SOLAR WATER HEATERS SELECTION AND INSTALLATION GUIDELINES

SEIAPI Sustainable Energy

SIDSDOCK SMALL ISLAND DEVELOPING STATES ISLAND ENERGY FOR ISLAND LIFE

WORLD BANK GROUP

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These guidelines have been developed for The Pacific Power Association (PPA) and the Sustainable Energy Industry Association of the Pacific Islands (SEIAPI). They represent latest industry BEST PRACTICE for selection and installation of Solar Water Heaters

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List of Abbreviations

ANSI	American National Standards Institute
AS	Australian Standard
ASTM	American Society for Testing and Materials
IAPMO	the International Association of Plumbing and Mechanical Officials
ICC	International Codes Council
IEC	International Electrochemical Commission
IPC	International Plumbing Code
ISO	International Organisation for Standardisation
LP	Liquid Petroleum
NZS	New Zealand Standard
SOPAC	South Pacific Applied Geoscience Commission
SWH	Solar Water Heating
TPR	Temperature Pressure Relief Valve
UV	Ultra Violet Light
UPC	Uniform Plumbing Code

1. Overview

This guideline has been prepared based on best industry practices and is aimed at small-scale residential and commercial solar water heating (SWH) systems in the Pacific. This guideline will assist individuals or technicians to confirm design parameters and to meet installation requirements for a solar water heating (SWH) system.

Section 2.0 of this guideline introduces the possible types of solar water heating systems including passive (thermosiphon) and active (pumped) SWH systems. This section also lists the applicable standards for the products and installation.

Section 3.0 explains the components of a solar water heating system in a passive and active system. It includes information on collectors, specifically flat plate and evacuated tube type collectors.

Section 4.0 details the basic design/sizing information for a solar water heating system. It covers determining the optimum collector orientation and tilt, hot water requirements, collector sizing, tank sizing, and the overall system layout and balance of system components.

Section 5.0 focuses on commercial SWH systems and covers a brief sizing approach.

Section 6.0 highlights and provides guidelines on installation and commissioning of SWH systems. This section presents recommended installation practices for collectors, tanks and the SWH balance of system components.

Finally, section 7.0 covers tips on maintenance and troubleshooting of SWH systems.

2. Introduction

This document provides the minimum requirements when confirming size and installing a solar water heater. The installation methodology adopted in this guideline reflects current industry best practices. However, this guideline is based on the range of products/systems typically used in the Pacific Islands and as such may not cover all configurations of solar water heating systems. Section 2.1 provides an explanation of the types of systems available.

2.1 Types Of Solar Water Heating (SWH) Systems

There are two different types of systems:

- Passive SWH (thermosiphon or close-coupled) systems
- Active SWH (non-thermosiphon, pumped or split) systems

And there are two types of water heating methods used in these systems:
- Direct water heating system (heats water directly)
- Indirect water heating system (uses a heat exchanger to deliver the solar generated heat to the hot water tank)

2.2 Passive SWH Systems (Thermosiphon) Or Close-Coupled Systems

Passive SWH systems have the collectors and tank close together. Both are usually located on the roof, with the tank above the collectors to take advantage of the thermosiphon effect (Figure 1).
The thermosiphon effect is the circulation of water that occurs naturally through the collector and storage tank due to convection. This phenomenon is used in passive SWH systems. In the hot water tank, the hottest water rises to the top of the tank by convection and the lower temperature water sinks to the bottom of the tank and flows from there to the lowest point on the collector by the convective force. As the water passes through the collector it gains heat and the convective forces cause it to rise through the collector and up into the storage tank. Thus as the water circulates through the collector it

gains more heat and the average temperature of the water in the storage tank rises.

This circulation of water will continue to heat the tank water until a point called stagnation is reached where the heat gained by the collector equals the loss of heat from the tank and collector. This happens because the water fed to the collector is already very hot and because heat losses go up as the temperature goes up, at some temperature heating from the collector equals heat lost from the tank and collector and the water can get no hotter. This stagnation temperature changes as the outside air temperature changes and if it is a very hot, sunny day, it may be possible to generate steam.
So to ensure that dangerous temperatures and pressures are not reached in this system, an automatic temperature-pressure relief valve (TPR valve) usually is installed at the tank.

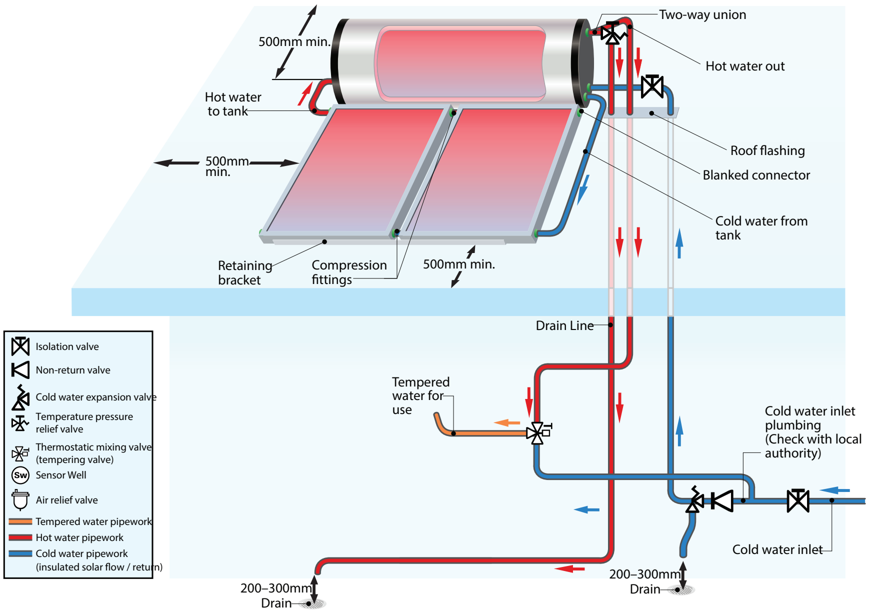


Figure 1: A Passive SWH System

There are also non-thermosiphon passive solar water heaters available. Batch water heaters as they are called, also known as ‘breadboxes’ are very simple passive systems for heating water using solar energy and have been used since the early 1900s. Batch systems consist of black storage tanks contained within an insulated box that has a transparent cover. Cold water is added to the hot water stored in the tanks whenever hot water is removed. Modern batch systems are used as preheating systems, where the water is then heated further by conventional gas or electric systems. To retain the heat within the water, the system requires insulated covering to be placed over the glazing at night to prevent the heat being lost to the environment.

Figure 2 below shows a typical batch water heater.

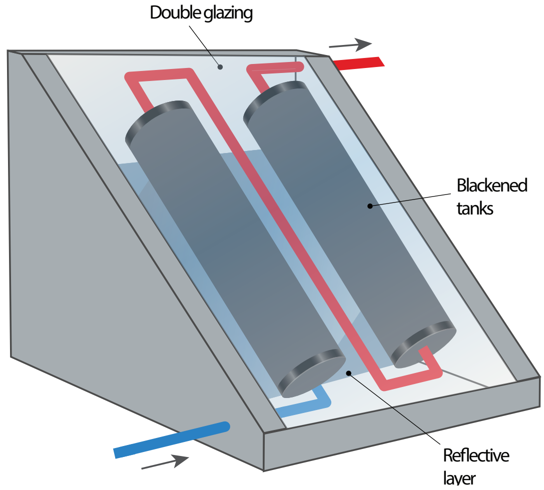
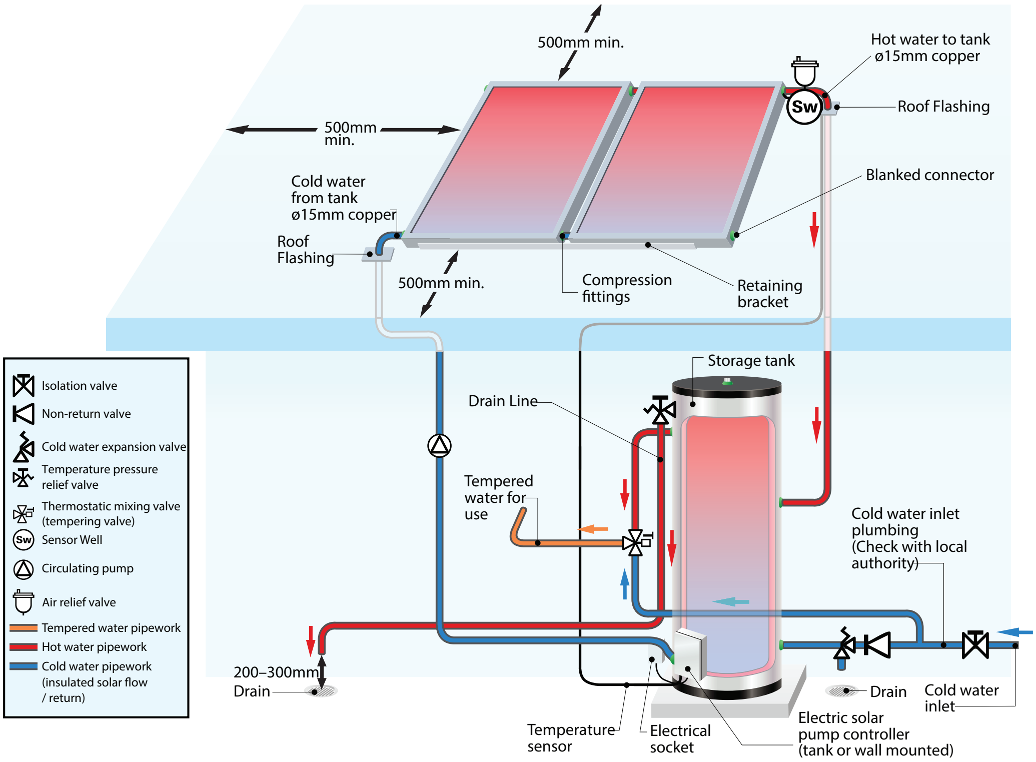


Figure 2: Layout Of A Batch Water Heater

2.3 Active SWH Systems

In an active (split) system, the water tank is installed where convenient and usually is below the collectors. Because there is no circulation possible by convection, a pump is used to circulate the water through the system (Figure 3). The pump is fitted with a controller that sends water to the collectors when the water in the collector is a higher temperature than the water in the tank. When the tank water reaches a temperature around 70° C (158° F), the controller shuts off the pump and so the tank temperature increases no further. Again, various protection valves are typically installed to ensure dangerous temperature and pressure levels are not reached in the tank or the collector loop.

Figure 3: Example Of An Active SWH System With Protective Valves



2.4 Direct Water Heating Systems

In a direct water heating system, the water that will be used in the building is circulated from the tank directly to the collectors where it absorbs heat from the sun's radiation. (This water is called the working fluid). Using water as the working fluid is common in both passive and active SWH systems.

2.5 Indirect Water Heating Systems

These systems work in a very similar way to the direct systems, but rather than 'directly' heating the water in the collectors, a heat transfer working fluid (e.g. propylene glycol) is used to absorb the heat of the sun's rays and then, using a heat exchanger, the energy is transferred to the water (Figure 4). The heat exchanger may be a jacket of working fluid around an inner tank or coils of pipe within the holding tank.

