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Promotion of the Efficient Use of Renewable Energies in Developing Countries

Chapter V Solar Thermal

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List of Acronymes

LPG	Liquid Petroleum Gas
MC	Moisture Content
Mf	Final Moisture Content
Mi	Initial Moisture Content
RH	Relative Humidity
LPG	Liquid Petroleum Gas
MC	Moisture Content

1 Solar thermal system types and applications

Beside electricity generation solar energy can be used in other different applications including solar thermal systems for hot water and heating, solar thermal systems for heating swimming pool, solar thermal systems for cooling, solar thermal systems for drying and solar thermal systems for cooking.

Using solar energy in these applications leads to the preservation of the fossil fuel which is being decayed from day to day. Furthermore, it is friendly environmental because it does not produce waste and green house gas especially carbon dioxide.

This textbook will discuss briefly on different types and applications of solar thermal systems. Solar water heating systems will be discussed in detail which includes the components of a solar water heating system, its dimensioning, installation and commissioning.

1.1 Solar thermal systems for hot water and heating

In addition to the energy cost savings on water heating, there are several other benefits derived from using the sun's energy to heat water. Most solar water heaters come with an additional water tank, which feeds the conventional hot water tank. Users benefit from the larger hot water storage capacity and the reduced likelihood of running out of hot water.

Some solar water heaters do not require electricity to operate. For these systems, hot water supply is secure from power outages, as long as there is sufficient sunlight to operate the system. Solar water heating systems can also be used to directly heat swimming pool water, with the added benefit of extending the swimming season for outdoor pool applications.

There are a number of service hot water applications. The most common application is the use of domestic hot water systems. Other common uses include providing process hot water for commercial and institutional applications, including multi-unit houses and apartment buildings, and in schools, health centers, hospitals, office buildings, restaurants and hotels. Small commercial and industrial applications such as car washes, laundries and fish farms are other typical examples of service hot water. Solar water heating systems can also be used for large industrial loads and for providing energy to district heating networks.

Figure 1 below shows standard solar water heating system with heating boiler for additional heating.

The solar collector mounted on the roof converts the light into heat. The collector is therefore the link between the sun and the hot water user. The heat is created by the absorption of the sun's rays through a dark coated, usually metal, plate – the absorber. This is the most important part of the collector. In the absorber is a system of pipes filled with a heat transfer medium (usually water or an antifreeze mixture). This takes up the generated heat. Collected together into a pipe it flows to the hot water store. In most solar water heating systems – by far the most commonly used type of solar thermal systems – the heat is then transferred to the domestic water by means of a heat exchanger. The cooled medium then flows via a sec-

and pipeline back to the collector while the heated domestic water rises upwards in the store. According to its density and temperature, a stratified system is set up in the store: the warmest water is at the top and the coolest is at the bottom.

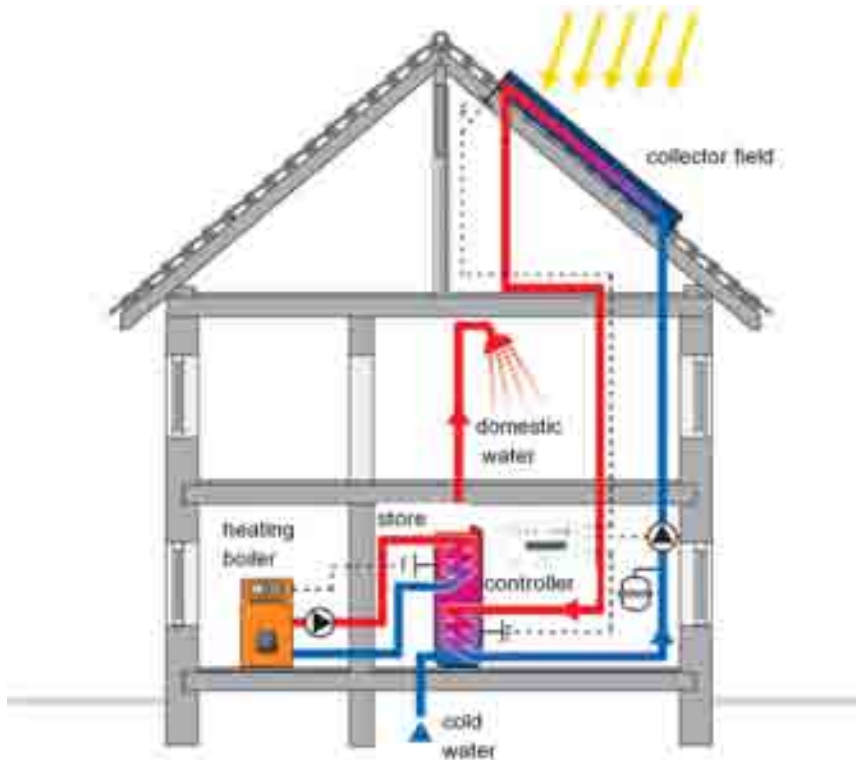


Figure 1: standard solar water heating system (DGS guide book on solar thermal systems planning and installing, 2005)

1.2 Solar thermal systems for swimming pool

The water temperature in swimming pools can also be regulated using solar water heating systems, extending the swimming pool season and saving on the conventional energy costs. The basic principle of these systems is the same as with solar service hot water systems, with the difference that the pool itself acts as the thermal storage.

Solar heating of open air swimming pool water has some decisive advantages over other methods of using solar energy thermally:

- Temperature level: the required temperature level is comparatively low, at 18 – 25°C. This permits the use of less expensive polypropylene absorbers.
- Simple system design: the pool water flows directly through the absorber, powered by the filter pump. The storage tanks normally required for solar energy systems are not required, as the pool itself takes over this function.

1.3 Solar cooling systems

Producing cooled air by making use of solar power may seem paradoxical at first sight. Generally, the sun tends to be viewed as a source of heat. However, there exist thermal processes to produce coldness, in which water is cooled or air-conditioning is directly driven by heat input. These processes are generally suitable for using heat provided by solar thermal collectors as the principal source of energy.

Table 1 shows the various thermally driven cooling processes. Among the processes available on the market, it is possible to distinguish between the closed absorption and adsorption processes and the open process of desiccant cooling.

Table 1: overview of thermally driven cooling technologies (DGS guide book on solar thermal systems planning and installing, 2005)

Process	Absorption	Adsorption	Desiccant cooling system
Type of air-conditioning	Chilled water (e.g. chilled ceilings)	Chilled water (e.g. chilled ceilings)	Air-conditioning (cooling, dehumidification)

In the closed processes, the cooling medium is not in direct contact with the environment. First of all, cold water is produced. This cold water can then be used in chilled ceilings, in concrete core conditioning, or also in the classical way in the air cooler of an air-conditioning system to reduce temperature and/or humidity. By contrast; in the open process of desiccant cooling the cooling medium (water) comes into direct contact with the air being conditioned. The cooling and dehumidification functions are directly integrated into the air-conditioning systems.

1.3.1 Absorption cooling

A thermal compression of the refrigerant is achieved by using a liquid refrigerant/sorbent solution and a heat source, thereby replacing the electric power consumption of a mechanical compressor. For chilled water above 0°C, as it is used in air conditioning, typically a liquid H₂O/LiBr solution is applied with water as refrigerant. Most systems use an internal solution pump, but consuming little electric power only. The main components of an absorption chiller are shown in Figure 2.

