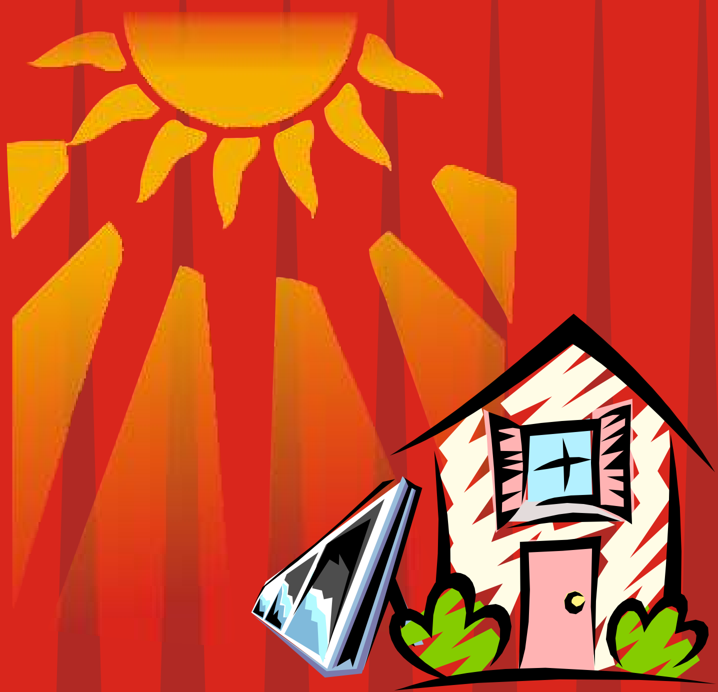

DOMESTIC HOT WATER FROM THE SUN

Basic facts for small systems
for the consumer

European Commission
Directorate General for Energy and Transport

ENERGIE PROGRAMME

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Contract No.: NNE5/2002/86
SOL-MED II
Widening the use of European Solar Thermal Technologies in Mediterranean Countries following the Successful Model of Greece. PART B: Italy, France, Romania, Bulgaria, and Turkey

Domestic Hot Water from the Sun

Basic facts for small systems for the consumer

exergia

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Any comments and questions on this publication may be sent to: **n.komioti@exergia.gr**

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Foreword

This document is intended to be used as a guide for the preparation of promotion material for **Solar Systems for the Production of Domestic Hot Water,** by **Manufacturers, Retailers, Promoters**, etc. It may be used also by **Regional and Local Authorities** for the same purpose.

The final promotion material is addressed to the **End Users of Domestic Hot Water**.

It contains short description of the various types of solar domestic hot water systems, as well as their components, i.e. the solar collectors, the hot water storage tanks, the control systems, etc.

The specific manufacturer, or retailer, or promoter may select the part of the text, that fits his products, and expand it as he considers appropriately. He may introduce

- the map with the solar radiation for the country or the region of his interest (Figures 2.1, 2.2, 2.3)
- the cross section(s) of his collector(s) (Figure 4.1)
- the Draw off Temperature Profile(s) of his system(s), (Figure 11.1)
- the meteorological data of his region (Figures 17.1 and 17.2)

or other material related to his specific products.

1. Introduction

Sunlight, or solar energy, has served humanity since the origin of mankind, but only in the last decades, the sun is being adopted to supply thermal and electrical energy. Solar energy, which is free, and abundantly available throughout most of the world, is being converted into:

- thermal energy, with the use of numerous variations of solar collectors (liquid or air heating);
- electrical energy, with the use of solar cells, which convert sunlight directly into electricity, through a phenomenon of solid-state physics termed photovoltaics.

Solar thermal systems, are used extensively for the heating water for domestic applications in southern European countries, as well as in northern European countries (Germany, Austria, Denmark, etc).

After some decades of technical development, the solar thermal market has reached maturity. High quality products are available in the market. The solar systems are reliable and their efficient operation can be guaranteed.

Solar systems for heating water for homes have some important advantages:

- They save money to the user, as there is no cost involved in their operation.
- Hot water is continuously available.
- They offer pollution-free energy from the sun and contribute to the reduction of carbon dioxide (CO2) emissions. Carbon dioxide has a greenhouse effect and the potential of global warming.

This document provides to the consumer information about the use of solar energy for water heating purposes at home.

- It can help the consumer to decide what kind of system to buy, from whom to buy, where to install it and other similar matters.
- Furthermore, it can guide him on how to obtain information about performance characteristics of the solar systems in order to evaluate their cost effectiveness and finally how to make the best use of the sun.

2. Solar potential

The performance of a solar system for heating water for domestic applications depends a lot on the available solar energy in the location where it is installed. The more solar energy is available, the more thermal energy is obtained in the form of hot water.

Figures 2.1, 2.2 and 2.3 present the solar radiation in Greece, in Cyprus and in the Iberian peninsula (from Reference [1]). All figures show the average daily solar energy on a horizontal plane. This is the average value for a whole year. The energy is given in kWh per square meter per day.

The solar collectors of a solar water heater are installed on a tilted plane (30° - 45° with respect to the horizontal plane). They are always facing south (north hemisphere). Solar energy on tilted surfaces is available.