Propylene glycol is typically chosen as the working fluid mainly because it is not toxic and provides excellent frost protection and good heat transfer. Though frost protection is not usually a problem in the Pacific Islands, an indirect water heating system may be used in areas having relatively salty or high mineral content water in order to avoid corrosion and scale formation in the collector loop. Automotive antifreeze (ethylene glycol) must NOT be used as the working fluid as it is quite poisonous and any pipes containing ethylene glycol should not be in any way associated with potable water tanks or piping.

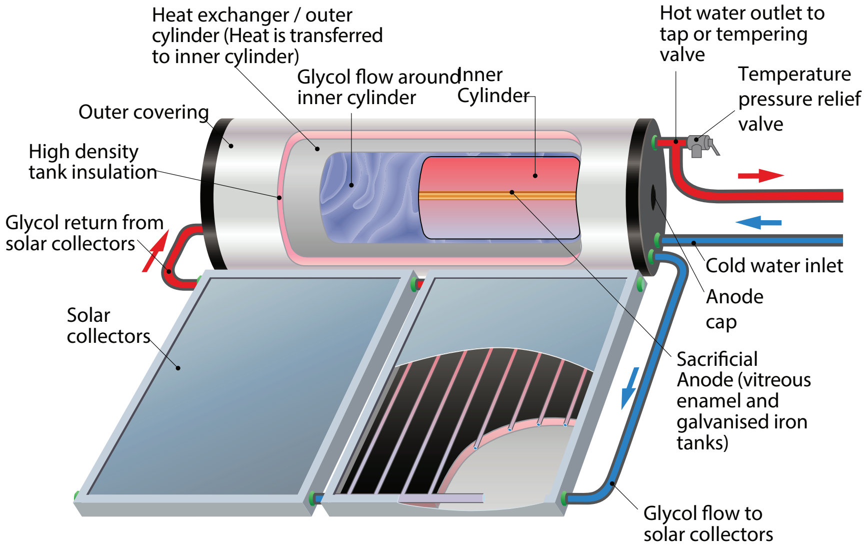


Figure 4: Example Of An Indirect System

Indirect systems should be preferred for sites that have a poor water supply quality. If the water supply is high in calcium content, indirect systems meant that water is never in direct contact with the fine pipes within the collector. This avoids the build-up of calcium carbonate in the collector pipe, preventing untimely failure of the system.

2.6 Standards Relevant To Solar Water Heaters

The following standards all have relevance to solar water heaters, some to a greater extent than others. Australian/New Zealand standards relevant to solar water heaters are:

- AS/NZS 1170.2 — Structural design actions: wind actions
- AS/NZS 2535.1 — (ISO 9806-1:1994 equivalent) Test methods for solar collectors – Part 1: Thermal performance of glazed liquid heating collectors including pressure drop
- AS/NZS 2712 — Solar and heat pump water heaters - design and construction
- AS/NZS 3000 — Electrical installations
- AS/NZS 3500 — Plumbing and drainage
- AS/NZS 3500.0 — Part 0: Glossary of terms
- AS/NZS 3500.1 — Part 1: Water supply
- AS/NZS 3500.4 — Part 4: Hot water supply systems
- AS/NZS 4020 — Testing of products for use in contact with drinking water
- AS/NZS 4234 — Heated water systems – calculation of energy consumption
- AS/NZS 4445.1 — Solar heating – Domestic water heating systems – Part 1: Performance rating procedure using indoor test methods
- AS/NZS 4692.1 — Electric water heaters – Part 1: Energy consumption, performance and general requirements
- AS/NZS 4692.2 — Electric water heaters – Part 2: Minimum Energy Performance Standard (MEPS) requirements and energy labelling
- AS/NZS 5601 — Gas installations
- AS/NZS 60335.1 — Household and similar electrical appliances – Safety – General requirements
- AS/NZS 60335.2.21 — Household and similar electrical appliances – Safety – Particular requirements for storage water heaters
- AS 1357.1 — Valves primarily for use in heated water systems – Protection valves
- AS 1357.2 — Valves primarily for use in heated water systems – Control valves
- AS 1361 — Electric heat-exchange water heaters: For domestic applications
- AS 1056 (series) — Storage water heaters
- AS 3498 — Authorisation requirements for plumbing products – Water heaters and hot-water storage tanks
- AS 3565 — Meters for water supply

-	AS 4032.3	Water supply — Valves for the control of hot water supply temperatures
-	AS 4552	Gas fired water heaters for hot water supply and/or central heating Standards applicable to heat pump water heaters.

Relevant US/international standards:

-	ASTM E1056 – 13	Standard Practice for Installation and Service of Solar Domestic Water Heating Systems for One- and Two-Family Dwellings
-	IAPMO/ANSI S1001.1	Design and installation of solar water heating systems
-	IAPMO IGC 190	Air base solar thermal collectors
-	IAPMO PS 96	Passive direct solar water heaters
-	ICC 900/SRCC 300	Standard for solar water heating systems
-	ICC 901/SRCC 100	Standard for solar thermal collectors
-	IPC	International Plumbing Code
-	ISO 9459	Solar heating – Domestic Water Heating Systems
-	ISO 9806	Solar Energy – Solar Thermal Collectors – Test methods
-	ISO 9808	Solar Water heaters – elastomeric materials for absorbers, connecting pipes and fittings
-	ISO 22975-1	(AS/NZS 4445.1 equivalent) Solar energy - Collector components and materials - Part 1: Evacuated tubes - Durability and performance
-	ISO 22975-2	Solar heating – Domestic water heating systems – Part 2: Heat-pipes for solar thermal application - Durability and performance
-	ISO 22975-3	Solar energy – Collector components and materials – Part 3: Absorber surface durability
-	UPC	Uniform Plumbing Code

3. Product Familiarisation

Understanding the components is vital before optimization can be carried out. The following explains the components of a SWH system.

3.1 Components Of A Solar Water Heating (SWH) System

The main components of a Solar Water Heating (SWH) system are:

1. Collectors (flat-plate type or evacuated-tube type).
2. Mounting Structures for different types of surfaces (roofs, ground, etc.).
3. Tanks (Stainless steel, Enamel lined, Galvanized iron) and Anodes.
4. Backup water heater. (electric or LP Gas)
5. Valve types (Non-return, Pressure Reducing, Isolation Gate, Thermosiphon Restrictor, Temperature–pressure relief, Expansion Control, Thermostatic Mixing, Air bleed).
6. Pipework and Insulation.
7. Pumps and Controllers.

3.2 What Are Collectors?

Solar collectors capture the sun's electromagnetic energy and convert it to heat energy. The solar collectors form a very important part of the SWH system.

There are 2 main types of collectors:

- Flat-plate collectors.
- Evacuated-tube collectors.

3.2.1 Flat-Type Collectors

Flat-plate collectors (Figure 5 and Figure 6) are designed to heat water to high temperatures and may even reach 100°C (212°F) at which point the water boils and becomes steam at sea level. A typical flat-plate collector size is 1m x 2m. Various parts of a flat plate collector are shown in Figure 5.

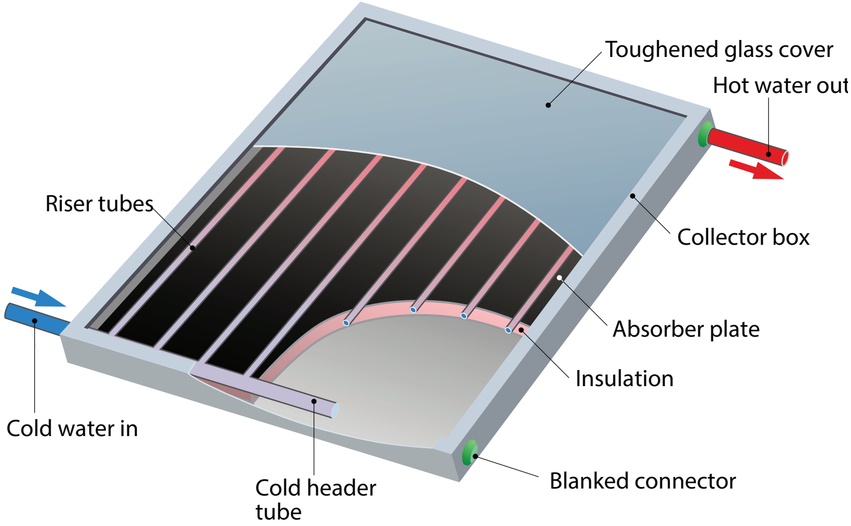


Figure 5: A Typical Flat-Plate Collector

Figure 6: Flat-Plate Collector Photo

A flat-plate collector includes:

a. Collector box - A box or frame that holds all the components together. The material is chosen for its environmental durability as well as its structural characteristics.

b. Transparent Collector cover - A transparent cover – usually tempered glass – over the collector box that allows the sun's rays to pass through to the absorber plate while greatly reducing the heat that is lost from the plate through convection and radiation. In general, the sun's heat energy passes quite easily through the collector cover as short-wave light. Heat energy re-radiates from the collector absorber as long wave infra-red energy. Glass prevents most of those long waves from leaving the area of the collector absorber, thus trapping the heat so it can be absorbed by the fluid in the collector tubes. The transparent cover, typically a single layer of glass, therefore serves as an insulation layer to allow the water to become substantially hotter than the surrounding air. However for some types of water heating installations, e.g. swimming pool heaters, the temperature must be only raised a few degrees and in that case there may be no expensive transparent cover installed as the heat losses remain small when the temperature difference between the surrounding air and the collector surface is small.

c. Insulation - Material between the absorber plate and the surfaces it is mounted on that blocks heat loss by conduction thereby reducing the heat loss from the collector box. The insulation must be able to withstand relatively high temperatures, so insulation that cannot handle the high temperatures, such as Styrofoam, is not suitable. Materials that are good insulators and are suitable for this purpose are rock wool or fibreglass. Typical insulation thickness is around 50mm.

d. Absorber plate - A flat, usually metal, surface inside the collector box is coated so it can efficiently absorb solar energy to produce heat and then transfer high levels of that heat to water. The absorber material may be painted black with a semi-selective coating or it may be electroplated or chemically coated with a spectrally selective material (selective surface) that increases its solar heating capacity by greatly reducing re-radiated heat from the absorber plate while retaining its ability to absorb solar energy efficiently.

e. Riser tubes - Highly conductive metal tubes (usually copper) in contact with the absorber plate through which the working fluid flows. The tubes remove heat from the absorber plate and transfer the heat from the absorber to the fluid. The collector may also incorporate headers, which are the fluid inlet and outlet tubes that connect all the riser tubes in parallel. Header tubes may also be referred to as the manifolds.

3.2.2 Evacuated-Tube Collectors

Evacuated-tube collectors generally have a smaller solar collecting surface because that surface must be encased by an evacuated glass tube. They are designed to work at higher temperatures (approximately 150°C) within the heat pipes. Common sizes of collectors are around 10, 20 and 30 tubes per collector.

Each tube includes the following elements:

- Highly tempered Glass vacuum tube.
- A metal tube with an absorber surface placed inside the vacuum tube.

The common principle in the two types of evacuated-tube systems (described below) is that the glass tubes have a vacuum that very effectively protects against heat loss.

