ICRC

SOLAR WATER HEATING SYSTEMS
A HOW-TO MANUAL

Assistance Division | ICRC

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Photo courtesy of Abri Beluga, October 2006, Potchefstroom, South Africa

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Foreword

Controlling the environmental footprint of the ICRC operational and support activities figures among the priorities mentioned in the "Framework for sustainable development at the ICRC" adopted by the ICRC Directorate. This objective aims at reducing the potentially negative impact of the ICRC's activities on the environment while maximising the use of its financial resources.

But there is more than the environment and economical aspect. There is also the social aspect, which must be bear in mind. Thus, in many places where the ICRC works, the resident's population experience shortage of electrical power supply. It is then a moral duty for the institution to avoid wasting that resource that should be shared, as much as possible, with everyone.

The benefits of solar water heating are considerable. By using the sun’s free energy, the ICRC can remarkably reduce the hot water energy consumption. It does not only cut energy costs but, the sun replacing hydrocarbon fuel, it minimizes the impacts on the environment by reducing carbon emissions, pollution and cost to extract and transport fuel. The pilot experience in 3 prisons of the Philippines is showcased in this manual to highlight the benefits of the technology. It is also to be noted that, depending on location and cost, the ICRC premises could be equipped with such devices as long as, from a financial and environmental perspective, it remains a viable option as demonstrated by the ICRC delegation in Amman.

The ICRC has mandated Jean-Christophe Hadorn (BASE Consultants SA) to help the Water and Habitat Unit to be able to select water heaters best suited for the different ICRC delegations and has contributed much to the content of this manual. We would also like to thank Martin Gauthier and Piero Morandini at OP_ASSIST_EH for their dedicated efforts to bring this manual to life and the numerous colleagues from FAD_AFI and WatHab who have been providing valuable comments throughout the review process.

We wish you a pleasant reading and encourage you to take action shall the conditions be favourable for such initiative. If you do so, please report to your respective Head of Sector when any such project is undertaken.

With our best regards,

Alain Oppliger	Philippe Dross	Jonas Baumgartner
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1. Introduction

Solar water heating is a technology based on a simple interaction where the sun heats water to be used when humans need it. Homemade systems have been built for years to provide hot water. However, maintenance and reliability for institutional use were the limitations. Nowadays, with the use of standardized components, the system performance has greatly improved, manufactured systems are widespread, their reliability is not questioned anymore and, in most cases, no electricity is required to function.

Solar water heating is not only a safe, simple and reliable technology, but it is also a very cost-effective solution. Acceptance of the technology is usually not an issue for the user as it is a "behind-the-screen" technology.

For most cases faced by the ICRC in the field, technology and cost should not be obstacles. The presence of suppliers and installers are probably the elements that can have more influence on how a solar water heating project will be conducted.

Available information on solar water heating is very much influenced by the numerous suppliers on the market trying to sell their own products. It has thus become necessary to provide a more objective manual to address all the relevant questions that can help in going ahead with such initiative.

This manual is intended for all the people involved in the management of residences, offices and all those who conduct activities where hot water is used (prison, hospital, orthopaedic centre, etc.). The tool is intended to be used by the ICRC delegates in the field, even those who are not necessarily skilled in solar or thermal energy. It provides a decision-tool to enable the project leader to assess the feasibility of the project and to identify the best available option for a given application, its supply, installation and operation and maintenance.

2. General considerations

2.1 Why install a solar water heating system (SWHS)?

The main reasons to install a SWHS are:

- the reduction of energy-associated costs;
- the reduction of negative impacts the ICRC activities may have, namely with regards to energy costs and the carbon footprint;
- the improvement of health and working conditions for staff when hot water is used for cooking in replacement of firewood or fossil energy.

2.2 How much savings can be expected?

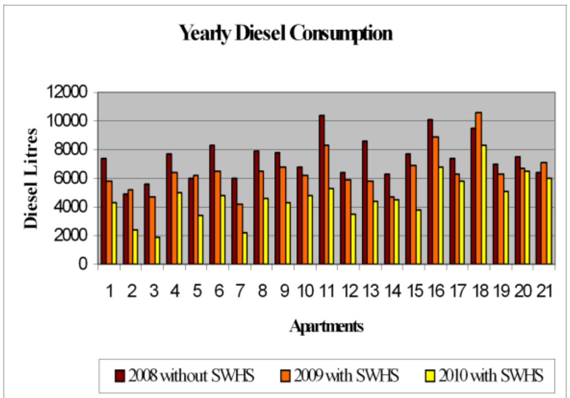
The payback period is usually below 3 years and, as shown at the ICRC delegation in Amman (Jordan), the cost recovery could be done in only 1 year. This depends on the context, but is greatly influenced by the cost of energy: the higher the cost of electricity or fuel, the shorter the payback period will be.

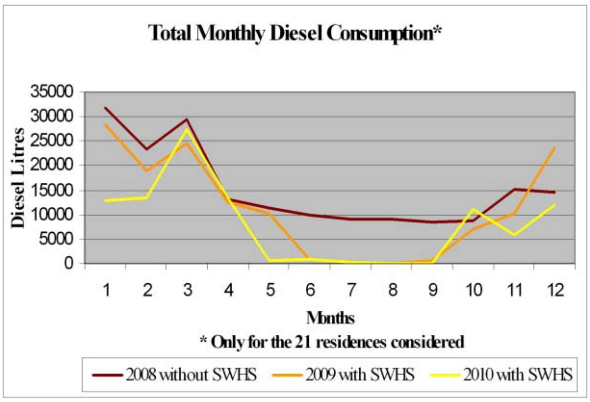
Hot water for domestic use in the ICRC residences in Jordan

In 2008, the ICRC Delegation in Amman began exploring the feasibility of installing solar water heating systems to generate hot water for residences. As the yearly average number of sunny days is 320, the solar solution seemed a natural one. 21 residences were equipped with SWHS. The landlords of the apartments agreed on sharing the 50% of the initial cost.

Results

By the end of 2009, the diesel consumption in the residences equipped with SWHS was 137’878 l compared with 157’547 l in 2008 when no SWHS were installed. This shows a decrease of 19'669 l representing 12,4% (an average of 187,3 l per month per residence). At a cost of about 0,79 CHF per litre, this resulted in 739 CHF saved per residence. Considering that each solar system cost less than 800 CHF, the investment was paid in approximately one year.
In 2010, the diesel consumption decreased by 38'149 l from 137’878 l to 99’729 l comparing with the one of 2009 due to a longer period of use (5 months).
In 2 years the diesel consumption was reduced by 37%.





2.3 Does a SWHS produce carbon free energy?

Yes, a SWHS uses a renewable energy source to produce carbon free energy. Although CO_2 is emitted during the manufacturing of the solar collectors, SWHS will become carbon negative after about 4 years.

2.4 Is a SWHS a self-sufficient technology?

No, when there is no sun, SWHS doesn't deliver hot water to the temperature desired. Depending on the needs and design criteria, it is generally a technological solution to be used as a complement to other energy systems (gas, diesel, wood, etc.).

2.5 Where to install a SWHS?

Today's solar hot water technologies can be operated efficiently and affordably in any climate worldwide. Solar collectors are typically installed on rooftops, building tops, or stand-alone facilities. It is vital to install the solar collectors so that they get the most direct sun exposure.

2.6 How much does a SWHS cost?

Besides being a very cost-effective solution, installing a solar water heating system is relatively cheap. A thermosiphon passive system (100-300 litres of hot water per day) costs from 500 CHF to 3'000 CHF while an active system (100-750 litres of hot water per day) costs from 3'000 to 8'000 CHF, installation costs included.

2.7 Who should pay for a SWHS?

When the ICRC is the owner of a premises, it pays for a SWHS that becomes property of the organization. When the ICRC rents a premises and the owner gives a formal and written approval to install a SWHS, the ICRC should in order of preference:

- ask the owner to pay for a SWHS that becomes his/her property;
- share the cost with the owner and ask him/her to deduct the ICRC's contribution from the rent. In this case, a SWHS becomes property of the owner;
- in case of long-term staying in the country, pay for a SWHS that becomes property of the ICRC and could be transported and installed in other premises at the end of the rent.