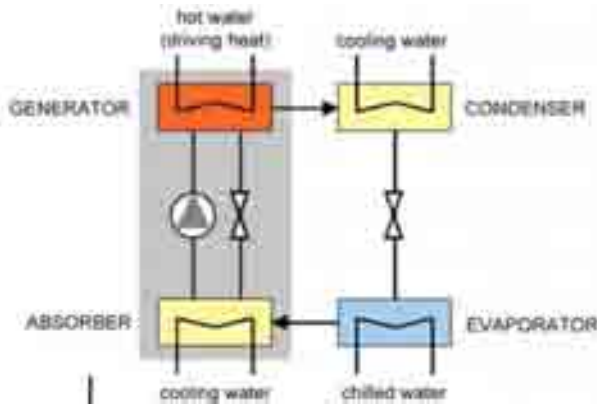


Figure 2: Absorption chiller (Marc Delorme, Reinhard Six and al., solar air conditioning guide, 2004)

1.3.2 Adsorption cooling

Here, instead of a liquid solution, solid sorption materials are applied. Market available systems use water as refrigerant and silica gel as sorbent. The machines consist of two sorbent compartments (denoted as 1 and 2 in Figure 3), one evaporator and one condenser. While the sorbent in the first compartment is regenerated using hot water from the external heat source, e.g. the solar collector, the sorbent in the compartment 2 (adsorber) adsorbs the water vapor entering from the evaporator; this compartment has to be cooled in order to enable a continuous adsorption. The water in the evaporator is transferred into the gas phase being heated from the external water cycle; here actually the useful cooling is produced. If the cooling capacity reduces to a certain value due to the loading of the sorbent in the adsorber, the chambers are switched over in their function. To date, only a few Asian manufacturers produce adsorption chillers.

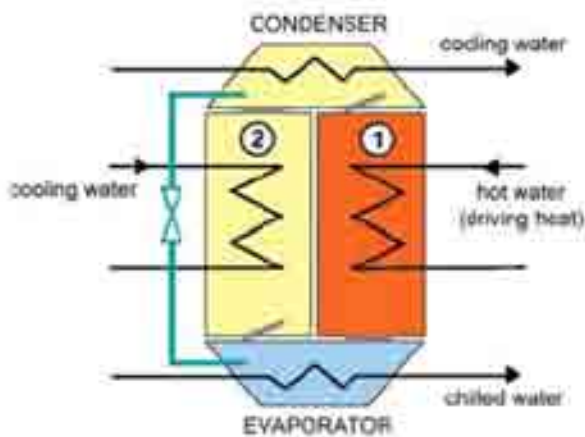


Figure 3: Adsorption chiller (Marc Delorme, Reinhard Six and al., solar air conditioning guide, 2004)

1.3.3 Desiccant cooling system

In contrast to the absorption and adsorption processes, the desiccant cooling system is termed an open process, as here the air is conditioned by coming into direct contact with the cooling medium. Water is used as the cooling medium, which gives this technology excellent environmental characteristic. In addition, the sorbent – either solid or liquid – also comes into direct contact with the conditioned air. This achieves the required dehumidification of the air.

1.3.3.1 Solid desiccant cooling with rotating wheels

The main components of a solar assisted desiccant cooling system are shown in Figure 4. The basic process in providing conditioned air may be described as follows.

- Cooling case: Warm and humid ambient air enters the slowly rotating desiccant wheel and is dehumidified by adsorption of water (1-2). Since the air is heated up by the adsorption heat, a heat recovery wheel is passed (2-3), resulting in a significant pre-cooling of the supply air stream. Subsequently, the air is humidified and further cooled by a controlled humidifier (3-4), according to the desired temperature and humidity of the supply air stream. The exhaust air stream of the rooms is humidified (6-7) close to the saturation point to exploit the full cooling potential in order to allow an effective heat recovery (7-8). Finally, the sorption wheel has to be regenerated (9-10) by applying heat in a comparatively low temperature range from 50°C-75°C, to allow a continuous operation of the dehumidification process.

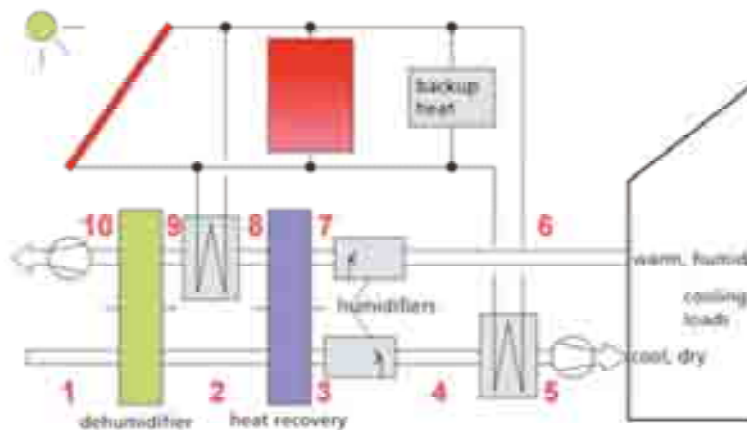


Figure 4: desiccant cooling system (Marc Delorme, Reinhard Six and al., solar air conditioning guide, 2004)

- Heating case: In periods with low heating demand, heat recovery from the exhaust air stream and enthalpy exchange by using a fast rotating mode of the desiccant wheel may be sufficient. In case of increasing heating demand, heat from the solar thermal collectors and, if necessary, from a backup heat source (4-5) is applied. Flat-plate solar thermal collectors can be normally applied as heating system in solar assisted desiccant cooling systems. The solar system may consist of collectors using water as fluid and a hot water storage, to increase the utilisation of the solar system.

This configuration requires an additional water/air heat exchanger, to connect the solar system to the air system. An alternative solution, leading to lower investment cost, is the direct supply of regeneration heat by means of solar air collectors.

1.3.3.2 Liquid desiccant cooling

A new development, close to market introduction, are desiccant cooling systems using a liquid Water/Lithium-Chloride solution as sorption material. This type of systems shows several advantages like higher air dehumidification at the same driving temperature range than solid desiccant cooling systems, and the possibility of high energy storage by storing the concentrated solution. This technology is a promising future option for a further increase in exploitation of solar thermal systems for air conditioning.

1.4 Solar drying systems

Most crops are seasonal and people have to preserve them for consumption during the off-season. Proper infrastructure does not exist for marketing, distribution and storage of excess produce, which are therefore often dried to extend the shelf life. Furthermore, dried fish is the main form of fish consumed. Therefore, drying of food products is an important link in the food production and consumption system.

Renewable energy resources have long been used for crop drying in traditional ways. The best example is the drying of paddy, fruits, fish, etc. by direct exposure to the sun. Although open sun drying is relatively simple, it is dependent on the weather conditions, has slow drying rates and susceptible to contamination. Biomass resources such as fuel wood and coconut shell have also been used in drying tobacco, copra, etc. On the other hand, use of electricity or conventional fuels such as kerosene and LPG is prohibitively costly in Cambodia. Improved solar drying systems use solar energy in more efficient ways and protect them from contamination.

Drying is simply the process of moisture removal from a product. Conventional drying systems are usually classified (according to their operating temperature ranges) into low and high temperature dryers. In the low temperature drying systems, the moisture content of the product is brought into equilibrium usually with the drying air by constant ventilation. These systems enable crops to be dried in bulk or for long term storage. They are most appropriate where preservation of certain nutrients in the product is desired and for crops intended for replanting. High temperature dryers are not objectives of this textbook.

It is hard and even impossible to classify all available dryer which has been being used in different places and applications. Nevertheless, the dryer can be classified according their operating temperature, fuel used etc. This is a so-called systematic classification of drying systems.

All drying systems can be classified primarily according to their operating temperature ranges into two main groups of high temperature dryers and low temperature dryers. However, dryers are more commonly classified broadly according to their heating sources into

fossil fuel dryers (more commonly known as conventional dryers) and solar-energy dryers. Strictly, all practically realised designs of high temperature dryers are fossil fuel powered, while the low temperature dryers are either fossil fuel or solar-energy based systems.

Solar-energy drying systems are classified primarily according to their heating modes and the manner in which the solar heat is utilised. In broad terms, they can be classified into two major groups, namely:

- Active solar-energy drying systems (most types of which are often termed hybrid solar dryers)
- Passive solar-energy drying systems (conventionally termed natural-circulation solar drying systems).