Evacuated-tube collectors are of 2 types:

1. Evacuated tube with a heat pipe type of collector

An evacuated heat pipe collector is made up of a copper heat pipe that contains a very small amount of liquid (often a small amount of water/alcohol mix). The heat pipe is encased in a two layer evacuated and hardened glass tube just like is used to insulate a Thermos® flask. The metal heat pipe has a selective surface that efficiently absorbs the sun's energy and heats the fluid inside. This causes the fluid inside the pipe to vaporize and then the vapour rises by convection to the part of the pipe that is located inside the water tank. When the vapour rises in the tube into the tank, the much cooler water in the tank condenses the vapour thereby extracting its heat and getting warmer. The condensed liquid flows back down the pipe to be once again converted to vapour and the cycle repeated. In this type of solar water heater, the heated water never moves through the collector pipe, the heat itself is moved from the collector pipe to the water tank by the liquid/vapour/liquid cycle that continues as long as the sun heats the heat pipe surface. The evacuated glass tube is included because it greatly reduces the heat lost from the collector heat pipes and allows the heat pipes to be hot enough to vaporize the heat exchange liquid. The vaporization/condensation cycle is repeated as long as the sun is heating the surface of the heat pipe tubing thus creating a highly efficient thermal engine for transferring the sun's energy from the tubes to the water in the tank. This process requires the tubes to be at a minimum of 20° tilt so the vapour rises properly to the top of the tube. The thermal efficiency increases somewhat as the tilt is increased but increasing the tilt may also reduce the absorption of solar energy over the day, so usually in the islands, they are tilted between about 20° and 40°.

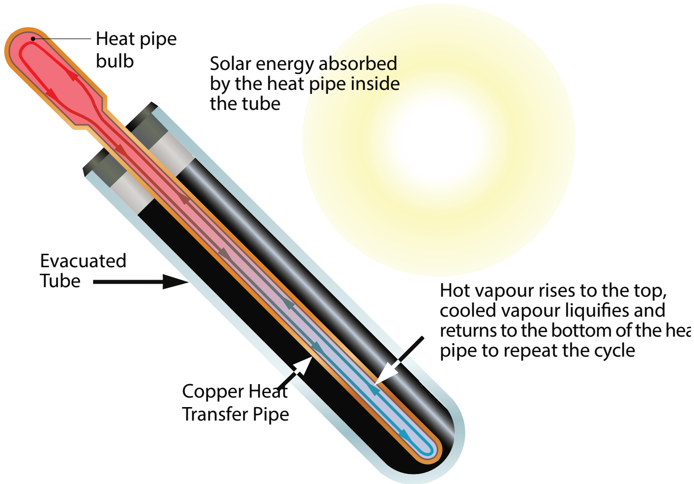


Figure 7: The Operating Principle Of A Heat Pipe Mounted In An Evacuated Tube

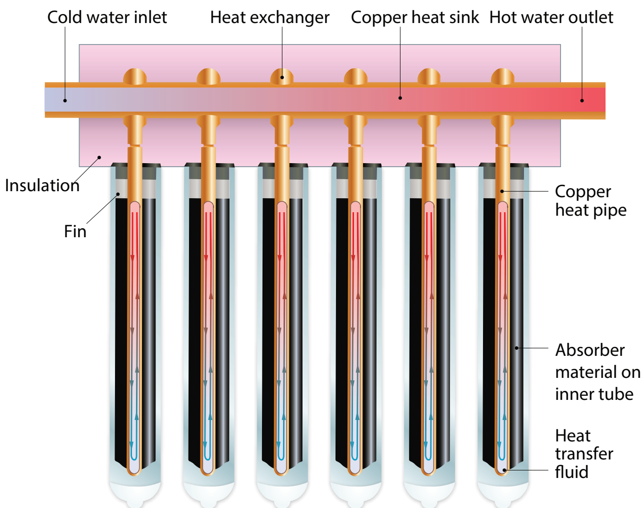


Figure 8: Evacuated Heat Pipe Collector

2. Evacuated U-tube collector

In this type of arrangement there are two manifolds covered by insulation. The manifolds are connected together by a series of 'U'-shaped tubes, as shown in Figure 9 and Figure 10. Cold water enters from one side and after absorbing the sun's energy exits as hot water from the other side into the hot water manifold.

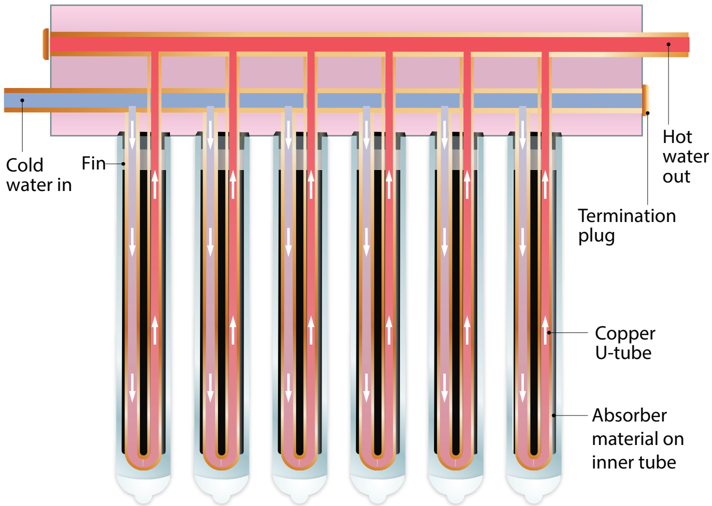


Figure 9: Evacuated U-Tube Collector Section View

Figure 10: Evacuated U-Tube Collector Photo

3.3 Tanks and Anodes

Water storage tank can be made of different materials. These can be:

Stainless Steel Tanks - This tank type is inert to rusting when the water quality is good. However, if the pH is less than 6.0 (acidic), these tanks are prone to corrosion. A simple but effective technique to increase the pH of the water would be to lower a concrete building block in the tank and allow it to slowly leach lime to neutralize the acidity in the water. These tanks are not recommended for water having a chloride content greater than 250 mg/L (salty water) as this may corrode the stainless-steel tank.

Galvanized Iron tanks - These tanks are cheaper to manufacture but can become prone to rust as the zinc galvanizing may break down over time when using with hot water. Any welding joints should be re-galvanized after the welding process.

Enamel lined tanks - These tanks are able to withstand corrosion from heat and poor-quality water due to the enamel coating inside the tank. But long-term expansion and contraction of the tank due to wide temperature changes cause the enamel coating to crack making them prone to corrosion. This problem can be overcome by using a **sacrificial anode** inside the tank.

Sacrificial anodes - Sacrificial anodes refer to a metal rod that is placed within a tank to protect the tank from corrosion. They are typically constructed of magnesium with small percentage of manganese, aluminium or zinc. These work on the principal of having a higher reactivity (corrosion tendency) than the tank material. This concept can be better explained by the galvanic series which lists the different metals starting from the most noble to the most active.

Increasing reactivity ↓

Noble, cathodic end
Platinum
Gold
Titanium
Silver
Nickel
Bronze
Copper
Tin
Mild steel and cast iron
Cadmium
Aluminium alloys
Zinc
Magnesium
Active, anodic end

Figure 11: Simple Galvanic Corrosive Table

For example, if the tank is made out of cast iron, all the metals below it can be used as a potential sacrificial anode material, but the further away one gets from the tank material, the better sacrificial anodic properties are achieved. In other words, magnesium is a better sacrificial anode than aluminium due to its relative distance from cast iron.

Powered anodes, or impressed current anodes, are non-sacrificial. The metal of the anode is titanium and theoretically will last the lifetime of the hot water cylinder. Powered anodes use an electrical supply to produce a very low current into the water to replace the electrolytic current produced by sacrificial anodes. It is good practice to remove the sacrificial anode (if already installed) from the hot water cylinder to maximise protection.

3.4 Evacuated-Tube vs Flat-Plate Collectors

Table 1 summarizes the advantages and disadvantages of evacuated-tube type collectors compared with the flat-plate collectors.

Table 1: Evacuated-Tube Collectors' Advantages and Disadvantages.

Advantages	Disadvantages
Evacuated-tube collectors are able to retain more heat than the flat-plate collectors and are more efficient in cooler climates.	The evacuated-tube collectors are more prone to damage from severe weather (like hail, strong winds etc.) and handling due to their more delicate construction.
The shape of evacuated-tube collectors ensures that the solar radiation is always perpendicular to the surface of the outer glass tube.	The evacuated tubes do not work efficiently at low tilt angles so they often have to be mounted such that the tubes cannot lie flush with the roof.
There are no problems with clogging of the collector due to minerals in the water being deposited inside the collector tubes. The actual water that is heated does not pass through the collector pipes.	For them to deliver hot water under pressure, a much more complex (and expensive) system using heat exchangers must be constructed
Repairs are limited to replacing just the tubes that are damaged, there is no need to remove the entire system for repairs. It is usually not even necessary to disconnect any of the plumbing.	

4. Design Approach and Sizing

4.1 Design Process

The flow chart below details the brief design procedure that can be adopted while designing/sizing or when confirming the parameters of a proposed SWH system.

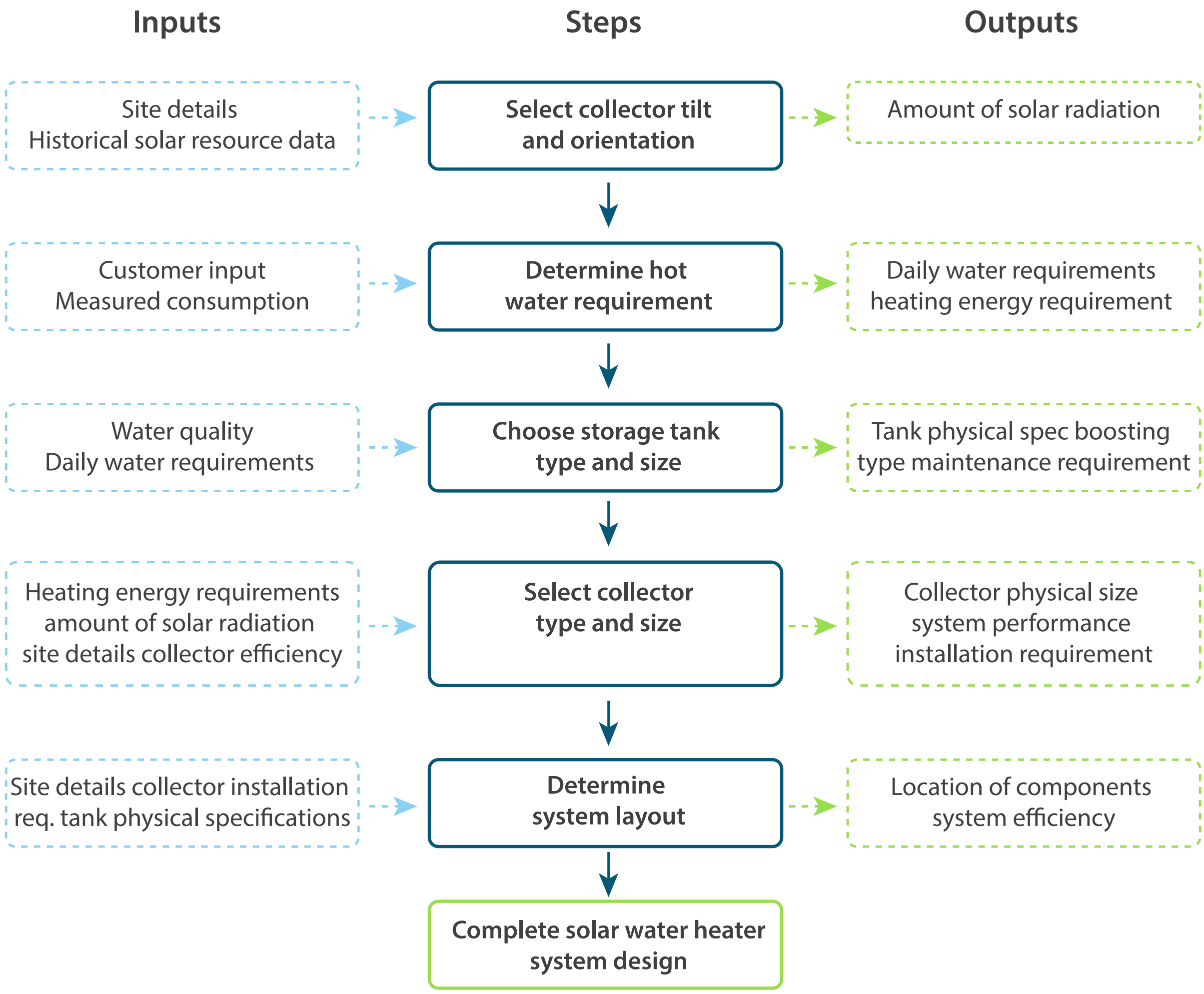


Figure 12: Flowchart Showing Brief Design Process Of SWH Systems

However, to collect some of this information, a site visit is important. The site visit will identify issues affecting design/sizing and also the available solar resource and water requirements.

