthly cost of solar heat can be less than other more conventional types of water heaters (also in conjunction with an existing water heater). At higher latitudes, solar heaters may be less effective due to lower solar energy, possibly requiring larger and/or dual-heating systems.[٤٠] In addition, government incentives can be significant.

The calculation of long term cost and payback period for a household SWH system depends on a number of factors. Some of these are:

- Price of purchasing solar water heater (more complex systems are more expensive)
- Efficiency of SWH system purchased
- Installation cost
- Price of electricity use for mains pumping (if this is used)
- Price of water heating fuel (e.g. gas or electricity) saved per kW.h
- Amount of water heating fuel used per month by a household
- Upfront state or government subsidy for installation of a solar water heater
- Recurrent or annual tax rebates or subsidy for operating renewable energy
- Annual maintenance cost of SWH system (e.g. antifreeze or pump replacements)
- Savings in annual maintenance of conventional (electric/gas/oil) water heating system

The following table gives some idea of the cost and payback period to recover the costs. It does not take into account annual maintenance costs, annual tax rebates and installation costs. However, the table does give an indication of the total cost and the order of magnitude of the payback period. The table assumes an energy savings of ٢٠٠ kW.h per month (about ٦,٥٧ kW.h/day) due to SWH. Unfortunately payback times can vary greatly due to regional sun, extra cost due to frost protection needs of collectors, household hot water use etc. so more information may be needed to get accurate estimates for individual households and regions. For instance in central and southern Florida the payback period could easily be ٧ years or less rather than the ١٢,٦ years indicated on the chart for the US.[٤١]

Costs and payback periods for residential SWH systems with savings of ٢٠٠ kW.h/month (using ٢٠١٠ data)							
Country	**Currency**	**System cost**	**Subsidy(%)**	**Effective cost**	**Electricity cost/kW.h**	**Electricity savings/month**	**Payback period(y)**

Brazil	BRL	٢٥٠٠[٤٢]	٠	٢٥٠٠	٠,٢٥	٥٠	٤,٢
South Africa	ZAR	١٤٠٠٠	١٥٠[٤٣]	١١٩٠٠	٠,٩	١٨٠	٥,٥
Australia	AUD	٥٠٠٠[٤٤]	٤٠[٤٥]	٣٠٠٠	٠,١٨[٤٦]	٣٦	٦,٩
Belgium	EUR	٤٠٠٠[٤٧]	٥٠[٤٨]	٢٠٠٠	٠,١[٤٩]	٢٠	٨,٣
United States	USD	٥٠٠٠[٥٠]	٣٠[٥١]	٣٥٠٠	٠,١١٥٨[٥٢]	٢٣,١٦	١٢,٦
United Kingdom	GBP	٤٨٠٠[٥٣]	٠	٤٨٠٠	٠,١١[٥٤]	٢٢	١٨,٢

Two points are clear from the above table. Firstly, the payback period is shorter in countries with a large amount of insolation and even in parts of the same country with more insolation. This is evident from the payback period less than ١٠ years in most southern hemisphere countries, listed above. This is partly because of good sunshine, allowing users in those countries to need smaller systems than in temperate areas. Secondly, even in the northern hemisphere countries where payback periods are often longer than ١٠ years, solar water heating is financially extremely efficient. This is partly because the SWH technology is efficient in capturing irradiation. The payback period for photovoltaic systems is much longer.[٤٠] In many cases the payback period for a SWH system is shortened if it supplies all or nearly all of the warm water requirements used by a household. Many SWH systems supply only a fraction of warm water needs and are augmented by gas or electric heating on a daily basis,[٣٩] thus extending the payback period of such a system.

Solar leasing is now available in Spain for solar water heating systems from Pretasol[٥٥] with a typical system costing around ٥٩ euros and rising to ٩٩ euros per month for a system that would provide sufficient hot water for a typical family home of six persons. The payback period would be five years.

Australia has instituted a system of Renewable Energy Credits, based on national renewable energy targets. This expands an older system based only on rebates.[٤٥]

Operational carbon/energy footprint and life cycle assessment[edit]

Terminology[edit]

- Operational energy footprint (OEF) is also called energy parasitics ratio (EPR) or coefficient of performance (CoP).
- Operational carbon footprint (OCF) is also called carbon clawback ratio (CCR).

- Life cycle assessment is usually referred to as LCA.