Three distinct sub-classes of either the active or passive solar drying systems can be identified (which vary mainly in the design arrangement of system components and the mode of utilisation of the solar heat, namely:

- Integral-type solar dryers
- Distributed-type solar dryers
- Mixed-mode solar dryers

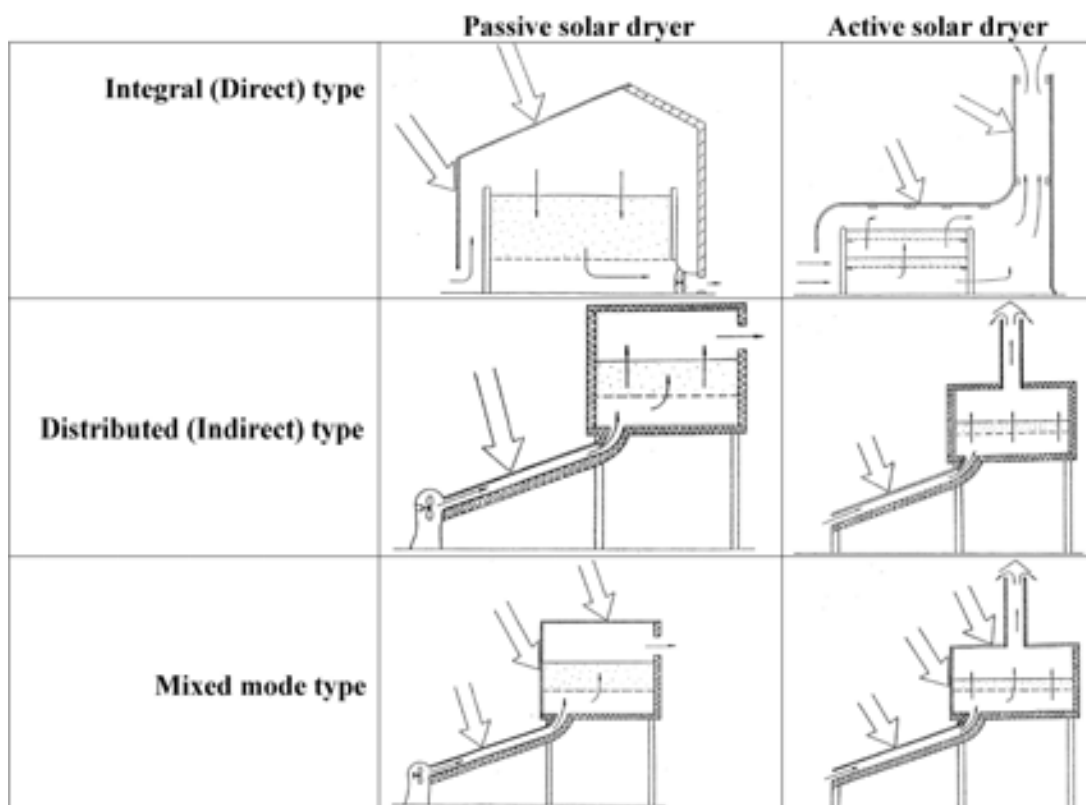


Figure 5: classification of solar dryer (O.V. Ekechukwu and B. Norton, *Energy conversion and management*, 40, 1999, p615-655)

1.5 Solar cooking

Around the world some two billion people struggle to find enough firewood, which they need primarily for cooking and heating. The problem is further exacerbated by the fact that in many developing countries cooking is traditionally carried out over three-stone fires. However, these can only make use of about 10 to 15 % of the energy produced. Collecting firewood is usually the responsibility of women and children, who often spend several hours each day on this task. If cooking is performed indoors, fumes and soot frequently cause respiratory diseases.

Solar cookers have repeatedly been seen as a solution to the firewood problem. “Cooking with the sun” also allows the use of a free, effectively inexhaustible source of energy, relieves the workload on women, and reduces the harmful effects on health arising from cooking. Moreover, fewer trees are chopped down, thus stopping deforestation and the advance of desertification, while at the same time guarding against global warming. These are the arguments of the proponents. It has to be said, though, that decades of efforts have not helped solar cookers to achieve a breakthrough. So far it is only on the treeless plateaus of Tibet that solar cookers have truly become established; roughly half of the million or so solar cookers in the world are used in China.

1.5.1 Parabolic cooker



Figure 6: parabolic cooker (GTZ publication, 2007)

Parabolic cooker concentrates the solar radiation directly onto the pot. The temperature can go up to 250 °C. That said, parabolic cookers are more difficult to build, and even if they are produced locally it is often necessary to import certain parts. This makes them notably expensive. They also have to be adjusted to track the position of the sun about every 25 to 30 minutes, and they are much more sensitive to wind, which makes everyday use more difficult. A further limitation arises from the fact that the users of these cookers are easily dazzled by the sun reflecting in the parabolic dish. On most models of parabolic cooker there is also the risk of the reflector becoming dirty when food boils over. If the reflector is dented or scratched in the course of cleaning, the effectiveness of the cooker is considerably diminished.

1.5.2 Butterfly or Papillon cooker



Figure 7: butterfly cooker (GTZ publication, 2007)

Another design similar to parabolic cookers is the butterfly or Papillon cooker, which is widespread in Tibet and West Africa. Compared with parabolic cookers these have the advantage that the cook is better able to handle the pot, the risk of dazzling is lower, and the reflector does not become dirty if the food boils over. The Papillon cooker, developed in Burkina Faso, can be folded up and stored in the house, which reduces the risk of theft. In Tibet the reflector wings of the butterfly cookers are made of cast iron or cement, lowering costs by an appreciable margin.

1.5.3 Flat plate collector cooker



Figure 8: flat plate collector cooker (GTZ publication, 2007)

Another type of solar cooker is the flat-plate collector cooker, in particular the Schwarzer cooker, named after its developer. This is suitable for use by institutions and individual households. This design uses collectors to heat a medium, for example steam, to transfer heat to where it is needed for cooking. These cookers can be enlarged as required, allowing their output to be matched to the needs of institutions. Their transportability is limited, but they have the advantage that they do not need to be adjusted to track the sun. As the cooking point is separate from the collector, it is also possible to cook in the shade or indoors. The inclusion of a thermal storage unit enables such cookers to be used after sunset, too. To date, around 250 to 300 Schwarzer cookers have been built in India and Africa, often by businesses.

1.5.4 Solar box cooker



Figure 9: solar box cooker (GTZ publication, 2007)

In solar box cookers (or solar ovens) the pot is placed inside a closed container, the interior of which is heated by solar radiation. Box cookers are simple to build, often using locally available materials. This makes it easier to produce them in developing countries and reduces procurement costs. Box cookers do not have to be realigned with the position of the sun as often as parabolic cookers, making them easier to use in everyday life. Although box cookers do not achieve the peak performance values of parabolic cookers, they are better able to compensate for fluctuations in solar irradiance. The maximum temperature reached by a box cooker is roughly 180 °C.

1.5.5 Scheffler cooker



Figure 10: scheffler cooker (GTZ publication, 2007)

As well as the solar cookers described above, which are primarily intended for families and small traders, a technically more sophisticated model has also been developed for large scale catering, suitable for preparing as many as several tens of thousands of meals. In the Scheffler cooker (named after its developer) solar energy is fed from reflectors or collectors via a system of pipes carrying hot steam to the stove, which is usually situated in a separate building. An electrical device enables the reflectors to track the course of the sun automatically; manual re-adjustment is required only every few days. So far several hundred such cookers have been built, mainly in India. They are very powerful and can also be fitted with a thermal storage unit that allows cooking to continue into the evening and even the night. The largest solar cooker in the world is a Scheffler cooker with 106 parabolic reflectors, which supplies energy to a canteen kitchen in Tirupati in India. The drawback of these cookers is the high initial cost. To this must be added the considerable amount of space these systems require, especially as a kitchen often has to be built as well. The Scheffler cooker is therefore not suitable for individual households.

2 Solar water heating systems

2.1 Components of solar water heating

Solar water heaters perform three basic operations: collection, transfer and storage. The main components of a solar water heating system are:

2.1.1 Collection

The main component to perform the collection is the collector. Collectors have the task of converting light as completely as possible into heat, and then of transferring this heat with low losses to the downstream system. There are many different types and designs for different applications, all with different costs and performances. There are three different types of collectors: unglazed flat plate collector, glazed flat plate collector and evacuated tube collector.

2.1.1.1 Unglazed flat plated collector

The simplest kind of solar collectors are unglazed collectors. These have no glazing or insulated collector box, so that they consist only of an absorber (See Figure 11).