Maintenance costs must be borne by the ICRC in any case. The ICRC delegates in the field must remember to include purchasing and maintenance costs into the budget and to apply the financial rules (AoE, etc.).

For institutional use (prison, hospital, orthopaedic centre, etc.), the strategy can vary from one context to another, but if there is the potential for many systems to be installed, the ICRC could invest on pilot projects with a view of scaling up implementation with authorities or other funding agencies. Maintenance costs must be borne by the authorities in any case.

3. Design

3.1 Objectives

This section proposes a simple decision tool to size and choose a solar installation for hot water preparation (40° to 80°C). Domestic hot water requires a minimum temperature of 42°C. To store more energy in the boiler and to overcome some of the distribution losses from tank to tap, the tank is often heated up to 80 or 90°C. This is however dangerous if the system does not have a security (mitigating) valve. The minimum temperature that is recommended in a storage tank is 60°C so that legionella, a pathogenic gram-negative bacterium causing legionellosis[1], cannot survive.

Solar water heaters use a tank to overcome the day-to-night problem of supply and demand. A SWHS operates between the supply water temperature (5 to 20°C depending on location and time of the year) and 95°C as a maximum. This allows to minimize the storage volume (temperature range is maximum) and avoid problems linked to boiling water and vapour. Stopping the solar collection when this maximum temperature is reached is however sometimes difficult to do and this is an important point to look at when selecting a system.

3.2 Technology

Domestic hot water is usually delivered at 50 to 60°C and can be produced by two basic types of solar technology: thermosiphon passive systems and active systems. The following table analyses the advantages and disadvantages of the two basic technologies for solar water heaters.

Technology	Advantages	Disadvantages
Thermosiphon passive system	• No auxiliary energy required • Cheap (500-3'000 CHF/unit) • Very easy to operate and maintain • Robust • Easy to install • Easy to transport	• Less efficient than the active • Not for cold climates • Durability < 10 to 15 years • The tank needs to be above the collectors • Tap water pressure should be sufficient to reach the tank • Need quality tap water that can stagnate
Active system	• More efficient than the passive • Designed for any climate • Durability > 20 years • Suited for a large number of users (up to 15 persons per device) • Able to cool water	• Auxiliary energy required • More expensive (3'000-8'000 CHF/unit) • More complex to operate and maintain

[1] Legionellosis is a potentially fatal infectious disease. Over 90% of legionellosis cases are caused by Legionella pneumophila, a ubiquitous aquatic organism that thrives in temperatures between 25 and 45 °C.
Legionellosis takes two distinct forms:
• Legionnaires disease, also known as "Legion Fever", is the more severe form of the infection and produces high fever and pneumonia (the time between the patient’s exposure to the bacterium and the onset of illness is 2 to 10 days);
• Pontiac fever is caused by the same bacteria but produces a milder respiratory illness without pneumonia that resembles acute influenza. Pontiac fever also has a spontaneous resolution (few hours to 2 days).

In the case of the ICRC projects, the size of the system to implement will be a key parameter to decide between the technologies, as the size depends upon the water demand.

3.2.1 Thermosiphon passive systems

In thermosiphon passive systems, buoyancy effect is the sole engine of the fluid movement from the collector (where it is heated up by solar radiation) to the tank (where it is stored for further usage). Their typical size ranges from 1 to 4 m^2 for collectors and from 100 to 300 l for storage.
Passive systems have the advantage of lower initial cost and higher reliability because of the absence of pumps, controllers or sensors. However, they have the disadvantage of possible overheating and freezing.

Figure 1: Thermosiphon passive system (photo)

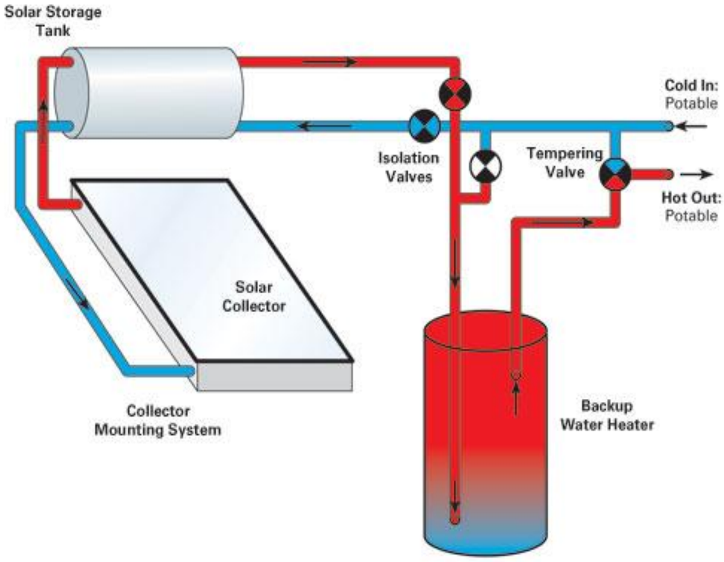


Figure 2: Thermosiphon passive system diagram

Another type of passive system is the integral collector storage, also called "breadbox". Combining collector and tank system in one unit, the storage is directly connected to the collecting plate, reducing all auxiliary flows. This system has the main disadvantage of being heavy on the roof.

Figure 3: Breadbox (photo)

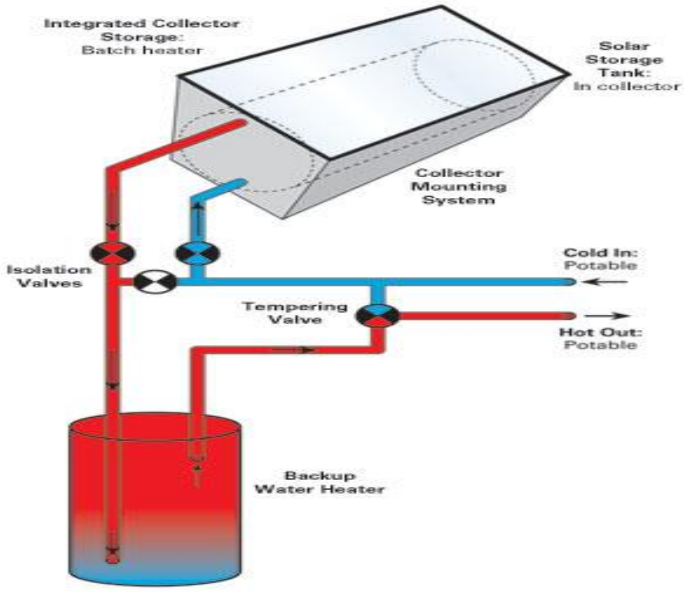


Figure 4: Integral collector storage system diagram

3.2.2 Active systems

In active systems, the flow is forced through a circulating pump, thus storing solar absorbed heat to a well insulated storage tank. These are often called “solar kits”. They are standardized (i.e. produced industrially) and most are certified by a test centre. Their typical size ranges from 4 to 6 m^2 for collectors and from 100 to 750 l for storage. They are protected against freezing by a glycol loop that needs care but not much maintenance. They can be operated without glycol with pure water. In this case, they must be drained back to avoid freezing and the design of the plumbing has to be done carefully to avoid low points. Glycol or water active systems can be drained back to avoid overheating problems in summer (they empty when getting too hot, above 100 °C). They are then called “drain back systems”.