4.2 Site Visit and Customer Hot Water Requirements

4.2.1 Customer Site Visit

Collating customer information is an important step in designing a SWH system. Time should be taken to conduct a detailed site survey as it can help make informed choices about the size, type, location and orientation of the SWH system.

The site survey should reveal at least the following:

- Number of residents, any special hot water needs
- Condition, slope and type of roof. Any shading issues and best direction for solar.
- Information on the existing plumbing and hot water tank, if any.
- Information on the local water pressure and quality and whether the residence has an elevated storage tank for mains water and/or a pressure pump.

Once the above has been completed by the system designer, it allows the designer to select which type of system is required: active or passive and whether a direct or indirect water heating system is best. Before selecting a system, it is necessary to consider a few key design points.

Some important considerations

A passive SWH system with direct water heating and tank connected to the collector to form a thermosiphon loop is by far the most common and practical choice for residential applications. However, other considerations when selecting the type of system include:

- Is the roof strong enough to hold the weight of a water tank?
- If not, where is the most suitable place on the ground for a tank, given that the existing hot and cold-water plumbing must be connected?
- Is there a section of the roof that is positioned to make it possible for the collectors to have a suitable orientation to the sun?
- Are there nearby shading considerations that may require extra collectors to be used?
- Is the roof tilt suitable or will a tilted mounting frame be required? (Minimum is 15° for a flat plate and 20° for evacuated tube collectors in a Passive (thermosiphon) SWH).
- If not, consider a batch water system which does not require a minimum tilt; the batch water system contains a tilted black tank in an insulated box lined with reflective foil.
- Is there an existing tank that is old and needing replacement?
- If the tank is in a good condition, is it suitable for a solar retrofit to be considered?
- If the existing tank is suitable are there extra hot water demands that requires that a larger system (and hence tank) should be installed?
- Does the quality of the local mains water (clean, suspended dirt, high mineral content, etc.) affect the choice of tank and collector material or would a propylene glycol based indirect heating system be more suitable?
- For commercial installations: where is the best location for tank(s) and collectors given the higher volumes of hot water required.
- Wind loading issues: these are very important to consider for the safe operation of the SWH system particularly in locations where cyclones/typhoons are likely. Solar water heaters high up on the roof can act as a wind sail and can potentially damage the roof. So, an edge zone of a 500mm minimum should be maintained when installing the collectors on the roof. If the installation is in a very windy area (top of a hill) or subject to cyclones/typhoons, a structural engineering calculation should be undertaken. At the very minimum, follow the manufacturer's instructions for high wind locations.

4.2.2 Siting the Collectors and Determining Collector Tilt and Orientation

Knowing the site-specific solar resource is important in designing SWH systems. Site-specific solar resource data may be obtained from in-country meteorological departments as well as websites that allow access to solar databases. Appendix 1 provides monthly solar irradiation data for a number of Pacific Island countries. Sometimes the solar radiation data also provides adjusted values for different collector orientations. This is valuable information for estimating the yield for SWH systems where the collectors are installed on a specific slope, or for finding the optimal angle to position collectors at a certain time of the year. Knowing how much solar energy is received on an area enables a solar water heating system to be sized to either displace a set amount of energy, or to heat a predetermined amount of water.

Solar collectors should be positioned to face the Sun over the course of each day to maximise the use of the available solar resource. Specific site constraints will affect the amount of solar resource that can be collected. The placement, orientation and inclination of the solar collectors at a site will be affected by:

1. Roof pitch and collector tilt angle

Solar collectors are best oriented such that the collector is perpendicular to the incoming sunlight. The altitude of the sun changes throughout the year and the altitude of the sun at any time on any given day can be calculated based on the latitude of the installation site. This means that solar collectors generally have the best annual output if they are placed at the same tilt angle as the latitude angle of the site and are oriented to face that tilt toward the equator. However, for aesthetic reasons and for ease of installation, the collectors are often installed flush/parallel to the roof as long as the roof tilt meets the minimum tilt angle required for the type of collector that is installed. Fortunately, for sites in the tropical islands, the reduction of solar input when not received at optimum tilt and orientation is not great and can be easily overcome by the use of a slightly larger collector area than would be needed if the orientation and tilt were optimal.

Manufacturers will specify the range of tilt angles and orientations that are acceptable for the solar collectors, based on where they are installed. Typical specification is within ± 20° from latitude angle and within ± 45° from the direction facing the equator although in general they should not have a tilt less than 10° so rain will run off fast enough to keep the glazing clean. Note for sites with latitudes between 0° and 10° the collectors can face either north or south. The manufacturer will also require a minimum tilt angle for thermosiphon SWH systems. This requirement must be adhered to in order for the system to function. Typically, this is 20° for evacuated tube heat pipe systems and 15° for passive flat plate thermosiphon systems. Greater tilts may provide higher efficiency, particularly for evacuated heat pipe systems. For further information about the effect of collector tilt on operation of the system, see the manufacturer's installation instructions.

The collector angle and orientation to be used is required in order to determine the amount of solar radiation received by the collectors at the installation site when installed in the proposed plane.

2. Available installation space

The dimensions of unobstructed roof space that is facing within 45° east and west of the direction of the equator should be determined. The location of obstructions such as roof ventilation shafts, chimneys, etc. should also be noted, as well as any other areas that must be avoided.

When calculating the amount of available roof space, remember that a minimum edge zone of 500 mm should be kept clear when installing the collectors on the roof. If the installation is in a very windy area (e.g. the top of a hill) or subject to cyclones/typhoons, a structural engineering calculation should be undertaken. At the very minimum, follow the manufacturer's instructions for high wind locations.

Knowing the dimensions of the space available will ensure that the solar collectors will fit on the roof space.

3. Local shading

Solar collectors should be installed in a position that is shade-free for at least three hours both sides of solar noon, i.e. from around 9am to 3pm. This is the time of the day when the Sun is highest in the sky, throughout the year. This makes it possible to obtain the maximum production from the SWH system. Check for potential shading objects such as trees, other buildings, and boundary walls.
The effectiveness of the collectors is greatly reduced when they are shaded.

Always ensure a shade analysis that considers the movement of the sun over a full year has been carried out. Shading analysis tools, such as the Solar Pathfinder, can identify shading objects and make it easy to prepare a sun path diagram to determine the occurrence of shading throughout the year.

Worked Example 1

A house in the Pacific is being considered for solar water heater installation. The house has a flat roof. The roof does not have any obstacles (no shading) and is structurally sound for installation. Putting the SWH flat on the roof will not be a good decision as the thermosiphon effect will not operate when the solar collectors are mounted flat.

A typical installation is shown below.

Figure 13: Typical Installation On A Flat Roof

4.2.3 Determining Hot Water Requirements

The daily hot water requirement is a key parameter for system sizing. The best way to obtain this data is to install an inline water meter that logs the water usage for weeks or months. However, due to the time it takes to gather the data and the additional cost involved, this is not always practical.

Guidelines exist on residential water usage (based usually on the number of occupants) to help estimate the hot water demand of households. A SOPAC Technical report (2000) estimated usage of around 38 litres per person per day in a study done on solar water heaters in Fiji and Tonga. This may vary from country to country depending on the climate and the life style. Alternatively, the average of 40-50 litres per person per day can be used as a rule of thumb.

Actual hot water requirements may differ from these figures and should be confirmed with the customer. A more accurate estimate of the hot water consumption can be obtained by asking the system owners questions about the household's hot water usage habits. Forms and questionnaires can also be created to more accurately estimate the hot water consumption and any seasonal variations.

Worked Example 2

A family of 4 people lives in a house that has 3 bedrooms. Let's estimate the hot water demand per day for this family:

Step 1: Identify the building type.
In this example it's a domestic residential house, so the daily hot water demand is assumed to be 40L per person.

Step 2: Specify the number of persons. In this case it is 4

Step 3: Multiply values from step 1 and 2: 40 L (10.6 gal) of water per person x 4 persons = 160 L (42.4 gal) per day.

4.3 Selecting the Tank and Determining the Collector Size

When selecting the storage tank for a solar water heating system, the designer needs to consider the tank material as well as the holding capacity of the storage tank. The tank material selected will be based partly on the water quality at the site and partly on customer budget. In residential systems, vitreous enamel lined tanks are the more common choice due to their affordability. Marine grade stainless steel tanks are considered to be higher in quality as they are more resistant to corrosion and require less maintenance as they do not require sacrificial anodes. Vitreous enamel storage tanks are recommended in areas with poor quality water due to the enamel coating inside the tank that resists damage. However, the sacrificial anode will need to be replaced regularly to combat corrosion.

Once the hot water requirement has been estimated, calculations are required to determine the size of the collectors and the tank, so that enough water will be heated and stored. The processes involved include:

- Calculating the required tank capacity in relation to the daily hot water demand.
- Matching the collector size to the storage tank size to meet the hot water requirements.
- Understanding that the collector size may have to be increased if a non-ideal location or shading exists.
- Assessing whether retrofitting SWH to an existing hot water tank is practical or whether a new tank must be installed.

4.3.1 Estimating the Tank Capacity For Solar Water Heating System

The storage water tank for solar water heating systems needs to be sized to cater for the hot water needs of the customer. As a general rule of thumb, size the storage tank to equal 1.5 times the daily hot water requirement of the building in Litres/Gallons per day. Then round that up to the nearest equal or larger tank size.

Worked Example 3

A family of 4 people lives in a house which has 3 bedrooms. Estimate the capacity of the hot water storage tank (for one day).

Step 1: Use the rule of thumb of sizing 1.5 times the daily hot water storage demand to get the tank size.