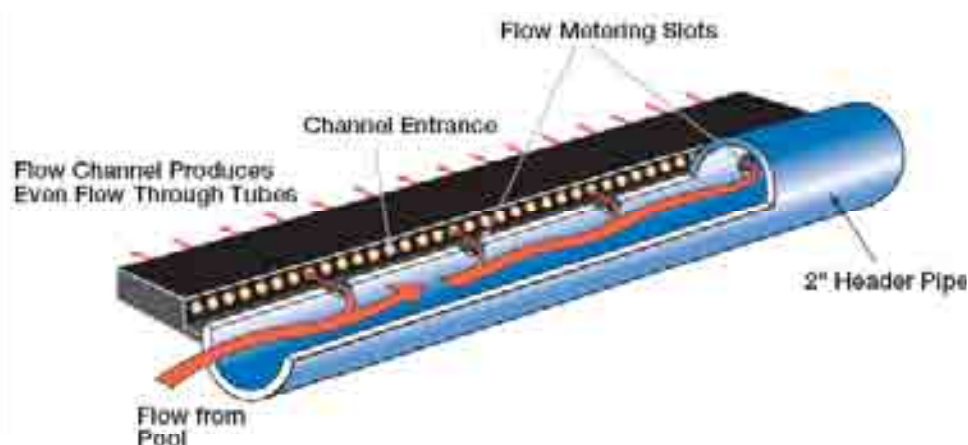


Figure 11: Unglazed flat plate collector (RETScreen International, 2004)

This collector has a lower performance at equal operating temperature than a glazed flat plate collector as it lacks the glass cover, housing and thermal insulation. It therefore has higher thermal losses and can be used only at very low operating temperatures, but because of its simple construction it is inexpensive.

The advantages of the unglazed flat plate collector are:

- The absorber can replace the roof skin, saving zinc sheeting, for example this leads to better heat prices through reduced costs.
- It is suitable for a diversity of roof forms, including flat roofs, pitched roofs and vaulted roofs. It can easily be adapted to slight curves.
- It can be a more aesthetic solution for sheet metal roofs than glazed collectors.

The disadvantages of the unglazed flat plate collector are:

- Because of the low specific performance, it requires more surface area than a flat collector
- Because of the higher heat losses, the temperature increase (above the air temperature) is limited.

2.1.1.2 Glazed flat plated collector

Almost all glazed flat plate collectors currently available on the market consist of a metal absorber in a flat rectangular housing. The collector is thermally insulated on its back and edges, and is provided with a transparent cover on the upper surface. Two pipe connections for the supply and return of the heat transfer medium are fitted, usually to the side of the collector.

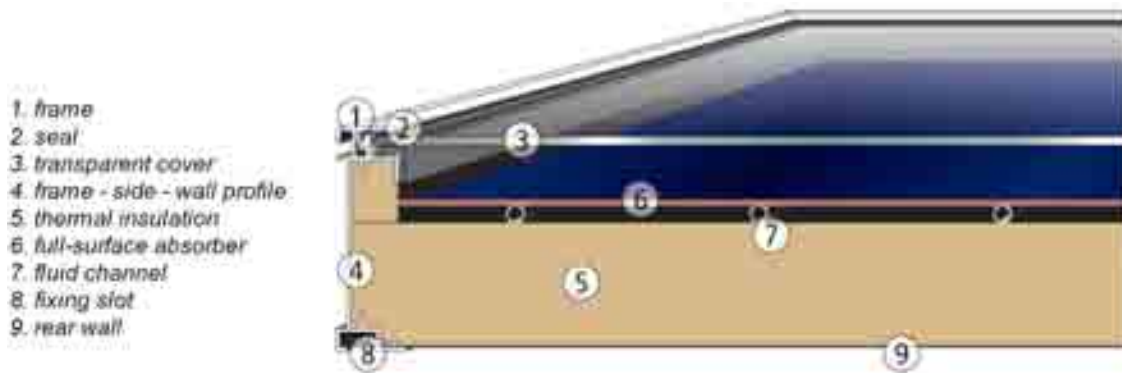


Figure 12: glazed flat plate collector (DGS guide book on solar thermal systems planning and installing, 2005)

Without the glass cover, glazed flat plate collectors weigh between 8 and 12 kg per m² of collector area; the glass cover weight between 15 and 20 kg per m². These collectors are made in various sizes from 1 m² to 12.5 m², or larger in some cases.

The advantages of the glazed flat plate collector are:

- It is cheaper than a vacuum collector
- It offers multiple mounting options (on roof, integrated in the roof, façade mounting and free installation)
- It has a good price/performance ratio
- It has good possibilities for do-it-yourself assembly

The disadvantages of the glazed flat plate collector are:

- It has a lower efficiency than a vacuum collectors
- A supporting system is necessary for flat roof mounting
- It is not suitable for generating higher temperatures, as required for, say, steam generation, or for heat supplies to absorption-type refrigeration machines.
- It requires more roof space than vacuum collectors do.

2.1.1.3 Evacuated tube collectors

To reduce the thermal losses in a collector, glass cylinders (with internal absorber) are evacuated. In order to completely suppress thermal losses through convection, the volume enclosed in the glass tubes must be evacuated to less than 10^{-2} bar.

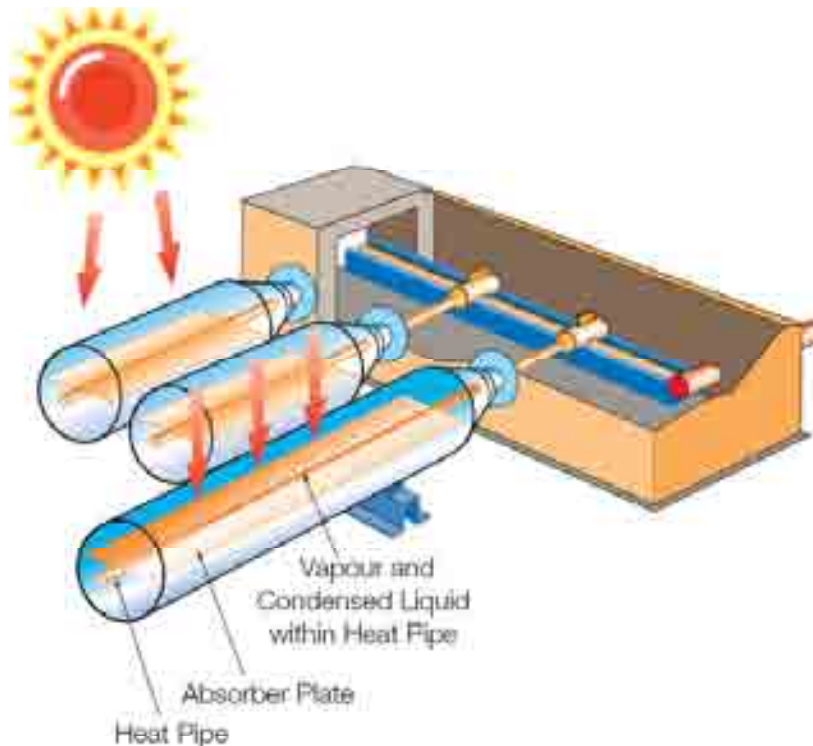


Figure 13: Evacuated tube collector (RETScreen International, 2004)

Additional evacuation prevents losses through thermal conduction. The radiation losses can not be reduced by increasing a vacuum, as no medium is necessary for the transport of radiation. They are kept low, as in the case of glazed flat plate collectors, by selective coatings. The heat losses to the surrounding air are therefore significantly reduced. Even with an absorber temperature of 120 °C or more the glass tube remains cold on the outside. Most vacuum tubes are evacuated down to 10^{-5} bar.

The advantages of the vacuum collector are:

- It achieves a high efficiency even with large temperature differences between absorber and surroundings.
- It achieves a high efficiency with low radiation
- It supports space heating applications more effectively than do glazed flat plate collectors
- It achieves high temperatures, for example for steam generation or air conditioning
- It can be easily transported to any installation location because of its low weight; sometimes the collector is assembled at the installation site.
- By turning the absorber strips it can be aligned towards the sun.

- In the form of direct through flow tubes it can be mounted horizontally on a flat roof, hence providing less wind load and lower installation costs. In this way penetration of the roof skin is avoided.

The disadvantages of the vacuum collector are:

- It is more expensive than a glazed flat plate collector
- It can not be used for in-roof installation
- It can not be used for horizontal installation for heat pipe systems (inclination must be at least 25°).