Figure 5: Active system (photo)

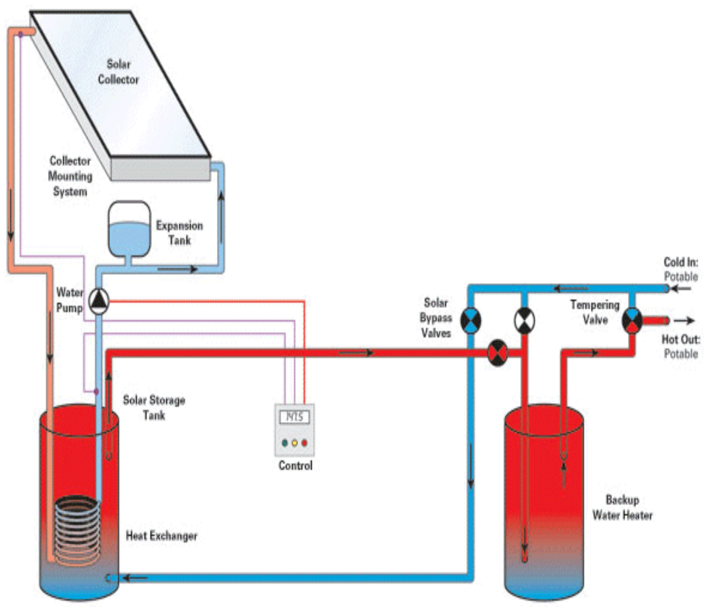


Figure 6: Active system diagram

Active systems require an auxiliary source of energy (electricity) for the circulating pump and controls. It is thus more complex than thermosiphon active systems to operate and maintain, but it is more efficient. This system also avoids having a heavy storage tank on the roof which may, according to the building characteristics, be a decisive factor.

3.2.3 Collectors

Systems can also differ from the types of solar collectors used:

- Evacuated collectors (also called vacuum collectors or vacuum tubes if they are made of tubes) are best used where high temperature must be reached. Vacuum tubes are glass tubes with a metal absorber embedded and the vacuum helps to greatly reduce the heat losses through convection and conduction when the absorber heats up thanks to the sun. The optimal range to use them is between 60 and 200°C.
- Glazed collectors (also called flat plate collectors) have the advantage of the greenhouse effect trapping the solar radiation reflected by the absorber into infrared radiation into the collector. They are heavier, subject to hailing and overheating. The optimal range to use them is between 30 and 90°C.

- Unglazed collectors are simple absorbers made from either plastic or metal (copper, stainless steel or aluminium) without any front or back transparent cover. They are the best performers at low temperature (10 to 30°C) thus used frequently to heat swimming pools in mild climate. They mostly never reach 100°C and thus can be used without special devices. They are good performers in sunny climate too. The optimal range to use them is between 10 and 60°C.

Although the choice of collectors is more a cost-based decision than a technical one and it is less important than the choice of the technology, the vacuum tubes are generally considered more efficient than the flat plate and the unglazed.

Figure 7: Vacuum tubes collector

Figure 8: Flat plate collector

Figure 9: Unglazed collector

3.2.4 Other components

Collector mounting system

The three most common mounting systems for solar collectors are the roof mount, the ground mount and the awning mount. Roof-mounted collectors are held by brackets, usually parallel to and a few inches above the roof. Ground-mount systems can be as simple as four or more posts in the ground, lengths adjusted to affect optimal tilt. An awning mount attaches the collectors to a vertical wall. Horizontal supports push the bottoms of the collectors out to achieve the desired tilt. When choosing a mounting system, roof mounts are usually the cheapest option, provided tilt and orientation are within acceptable parameters. If weight is an issue, ground mounts can be a good choice. Wall mounts are another solution that can work well in some situations.

Solar storage tank

A solar water tank is an insulated water storage tank. Cold water that used to go directly to your conventional water heater enters the solar tank and solar-heated water exits. In closed-loop systems, the water is heated by contact with a coil of pipe containing the water or antifreeze that circulates through the collectors. In open-loop systems, the potable water is directly circulated through the collectors. The preheated solar water is then plumbed back to the cold side of your existing heater, which now functions as a backup. Whenever hot water is turned on in the house, preheated solar hot water is moved from the solar tank to the backup heater.

Water pump

Pumps are used in active systems, but are not required in batch or thermosiphon systems. They circulate water or antifreeze between the solar collector and the storage tank. The right pump for the job depends on the size of the system and the distance and height between the collector(s) and the storage tank. AC pumps plug into a wall outlet while DC pumps are powered from a DC source, such as a photovoltaic panel. Good pumps can last as long as 20 years with heavy use.

Heat exchanger

Heat exchangers are used in closed-loop solar hot water systems. They enable the transfer of heat from one fluid to another without the two mixing. Internal heat exchangers are inside the tank and not visible. They can be as simple as a coil of pipe resting in the bottom of the tank, or wrapped around the outside beneath the insulation and cover. As the heated fluid from the solar collector travels through the coil, the heat is passed from the hotter fluid to the cooler potable water. The solar fluid and potable water flow counter to one another, and heat is transferred within the heat exchanger pipe. Fluid may be moved with pumps, thermosiphoning, or a combination of the two. A heat exchanger is generally used in cold climates prone to freezing with glycol fluid.

Expansion tank

Closed-loop systems require an expansion tank. An expansion tank has a chamber in which air is locked inside a bladder or diaphragm. It screws into standard 1/2-inch or 3/4-inch threaded plumbing fittings. When pipes are filled with heat-transfer fluid (water and glycol) and the operating pressure of the system is set, the fluid will occupy a given volume based on the temperature. As the fluid is heated by the sun, it expands. This is where the expansion tank is critical. The expansion tank allows the fluid to safely expand by compressing the air in the chamber. The size of the expansion tank needed depends on the total volume of fluid, which is determined by the number and size of collectors, and the length and diameter of the pipes in the solar loop.

Controls

In active systems using pumps, whenever the collector is hotter than the storage tank, the pump should be on and the system circulating. When the tank is hotter than the collector, the pump should be off. This function is performed by a differential thermostat control system. If a PV-powered pump is used a thermostat should also be installed but it is sometimes intentionally left out to simplify. The differential thermostat controller compares heat sensor readings from the storage tank and collectors, and switches the pump accordingly.

Isolation valve

An isolation valve should be a part of every solar water heating system to isolate the solar tank in case of a problem, while still allowing the backup water heater to remain in service. The isolation valve is a manual valve or valves placed in both the incoming and outgoing potable water lines to the solar tank. It can be a three-valve configuration, or a three-port and two-port valve. Manually turning the valve or valves will place the solar tank "on line" or "off line". It works by directing the flow either through or bypass the solar tank. These valves can also be plumbed to bypass the backup gas or electric water heater, allowing them to be turned off (eliminating standby heat loss) during the seasons when the SHWS can supply 100 percent of the household's hot water.

Backup water heater

The backup water heater ensures that hot water is at the tap whether the sun shines or not. On a sunny, hot day, if the sun has preheated the water to 60°C or more, the backup water heater uses no energy at all because the solar preheat temperature is greater than the typical 49°C thermostat setting. On a day when the solar preheat is 29°C, the backup heater boosts the temperature for the remaining 20°C. Since incoming cold-water temperatures are at ground temperature (usually about 10°C), 29°C represents 50 percent of the energy needed to bring the water from 10°C to 49°C. Not all backup water heaters use a tank. Keeping a tank of water warm between uses can account for 15 percent or more of the total energy used for hot water. Tankless water heaters eliminate this standby loss. Solar hot water systems and tankless water heaters are a winning combination but be aware that when the solar tank is cold, the tankless water heater must have a high energy input of typically 10 to 20 kW for a shower.

Tempering valve

On a sunny day, the water in your collectors can reach scalding temperatures. A tempering valve can save you from a 70°C shower. The tempering valve goes at the very end of the chain, right after the backup water heater and before the faucet. If the water coming out of the backup heater is too hot, the tempering valve opens to mix cold water back in and prevent scalding. The temperature of the hot water can be set by the user on most valves. For instance, a popular valve allows a temperature setting between 49°C and 71°C. But 71°C is a too high value for tap water. Do not exceed 55°C unless the water is used for other purposes and the users are aware of the danger.

3.3 Feasibility

To confirm the suitability of installing a SWHS on a selected building, a feasibility study has to be conducted. A complete set of questions is available in Annex 1, but typically this should comprise:

- **Case description.** Choice and description of the beneficiaries, current situation, current costs, purpose of usage of hot water, desired temperature, etc.