In worked example 2, the daily hot water requirement is 160 L per day. So, the tank capacity should be, = 160 x 1.5
= 240 L (63.4 gal)

Step 2: Rounding up the obtained value to a commonly available sized tank.

We round the value obtained in Step 1 to 300L (80 gal) as this is a commonly available size.

Some typical tank sizes available are 180L (50 gal), 300L (80 gal), 330L (90 gal), 440L (116 gal), 480L (130 gal), etc., however these sizes may vary from one manufacturer to another.

4.3.2 Estimating the Collector Size for a Solar Water Heating system

Solar Collectors are the most important part of the SWH system as they capture the sun's energy and heat the water. The collectors heat the required daily volume of hot water during the sunlight hours and then store this in the well-insulated hot water storage tank.

For an initial estimate of the size of the collectors, a simple rule of thumb is:

- 1 m^2 (10.8 ft^2) flat plate collector per 80 L (21.2 gal) of tank capacity or
- 10 evacuated tubes per 100 L (26.4 gal) of tank capacity.

Worked Example 4

A family of 4 people lives in a house which has 3 bedrooms. Estimate the size of collector for daily hot water need for both flat and evacuated tube type solar collectors.

For Flat plate collectors:

Step 1: Use the tank value calculated in worked example 3 and utilize the rule of thumb to obtain the area of the flat plate collectors. The tank size recommended was 300 L (80 gal) per day. So, the collector size would be, = 300 ÷ 80
= 3.75 m^2 (40.4 ft^2)

Step 2: Rounding up the obtained value to a commonly available size
We round the value obtained in Step 1 to 4m^2 (43 ft^2) as 2m^2 (21.5 ft^2) collectors are commonly available. Therefore 2 x 2m^2 collectors can be used to satisfy this requirement.

For Evacuated tube collectors

Step 1: Use the tank value calculated in worked example 3 and utilize the rule of thumb to obtain the area of the flat plate collectors. The tank size recommended was 300 L (80 gal) per day.
So, the collector size should be, = (300 ÷ 100) x 10
= 30 tubes

Common numbers of tubes per collector are 10, 22, 30, and 44.

4.3.3 Provision For Collector Size In A Non-Ideal Location Or If Shading Exists

The above sizing for collector and tank assumes that the solar collectors are facing the equator and are at an optimum tilt angle. However, in a real scenario, this probably will not be the case and there also may be some shading so that there is less than optimal exposure to sunlight.

The best practices for sizing, as mentioned previously will likely change if:

- Roof does not face within 25° of the equator.
- Roof tilt angle is greater than 20°.
- Shading from surrounding trees or buildings is present.
- Locations have substantially more or less solar peak sun hours than assumed.

For instance, on a roof tilted at 30° and facing west, or experiencing shading for half the day, it would be best practice to reassess the available solar resource and add extra collectors on the roof to compensate for the loss in the heat energy due to sub-optimal tilt/orientation.

4.4 Determining System Layout

When locating the storage tank and collectors it is important to consider any pipe run requirements, roof integrity, as well as the location of existing water and electricity connection points. To reduce heat loss in pipes, the storage tank should be located as close as is practical to the points of hot water use, such as the kitchen, laundry and bathroom. Similarly, the length of pipework between solar collectors and tank should also be minimised in order to keep both costs and heat losses down.

4.4.1 Pipework Sizing

Only copper pipes with insulation should be used on the hot water side, as plastic pipes cannot withstand the high-water temperatures and pressures that can occur.
Consider the following when sizing pipework diameters:

- Pipe diameter between the storage tank and the solar collectors needs to be sized appropriately taking the following into consideration:
    - Flow rate needed
    - pressure
    - pipework length
- Flow and return line diameters in a non-thermosiphon SWH system should be a minimum of 15 mm (0.6 inch) copper for mains pressure and pumped systems. The velocity and pressure of water flow between the storage tank and collectors can vary greatly in SWH systems.
- Pipework in a system driven by thermosiphon flow needs to be larger, typically 25 mm (0.98 inch) diameter.

The SWH system manufacturer will provide guidance on the suitable pipe diameter for the expected pressure, flow rate and pipework length. Always follow the manufacturer's recommendations.

4.4.2 Selection of Circulation Pump

Similar to pipe sizing, manufacturers will provide guidance on selection of the circulation pump in split systems based on the system configuration. If the installation of an alternative circulation pump is desired, consult the manufacturer to ensure compatibility between the SWH system and the chosen circulation pump.

4.4.3 Pipe Insulation

All exterior piping insulation must be protected from environmental and ultraviolet ray degradation by using purpose-made UV resistant coatings, paints or shielded wraps. All pipes between the hot water storage tank and collectors must be insulated for efficient operation (Figure 14).

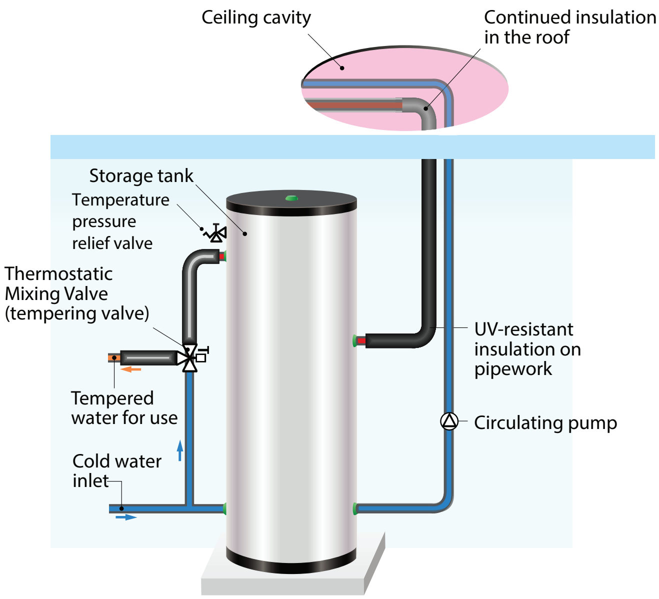


Figure 14: Typical Pipe Insulation

Continuity in pipework insulation must be maintained, although sometimes many lengths may need to be joined to cover the full length of pipework. In those instances, the joint should be taped and UV resistant tape used where the joint is made on external pipework. Where pipework penetrates the roof material, the insulation should go through the penetration with the pipework using feed through materials that can be sealed against leaks.
Typical insulation thickness should be between 13 mm and 25 mm (0.51 inch to 1 inch).

Insulation is always required on hot water pipework at the following locations:

- Between solar collectors and the tank.
- Between storage tank and auxiliary heating element (e.g. gas or electric booster element).
- Within 500 mm (19.7 inches) from the hot water outlet of the storage tank that goes to the end use points, unless there is a heat trap. A heat trap, a downward bend in pipe installed close to the tank which prevents unwanted thermo-siphoning of hot water, then insulation up to and including the heat trap is sufficient.
- All vent pipes to 300 mm (11.8 inch) above the working water level.

4.4.4 Retrofitting An Existing Hot Water Tank

An existing gas or electric hot water tank may be used if it is in good condition and of an appropriate size to be connected to a SWH system. The tank and solar collector should be sized at around 1.5 times the daily hot water demand. The original storage tank will typically have only one cold inlet and one hot outlet, so a 5-way valve may need to be fitted though that can be expensive. The 5-way valve provides the necessary connections for the flow and return lines to the solar collectors through a single fitting. Figure 15 demonstrates the flow of hot and cold water in a 5-way valve fitted to the cold-water inlet of an existing gas or electric hot water storage tank.

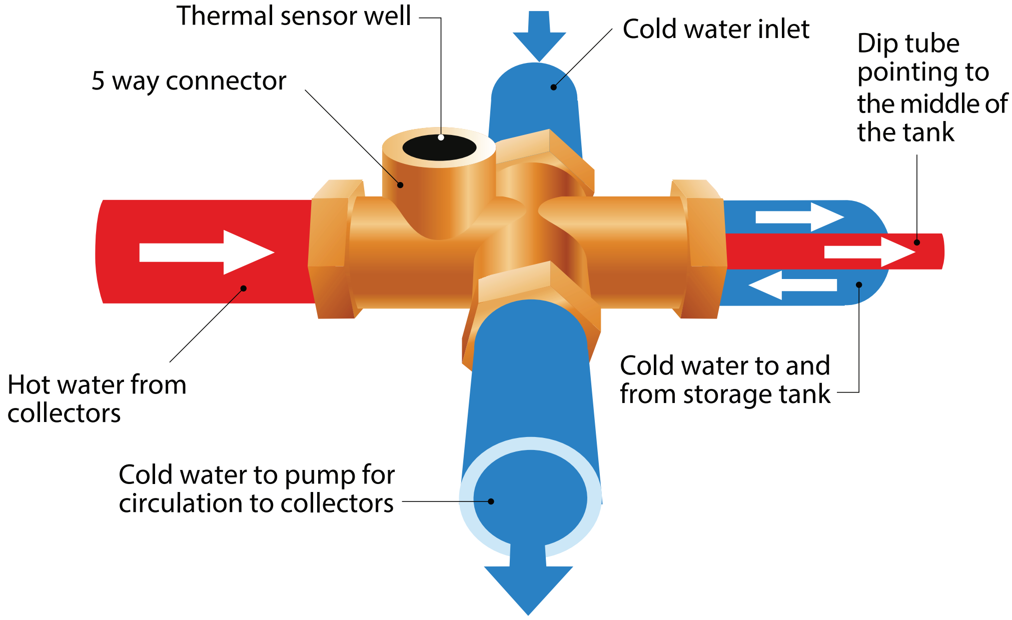


Figure 15: A 5-Way Connector

In the 5-way valve, cold water flows through one connection supplying the storage tank. The circulation pump then draws water from the storage tank through another outlet on the connector, and circulates it to the solar collectors. The heated water returns to the storage tank through the hot-water inlet in the 5-way valve, and is then directed towards the middle of the tank via a short upward turned dip tube. Figure 16 shows a five-way valve and the associated plumbing fitted to an existing electric storage tank.