2.1.2 Storage

The energy supply by the sun can not be influenced, and rarely matches the times when heat is required. Therefore the generated solar heat must be stored. It would be ideal if this heat could be saved from the summer to the winter (seasonal store) so that it could be used for heating. There are stores that store heat chemically, currently available as prototypes, which should be available on the market in the near future. Even for short term storage over one or two days, to bridge over weather variations, developments are still taking place.

Storage tanks can be vented or unvented. Unvented tanks are offered in stainless steel, enamelled or plastic-coated steel or copper. Stainless steel tanks are comparatively light and maintenance-free, but significantly more expensive than enamelled steel tanks. Also, stainless steel is more sensitive to water with high chloride content. Enamelled tanks must be equipped with a magnesium or external galvanic anode for corrosion protection reasons. Cheaper plastic coated steel tanks are also offered. Their coating must be free of pores, and they are sensitive to temperatures above 80 °C. Vented plastic tanks are similarly sensitive to higher temperature. In some countries the predominant material used for tanks is copper. The advantages of copper are its lightness and the ease of fabricating it in different sizes.

2.1.3 Transfer

The heat generated in the collector is transported to the store by means of the solar circuit. This consists of the following elements:

- The pipelines, which connect the collectors on the roof and the stores
- The solar liquid or transport medium, which transports the heat from the collector to the store
- The solar pump, which circulates the solar liquid in the solar circuit (thermosyphon does not have pump)
- The solar circuit heat exchanger, which transfers the heat gained to the domestic hot water in the store
- The fitting and equipment for filling emptying and bleeding
- The safety equipment. The expansion vessel and safety valve protect the system from damage (leakage) by volume expansion or high pressures.

2.1.3.1 Pipelines

Copper is the most frequently used material for the transport pipeline between collector and store. Many types of fitting made of copper, red bronze or brass are available for Cu/Cu connections and the transitions to other system components with threaded connections. Steel pipes are also often used, mostly for larger systems. Using galvanized pipes together with antifreeze fluids is not recommended, as this leads to corrosion problems.

To avoid heat losses, it is important to insulate the complete piping without gaps and open spots. That means that even the fittings, valves, store connection, plugs, flanges and similar must be well insulated.

External pipelines must be UV and weather resistant as well as being waterproof, and should offer protection from animal damage.

2.1.3.2 Solar liquid

The solar liquid transports the heat produced in the collector to the solar store. Water is the most suitable medium for this, as it has some very good properties.

- High thermal capacity
- High thermal conductivity
- Low viscosity

More over, water is noncombustible, non toxic and cheap.

As the operating temperatures in collectors can be between -15°C and $+350^{\circ}\text{C}$, if we use water as the heat transfer medium we shall have problems with both frost and evaporation. In fact, water freezes at 0°C and evaporates at 100°C . Through the addition of 40% propylene glycol, which is predominantly used at present, frost protection down to -23°C is achieved, together with an increase in the boiling point to 150°C or more, according to the pressure.

Water is highly corrosive. This is further increased by the propylene glycol. For this reason a whole range of inhibitors are used, each inhibitor offering corrosion protection for a specific material. Other effects of the addition of glycol are:

- Reduced thermal capacity
- Reduced thermal conductivity
- Increased viscosity
- Increased creep capacity

2.1.3.3 Solar pumps

For pumped systems, the use of electricity for pumps should be kept as low as possible, and therefore over dimensioning of the power of the pump should be avoided. The pump should be chosen in a manner that a difference of between 8°C and 12°C is produced between the feed and return lines.

2.1.3.4 Solar heat exchanger

For the transfer of the heat gained from the sun to the domestic hot water, a heat exchanger is required in twin circuit systems. We can differentiate between internal and external heat exchangers.

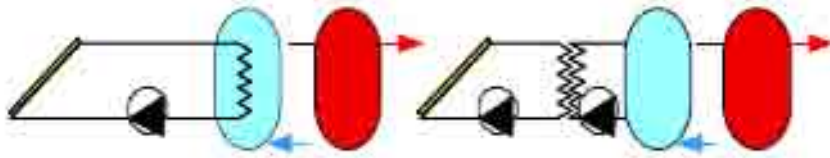


Figure 14: Internal and external heat exchanger (Manual for design and installing of solar thermal system, ADEME 2002)

2.1.4 Controller

The controller of a solar thermal system has the task of controlling the circulating pump so as to harvest the sun's energy in the optimum way. In most cases this entails simple electronic temperature difference regulation. Thermosyphon does not have controller.

Two temperature sensors are required for standard temperature difference control. One measures the temperature at the hottest part of the solar circuit before the collector output (flow); the other measures the temperature in the store at the height of the solar circuit heat exchanger. The temperature signals from the sensors are compared in a control unit. The pump is switched on via a relay when the switch-on temperature is reached.

The switch-on temperature difference depends on various factors. Standard settings are from 5°C to 8°C. In principle, the longer the pipeline from the collector to the store, the greater the temperature difference that should be set. The switch-off temperature difference is normally around 3°C. A third sensor can be connected for temperature measurement in the upper area of the store, which permits the draw-off temperature to be read.

An additional function is switching off the system when the maximum store temperature has been reached, as a means of over heating protection.

Frost protection is effected by adding antifreeze to the collector fluid, or by using the drain-back system. In the latter system, the collector circuit is only partly filled with water, and when the pump is off the collector is completely dry. This obviously places special requirements on the design of the collector and the piping. Drainback systems, when well designed so that no water is left in the collector or any piping that could freeze when the pump is switched off, automatically work together correctly with a temperature differential controller. When the danger of freezing occurs, the pump will be switched off because the store will then be always warmer than the collector.

2.2 Possible configuration of solar water heating system

The standard system in Figure 15 has been widely accepted for use in small systems, and is offered by many manufacturers. It is a twin circuit (indirect) system with an internal heat exchanger for solar heat feed and a second one for top-up heating by a heating boiler. In the store there is domestic hot water, which can be limited to a set maximum draw-off temperature by means of thermostatic three way blending valve.

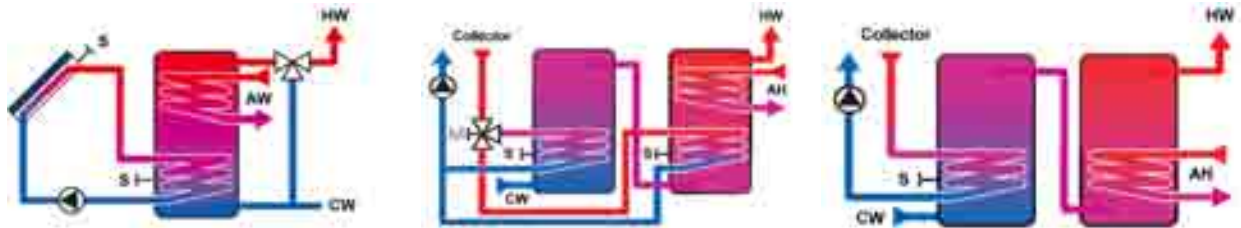


Figure 15: Standard system for domestic hot water (DGS guide book on solar thermal systems planning and installing, 2005)

The circuitry is comparatively easy to implement, as well-tried control principles are used. The solar circuit pump is switched on as soon as the temperature in the collector is 5 – 8°C higher than in the lower store area. When the temperature on the boiler controller for the standby volume falls below a set temperature, the boiler provides the necessary top-up heating. In the case of cascade connection of two stores, either both stores can be heated by solar energy where the draw-off store is charged as a priority, or only the preheating store is charge by solar energy and draw-off store is top-up heated as necessary.

Through the use of special stratified store either as a domestic hot water store or as a buffer store (see Figure 16), which is used only for domestic water heating for hygiene reasons, the heat from the solar collector is specifically fed into the heating for hygiene reasons, the heat from the solar collector is specifically fed into the matching temperature layer in the store. The significantly reduced mixing process leads to a usable temperature level much faster than for all the other systems described here, and the frequency of auxiliary heating is reduced. When the stratified store operates with buffer water, the heat for the domestic water is discharge by means of an external once-through heat exchanger. Also important for the performance of this system is good matching of the discharge control system to the different tapping rates. Figure 17 shows a buffer store with external charging and an internal output heat exchanger, which includes an internal downpipe and direct auxiliary heating by the boiler (for hygiene reasons it is exclusively used here for domestic water heating).