- **Solar access.** Technical feasibility of the installation taking in account the proposed location, the climate, the environment and the existing structures.

- **Monitoring and maintenance.** Capacity to operate and maintain the system.

- **Local installer.** Presence and capacity of local suppliers, proposed products and associated services like warranty, after-sales service and maintenance.

- **Current network.** Capacity of the existing water supply source/network to fit with the system and the needs. It will allow assessing whether prior works needed to be conducted before installing the systems.

3.4 Design: step-by-step

3.4.1 Step 1: Hot Water demand

Hot water requires a minimum temperature of 42°C but it is usually delivered at 50 to 60°C. The hot water demand (Wd) is fundamental to dimension a solar water system. The following figures can be used if you do not have precise information:

- For domestic use (shower and hygiene) in residences = about 50 litres/person/day
- For cooking use in prisons, hospitals, orthopaedic centres, etc. = about 2 litres/person/day

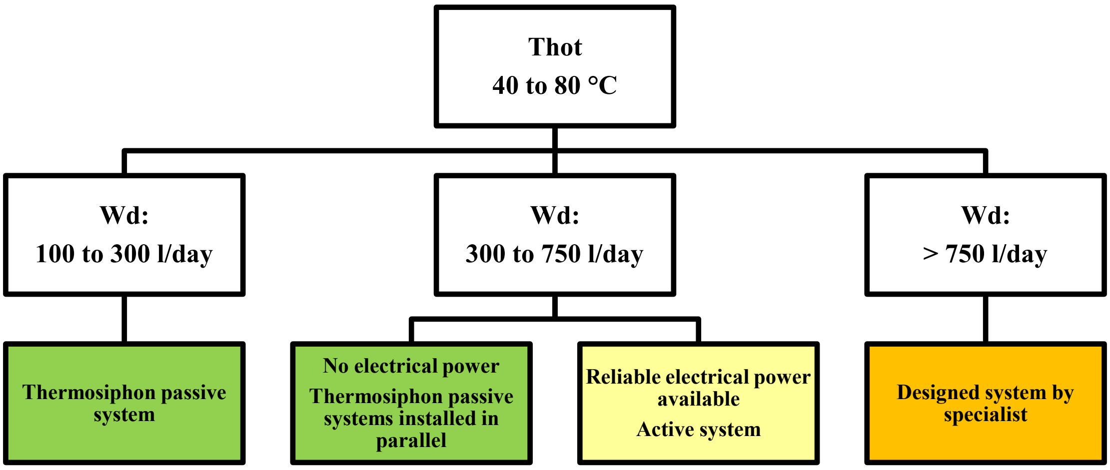


Figure 10: Technology choice diagram

3.4.2 Step 2: Location

The installation of a thermosiphon passive system requires a place (rooftops, building tops, or stand-alone facilities) above the water distribution points, free of interferences that could jeopardize the efficiency of the system (trees, buildings, etc.). The collectors must also stand local wind conditions. The estimate size of a 300 l capacity system is 5 m^2.
Active systems are more flexible as the storage tank does not need to be higher than the panels; they can be located in the building. Only sun exposure to the panels must be secured.

3.4.3 Step 3: Weight

The installation of a thermosiphon passive system requires a reliable supporting structure (rooftops, building tops, or stand-alone facilities) standing with its total load: collector and storage tank full of water. The estimate weight of a 300 l capacity system is 400 kg (100 kg collectors and storage tank + 300 kg water).

3.4.4 Step 4: Orientation

To get the most from a solar system, you need to position it in the direction that captures the most sun. In the Northern hemisphere, the collector should face South for optimal efficiency, while facing North when installed in the Southern hemisphere. In addition, based on daily load profile, East/West orientation will be favored. For instance, if a noon distribution is needed in a given location in the Northern hemisphere, a South-East orientation would be optimal.

3.4.5 Step 5: Tilt

Solar panels must be oriented at the proper tilt angle to the light source for maximum heat output. Usually, as days are shorter during winter, this will be the most critical period to cover and tilt angle should be adjusted to perform to a maximum. For most cases, the reduced performance in summer will be marginal so that there is no need to adjust the tilt angle panels. It is recommended to use the latitude + 10° for a year around demand. A minimum angle of 10° also reduces dust accumulation.

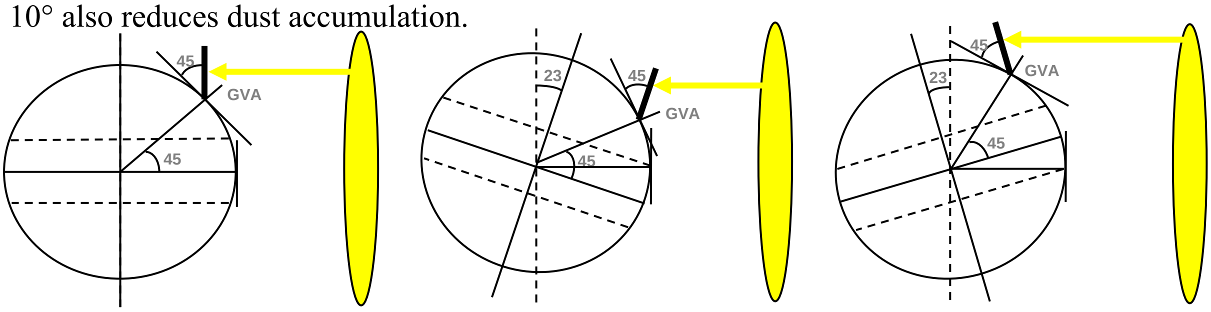


Figure 11: Spring and Autumn equinoxes *Summer solstice* *Winter solstice*

3.4.6 Step 6: Energy demand

Depending on the orientation, tilt and location, 1 m^2 of solar collector can supply a certain quantity of energy in kWh/day (Es1). To calculate the solar irradiance (Es1), it is recommended to visit: http://www.solarelectricityhandbook.com/solar-irradiance.html

Energy received by 1 m^2 of solar collector: Er = range from 3 to 7,5 kWh/day
Average efficiency (Eff) = 10 to 60% depending mainly on the sun, the quality of the collectors and the average tank temperature (higher efficiency when the operating temperature is low)
Energy supplied by 1 m^2 of solar collector: Es1 = Er * Eff

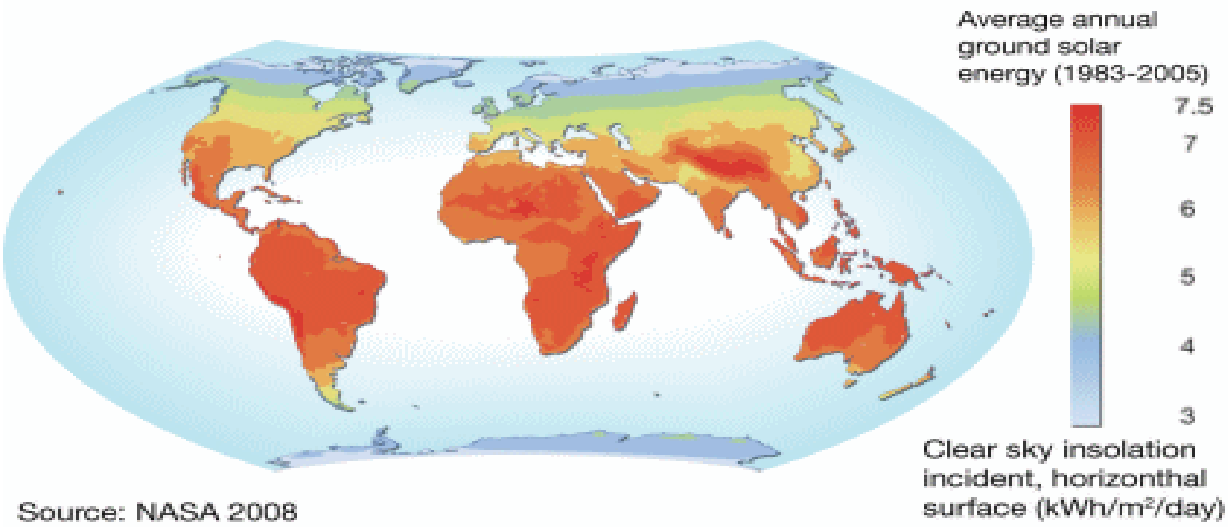


Figure 12: Average annual ground solar energy map

The energy demand (Ed) in kWh/day depends on the Water demand (Wd) in m^3/day, the temperature of hot water demand (Thot) in °C and the temperature of water supplied by the network (Tsup) in °C.

$$Ed = Wd * (Thot – Tsup) * 1,163 \text{ kWh/m}^3\text{°C}$$

3.4.7 Step 7: Collector Area needed

The solar collector area is the flat panel area of the solar hot water system that is exposed to the sun. It depends on the Energy demand (Ed) and the Energy supplied (Es1).