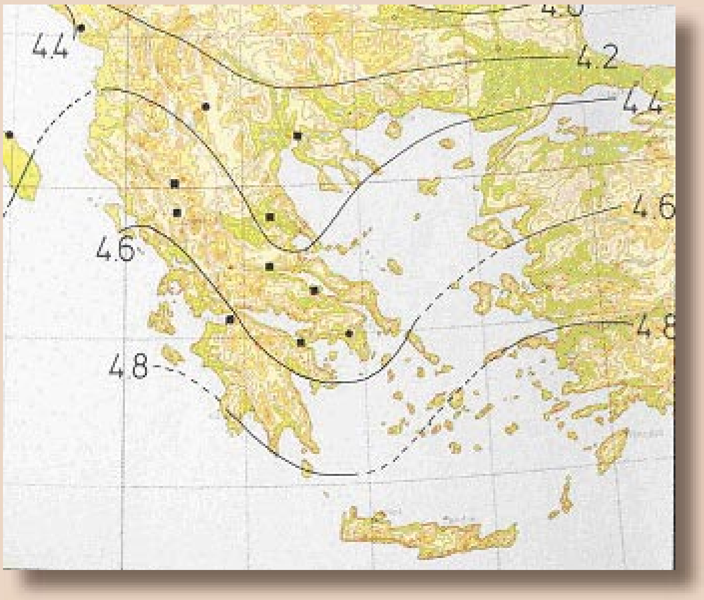

Figure 2.1 Solar energy in Greece
(daily average values in kWh per square meter)

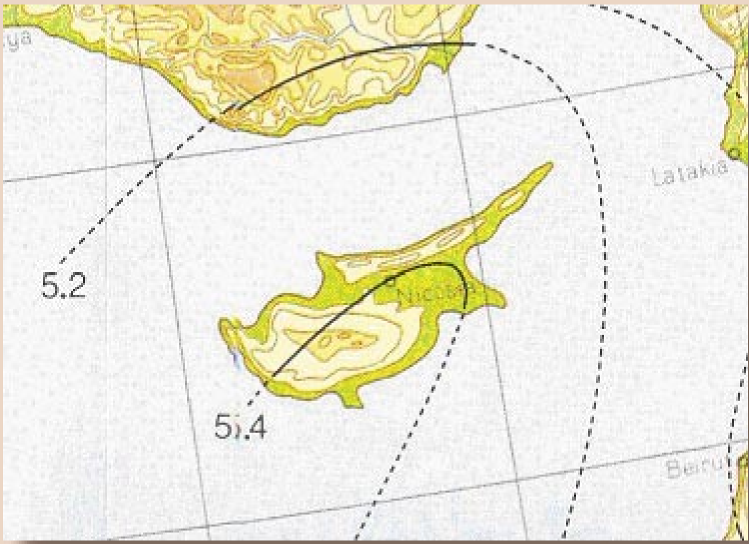

Figure 2.2 Solar energy in Cyprus
(daily average values in kWh per square meter)

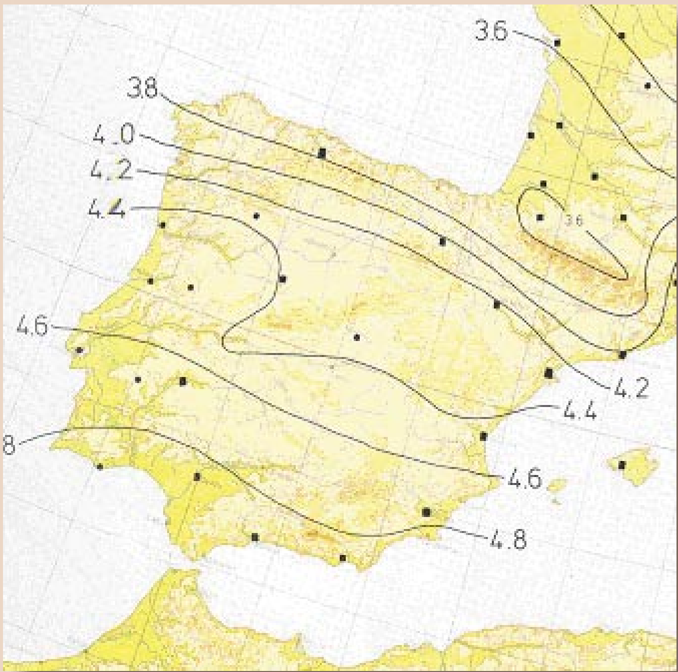

Figure 2.3 Solar energy in the Iberian peninsula (Spain and Portugal),
(daily average values in kWh per square meter)

3. Basic components of solar systems for heating domestic water

The solar systems for heating domestic water are different from the familiar electric water heaters, in the fact that some collectors absorb the solar radiation and convert it to usable heat. The collectors usually go to the roof of the house or in other places, where they are exposed to direct solar energy during the day.

A solar domestic hot water system consists of the solar collector (or collectors), the hot water storage tank, the supporting structure and the piping connecting the various components (including a pump and control equipment in some systems).

There are solar domestic hot water systems, which are mounted (both the collectors and the hot water storage tank) on the roofs (usually flat) of houses or apartment buildings. Such a system is shown in Figure 3.1 The system shown has two solar collectors.

There are also solar domestic hot water systems which have collectors mounted on the roof, but have the hot water storage tank on a lower level, such as on the ground floor or in the basement. In this case, a pump is required to transfer energy from the collector to the storage tank, while a differential thermostat (control system) controls the operation of the pump. Usually such a domestic hot water system has more capacity (larger collector area, larger tank) than a simple thermosiphon system.