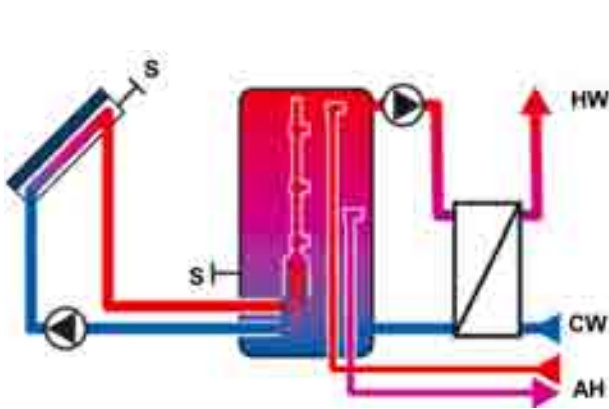


Figure 16: Stratified store as buffer storage (DGS guide book on solar thermal systems planning and installing, 2005)

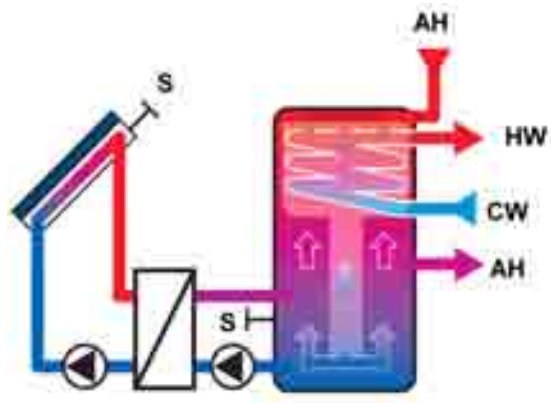


Figure 17: Buffer store with external charging (DGS guide book on solar thermal systems planning and installing, 2005)

In twin store system (see Figure 18) the solar circuit charges a buffer store via an internal or external heat exchanger, from which in turn a downstream domestic water store is supplied with heat. This then receives auxiliary heating in the upper area. This variant has proved to be more favourable than auxiliary heating in the buffer store. In larger systems the store volume is divided into buffer and domestic water areas for water hygiene reasons and for energy saving.

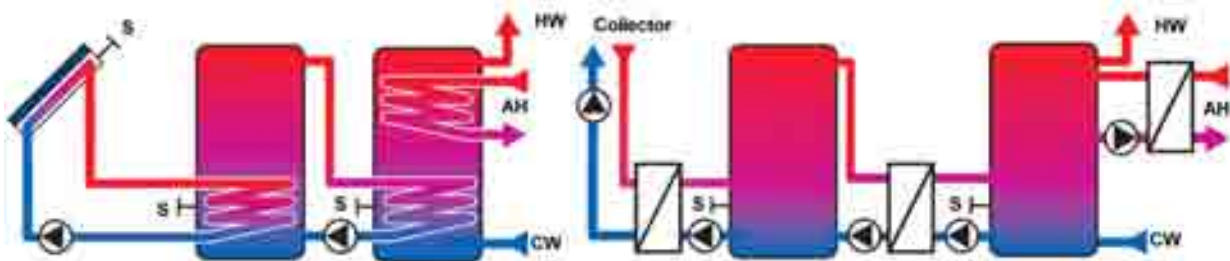


Figure 18: Twin store systems (DGS guide book on solar thermal systems planning and installing, 2005)

Figure 19 shows a combined store system: for hygiene reasons, this is used here exclusively for domestic water heating. In comparison with standard systems, this store contains a smaller domestic water volume. Hence the water dwell time in the store is shorter. The surrounding buffer (thermal storage) water is used only as intermediate storage for the heat.

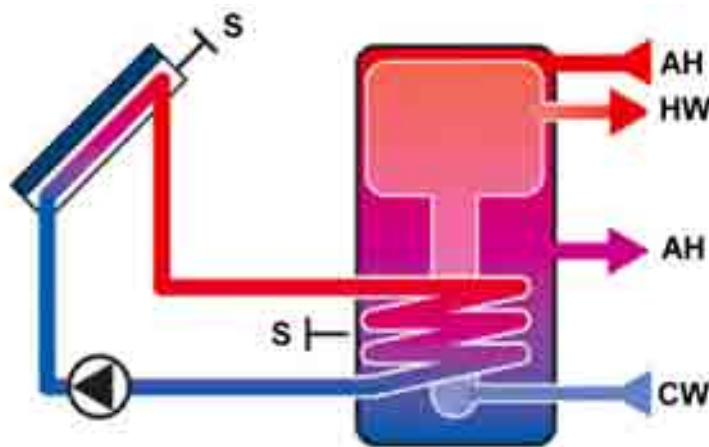


Figure 19: Combined store system (DGS guide book on solar thermal systems planning and installing, 2005)

3 Solar thermal system dimensioning, installation, commissioning and maintenance

This part will cover dimensioning of a solar thermal system for domestic hot water, their installation and commissioning.

3.1 Dimensioning of system components

3.1.1 Design objectives

In sunny climates, the common design goal is either to supply the hot water consumption fully from solar energy, or to supply full coverage for most of the year and use a back up heater (often an electrical element immersed in the solar tank) for a few weeks or months per year.

3.1.1.1 Solar fraction

The solar fraction is described as the ratio of solar heat yield to the total energy requirement for hot water heating. The higher the solar fraction in a solar energy system, the lower the amount of fossil energy required for auxiliary heating: in the extreme case (100%) non at all.

3.1.1.2 System efficiency

The system efficiency gives the ratio of solar heat yield to the global solar irradiance on the absorber surface with respect to a given period of time. The system efficiency is strongly dependent on the solar fraction. It is higher at lower solar fractions (when the solar water heater size is small compared with the hot water demand). If the solar fraction is increased by increasing the collector area, the system efficiency is reduced, and every further kilowatt-hour that is gained becomes more expensive. This counter effect of the two variables can be seen in Figure 20.

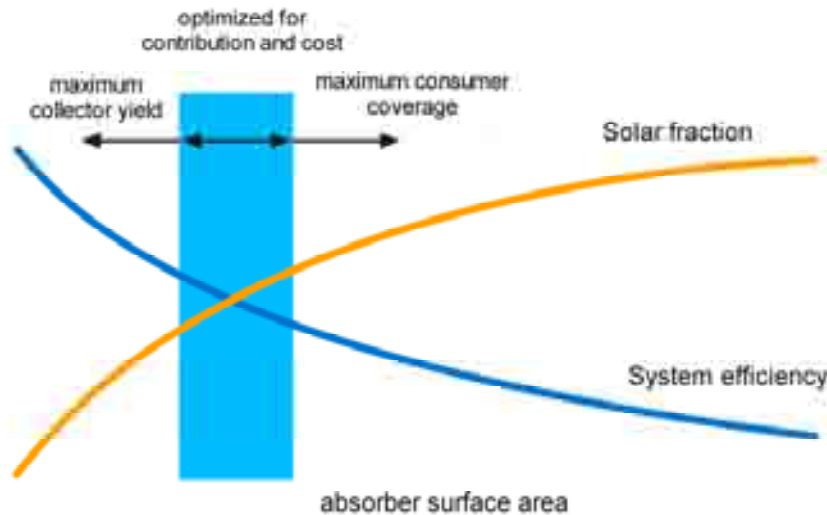


Figure 20: solar fraction and system efficiency (DGS guide book on solar thermal systems planning and installing, 2005)

There are 4 different methods for dimensioning a solar thermal system namely:

- Rough determination of size with an approximation formula
- Detailed calculation of the individual components
- Graphical design with nomographs
- Computer aided design with simulation programs

The last three methods are out of the scope of this textbook. Therefore, only the first method will be discussed.