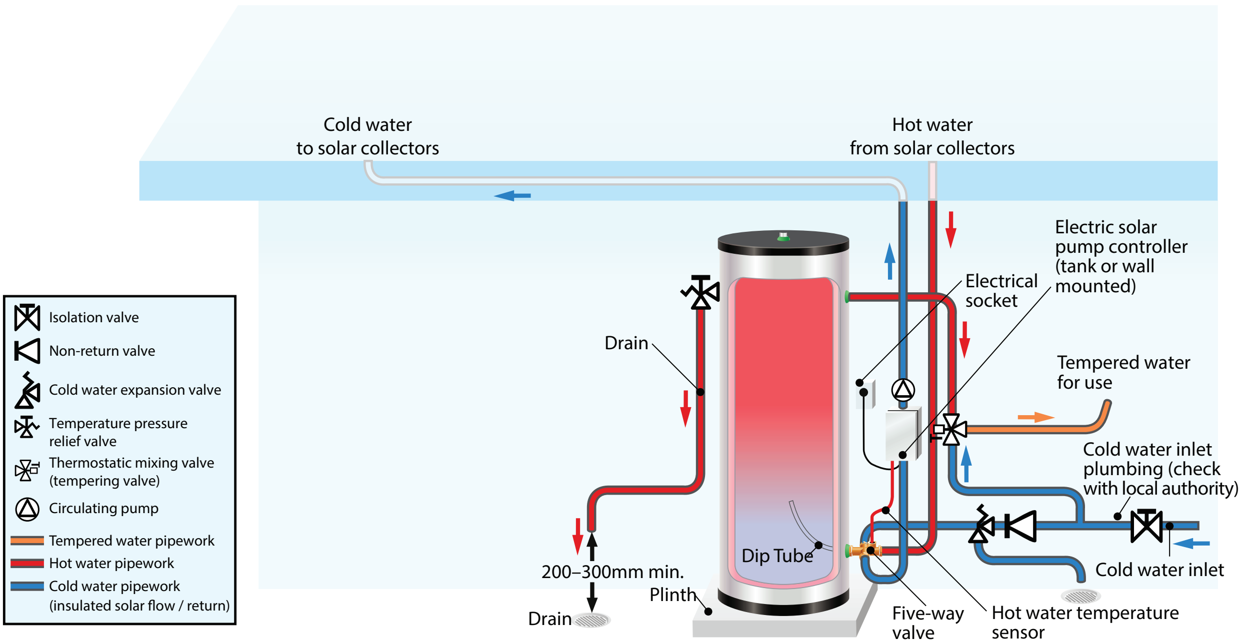


Figure 16: A Five-Way Valve Connected To An Existing Hot Water Tank With All the Connections

The 5-way valve is simple in concept as it is just an addition to an existing water tank, but the use of this valve should be assessed, as it may be expensive. Replacement of the existing hot water tank with one having the proper fittings for solar water heating may be a better solution.

4.5 Finalising Sizing and Selection

Based on tank size, collector size and type of system appropriate, a selection can be made from the range of system sizes and types available from manufacturers. Consideration should be given and the selection should be made based on efficiency, quality of products, reliability, warranty, etc. It is recommended that the customer/installer reviews and understands all specifications prior to the purchase and installation. A thorough market survey will help determine the higher quality and more reliable systems for installation.

5. Commercial SWH Systems

Commercial solar water heating systems are used for large installations such as factories, hotels, hospitals, and schools. The design process for commercial SWH systems is similar to residential SWH in terms of collector siting, matching of tank and collector and planning of the system layout.

The recommended procedure includes:

- Assessment of commercial premises' hot water demand in consultation with the customer.
- Scale up the design of SWH systems to meet the size and special requirements of larger commercial systems including incorporating backup heating sources and their controls.
- Understand the issues relating to tank sizing and placement.
- Understand the issues associated with the piping connecting the storage to the collector.
- Configure parallel connections to collectors with hot & cold manifolds if necessary.
- Determine if there is a need for a secondary hot water circulation system to supply continuous hot water to all parts of the facility, e.g. as in the case of a hotel where instantly available hot water is needed in all rooms.
- Understand the options to retrofit solar to existing commercial hot water systems.

5.1 Assessing Commercial Hot Water Requirements Of the Customer

Determining the hot water requirements accurately is crucial for a commercial SWH system. Consult with the customer and refer to hot water consumption data of all buildings to ensure that the design can fulfil the hot water usage and the required hot water temperature. For long piping runs be sure to include all anticipated losses of heat from the pipes in the design requirements.

5.2 Scaling Up For Commercial SWH Systems

Scaling up of the commercial solar water heating systems can introduce unique challenges. Some of them are:

- Need for a continuous flow of hot water 24 hours a day.
- Hot water may be needed at widely separated parts of the facility.
- There may be concentrated periods of hot water use in the morning or the evening.
- The solar collector is another source of heat, with its own controller and pump(s). This may need to be integrated with the controls for the other heat sources such as electricity, steam boilers or heat recovery units.
- Controllers for Commercial systems often have multiple input and output terminals to control backup heating. They may also have a digital storage card or other approach for updating firmware and software. These systems are mostly provided as a complete package and as such the manufacturer's instructions must be followed.

5.3 Tank and Collector Area Sizing

The hot water tank size is determined by the daily hot water demand. A greater reliance on the use of available booster systems, for example steam boilers, may allow the tank size to be reduced. Collector areas are generally scaled in the same proportion as for residential: i.e. $1m^2$ ($10.7 ft^2$) per 80 L (21.1 gal) of tank capacity though a somewhat larger collector may be needed if the pipe runs between collectors and storage are unusually long since piping heat losses will be greater than normal.

5.4 Layout Of Collectors For Commercial SWH Systems

Systems can be either: Passive SWH collector tank sets on the roof (Figure 17) or Active SWH with the tank(s) on a lower floor or even in the basement (Figure 18) with pumps to circulate the water from the tanks to the collectors and back. Good collector loop insulation is required.

Layout of collectors should ensure a balanced resistance for water through hot and cold manifold pipes. Collectors should be arranged to allow servicing between units and sections able to be isolated and worked on without having to turn off the entire SWH.

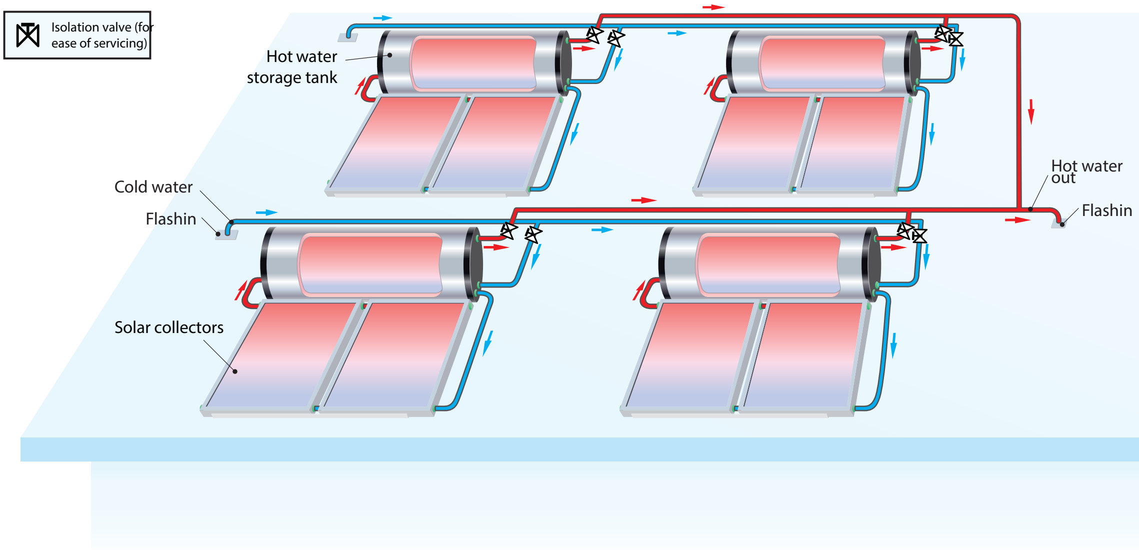


Figure 17: Passive Commercial SWH System

Figure 17 shows a thermosiphon close-coupled SWH (passive) system. The isolation valves are provided into and out of each tank so that service work can be carried out and any collector or tank removed or serviced without shutting the entire system down.

These passive systems can be used as a group to service different parts of the facility. Within the group however, the layout of collectors is important to ensure uniform hot and cold manifold pipe lengths. Consult manufacturer's recommendations for the maximum number of passive tank/collector array in series.

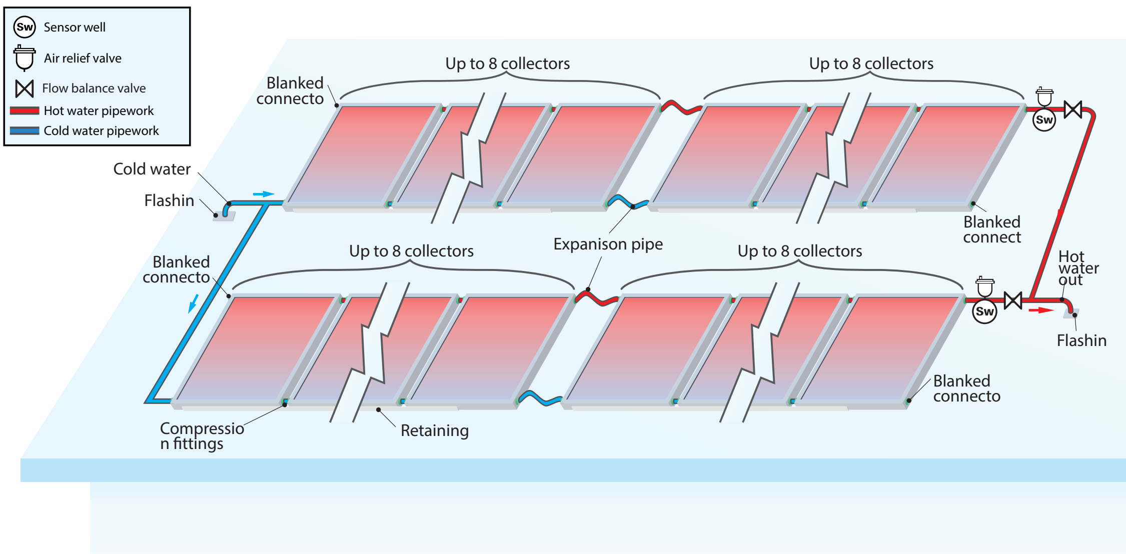


Figure 18: Active Commercial SWH System

For an active system the large tanks would ideally be installed as close to the array as practical. Often, however, the tanks are in the basement with other backup heating, steam boilers and other utilities. Good insulation on the pipework is essential because of the volume of water and distances of pipe run.

The layout of collectors should ensure balanced resistance for water through hot and cold manifold pipes. Cold water should enter the array and hot water leave the array at diagonally opposite corners. Flow balance valves can be useful when used during commissioning to ensure even flow rate through each array. The maximum number of collectors that can be connected together is typically 5–8. Always follow the manufacturer's instructions.

An expansion joint needs to be included after a few collectors to accommodate the thermal expansion of the metal frames and the joints.

5.5 Understanding The Basic Function Of Secondary Circulation Systems In Supplying Hot Water To the Facility

Many of the commercial hot water installations require a secondary circulation pump (ring main) to reduce the amount of time it takes hot water to reach the most distant tap. Good insulation must to be used in order to ensure that, given the continual flow of water, the heat loss is minimal.

Also, designers should consider the following issues:
- Temperature of the water needed.
- Water pressure and rate of flow of water.
- Frictional losses can be high (especially if there are many 90° bends in the pipework).
- Pipe dimensions (diameter and length).

5.6 Options To Retrofit To Existing Commercial Hot Water Systems

Retrofitting solar to large existing commercial hot water tanks is usually not practical as existing tanks are unlikely to have solar collector loop outlets.

To do this would require a second heat exchange type (active indirect) system complete with a tank that has a second pump to feed water back and forth to the main storage tank. The controller would have to control both pumps. Multi-storey buildings will have to investigate the feasibility of running new pipework from existing storage tanks up to collectors on the roof.

6. Installation and Commissioning of Solar Water Heaters

6.1 Pre-Installation Checklist

Each installation will have different requirements such as site access, solar irradiance, roof tilt & orientation, water quality, availability of trained manpower, customer's requirements for hot water etc.