Collector area needed in m^2: A = Ed / Es1

3.4.8 Step 8: Storage Volume needed

The storage volume depends on the collector Area (A), the daily load profile and the location.

Storage Volume (Vs) in litres:

- Vs = A * 10 l/m2 for heat demand in phase with sunshine hours
- Vs = A * 25 l/m2 for heat demand mainly at evening and/or morning and in sunny locations with latitude <25°
- Vs = A * 40 l/m2 for heat demand mainly at evening and/or morning and in locations >25 and <40° latitude
- Vs = A * 50 l/m2 for heat demand all day long in any location or mainly at evening and/or morning in mid Europe climate with latitude >40°

3.4.9 Step 9: Final decision

Knowing A and Vs, it is now possible to take the final decision about the SWHS to install. If the systems available on the market don't respond to the needs, it is recommended:

- not to oversize the collector Area (A) to avoid overheating problems;
- not to undersize the storage Volume (Vs) to satisfy the hot water demand (Wd).

The Philippines case study[2]

In 2010, a pilot experiment has been conducted in three jails in the Southern Philippines (Panabo, Digos and Valencia) by installing solar water heaters for cooking purposes. The main purpose was to reduce the fuel consumption in order to improve the working conditions in kitchens, to reduce the fuel expenses and to have a positive impact on the carbon footprint. Although these systems already demonstrated their efficiency at domestic level, its reliability and pertinence remained to be determined in detention facilities.

Jail population in Panabo District Jail = 308 inmates
Hot Water demand (Wd) = 195 l of water/meal x 3 meals/day = 585 l/day = 0,585 m^3/day
Energy received by 1 m^2 of solar collector in the Philippines (Er) = 7,5 kWh/day
Energy supplied (Es1) = 7,5 * 60% = 4,5 kWh/day
Energy demand (Ed) = 0,585 * (60 - 30) * 1,163 = 20,4 kWh/day
Collector area needed in m^2 (A) = 20,4 / 4,5 = 4,5 m^2
Storage volume (Vs) = 4,5 * 50 = 225 l

[2] For more information on this case study, please refer to the document "The ICRC Water and Habitat Unit (2012). WatHab in Prisons – No 2 – Solar Water Heaters in Detention Facilities".

The decision was to install 2 solar collectors of 2 m^2 each (2 * 2 m^2 = 4 m^2) with a storage tank of 300 litres of capacity[3].

The pilot experiment of installing solar water heaters in places of detention was launched to address the needs of both the inmates and the jail authorities, and to have positive impact on the carbon footprint. The results of the experiment showed that the system is adapted to the needs of the stakeholders and can be a reliable alternative to reduce the energy-associated costs and, therefore, to address positively the problems of the jails' finances.
Regarding the impact on the working condition and inmates' health, the system should be seen as a complement to other techniques like biogas digesters and energy-saving stoves.
Conclusions on a potential effect on reducing the carbon footprint are more debatable, while the impact on reducing the LPG-generated methane, a gas with a high greenhouse effect, can be considered as positive.
In the end, the installation of solar water heaters in jail facilities proved to be beneficial and can be developed in similar contexts.

3.5 CO_2 reduction

SWHS produce carbon free energy but CO_2 is emitted during the manufacturing of the solar collectors. As a matter of fact, SWHS become carbon negative after about 4 years.

Transportation also causes CO_2 emissions. As estimates, we can use the following figures:

- road transport: 62-110 g/tkm (gram of CO_2 per tonne-kilometre);
- rail transport: 18-35 g/tkm,;
- air transport 665: g/tkm;
- water transport: 2-7 g/tkm for sea transport;
- water transport: 30-49 g/tkm for inland waterways.

CO_2 reduction in the Philippines

Before the installation of SWHS, Panabo jail authorities consumed 255 kg/day of wood to heat water. After the installation, they use 192,3 kg/day. This shows a decrease of 62,7 kg/day representing 24,6%.
As shown in the table, wood has a lower heating value (LHV) of 3 kWh/kg, so 62,7 kg of saved wood would generate 188,1 kWh. As wood releases 0,39 kg CO_2/kWh, 62,7 kg of saved wood would save the release of 73,36 kg of CO_2/day.

Type of combustible	Density (kg/m^3)	LHV (MJ/kg)	LHV (kWh/kg)	Specific CO_2 emission (kg CO_2/kWh)	Tonne of oil equivalent (toe)
Diesel	840	41,83	11,62	0,24	0,905
Natural gas	0,719	49,6	13,77	0,23	1,300
LPG	1,876	46	12,78	0,26	1,205
Butane	2,464	45.5	12,64	0.27	1,185
Coal	700-800	23,98-27,72	6,66-7,7	0,37	0,450
Wood	350-1'100	10,8-21	3-5,83	0,39	0,450

[3] The storage volume (Vs) was calculated multiplying the collector area needed (A) by 50 and not by 25 to satisfy the hot water demand all day long.
A storage tank of 300 l was purchased because no storage tanks of 225 l were available on the local market.

3.6 Conclusions

Different solutions can be proposed when domestic hot water is required and, generally, it can be concluded that it is recommended to use:

- a thermosiphon passive system, 1 to 4 m^2 of solar collectors, suited for 100 to 300 l of hot water per day at 50 to 60ºC, with a testing certificate, in order to propose a reliable and simple solution (a number of those units installed in parallel if the demand is larger);
- an active system (solar kit), 4 to 6 m^2 of solar collectors, suited for 100 to 750 l of hot water per day in locations where electricity grid is reliable;
- an engineered system for special cases that has to be designed by a skilled person using locally available components and has to be checked by a WatHab engineer. This could be the solution for demand that is not only domestic hot water but heating of large spaces, cooking or boiling or industrial needs. When the hot water demand in one place exceeds 2 to 3 m^3/day, special solutions have to be designed. It would be preferable to choose a solution that can be deployed in different places, complete and autonomous such as a central storage system or a multiple roof top storage system. Central storage systems are generally recommended where usage exceeds a hot water draw of 1'500 litres per day, whereas roof top systems are generally regarded as suitable for installations requiring less than 2'500 litres per day.

4. Supply

4.1 Suppliers

The main criteria for the selection of a supplier are:

- proven quality and efficiency;
- warranty (> 5 years);
- after sale service;
- cost.

There are more than 1'700 solar water heater companies in the world. See for most of them in: http://posharp.com/
On this website, it is possible to select the suppliers by country and find those who have in-country representatives.
Another good source is: http://www.ecobusinesslinks.com/solar_water_heater.htm

There are numerous companies that can be a partner or a supplier for solar water heater projects. To better ensure the sustainability of a project, it is highly recommended to work with a local dealer or installer, who can be available for service, maintenance and repair.

Some of the companies that have the best world coverage are:
Solahart, Australia: http://www.solahart.com.au/
Helioakmi, Greece: http://www.helioakmi.com/

It is recommended to buy officially tested systems available in the local market and to think about international procurement only when purchasing more than 10 systems.