Carbon/energy footprint[edit]

The source of electricity in an active SWH system determines the extent to which a system contributes to atmospheric carbon during operation. Active solar thermal systems that use mains electricity to pump the fluid through the panels are called 'low carbon solar'. In most systems the pumping cancels the energy savings by about ٨٪ and the carbon savings of the solar by about ٢٠٪.[٥٦] However, some new low power pumps will start operation with ١W and use a maximum of ٢٠W.[٥٧][٥٨] Assuming a solar collector panel delivering ٤ kW.h/day and a pump running intermittently from mains electricity for a total of ٦ hours during a ١٢-hour sunny day, the potentially negative effect of such a pump can be reduced to about ٣٪ of the total power produced.

The carbon footprint of such household systems varies substantially, depending on whether electricity or other fuels such as natural gas are being displaced by the use of solar. Except where a high proportion of electricity is already generated by non-fossil fuel means, natural gas, a common water heating fuel, in many countries, has typically only about ٤٠٪ of the carbon intensity of mains electricity per unit of energy delivered. Therefore the ٣٪ or ٨٪ energy clawback in a gas home referred to above could therefore be considered ٨٪ to ٢٠٪ carbon clawback, a very low figure compared to technologies such as heat pumps.

However, PV-powered active solar thermal systems typically use a ٥–٣٠ W PV panel which faces in the same direction as the main solar heating panel and a small, low powerdiaphragm pump or centrifugal pump to circulate the water. This reduces the operational carbon and energy footprint: a growing design goal for solar thermal systems.

Work is also taking place in a number of parts of the world on developing alternative non-electrical pumping systems. These are generally based on thermal expansion and phase changes of liquids and gases, a variety of which are under development.

Life cycle carbon/energy assessment[edit]

Now looking at a wider picture than just the operational environmental impacts, recognised standards can be used to deliver robust and quantitative life cycle assessment (LCA). LCA takes into account the total environmental cost of acquisition of raw materials, manufacturing, transport, using, servicing and disposing of the equipment. There are several aspects to such an assessment, including:

- The financial costs and gains incurred during the life of the equipment.
- The energy used during each of the above stages.
- The $CO_{٢}$ emissions due to each of the above stages.

Each of these aspects may present different trends with respect to a specific SWH device.

Financial assessment. The table in the previous section as well as several other studies suggest that the cost of production is gained during the first ٥–١٢ years of use of the equipment, depending on the insolation, with cost efficiency increasing as the insolation does.[٣٩]

In terms of energy, some ٦٠٪ of the materials of a SWH system goes into the tank, with some ٣٠٪ towards the collector[٥٩] (thermosiphon flat plate in this case) (Tsiligiridis et al.). In Italy,[٦٠] some ١١ GJ of electricity are used in producing the equipment, with about ٣٥٪ of the energy going towards the manufacturing the tank, with another ٣٥٪ towards the collector and the main energy-related impact being emissions. The energy used in manufacturing is recovered within the first two to three years of use of the SWH system through heat captured by the equipment according to this southern European study.

Moving further north into colder, less sunny climates, the energy payback time of a solar water heating system in a UK climate is reported as only ٢ years.[٦١] This figure was derived from the studied solar water heating system being: direct, retrofitted to an existing water store, PV pumped, freeze tolerant and of ٢٫٨ sqm aperture. For comparison, a solar electric (PV) installation took around ٥ years to reach energy payback, according to the same comparative study.

In terms of $CO_{٢}$ emissions, a large degree of the emissions-saving traits of a SWH system is dependent on the degree to which water heating by gas or electricity is used to supplement solar heating of water. Using the Eco-indicator ٩٩ points system as a yardstick (i.e. the yearly environmental load of an average European inhabitant) in Greece,[٥٩] a purely gas-driven system may be cheaper in terms of emissions than a solar system. This calculation assumes that the solar system produces about half of the hot water requirements of a household. The production of a test SWH system in Italy[٦٠] produced about ٧٠٠ kg of $CO_{٢}$, with all the components of manufacture, use and disposal contributing small parts towards this. Maintenance was identified as an emissions-costly activity when the heat transfer fluid (glycol-based) was periodically replaced. However, the emissions cost was recovered within about two years of use of the equipment through the emissions saved by solar water heating. In Australia,[٣٩] the life cycle emissions of a SWH system are also recovered fairly rapidly, where a SWH system has about ٢٠٪ of the impact of an electrical water heater and half of the emissions impact of a gas water heater.

Analysing their lower impact retrofit freeze-tolerant solar water heating system, Allen *et al.* (qv) report a production $CO_{٢}$ impact of ٣٣٧ kg, which is around half the environmental impact reported in the Ardente *et al.* (qv) study.

Where information based on established standards are available, the environmental transparency afforded by life cycle analysis allows consumers (of all products) to make increasingly well-informed product selection decisions. As for identifying sectors where this information is likely to appear first, environmental technology suppliers in the microgeneration and renewable energy technology arena are increasingly being pressed by consumers to report typical CoP and LCA figures for their products.