Such a solar system for heating water is shown schematically in Figure 3.2

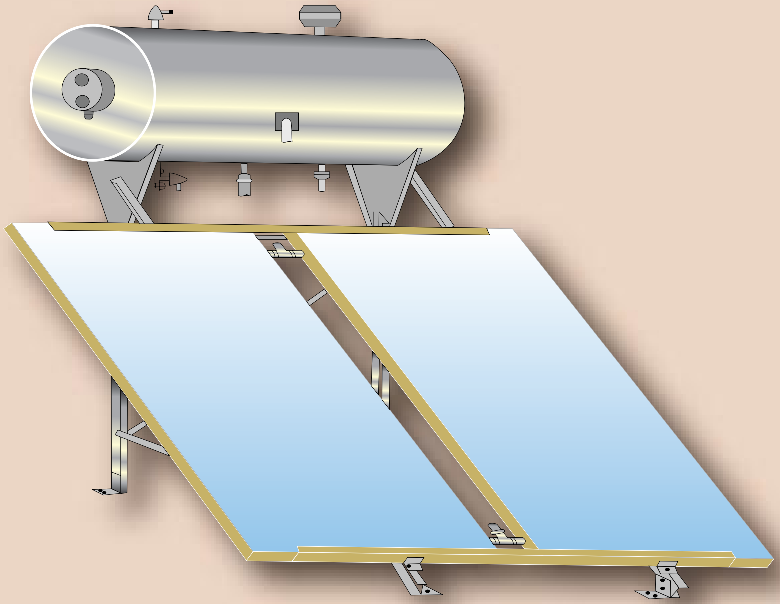

Figure 3.1 Typical solar domestic water heater of thermosiphon type

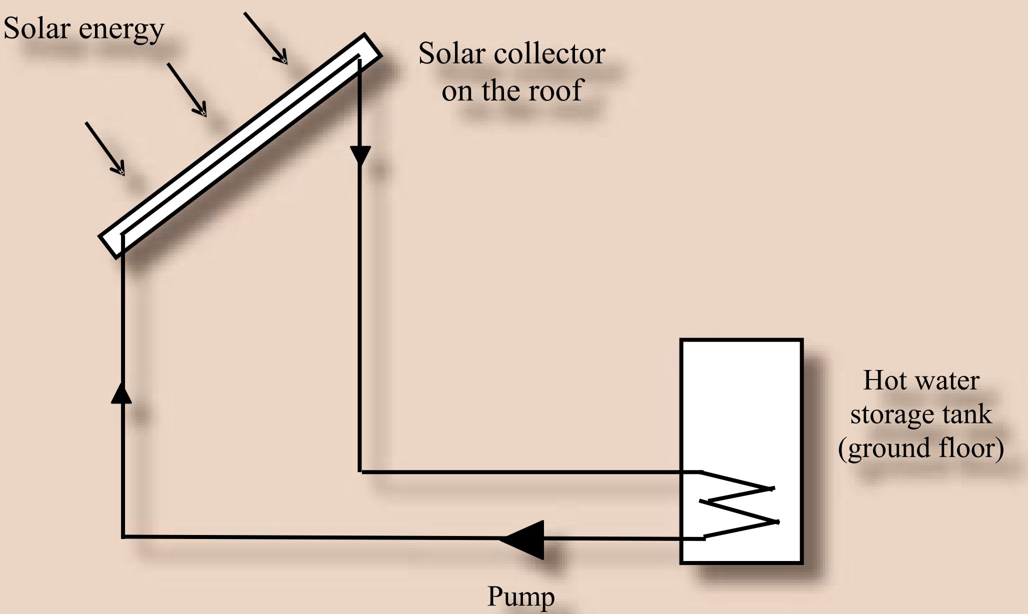

Figure 3.2 Typical solar domestic water heater with pump (schematically)

4. The solar collector

The main components of the solar collector are the frame, the insulation, the transparent cover (glazing) and the absorber. The absorber is the part inside the collector, which consists of a black metallic surface (usually copper or aluminium fins) and metallic tubes (usually from copper). Absorber surface and tubes are well bonded. Schematically these components are shown in Figure 4.1

When a solar collector is exposed to the sun, the solar irradiation, which falls on the collector penetrates the glass and is absorbed by the black surface, which is heated. Next, the heat transfer fluid (water, or water and antifreeze etc), that is in the absorber tubes, is also heated and it transfers the energy to the water in the storage tank.