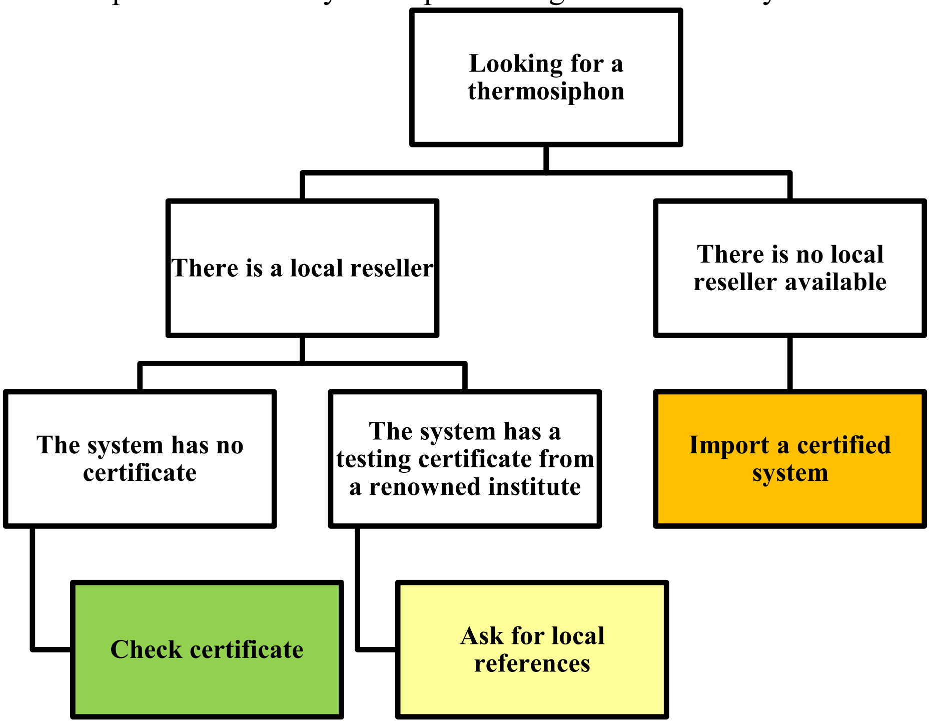


Figure 13: Suppliers choice diagram

A reliable system must:

- be easy to install and start without mistakes or misconnections;
- be based on long-lasting components (plastics and insulation are the weakest parts);
- not corrode;
- work without any daily care, safely, noiselessly and smoothly;
- operate automatically in every situation (cold or hot weather, empty or full tank);
- resist to hard climatic conditions (wind storms, snow fall, ice fall, lightning);
- run or be protected in case of electricity failure or shortage or a tension fall;
- restart automatically after safety shut down or stop of electricity supply;
- signal a default (warning lamps or equivalent);
- be easily reset;
- provide protection against overheating consequences;
- not favour legionella development;
- not allow hot temperature delivery when not desired;
- be easily dismounted, changed or repaired;
- not be damaged or stolen easily;
- not have an automatic relief valve that is not visible (leakage must be detected).

4.2 Testing

The collectors should have a "Solar keymark" as a proof of quality or an equivalent international label. Unfortunately, there is no keymark for global systems at present. Therefore, testing must assess:

- the overall quality of a system and not only of its components;
- its productivity in terms of kWh collected per m^2 of collector, which is a very good figure of merit for a system (the minimum should be 400 kWh/m^2 for a domestic hot water system tested in Swiss conditions);
- its overheating protection (one of the weakest point of the technology).

It is recommended to ask the supplier on tests that have been conducted which can be trusted if issued by a legitimate institution (a solar national research centre most of the time) according to international standards (EN 12975, 12976 and 12977 for Europe Norms, ISO 14001:2004 and ISO 14004:2004 for Asian-Pacific Economic Cooperation (APEC) Norms, ISO 10217:1989, ISO 9459-1:1993, ISO 9459-2:1995 and ISO 9459-5:2007 worldwide).

It is recommended that the chosen system be tested officially according to the CEN (European standards committee) standards. Several institutes in Europe perform such tests at the request of the manufacturer:

- SPF in Switzerland: http://www.solarenergy.ch

Switzerland has one of the most reliable test centre in the world: SPF tests also systems (not only collectors) and provides online a database of all systems that have been tested for more than 20 years.

- ISE in Germany: http://www.ise.fraunhofer.de/servicebereiche/testlab-solar-thermal-systems
- ISFH in Germany: http://www.isfh.de/institut_solarforschung/solarthermie.php?_l=1
- AIT in Austria: http://www.arsenal.ac.at/products/products_en_pvst_fest_pruef_en.html

- CSTB in France: http://www.cstb.fr/
- SeRC in Sweden: http://www.e-science.se/

For other centres it is wise to ask SPF if the centre which has tested the foreseen product is reliable.

Testing for consumers is also popular in Germany. The consumer journal “Stifftung Warentest” periodically orders to the ITW Research Institute in Stuttgart system tests that can help to choose. It is wise to consult before purchasing. Picking a system that has received a good grade in such tests is a guarantee.

When going for a self-built solar installation, easy operation & maintenance and availability of spare parts must be kept in mind.

If the installation is to be designed and built by a local installer using local or imported components, advices on quality of components should be asked for on a case to case basis, especially if quality cannot be asserted by labels for components such as a “solar keymark” for the collectors.

5. Operation & Maintenance

5.1 Installation

The location of the installation is a critical parameter that should take in account the following criteria:

- **Heat losses.** In order to avoid too many heat losses, the system should be installed as close as possible from the usage point.

- **Environment.** The surrounding environment has to be free of interferences that could jeopardize the efficiency of the system (trees, building, etc.).

- **Accessibility.** To ensure a smooth maintenance of the installation, the access has to be facilitated.

- **Security.** The installation should be protected from vandalism. Solar Water Heaters are not as prone to theft as solar panels for electricity. However, vandalism can be an issue in some contexts and measures taken, if necessary, to protect from eyesight and limit access.

- **Structure.** The supporting structure has to stand with the total load that includes the collector and the storage tank full of water.

For a thermosiphon passive system, unskilled labour can succeed to make the installation. It is not a very difficult task but the material can be heavy and will often require at least two persons.

A local installer will be required for a complex system like an active system installed in series with an existing boiler.

The critical points during installation are:

- access to the components must be kept possible for easy repair or replacement;
- avoid shocks on collectors;
- connect all pipes with watertight and airtight devices;
- fill up the system with demineralised water if possible (if not already a glycol water industrial mixture);
- respect the prescribed pressure in the system;
- de-air carefully;
- observe the operation during a few days before final commissioning;
- check how easy the replacement of the pump (if any) can be done;
- write a short commissioning report: what was made? by whom? why? when?;
- check the roof appropriate resistance (if not, consider an alternative location or reinforcing);
- check the roof slope suitability (if not, foresee an additional structure).

γ = angle desired (tilt)

Slope not steep enough case

$\alpha + \beta = \gamma$
$\beta = \gamma - \alpha$
$\tan\beta = x / L$
$x = L * \tan\beta$

Too steep slope case

$\gamma = \alpha - \beta$
$y = L * \tan\beta$

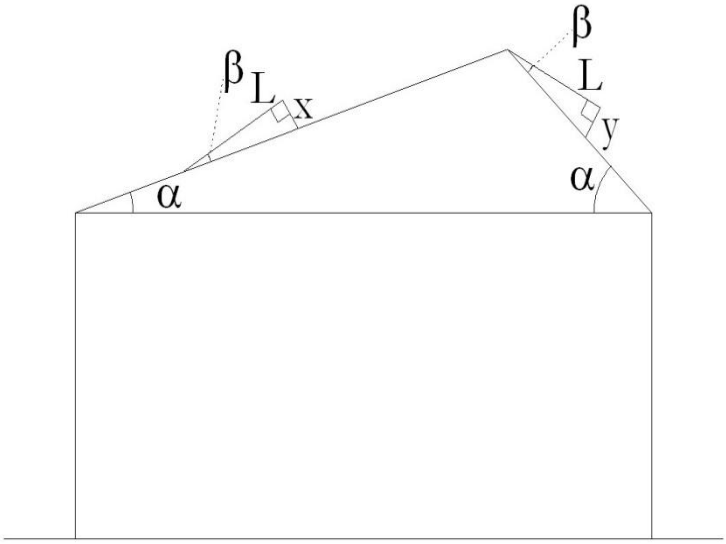


Figure 14: Tilt design

5.2 Operation & Maintenance

Standard systems (tested systems) are more robust and require lower maintenance.
Checking the system or reading meters once a month can be done by local staff.
A contract with a local installer (plumber) is indicated for service and maintenance, especially in case of locally made solutions (not "factory made" solutions).