In summary, the energy and emissions cost of a SWH system forms a small part of the life cycle cost and can be recovered fairly rapidly during use of the equipment. Their environmental impacts can be reduced further by sustainable materials sourcing, using non-mains circulation, by reusing existing hot water stores and, in cold climates, by eliminating antifreeze replacement visits.

Do-it-yourself (DIY) systems[edit]

People have begun building their own (small-scale) solar water heating systems from scratch or buying kits. Plans for solar water heating systems are available on the Internet.[٦٢]and people have set about building them for their own domestic requirements. DIY SWH systems are usually cheaper than commercial ones, and they are used both in the developed and developing world.[٦٣]

System specification and installation[edit]

- Except in rare instances it will be insufficient to install a SWH system with no electrical or gas or other fuel backup. Many SWH systems have a back-up electric heating element in the integrated tank, the operation of which may be necessary on cloudy days to ensure a reliable supply of hot water.
- The temperature stability of a system is dependent on the ratio of the volume of warm water used per day as a fraction of the size of the water reservoir/tank that stores the hot water. If a large proportion of hot water in the reservoir is used each day, a large fraction of the water in the reservoir needs to be heated. This brings about significant fluctuations in water temperature every day, with possible risks of overheating or underheating, depending on the design of the system. Since the amount of heating that needs to take place every day is proportional to hot water usage and not to the size of the reservoir, it is desirable to have a fairly large reservoir (i.e. equal to or greater than daily usage,) which will help prevent fluctuations in water temperature.
- If ample storage is pre-existing or can otherwise be reasonably acquired, a large SWH system is more efficient economically than a small system.[٥٩] This is because the price of a system is not linearly proportional to the size of the collector array, so the price per square meter of collector is cheaper in a larger system. If this is the case, it pays to use a system that covers nearly all of the domestic hot water needs, and not only a small fraction of the needs. This facilitates more rapid cost recovery.
- Not all installations require new replacement solar hot water stores. Existing stores may be large enough and in suitable condition. Direct systems can be retrofitted to existing stores while indirect systems can be also sometimes be retrofitted using internal and external heat exchangers.
- The installation of a SWH system needs to be complemented with efficient insulation of all the water pipes connecting the collector and the water storage tank, as well as the storage tank (or "geyser") and the most important warm water outlets. The installation of efficient lagging significantly reduces the heat loss from the hot water system. The installation of lagging on at least two meters of pipe on the cold water inlet of the storage tank reduces heat loss, as does the installation of a "geyser blanket" around the storage tank (if inside a roof). In cold climates

the installation of lagging and insulation is often performed even in the absence of a SWH system.

- The most efficient PV pumps are designed to start very slowly in very low light levels, so if connected uncontrolled, they may cause a small amount of unwanted circulation early in the morning – for example when there is enough light to drive the pump but while the collector is still cold. To eliminate the risk of hot water in the storage tank from being cooled that way this is very important. solar controller may be required.

- The modularity of an evacuated tube collector array allows the adjustment of the collector size by removing some tubes or their heat pipes. Budgeting for a larger than required array of tubes therefore allows for the customisation of collector size to the needs of a particular application, especially in warmer climates.

- Particularly in locations further towards the poles than ٤٥ degrees from the equator, roof mounted sun facing collectors tend to outperform wall mounted collectors in terms of total energy output. However, it is total **useful** energy output which usually matters most to consumers. So arrays of sunny wall mounted steep collectors can sometimes produce more useful energy because there can be a small increase in winter gain at the expense of a large unused summer surplus.

Standards[edit]

Europe[edit]

- EN ٨٠٦: Specifications for installations inside buildings conveying water for human consumption. General.

- EN ١٧١٧: Protection against pollution of potable water in water installations and general requerements of devices to prevent pollution by backflow.

- EN ٦٠٣٣٥: Specification for safety of household and similar electrical appliances. (٢–٢١)

- **UNE ٩٤٠٠٢:٢٠٠٥** Thermal solar systems for domestic hot water production. Calculation method for heat demand.