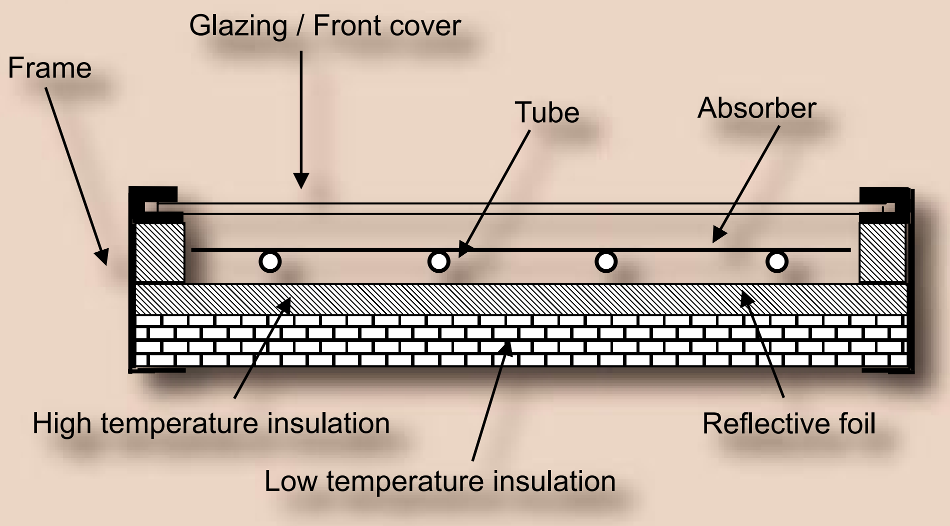

Figure 4.1 Typical cross section of a glazed liquid heating solar collector

Under certain conditions, like in summer and when the solar system is not used (like in vacation period for the user), the absorber surface can develop high temperatures (stagnation temperature), which can reach 150ºC or even 200ºC in some collectors. This is the reason that close to the absorber the insulation should sustain high temperatures.

Matt black paint is used for the absorber surface in the common collectors, which can operate efficiently to temperatures up to 50°C - 60°C.

Selective coatings, used on the absorber surface, result to efficient operation of the collector

- at higher temperatures of 60°C - 80°C and
- in places with rather low solar radiation (Northern Europe)

Common glass is used for the front cover of the collectors. It is noted that the green appearance of the common glass (as seen from the side) is due to the existence of iron oxides. They reduce its transmittance to the solar radiation.

Tempered glass, with low content in iron oxides, has higher transmittance to solar radiation compared to common glass, therefore it gives higher performance to the solar collectors.

Tempered glass has also much greater durability than common glass and therefore the possibility of breakage is almost eliminated. In addition, in the rare case of breakage, it shatters into small harmless bits of glass (as happens with car windows), so it offers safety against accidents.

The frame provides the structural stiffness in a collector. It holds together the transparent cover, the absorber and the insulation.

The integrity and long term durability of a collector depends strongly on the design and the quality of the sealing assembly around the cover and around the fluid inlet and outlet pipes.

Water-tightness between the frame and the transparent cover is very important for the collector reliability.

Because of the risks of water penetration in solar collectors with aging (and not only), it may be considered preferable that the casing is designed with **drain holes** and possibly with adequate **ventilation**. At the same time provision should be taken to prevent insects from entering the collector.

A solar collector is required to absorb solar irradiance and to transfer the absorbed energy into a heat transfer fluid with a minimum of heat losses. The **thermal efficiency** of the collector is defined as the ratio of the energy transferred to the fluid to the corresponding solar energy.

The thermal efficiency of a solar collector is high when its operating temperature is low. In contrast, its efficiency is low when the operating temperature is high. In the latter case, a collector at a high temperature loses energy towards the surrounding environment from all sides, especially through the transparent cover.

5. The hot water storage tank

The tank

Hot water storage tanks (solar applications, conventional heating by electric heaters or other means) are designed considering pressure requirements. Corrosion protection is the other important design parameter. It is to be noted that the water temperature in a solar hot water system can reach the level of 90°C - 95°C

Mild steel is the most commonly used material for the construction of hot water storage tanks, because it has the strength for the pressure requirements (6 bar or more) with a tank wall thickness of 2mm-3mm at reasonable cost. Corrosion protection in the water side of the tank is achieved by the use of **glass enamel coating**.

It is noted that enamelling is applied usually in two coats. The ground coat achieves adhesion with the steel and the cover coat sustains hot water corrosive action.

Many years of established experience has shown that properly constructed and enamelled hot water storage tanks, with a magnesium anode for cathodic protection (it protects areas that might not be covered with enamel) present reliable products with long life (decades). It is only necessary to regularly inspect the function of the anode (especially in the beginning).

Stainless steel is another material used for the tank construction. This material by itself is resistant to corrosion. Proper quality of steel and a sophisticated welding process are required, otherwise there is danger for tank failure.

Use of mild steel and an **internal tank from corrosion resistant material** is another technology for tank construction. Thin copper sheets (Europe) and polymer materials (Europe, U.S.A.) have been used for the construction of the internal tank. The material of the inner tank should withstand the expected high temperatures of the hot water and should be physiological inert and be approved for direct contact with food.
Special measures should be taken in order to avoid the development of vacuum inside the internal tank when hot water is used. Installation of a vacuum breaker in the cold water supply line is one of them.

The heat exchanger of the tank

All solar domestic hot water systems of closed type (see paragraph 9) require a heat exchanger in the solar storage tank. The use of a heat exchanger allows a wider choice of materials in the solar absorber and system pipe work, because anti-freeze and corrosion inhibitors can be added to the fluid.

The **double-wall** (or jacket) design of heat exchanger has been used extensively with glass enamelled tanks, but its use has not been limited there. It provides a large exchange area and its construction is relatively easy. Corrosion protection of steel in the heat exchanger area (i.e. between the two walls or jackets) is very important, because of the high temperatures, the possibility of "free" space (not covered by fluid) at the top of the exchanger and the presence of highly corrosive steam (under certain conditions).