Main risks in operation which would have affected the choice and design of a solar installation are:

- The hot water demand (Wd) is not what was predicted or expected. If it is more, then it will not cause a problem; the productivity of the solar system will even be higher. If it is less, the system may tend to have too frequent overheating of the collectors, reducing the lifetime of the installation. This is one of the most problematic risks, so there is a clear recommendation of under sizing solar collectors when the future Wd is uncertain.

- The system is not monitored, checked periodically or maintained and does not function properly or at all in the end. This is frequent in systems where a back-up or auxiliary energy source exists. One even does not notice that the solar part is not working if no one is devoted to checking the installation or the costs of the auxiliary energy.

Operation and Maintenance in the Philippines jails

Proper operation and follow-up of maintenance are crucial to ensure a long-term durability of the systems. Prior to any “go ahead” decision, discussions have been held with the jail authorities at national and local level. Responsibilities and obligations have been raised and agreed by both parties.

The jail authorities committed to:

- appoint an engineer of the Bureau of Jail and Management (BJMP) to supervise the project and acting as focal point with the ICRC Water and Habitat team;
- guarantee the safety of the installation;
- monitor the collection of data by the inmates and the staff;
- transmit cost data;
- set up teams in kitchen in charge of basic maintenance of the panel and the distribution system. Though maintenance is minimal and after sale service is include in the contract with the supplier, regular cleaning of the collectors with clean water has to be performed.

The ICRC committed to:

- take in charge the installation technically and financially;
- instruct and train the kitchen staff to the operation and maintenance;
- provide any necessary tool to the smooth running and to the monitoring phase;
- report the final results of the pilot experiment.

The most important points to observe during operation are:

- At least once a year pay a visit to the installation
- Check periodically the temperatures from the solar collectors and in the tank. Ask someone to note them every day if possible
- Check the pump if there is one (noise, vibrations,..), when in operation (on a sunny day)
- Look for leakages and find the sources to fix them
- De-air the circuits if necessary
- Every 2 years check the glycol content (in a system with glycol), using a refractometer or by visual transparency of some sample in a transparent bottle (less precise).
- Clean the collector glazing at least once a year, if close to a railway or a highway cleaning once a month is recommended
- Change the storage corrosion anode if present in the installed system, when prescribed by manufacturer
- Look for corrosion points on collectors, storage and piping
- Look for insulation of pipes and collectors if still in good shape
- Inspect the collectors for dirt, leakage, breakage, corrosion of absorbers or pipes or frame
- Check the functioning of the solar collectors temperature probe (on a sunny day the collectors should start collecting when they reach a temperature higher than that of the tank)
- Check the collectors supporting frame for any corrosion
- Ask the users how they evaluate the service provided by the solar installation

- Note:
  - the hours of operation of the solar pump if the system provides the reading
  - the hot water consumption
  - the electricity needed for the solar pump if there is a meter
  - the auxiliary energy needed
- Plot the values and compare them from month to month and year to year to detect deviations indicating a possible drift or failure.
- Write a report after every visit (see Annex 3 for an inspection report format example) and inform the responsible person of any irregularity.

The ICRC strongly recommends to write a yearly report for the first 3 years. This will helps to evaluate the performance of the systems, establish the payback period and underline any drawback that may require closer follow-up/inspection.

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7. Annexes

7.1 Assessment Checklist for a solar water heating project

To be answered by the beneficiaries

Case description

1. Name, address, mail
2. City
3. Country
4. Exact location of case
5. Owner of building
6. Usage (shower, cooking, cleaning, others)
7. Temperature of water usage
8. Size of daily load: number of persons to be supplied daily or volume of hot water needed
9. Days in week / month / year of water usage
10. Other special comments on water usage
11. What is the current way of heating?
12. Age of system
13. Status of system
14. How much did it cost when installed?
15. Is the system to be replaced? Rapidly? in months? in few years?
16. Will the system remain if solar is implemented?
17. What other auxiliary (back-up) heat source would be available if solar will e used only for a part of load?
18. What is the current fuel used (wood, electricity, gas, coal, diesel, LPG, others)?
19. How much is used? per day, month or year
20. Do you know the cost of the fuel?
21. Do you know the operational annual cost of the current water heating system?
22. Who pays the bill?
23. Who is taking care of the current installation?
24. Is there a particular threat for the installation (vandalism, robbery, others)?
25. Is there a telephone line we could use to remote control the installation?
26. Is there an internet access (cable or wireless)?
27. Has the installation of the system the potential to be replicable in the region?
28. What dependency a solar system would create to whom? if any
29. What will be the site in 10 years? 20 years?
30. Is recycling of the solar components in 20 years possible?
31. Is there a sketch, scheme or map of the system?
32. Can you take pictures of the current installation and possible location of collectors?

Solar access

33. Is there a sunny place to install the solar collectors?
34. What type: slanted roof type, flat roof type, yard close to house, parking lot or roof, field, other? Can you mail photos and dimensions?
35. What type of under structure is there? (concrete slab, wood beams, brick walls, others)

36. Can it sustain 200 kg? 400 kg? 600 kg? How much?
37. Shadow on site?
38. Do you know the possible tilt angle for solar collectors? (0 = horizontal, 90 = vertical)
39. Do you know the possible orientation? (90 = East, 180 = South, 270 = West, 360 = North)
40. Is there a room where a storage tank can be placed? What area is available (needed: min 1,5 m^2 x 2 m height)?
41. How wide is the entrance door of this room? Are there steps to reach the room?
42. Is there an easy way to go with 2 pipes from solar collectors location to storage room?
43. Do you think a thermosiphon is most suited?
44. How many thermosiphons could find a place? (Typical width 2m)
45. Is a solar active solution possible?
46. How much surface is available for collectors?
47. Will someone be potentially disturbed by a solar installation? (Reflection, etc.)
48. Is there already a solar installation nearby?
49. Is there a need for antifreeze in the solar loop in winter?

Monitoring and maintenance

50. Will you be available to monitor the installation during 2 years?
51. Will you be available to maintain the installation? (for the first year check every two months if everything OK)
52. Is there someone with plumbing skills?
53. Until when will the ICRC be responsible of monitoring and maintenance?

Local installer

54. Do you know a local solar installer?
55. Name and location?
56. What products does he offer?
57. Have you met him?
58. What is your impression about its experience and skills?
59. Do you know a local plumber?
60. Who is repairing when needed the current installation?
61. Could he repair the solar installation as well?

Current networks

62. Do you know the cold-water network pressure?
63. Does it tap slowly usually or with strong flow?
64. Is it easy to get water where the solar storage tank could be installed?
65. Can you state the water quality? Dirt/no dirt, hard/soft, other?
66. Are current pipes corroded somehow? How?
67. Are there water shortages?
68. Is there electricity on site? Close to the room where we can install a tank?
69. Are there shortages of electricity? Often? When?
70. What is the quality of the electrical network?
71. What laws govern the water supply? Quality and temperature (if any)?