3.1.2 Collector surface area

For a tropical climate, the collector area can be estimated under the following assumptions:

- Average hot water requirement, 35 – 65 litres (45°C) per person per day
- Favourable solar irradiance conditions
- Yearly average solar fraction = approximate 80% (auxiliary heating is necessary only in a few months). Solar fraction here means the ratio of solar heat yield to the total energy requirement for hot water heating. If solar fraction is equal to 80%, this means that 80% of energy for heating water during the year comes from solar energy. Another 20% comes from another heating source.
- Collector at optimal or almost optimal orientation and tilt angle
- No or little shading

The rule of thumb for such situations is 0.35 – 0.6 m² of glazed flat plate collector area per person ($E_G=2000 \text{ kWh/m}^2\text{a}$). It should be mentioned here that E_G is the total solar radiation received in one square meter per annum. In order to get E_G for the case of Cambodia, please refer to Figure 21 shown in different region of the map below. Multiply this figure by the number of 365 days, we will get E_G .

larger diameters and/or shorter lengths will probably be required to ensure proper flow; for low flow systems the diameters and pumps powers can be much lower.

Table 2: solar circuit pipe diameter in relation to collector surface area and length of solar circuit pipes (DGS guide book on solar thermal systems planning and installing, 2005)

Collector surface area (m ²)	Total length (m)				
	10	20	30	40	50
Up to 5	15/I	15/I	15/I	15/I	15/I
6 – 12	18/I	18/I	18/I	18/I	18/I
13 – 16	18/I	22/I	22/I	22/I	22/I
17 – 20	22/I	22/I	22/I	22/I	22/I
21 – 25	22/I	22/II	22/II	22/II	22/III
26 – 30	22/II	22/II	22/III	22/III	22/III

The roman characters identify the respective circulation pumps. I = 30-60 W power consumption. II, III = 45-90 W

Example: For a pumped, high flow system with a collector surface area of 6 m² and a total length of feed and return pipes of 20 m, a solar circuit pipe diameter of 18 mm is obtained, and a corresponding circulating pumps with a power between 30 and 60 W.

When the collector is filled with antifreeze fluid and it is allowed to boil dry in overheating situations, there must be an expansion vessel of sufficient size to contain the displaced collector fluid. The volume of the expansion vessel can be obtained from Table 3. It depends on the collector surface area and the system height between the expansion vessel and the edge of the collector.

Table 3: design of expansion vessel volume for a safe stagnation temperature in relation to collector surface area and system height (DGS guide book on solar thermal systems planning and installing, 2005)

System volume (l)	Collector surface area (m ²)	System height (m)					
		2.5	5	7.5	10	12.5	15
18	5	12	12	12	12	18	18
20	7.5	12	12	12	18	25	35
23	10	12	12	18	25	35	35
24	12.5	12	18	25	35	35	35
25	15	18	25	35	35	35	35
29	17.5	25	35	35	35	50	50
35	20	25	35	35	50	50	50
37	25	35	35	50	50	50	80
40	30	35	50	50	50	80	80

The table does not take into account the vapour volumes that can occur in the collector connecting lines in evacuated tube collector systems under certain circumstances.

From the table and expansion vessel volume of 12 l can be obtained for our example.

3.2 Costs and yields analysis of a solar water heating system

3.2.1 Prices of a solar water heating system

In new building the installation cost is reduced in comparison with retrofitting because there are fewer safety measures and no replacing floor coverings etc. and the collector installation can take place during other roofing operations. Table 4 shows a local price of a solar water heating system:

Table 4: local price of a solar water heating (Khmer solar price list, 2007)

Volume of water in l	80	120	150	180	200	500	1000	> 1000
Price in US\$	475	600	660	785	850	1200	2100	2.1/l

3.2.2 Energy balance and yields for a thermal solar system

The performance (or solar yield) of thermal solar systems, assuming that the dimensioning has been matched to the hot water requirements, is established by means of the losses on the way from the collector to the tap. Figure 22 shows the balance of a standard solar system with glazed flat plate collectors.

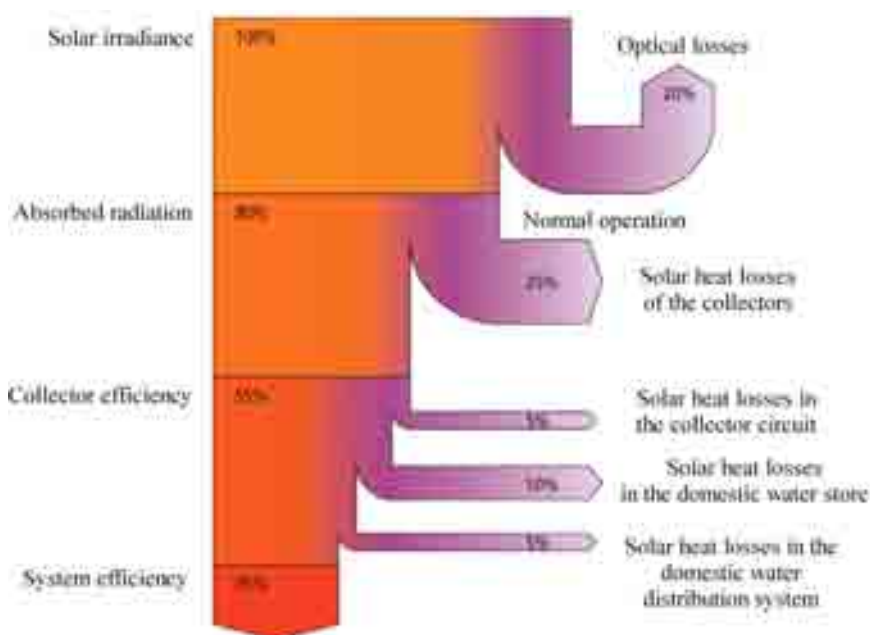


Figure 22: energy balance for a solar thermal system (DGS guide book on solar thermal systems planning and installing, 2005)

The average system efficiency for a well-designed thermal solar system with glazed flat plate collectors is about 35 - 45%. With global solar irradiance of 1000 kWh per annum of thermal energy. If evacuated tube collectors are used, the efficiency is increased to about 45 - 50%, because of the lower heat losses at the collector. A comparison with the costs for fossil heat generation shows that solar hot water generation can compete extremely well with electrical

hot water heating, even if it still requires subsidy. A significant reduction of the system costs is achieved for new buildings (saving on tiled areas, lower installation costs etc.) in comparison with retrofitted installation the costs arising are up to 20% less.

3.3 Installation

Table 5: installation check list (DGS guide book on solar thermal systems planning and installing, 2005)

Delivery of material	Check for transport damage	
	Check the completeness and correctness of the delivery	
Setting up the site, preparatory work	Establishment of the collector position	
	Establishment of transport route for the collectors	
	Preparation of the materials and tools required for installation	
Collector installation	on-roof installation <ul style="list-style-type: none"> • Advantage: fast and simple installation, roof skin remains closed, greater flexibility • disadvantage: additional roof load, visually not so attractive as in-roof installation, piping partly installed above roof 	
	in-roof installation <ul style="list-style-type: none"> • advantage: no additional roof load, visually more appealing, pipes are laid beneath the roof cover, saving of roof tiles • disadvantage: more expensive, roof skin is broken through, less flexible 	
	mounting on a flat roof <ul style="list-style-type: none"> • advantage: fast and simple installation, no stand cost, no penetration of roof skin at the fixing points, low roof loading • disadvantage: higher costs for evacuated tube collectors, lower yield when the sun is at low level 	
	installation on the façade <ul style="list-style-type: none"> • advantage: uniform yield profile per year, lower thermal loads, positive effect in architectural façade configuration • disadvantage: lower annual global solar irradiance than a roof installation 	
	construction of the collector field	
	parallel connection	
	series or row connection	
	combination of series and parallel connections	
Installation of the solar circuit	Installation of pipe	
	Installation of fittings	
	Installation of thermal insulation of pipes	

Store installation	Connection of solar circuit	
	Connection of additional heating system	
	Cold water connection	
	Hot water connection	
	Insulation of the store	
Installation of fittings	Fittings in the solar circuits	<ul style="list-style-type: none"> • combined filling and emptying taps • circulating pump • return-flow provender • expansion vessel • safety valve • vents • air separators • display instruments • shut-off fittings • dirt filters
	Fitting for the domestic hot water piping	thermostatic mixing valve dirt filter
Installation of sensors and controllers	installation and connection of sensors	
	control unit installation	