Heat exchangers inside the tank is another alternative. The deposits on the water side of the exchanger is an issue to be considered. Copper tubes with two headers have been used for heat exchangers inside the tank. Another design is made from a copper or steel pipe (galvanized or glass enamelled) of small diameter, shaped in a helical form.

6. Thermosiphon type solar domestic hot water systems

This type of solar domestic hot water system consists of the solar collector (or collectors) and the hot water storage tank, which is mounted above the collector. It is widely used in Greece, Cyprus and other Mediterranean countries. Figure 3.1 presents such a system, while a schematic presentation of it is also shown in Figure 6.1.

The fluid circulates automatically inside the copper tubes of the absorber and the heat exchanger of the storage tank. Its circulation is based on the fact that the heat transfer fluid in the tubes of the absorber, when heated, becomes lighter. This flow of fluid inside solar domestic hot water systems is known as natural or thermosphonic flow. The thermosiphon principle is shown schematically in Figure 6.1

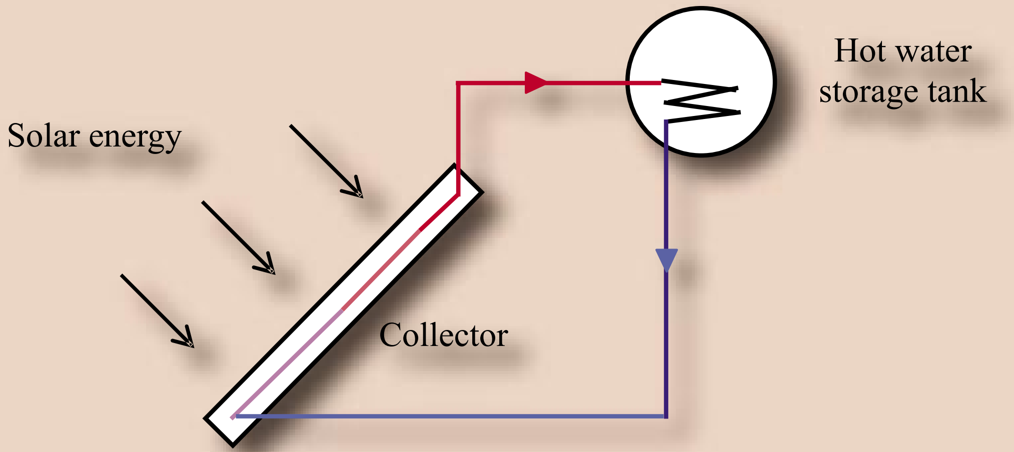

Figure 6.1 Schematic presentation of a thermosiphon system

For the proper operation of a solar domestic hot water system, it is required that the storage tank is above the collector. If there is not a suitable height difference, it has been observed that the solar hot water in the storage tank loses its temperature during the night. This is due to a phenomenon called reverse flow, i.e. conditions appear which allow the heat transfer fluid to move inside the absorber piping in the opposite direction than that of the normal operation. Thus, warm fluid flows to the collector, where it eventually cools.

7. Forced circulation solar domestic hot water systems

Besides solar domestic hot water systems, which operate with natural circulation, there are also cases, where the solar collectors are mounted on the roof, but the hot water storage tank is situated elsewhere, for example on the ground floor or in the basement of a house. Such a system is shown schematically in Figure 3.2.

In this case, a pump is required for the circulation of the heating fluid. In addition, a control system (usually a differential thermostat) is required for the operation of the pump only when it is necessary (when there is sunlight, etc).

These systems are known as forced circulation solar water heating systems and they are usually installed in single family houses.

8. Direct (open loop) solar domestic hot water systems

In open loop solar domestic hot water systems, the water for consumer use passes through the collector. In this case, there are two problems.

- The solar domestic hot water system is not automatically protected from freezing weather conditions. Action must be taken by the consumer to drain it, with the help of suitable valves and air venting, which must be installed when installing the solar domestic hot water system.
- Deposits, in areas with very hard water, might block the copper tubes of the absorber. As a consequence, there is a constant decrease in the efficiency of the solar domestic hot water system.

An open loop solar domestic hot water system could only be used in areas with limited possibilities of freezing weather conditions. In the rare case of such freezing conditions, it is recommended that there be provision for valves and air venting for draining (emptying) the solar domestic hot water system. The problem of deposits in the case of hard water is not easily dealt with.

9. Indirect (closed loop) solar domestic hot water systems

The use of a heat exchanger, in the hot water storage tank of a closed loop solar domestic hot water system, allows the use of a "separate" (from the hot water) heat transfer fluid to carry heat from the solar collector to the storage tank. In this case, the hot water for consumer use does not pass through the collector.

The use of a heat exchanger allows a wider choice of materials in the solar absorber and system pipe work, because anti-freeze and corrosion inhibitors can be added to the fluid

In this closed loop system, antifreeze is be used in the heat transfer fluid. Therefore, by using the correct proportion, it is possible to reliably protect the solar domestic hot water system from freezing weather conditions in the area where the system has been installed.

As a rule, a closed loop solar domestic hot water system should be used.

10. Basic requirements for the installation

A solar domestic hot water system should be installed in a location so that plenty of sunshine falls onto its collector. The solar collectors accept the maximum amount of solar energy during a day when

- They face true south (collector orientation);
- The sun rays fall perpendicular (as much as possible) on the collector surface (the collectors should have a tilt to the horizontal plane);
- Their view to the sun is unobstructed especially when the sun's rays are most intense (shading)

Collector orientation

The solar collectors should face true south in order to have as much solar energy falling on them as possible, during a day.