The designer/installer should ensure that all the above issues are addressed before the system is installed. The customer's information should be used by the designer/installer of the system to ensure that the customer's needs have been addressed and the customer has been made aware of any problems or issues before hand.

The installer should also:

- Check that the SWH product components supplied are correct and that correct installation and maintenance tools and manuals are on hand.
- Ensure that the safety risks on the site are assessed using a Job Safety Analysis (JSA) worksheet or similar. Always remember that the JSA worksheet should be filled out on the day of installation and not before because environmental conditions like rain, etc. can alter the risks that may be assumed for at the site on the day of installation.
- A solar access site assessment should be completed and the customer should be made aware of any potential shading issues that might affect the yield of the system.
- The strength of the roof to accommodate the SWH system should be re-assessed before the actual installation is done. If the installer is concerned about the roof's capacity to hold the weight of a SWH tank, the retail company/system designer should be contacted. A good indicator of the roof's weight bearing capacity is that there is already a mains water holding tank installed.
- Always use the correct tools as recommended by the manufacturer. Also refer to the user manuals at all times and ensure that the manufacturer's recommendations are followed correctly.

6.2 Installation Of Collectors and Mounting Frames

A few points to remember while installing collectors on the roof/ground are:

- Collectors should be unpacked and handled with care. This is a point of particular importance if installing evacuated tubing collectors, as they are more fragile.
- For a passive thermosiphon-based system, proper lifting equipment for the collectors and tank should be used as the combined system can be heavy to lift. Always have a work partner on the site for assistance or in case of an emergency situation.
- The collectors should be kept at least 500mm from all edges of the roof, both from a service and wind loading perspective.
- The collectors should be mounted at the correct tilt and orientation for the particular location so as to ensure the best system yield. If that is impossible, the size of the collector will need to be increased to offset the lower yield due to improper orientation.
- Gloves should always be worn when handling evacuated tubing-based collectors as the pipes inside can reach temperatures of more than 150°C. As a best practice, it is recommended to remove the covering material over the tubes only while commissioning the system.
- Installation of a heat-pipe type evacuated tube collector's heat pipe system generally uses a thermal paste on the heat bulb for efficient transfer of heat and the rubber grommet needs to be moistened with soapy water so that the heat pipe can be inserted easily into the tube. On the other hand, U-tube based collectors come pre-assembled onto the manifold.
- The waterproof integrity of the roof should not be compromised at any time during or after the installation process. All the drill waste should be removed and the roof should be left in a clean condition.
- It is advisable to photograph the roof space before and after the installation process as a way of verifying that the roof has not been damaged during the installation.
- Installation of collectors should be done as per manufacturer's recommendations and guidelines.
- Considerations for different roof types:

Tiled Roofs

- On tiled roofs, the support straps or hook for the collectors will need to be screwed firmly onto the rafters (roof structure) and not to the tile battens. This will require the removal of a section of tiles at each strap to expose the rafters. The support strap should be bent to run flush with the rafters.
- When placing a tile back to its original position, ensure that the supporting strap fits snugly under the tile without lifting it up. The roof surface should be checked for lifted or cracked tiles after installation to ensure that the roof surface remains watertight.

Metal Roofs

- Installing collectors on metal roofs require screwing through the metal sheeting and into the metal or wood purlin or rafter. Mounting frames may also be used to hold the collectors by direct bolting through the roof. It is important to drill through the sheeting ridges and not the valleys to reduce the likelihood of water ingress through the roof surface (Figure 19).
  Be careful not to tighten fasteners so tight as to crush the roofing ridges out of their proper shape.

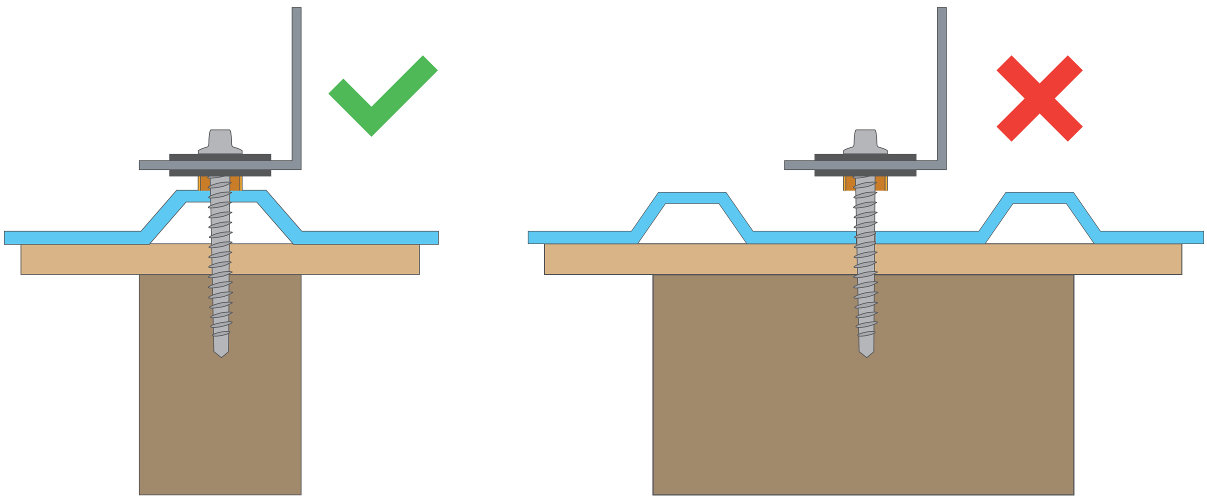


Figure 19: Screw Position On Corrugated Metal Roof

- Separation material or rubber pads should be used with the roofing screws to lift the metal frame off the roofing material to prevent galvanic corrosion between dissimilar metals (see Figure 20: Galvanic isolation of mounting screw and metal roof). All galvanically dissimilar metals need to be galvanically isolated. These include the mounting frame, collector frames, mounting support, roof brackets and the roof itself. Failure to do this can cause the roof and/or parts of the system to corrode.

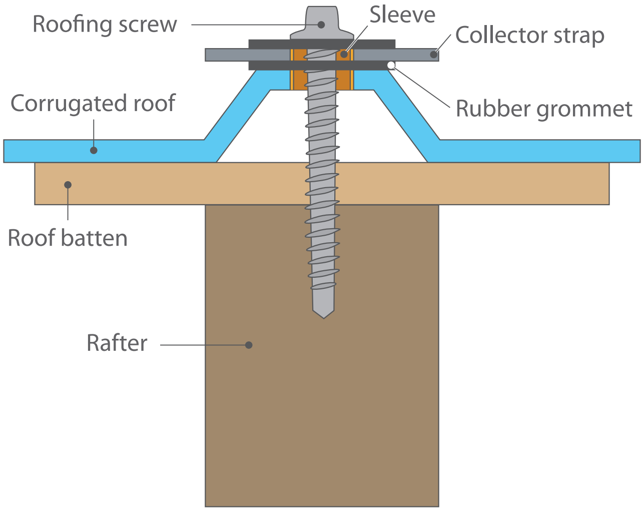


Figure 20: Galvanic Isolation Of Mounting Screw and Metal Roof

- The lower rail for Passive SWH system must be skewed (angled) by 12 to 15 mm per collector to ensure the thermosiphon effect works correctly (see Figure 21). This means that the hot return end is positioned higher than the cold entry end.

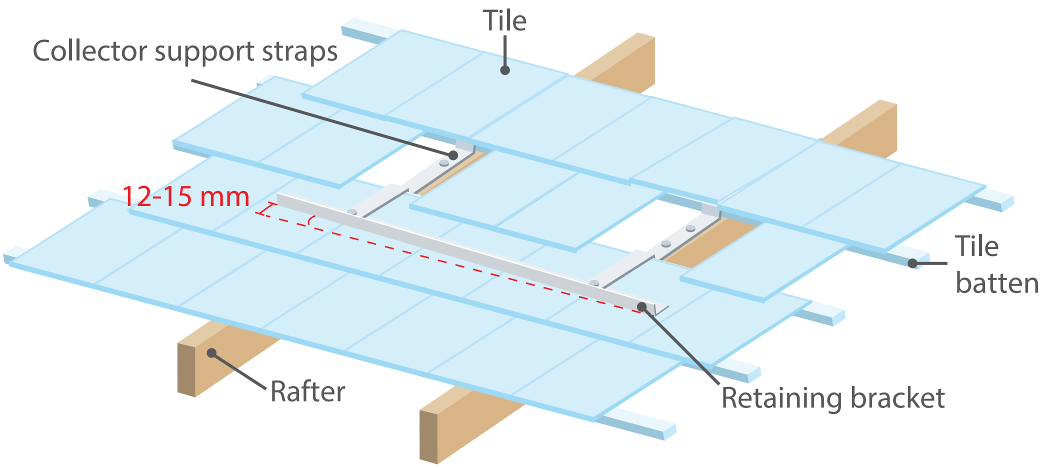


Figure 21: Passive SWH System On A Corrugated Metal Roof Installed Slightly Skewed To Ensure Thermosiphon Effect Occurs

6.2.1 Installing Rack Mounting Collectors

Mounting frames are used in rack mount systems to adjust collector tilt and orientation. They are most commonly used for systems installed on flat roofs or on the ground (Figure 22). Mounting frames can also be installed on pitched roofs to adjust collectors to have the desired orientation (Figure 23).

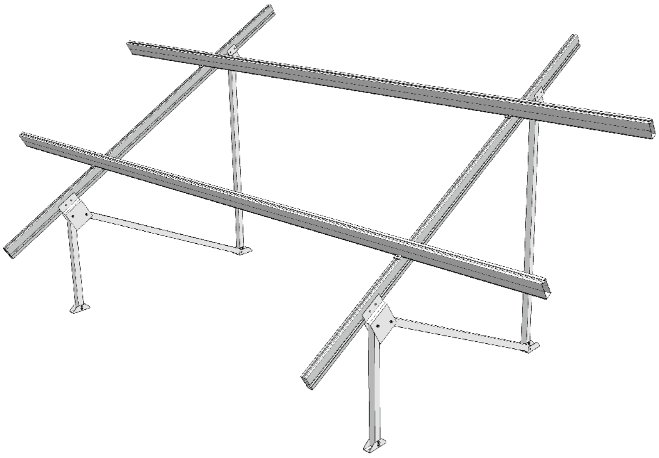


Figure 22: A Standard Flat Roof Mounting System

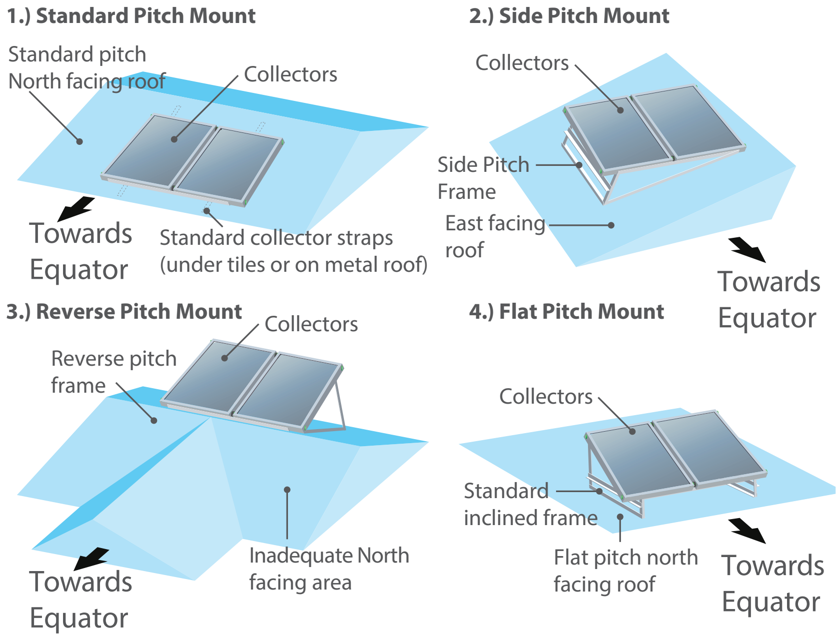


Figure 23: Mounting Of the Collectors On Different Mounting Systems Facing Equator

Mounting frames are typically attached to roofs via screws onto underlying supporting structures. However, ballasts also exist to weigh down the frame and collector on roofs where penetration of the roof surface is not desirable, such as concrete roofs.