To be answered by the designer

Case issues

72. Heat demand by day, month, year
73. Current fuel or electricity consumption (primary energy)
74. Current CO_2 emission
75. Current cost of operation
76. Type of solar system foreseen
77. Type of monitoring to install (temperature sensors, etc.)
78. Size of system (m^2, m^3)
79. Future fuel consumption
80. Solar fraction
81. CO_2 saved
82. Total weight of system
83. How the solar part will work with auxiliary (back-up) heat source?
84. Cost of system
85. Cost of installation
86. Cost of dismantling current installation
87. Cost of operation
88. Durability to external threats (corrosion)
89. Durability to internal conditions (internal corrosion due to water)
90. Is there a local supplier?
91. Is there a local installer?
92. Is there export to the country of solar ready-made systems? Of collectors?
93. What warranties can we get?
94. Who will install?
95. Who will finance?
96. Legal aspects
97. Regulatory aspects

System technical generic issues

98. Reliability and robustness
99. Easy to install and maintain (dismantling, spare parts, screws and bolts, recycling)
100. Safety: vandalism, robbery
101. Tested and certified
102. Local installers or possible repair by local team: what dependency does it create to whom?
103. Warranty service available

Financial issues

104. Initial cost
105. Cost of kWh compared to current solution?
106. Payback time?
107. How the solution will be financed?
108. What impact on cost of kWh?
109. What financial dependency does it create to whom?

Strategic issues

110. Is the case adapted to the ICRC (access, timeframe, budget, etc.)
111. Fuel and CO_2 savings are enough?
112. Other benefits for any stakeholders?
113. Overall risk assessment is low?
114. Potential to replicate is high?
115. Demonstration effect is real?
116. Can we evaluate or measure the output of the case?
117. Is there an implementation plan? Realistic?
118. Can we communicate on the case? Internally? Externally?

Risk analysis

These points should be reviewed before taking a final decision. Give a grade from 0 to 10 to each. If the total score is below 50 points, SWHS is recommended. If it is between 50 and 100 points, SWHS must be considered. If it is over 100 points, SWHS must be discarded.

1. Consumption overestimated (0 = no risk, 10 = we base our figures only on rough estimations)
2. Temperature underestimated (0 = no risk we have measured the actual ones, 10 = estimation)
3. No will to change (0 = no risk every user is asking for solar, 10 = there are strong opponents to a solar installation among the future actors)
4. Risk of No delivery of system (0 = no it is assured, 10 = no practical path, etc.)
5. Technical risk remaining (0 = no we have already experiences with the system we are planning, 10 = it will be a one design solution by a local engineer)
6. No human resources to take care of if (0 = no there is a committed engineer on site, 10 = it is far from any technician or dedicated person)
7. No installers (0 = no there is one and we know him very well, 10 = no installers around)
8. No repairing possible (0 = no very convenient, 10 = far away and the installation will have to work in stand-alone for months)
9. No clear benefit locally (0 = no it is a clear advantage for the users in terms of providing hot water, 10 = there is already a very good solution for hot water production)
10. No clear benefit globally (0 = no it will be a show case with an expected deployment, 10 = it is a one shot small project)
11. No feedback possible (0 = no it is monitored and followed by committed persons who will be eager to report on the installation, 10 = it is lost without monitoring and feedback possible from any user)
12. No budget to operate (0 = no there is enough little money to repair if necessary, 10 = there is no money available after installation if something goes wrong)
13. Overall feasibility and overall risks linked to human attitude with the installation during 10 years? (0 = very good assessed by skilled persons, 10 = seems to be very complicated)
14. Fossil fuel savings or depleted resource savings (0 = very high, 10 = very low)
15. CO_2 savings (0 = very high, 10 = very low)

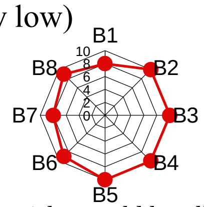

Figure 15: a radar to assess the risk of a project. Risky would be all 10, not risky would be a point in the centre

7.2 Installation Checklist for a solar water heating system

ICRC

a) Installation

Date	………………………………………
Installer name	………………………………………

b) SWHS user

Residence code	………………………………………
Name	………………………………………
Address	………………………………………
	………………………………………
Phone	………………………………………
GPS location	Lat………………Long……………....

c) SWHS

Brand and type	………………………………………
Kind of system	□ Passive □ Active
Year of manufacture	………………………………………
Manual available	□Yes □No…………………………....
Warranty	………………………………………

d) Collector

Area	..………………………………… m²
Number of collectors	………………………………………
Type of collectors	………………………………………
Orientation	...……………………………………
Tilt	……...……………………………°

e) Backup heating

Energy source (electricity/gas/oil)	………………………………………

Hot water storage (integrated/separate tank/flow through)...……………………………………

Brand and type ………………………………………

Power ...…………………………………kW

f) Visual inspection (All right? Yes/No)

Supporting frame (strong)	□Yes □No…………………………...
Storage tank (location)	□Yes □No…………………………...
Storage tank insulation (tight)	□Yes □No…………………………...
Connection of pipes from storage tank to collector and user points (right position, insulation)	□Yes □No…………………………...
Holes done in roof/walls are protected against weather	□Yes □No…………….…………...
Non-return valve (right position)	□Yes □No…………………………...
Positioning of circulation pipes between collector and tank (right slope, no sharp bends)	□Yes □No…………………………...
Insulation circulation pipes (complete length, weather-resistant material)	□Yes □No…………………………...
Position expansion tank, vent pipe or safety valve	□Yes □No…………………………...
Collector sensors (correctly attached to hot and cold water circulation pipes)	□Yes □No…………………………...
Circulation pump (position, power … W)	□Yes □No…………………………...
Control unit (position)	□Yes □No…………………………...
Sensor cables (proper connections, right size and insulation cables)	□Yes □No…………………………...
Water meter installed for hot water (if so indicate Reading on the installation)	□Yes □No……………………….…...

Backup heating

1) manual switch (location)	□Yes □No…………………………...
2) thermostat setting …°C, range … °C	□Yes □No…………………………...
3) proper electrical wiring	□Yes □No…………………………...

7.3 Inspection Checklist for a solar water heating system

ICRC

a) Inspection

Date	……………………………………
Inspector name	……………………………………

b) Visual inspection (All right? Yes/No)

Supporting frame (attached to roof/grouting)	□Yes □No…………………………..
Storage tank (no leaks)	□Yes □No…………………………..
Storage tank insulation (no gaps)	□Yes □No…………………………..
Connection of pipes from storage tank to collector and user points (air release valve)	□Yes □No…………………………..
Circulation pipes between collector and tank (air release valve)	□Yes □No…………………………..
Insulation circulation pipes (condition of insulation)	□Yes □No…………………………..
Control unit (settings)	□Yes □No…………………………..
Backup heating thermostat setting …°C, range … °C	□Yes □No…………………………..
Collector glass cover (clean, no cracks, water-tight, no condensation)	□Yes □No…………………………..
Absorber (no corrosion, no leaks, paint/coating in good condition)	□Yes □No…………………………..
Check vacuum tube systems	
1) Check vacuum (vacuum lost, hot tubes)	□Yes □No…………………………..
2) Check tube/tank seals on leakage	□Yes □No…………………………..
3) Check condition "getter" (silver part white)	□Yes □No…………………………..

c) Testing and measurements

Meter reading (if present for hot water)	□Yes □No…………………………..
Hot water outlet temperature	...………………………………°C
Circulation with thermosiphon systems (temperature difference between hot and cold junctions)	□Yes □No…………………………..

Forced circulation (important: for this test, the sun should be shining and the pump running. Check circulation by feeling or measuring the temperature difference between the hot and cold pipes) □Yes □No…………………………...

Differential Temperature Control switch on and off test

Note DTC-setting: T(DTC) ..…..………………………………°C

Measure collector inlet temperature: T(in) ...…..………………………………°C

Measure collector outlet temperature: T(out) ..…..………………………………°C

Is T(out)-T(in) higher than T(DTC)? □Yes □No…………………………...

If possible cool down the hot sensor or warm up the cold sensor, does pump switch off? □Yes □No.…………………………...

d) User opinion

Temperature of hot water □ Satisfactory □ Not satisfactory

Quantity of hot water supply □ Satisfactory □ Not satisfactory

Constant temperature (e.g. during bathing) □ Satisfactory □ Not satisfactory

e) Remarks

……………………………………………………………………………………………...…

……………………………………………………………………………………………...……