In many cases, a slight westerly orientation is preferable to true south, in order to take advantage of the afternoon's higher outdoor temperatures, which leads to better collector performance.

Divergence of up to 20^o from southern orientation creates a very small reduction of the amount of solar irradiation on the collector plane. For greater divergence of up to 45^0, the reduction is in the order of 15% during winter months and relatively small (approximately 5%) during summer months.

Collector tilt

A tilt of the collector plane to the horizontal plane equal to the local latitude (at the equator the latitude is 0^o, at the north pole is 90^o) makes possible for the collectors to catch the most solar energy during the year.

The majority of solar domestic hot water systems in the Mediterranean countries have collectors at a tilt angle of 45^o to the horizontal plane

When the tilt is in the range of 25^o to 50^o, there is a change in the annual energy gain, which, however, does not exceed 5%. Thus, it is possible to mount collectors on roofs with usual slopes of 25^o to 50^o without actually having problems of efficiency or malfunctioning.

Shading

Large obstructs should be avoided in front of the solar collectors, because their shadow during the period 09:30 to15:30 will reduce their performance. Small shadows early and late in the day make no difference in the collector performance.

11. Performance of a solar domestic hot water system

There is an International / European standard (ISO 9459-2 or EN 12976-2), regarding the performance of solar domestic hot water systems. The corresponding Test Report includes, among other data useful to the manufacturer, data related to the energy and to the volume of hot water delivered by the system, during all the months of the year. It also provides data related to the night losses of the tank.

All reliable manufacturers have tested their solar domestic hot water systems according to this standard.

A typical thermosiphon type system is expected to deliver 600kWh to 800kWh per square meter of collector area and per year, under certain conditions (one draw off of one tank volume at the end of the day).

Measurements have shown that the temperature of the domestic hot water, during draw off, of a typical solar domestic hot water system, remains constant for 70 - 80% of the water volume of the storage tank. This percentage depends on the season of the year.

A typical diagram of the hot water temperature from a thermosiphon type solar system (draw-off temperature profile) is shown in Figure 11.1. The same Figure 11.1 also shows the temperature of city water with which the solar domestic hot water system is supplied.

Diagrams like the one shown in Figure 11.1 are included in the Test Report for a domestic hot water system, tested according to the standard mentioned previously.

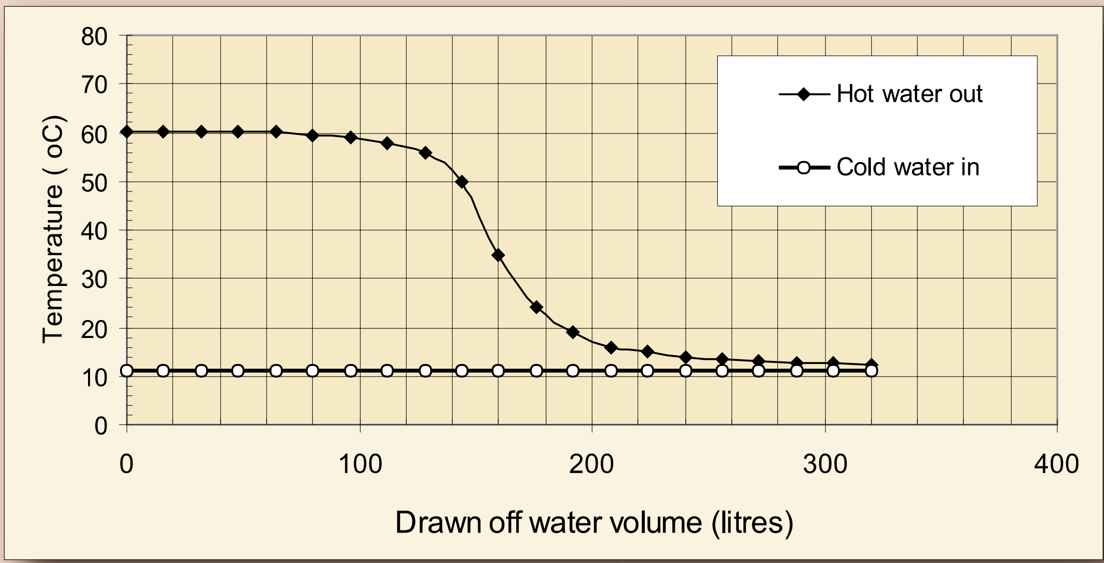

Figure 11.1 Temperature of the hot water of a solar domestic hot water system with a tank volume of 160 litres (thermosiphon type)

It is obvious from Figure 4.1 that the temperature of hot water remains higher than the cold water temperature up to a volume of 300 litres (the tank volume is 160 litres). This is due to the mixing, during draw off, of the hot water in the tank with the cold water entering the tank.

The maximum temperature of the hot water, which a solar domestic hot water system provides us with on a specific day, depends on

- the available solar energy of that particular day
- the ambient air temperature and
- the temperature of the cold water on the morning of that particular day.

Thus, if the solar DHW system is full of cold water from the city network in the morning, it is expected that the hot water will reach a temperature in the order of

- 55°C – 65°C during sunny spring / summer day and
- 35°C – 40°C during a sunny winter day.

In cases where the storage tank has hot water from the previous day, even higher temperatures are expected.