United States[edit]

- OG-٣٠٠: OG-٣٠٠ Certification of Solar Water Heating Systems.[٦٤]

Australia[edit]

- Renewable Energy (Electricity) Act ٢٠٠٠

- Renewable Energy (Electricity) (Large-scale Generation Shortfall Charge) Act ٢٠٠٠

- Renewable Energy (Electricity) (Small-scale Technology Shortfall Charge) Act ٢٠١٠

- Renewable Energy (Electricity) Regulations ٢٠٠١
- Renewable Energy (Electricity) Regulations ٢٠٠١ - STC Calculation Methodology for Solar Water Heaters and Air Source Heat Pump Water Heaters
- Renewable Energy (Electricity) Amendment (Transitional Provision) Regulations ٢٠١٠
- Renewable Energy (Electricity) Amendment (Transitional Provisions) Regulations ٢٠٠٩

All relevant participants of the Large-scale Renewable Energy Target and Small-scale Renewable Energy Scheme must comply with the above Acts.[٦٥]

APPENDIX ١. Worldwide use[edit]

Top countries worldwide[edit]

Solar hot water system installed on low cost housing in the Kouga Local Municipality, South Africa

Top countries using solar thermal power, worldwide: GW$_{th}$[١١][٦٦][٦٧][٦٨][٦٩][٧٠][٧١]

#	Country	٢٠٠٥	٢٠٠٦	٢٠٠٧	٢٠٠٨	٢٠٠٩	٢٠١٠
١	China	٥٥,٥	٦٧,٩	٨٤,٠	١٠٥,٠	١٠١,٥	١١٧,٦
–	*EU*	١١,٢	١٣,٥	١٥,٥	٢٠,٠	٢٢,٨	٢٥,٣
٢	United States	١,٦	١,٨	١,٧	٢,٠	١٤,٤	١٥,٣
٣	Germany	–	–	–	٧,٨	٨,٩	٩,٨
٤	Turkey	٥,٧	٦,٦	٧,١	٧,٥	٨,٤	٩,٣
٥	Australia	١,٢	١,٣	١,٢	١,٣	٥,٠	٥,٨

Top countries using solar thermal power, worldwide: GW_{th} [١١][٦٦][٦٧][٦٨][٦٩][٧٠][٧١]							
#	Country	٢٠٠٥	٢٠٠٦	٢٠٠٧	٢٠٠٨	٢٠٠٩	٢٠١٠
٦	Brazil	١,٦	٢,٢	٢,٥	٢,٤	٣,٧	٤,٣
٧	Japan	٥,٠	٤,٧	٤,٩	٤,١	٤,٣	٤,٠
٨	Austria	–	–	–	٢,٥	٣,٠	٣,٢
٩	Greece	–	–	–	٢,٧	٢,٩	٢,٩
	World (GW_{th})	٨٨	١٠٥	١٢٦	١٤٩	١٧٢	١٩٦

Solar heating in European Union + Switzerland[edit]

Solar thermal heating in European Union (MW_{th})[٧٢][٧٣][٧٤]				
#	Country	٢٠٠٨	٢٠٠٩	٢٠١٠[٦٨]
١	Germany	٧،٧٦٦	٨،٨٩٦	٩،٦٧٧
٢	Greece	٢،٧٠٨	٢, ٨٥٢	٢،٨٥٩
٣	Austria	٢،٢٦٨	٢،٥١٨	٢،٦٨٦
٤	Italy	١،١٢٤	١،٤٠٤	١،٨٧٠
٥	Spain	٩٨٨	١،٢٦٢	١،٤٧٥
٦	France	١،١٣٧	١،٣٧١[F]	١،١٠٢
٧	Switzerland	٤١٦	٥٣٨	٦٢٧
٨	Cyprus	٤٨٥	٥١٥	٥٠١
٩	Portugal	٢٢٣	٣٤٥	٤٧١
١٠	Poland	٢٥٦	٣٥٧	٤٥٩

١١	UK	٢٧٠	٣٣٣	٤٠١
١٢	Denmark	٢٩٣	٣٣١	٣٦٨
١٣	Netherlands	٢٥٤	٢٨٥	٣١٣
١٤	Belgium	١٨٨	٢٠٤	٢٣٠
١٥	Sweden	٢٠٢	٢١٧	٢٢٧
١٦	Czech Republic	١١٦	١٤٨	٢١٦
١٧	Slovenia	٩٦	١١٢	١٢٣
١٨	Hungary	١٨	٥٨	١٠٥
١٩	Ireland	٥٢	٧٥	٩٢
٢٠	Slovakia	٦٧	٧٦	٨٥
٢١	Bulgaria *	٢٢	٩٠	٧٤
٢٢	Romania *	٦٦	٨٠	٧٣
٢٣	Malta*	٢٥	٢٩	٣٢
٢٤	Finland *	١٨	١٩	٢٣
٢٥	Luxembourg *	١٦	١٩	٢٢
٢٦	Estonia*	١	٢	٢
٢٧	Lithuania *	٣	٢	٢
٢٨	Latvia *	٥	١	١
Total	EU٢٧+Sw (MWth)	١٩،٠٨٣	٢٢،١٣٧	٢٤،١١٤
* = estimation, F = France as a whole				