Figure 23: roof installation and mountings (DGS guide book on solar thermal systems planning and installing, 2005)

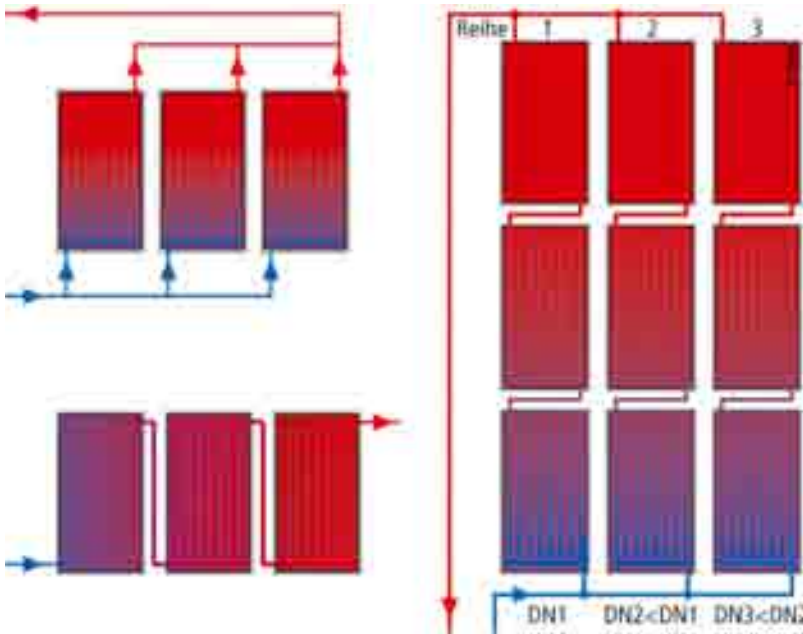


Figure 24: collector connection type (DGS guide book on solar thermal systems planning and installing, 2005)

3.4 Commissioning of a solar water system

The necessary steps to start up a thermal solar energy system are:

- Flush out the solar circuit
- Check the leak
- Fill with solar liquid
- Set pumps and controller

3.4.1 Flusing out the solar circuit

A thorough flushing process removes dirt and residual flux from the solar circuit. Flushing should not be carried out in full sunshine or during frost, as there is a risk of evaporation or freezing. The flushing process initially takes place via valves 1 and 2 (see Figure 25). Valve 1 is connected to the cold water line by a hose; a further hose on valve 2 is laid to the drain. All fitting in the solar circuit should be set to through flow (gravity brake, shut off taps). Finally, in order to flush out the heat exchanger valve 2 is closed, after attaching a hose to it valve 4 is opened, and valve 3 is closed. The flushing process should last for about 10 minutes.

3.4.2 Leak testing

The pressure test takes place after flushing. For this purpose valve 4 is closed, and the system is filled with water through valve 1. The system pressure is then raised to a value just below the response pressure of the safety valve – maximum 6 bars. Then valve 1 is closed, the pump is manually started, and the solar circuit is vented via the vents or the pump (vent

screw). If the pressure falls significantly as a result of bleeding, it must be increased again by additional filling. The system is now ready to be tested for leaks (visually and by hand). A leak test using the pressure gauge is not possible because of irradiation-caused pressure variations over the course of a day. At the end of the leak test the function of the safety valve can be tested by increasing the pressure further. The solar circuit should finally be fully emptied again by opening taps 1 and 2.

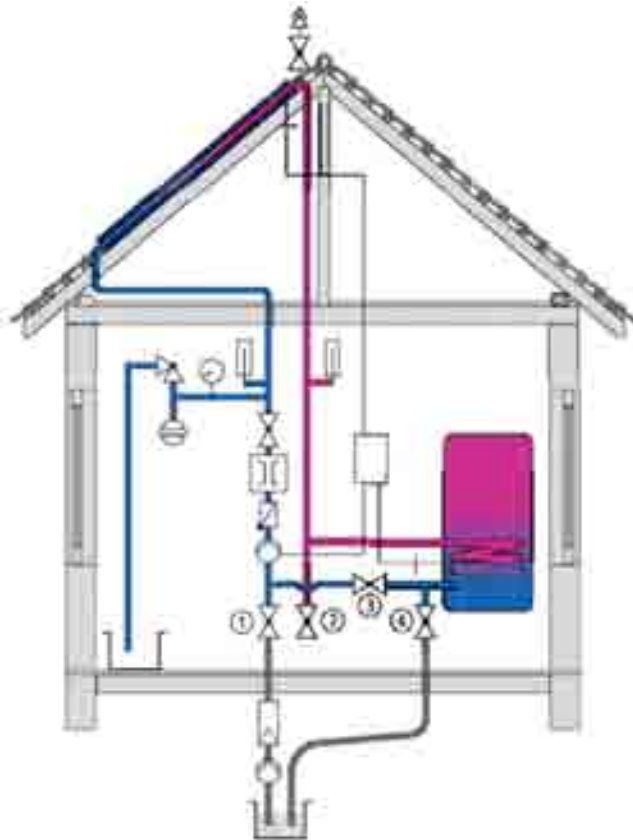


Figure 25: flushing process of a solar water heating system (DGS guide book on solar thermal systems planning and installing, 2005)

3.4.3 Filling with solar liquid

After mixing the antifreeze concentrate with water to achieve the desired level of frost protection the solar liquid is pumped into the solar circuit through valve 1. As the solar liquid – compared with water – is much more likely to creep, it is necessary to recheck the system for leaks. A general procedure to release the air from the solar liquid is as follows – but always checks the installation instructions for the specific products, as differences may occur.

3.4.4 Setting the pump and controller

The pump should be capable of generating the pressure required in its medium performance range. With full irradiation, this leads to a temperature difference between the feed and return lines of about 10-15 °C in high flow operation and 30-50 °C in low flow operation. The actual volumetric flow can be controlled with the help of a taco-setter or a flow meter.

The switch-on temperature difference of 5 – 10°C and the switch-off difference of about 2°C should be set on the controller. In this way, on the one hand the heat generated in the collector is transferred to the store at a useful temperature level, and on the other hand no unnecessary pump energy is used.

3.5 Maintenance

A solar thermal system requires very little maintenance; however, a regular check is recommended.

3.5.1 Visual inspection

The visual inspection involves checking the collectors and the solar circuit for visual changes:

- Collectors: contamination, fixings, connections, leaks, broken glass, tarnishing on tubes
- Solar circuit and storage tank: tightness of thermal insulation, leaks, check/clean any dirt traps, pressure, filling level

3.5.2 Checking the frost protection

The frost protection of antifreeze fluids is checked with a hydrometer or refractometer. For this purpose a given amount of solar liquid is removed. Either the temperature to which the system is protected is shown directly, or a specified density is read off. This allows the actual content of antifreeze mixture to be established from a density-concentration diagram and thereby the freezing point.

For the drain back systems, the level of the collector fluid needs to be checked: if necessary fill the circuit to its proper level.

3.5.3 Checking the corrosion protection

- Solar circuit: checking the corrosion protection of the solar liquid is done directly by establishing the pH value. Test strips are suitable for this with which the pH value can be read from a color scale. If the pH value falls below the original value to under 7, the frost protection mixture should be exchanged.
- Store tank (only for tanks with anodes): the magnesium sacrificial anode can be tested by measuring the current between the detached cable and the anode using an ammeter. If the current is over 0.5 amps, there is no need to renew the anode. In case of a powered anode, only the LED indicating proper functioning needs to be checked.

3.5.4 Monitoring the system parameters

The pressure and temperature, and the controller setting, must be checked. During operation the system pressure varies, depending on the temperature. After complete bleeding it must not vary from the set value by more than 0.3 bars. It must never fall below the admis-

sion pressure of the vessel. The temperature difference between feed and return lines should in full irradiance conditions not exceed 20°C and not drop below 5°C in high flow systems. The controller settings and functions must be tested. If provided, within the scope of maintenance the data for system function and yield monitoring can also be recorded. Among these are operating hours of the solar system pumps and quantity yield. The solar circuit pump should have an approximate annual running time according to the sunshine hours at the respective location.

4 References

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