12. Choosing the right size of solar domestic hot water system

It has been established (measurements), in consumer households with solar domestic hot water systems, that the average hot water consumption per person and per day is of the order of 40 litres. This quantity of 40 litres per day and per person refers to hot water, which the consumer uses directly from the storage tank of the solar domestic hot water system, before mixing with cold water. It includes dishwashing and clothes washing with hot water from the solar domestic system.

This data assists to determine the size of a solar domestic hot water system. For instance, the full needs (including dishwashing and clothes washing) of a four member family can be covered by a 160-litre solar domestic hot water system. The individual needs of the family should be considered and the in case of reduced ones, use of a 120-litre solar domestic hot water system may should be examined.

The following table offers an initial choice of solar DHW system, according to the number of family members.

Family members	Tank volume (litres)	Collector area (m^2)
2 - 4	120	2.0
4 - 6	160	2.5
6 - 7	200	3.5

13. Efficient use of a solar domestic hot water system

A solar collector is required to absorb solar irradiance and to transfer the absorbed energy into a heat transfer fluid with a minimum of heat losses. The thermal efficiency of the collector is defined as the ratio of the energy transferred to the fluid to the corresponding solar energy.

The thermal efficiency of a solar collector is high when its operating temperature is low. In contrast, its efficiency is low when the operating temperature is high. In the latter case, a collector at a high temperature loses energy towards the surrounding environment from all sides, especially through the transparent cover.

Therefore, the main principle for efficient operation of a domestic hot water system is for the water in the storage tank to be at a low temperature in the morning, when solar radiation begins to increase.

Thus, if there is a need to use the auxiliary electric heater of the storage tank during the night, it is recommended to use the hot water by the morning of the next day. This way the solar collector will be able to start to operate at a low temperature and therefore efficiently.

Another piece of advice is to use hot water during the day and not collectively at night or the following morning. In this case, increased efficiency rates have been measured in the order of 20-25%.

Hot water is used in the residential sector in order to cover the needs

- in the kitchen, mainly through a dishwasher (20%-25% of the total hot water needs).
- for clothes washing, mainly through a washing machine (30%-35% of the total hot water needs)
- for bathing / showering

The use of solar hot water, from a solar domestic hot water system, presents some difficulties in dishwashing and clothes washing. These difficulties are discussed next, together with recommendations for overcoming them.

14. Dishwashing with solar hot water

Hot water from a solar domestic system **can not** be used directly in a dishwasher. The reason is that the manufacturer of the dishwasher specifies a maximum temperature for the feeding water, usually of the order of 60°C. A domestic solar system can develop, during summer, water temperature higher than 60°C (it can be up to 95°C) under some conditions (limited use of the hot water).

A **mixing valve** (to mix in some cold water) installed at the hot water output of the domestic solar system can control the temperature of the hot water to the user so that it does not exceed 60°C. Under these conditions, solar hot water can be used in a dishwasher. At the same time the user of hot water is protected from water temperatures higher than 60°C, which may cause burns to him.

Mixing valves are used in many hot water applications in large installations, but they are rather expensive. Low cost, simple mixing valves exist that can be used in a domestic solar system. Their cost is lower than 50 Euro.

15. Clothes washing

Hot water from a solar domestic water heater can be used in a washing machine in the case that it (the washing machine) has two **feeding pipes**, one for hot water and one for cold water. Such washing machines exist and their cost is not higher than the cost of a washing machine with one feeding pipe (cold water). Their washing cycle is faster, because it does not require time for water heating.

16. Safety issues

The collectors, the hot water storage tank, the pump and the control equipment (where applicable) should be located so that the installer and the maintenance personnel can reach them safely.

The solar domestic hot water systems can develop, under certain conditions (limited use of the hot water during summer), water temperatures that can reach 95°C. The maximum safe temperature for hot water systems is 60°C in order to avoid scalding, (i.e. burns).

Under these conditions it will be necessary to install a **mixing valve** (to mix in some cold water) at the hot water output of the domestic solar system to control the temperature of the hot water to the user so that it does not exceed 60°C. Low cost, simple mixing valves exist and their cost is lower than 50 Euro. (see also paragraph 14 on dishwashing.)

17. Meteorological data

A solar domestic hot water system is supplied with water from the city network and, with the help of the sun, heats the water so that it can be used for the needs of a family. The city water temperature and the solar radiation are discussed further in this paragraph.

City water temperature

The temperature of water from the city network does not remain stable during the year. During winter, the temperature is in the order of 10°C, while during summer months water temperature might exceed 25°C.

Figure 17.1 below shows the mean monthly values of the temperature of water from the city network for some city

Water must be at a temperature in the order of 45°C to be used for the needs of a family. Thus, in winter, water temperature must be increased by 30°C-35°C, while in summer by 15°C -20°C, which means half of what is required in winter.

The temperature, which the water in a solar domestic hot water system finally reaches at the end of a sunny day also depends on the temperature of the water in the morning i.e. the city water temperature. The higher the initial water temperature is, the higher the final water temperature will be.

So considering two cities of the same country, one north in the country and one in the south, the city water of the northern city generally will be colder. Under these conditions, the domestic hot water system in the south will produce hotter water and it will seem to be more effective. Both solar domestic systems might provide to the water the same amount of energy from the sun.

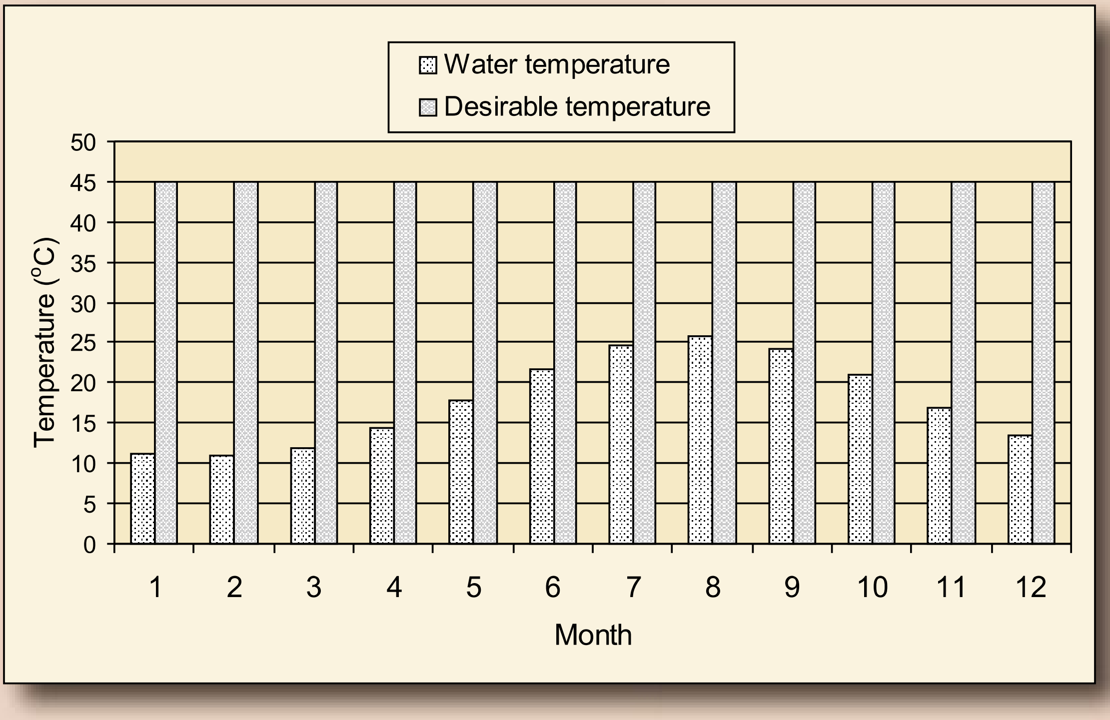

Figure 17.1 Mean monthly values of the temperature of the city water of some city

Solar energy

A domestic hot water system heats the water with the help of solar energy. The available solar energy varies during the year. It is high in summer, but low in winter, about 1/3 of what is available during summer.

Figure 17.2 shows the mean monthly values of the daily solar energy on the plane of the collector for some city

By observing Figures 17.1 and 17.2, it can be seen that in winter, when water is cold, there is little solar energy available. On the contrary, in summer, when city water is warmer, there is abundant solar energy.

It is obvious that, in winter, the use of an auxiliary electric heater is necessary, mainly during cloudy weather conditions. On sunny days, there is considerable solar contribution for water heating.

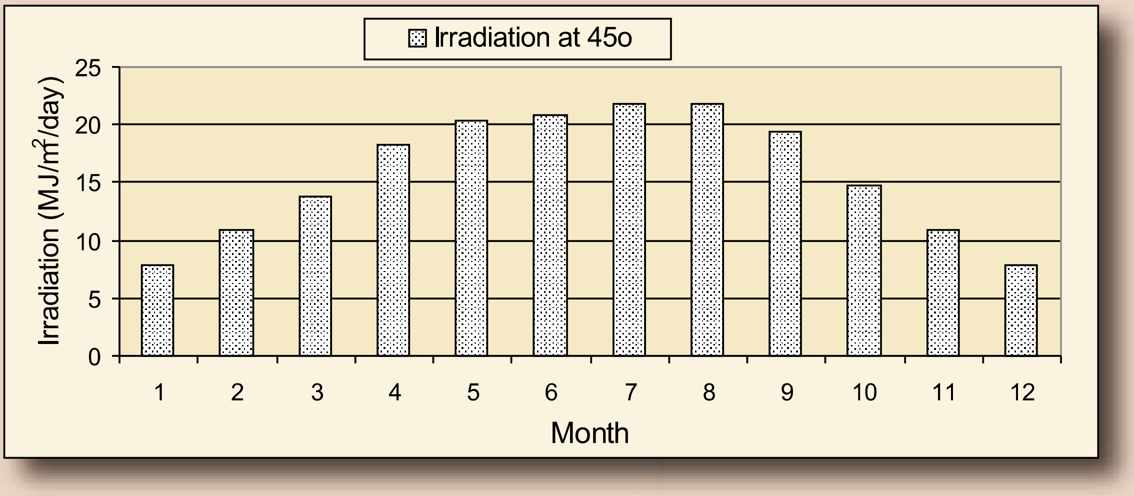

Figure 17.2. Mean monthly values of the daily solar energy of some city

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[1]. European SOLAR RADIATION Atlas, Volume I: Horizontal Surfaces, Commission of the European Communities, VERLAG TÜV RHEINLAND 1984.

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