6.2.2 Installing Collectors in Cyclone Prone Regions

Strong winds generated during tropical cyclones/typhoons can cause extensive damage to buildings and property. Additional attachments are required to support the collectors through strong winds. Manufacturers will typically specify the installation specifications that are deemed to comply with a region's wind loading requirement. However, additional assessment may be required if the manufacturer's documentation is lacking, or if the installation method shown by the manufacturer is not suitable for the installation surface. Collectors must be attached to the roof structure in a manner that is compliant with local building regulations.

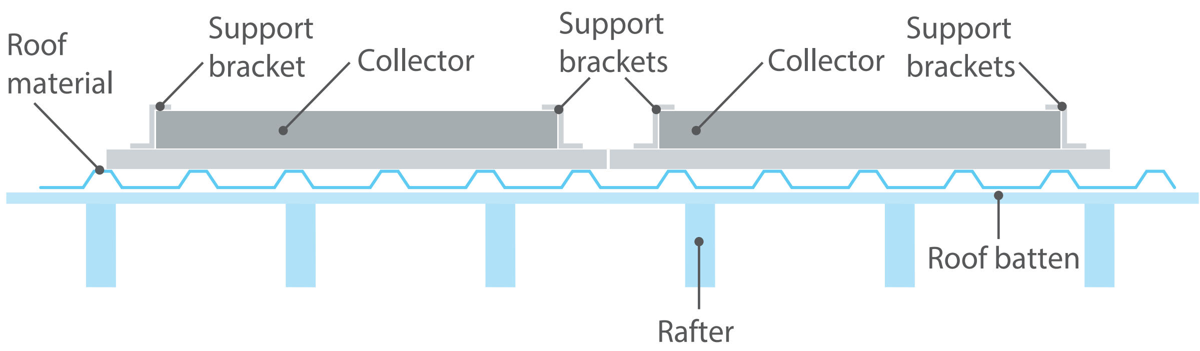


Figure 24: Side View Of High-Wind Mounting On A Metal Roof

Note: the support system is bolted through the roof material onto the rafters as required (refer figure 20).

6.3 Installation of Storage Tanks

Tanks are the heaviest component of the entire SWH system. Care should be taken with the following:

- Proper lifting equipment should be used to lift the heavy tank in a passive SWH system up onto the roof. Since the tank is mounted on the ground or floor in an active system (one using a pump for water circulation from tank to collectors), a secure and level base is required that can support the substantial weight of the filled tank.
- The tank should be positioned such that connection to inlets and outlets are easy to complete. Also, a safe separation should be maintained between the water pipes and the electrical connections.
- The pipework should be properly insulated. This insulation should include all exposed Polypropylene Random Copolymer (PPR) pipe (not UV resistant), all collector circuit pipe work, and all hot water delivery pipework.
- Care should be taken to ensure that there are no air pockets in the installed pipework.
- Care should be taken while transporting and installing tanks that have a sacrificial anode. Always transport these tanks upright to protect the anode which can easily be damaged.
- Installation of SWH tanks should be done as per manufacturer's recommendations and guidelines.

6.4 Installation of SWH balance of systems (BOS)

Some important points to consider on the installation of SWH balance of systems are as follows:

- SWH systems must use metallic pipes and fittings that can continuously withstand the maximum water temperature generated by the solar collectors. Due to the high-water temperatures that can be experienced in the collector loop, plastic pipes are not suitable in these applications and copper is usually used. There may also be restrictions on the material of pipes that connect to the SWH system.
- Roof penetrations should be watertight and secure. UV-resistant flexible rubber mouldings (such as Dektites®) can be used to make the roof penetrations watertight and secure.

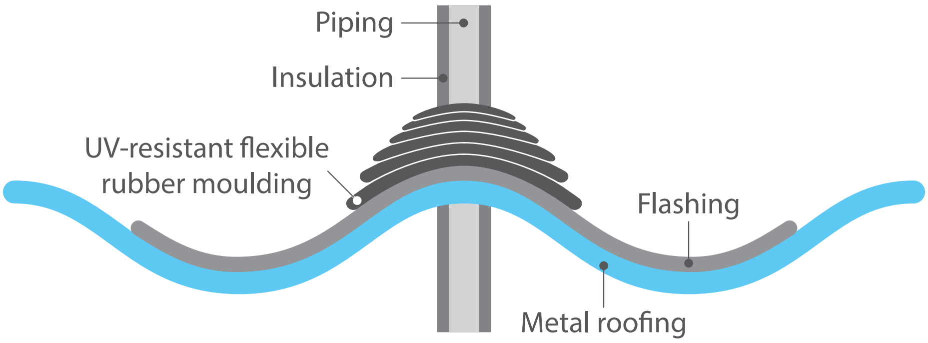


Figure 25: Making the Roof Penetration Water Tight and Secure

- All electrical work must be done by a suitably qualified electrician. Existing metallic pipes may be electrically bonded to earth. If there is a fault in the electric system, cutting through metallic pipes, or even disconnecting the water meter, can cause a fatal electric shock.
- In case of an active SWH system, the electrical connection to the pump needs to be arranged such that that it is well insulated from any water leaks or drips (Figure 26). Similar arrangements need to be done for electric booster elements as well.

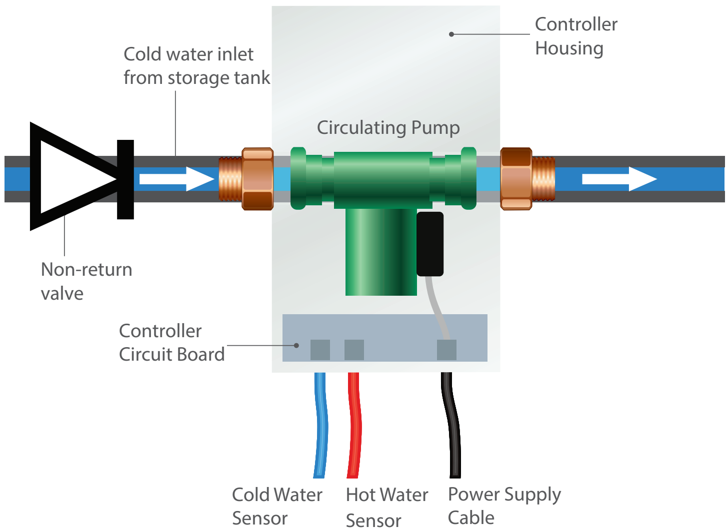


Figure 26: Circulating Pump With Hot and Cold Sensor Connections

- Different valve types like Non-return, Pressure Reducing, Isolation Gate, Thermosiphon Restrictor, Temperature-Pressure Relief (TPR), Expansion Control, Thermostatic Mixing, Air bleed etc. should be installed in in their proper locations. Also, some of these valves are optional and are only required only under certain circumstances.
- The valves should be installed in such a way that there is ample accessibility for maintenance and troubleshooting.

Figure 27: TPR (Left) and Thermostatic Mixing Valve (Right), Showing Ample Accessibility

- Installing the pump and controller for the active SWH systems to the tank jacket (Figure 28) will require that the screws used to attach these components to the tank jacket are the correct length, i.e. they cannot be too long or they may penetrate the wall of the tank and cause leaks.

Figure 28: Controller & Pump Securely Attached To The Tank Jacket

- Circulation pumps are operated by controllers that measure the temperature at the solar collector and the storage tank to determine whether pump operation is appropriate or not (Figure 29). Most system manufacturers will provide designated connection points for the temperature sensors. The connection points are typically located near the hot water output at the collector array and near the bottom of the storage tank.

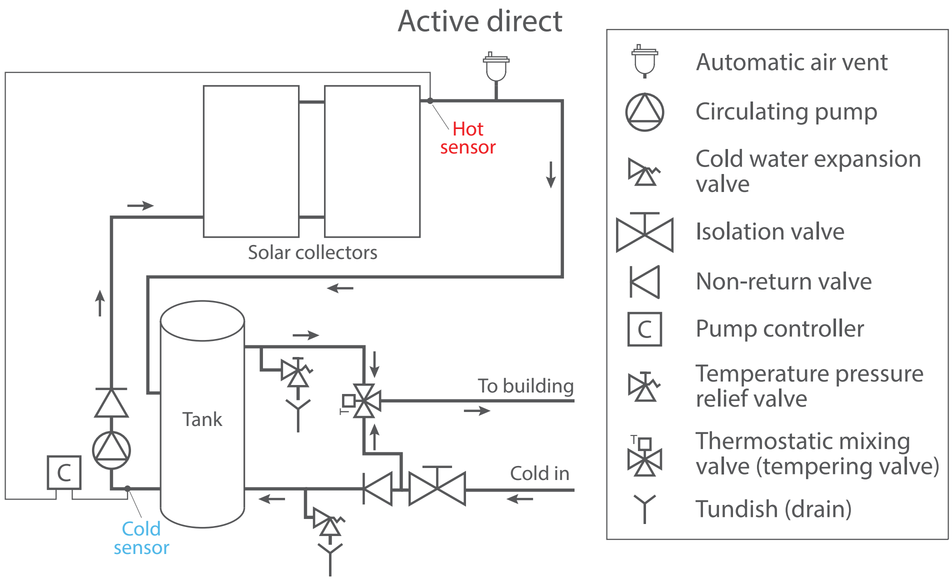


Figure 29: Location Of Controller Temperature Sensors

- Some systems have two sensors at the storage tank which allows the booster element to be operated in a more efficient manner. If a designated connection point is not provided by the manufacturer, the solar collector sensor should be installed as close as possible to the collector's hot outlet.
- It is recommended that all wiring to the pump and controller is installed in conduit to protect them from damage. If the pump is connected to an outdoor general power outlet, ensure that the connection is waterproof. The thermal sensor cable run from the roof should be secured to beams and along the wall for support. The cable run should also be kept away from the flow and return pipework as they can interfere with the temperature reading.
- If installing a five-way valve to an existing tank then all the connections need to be correctly installed. Always follow the manufacturer's user manual to know how to correctly connect a five-way valve.

6.5 Commissioning the System

Each system configuration should be commissioned according to the manufacturer's instructions, however, Table 2 summarises the recommended testing and commissioning actions for SWH systems. Neglecting these instructions may void the products' warranties.

Table 2: Recommended List Of Commissioning Actions.

Check points	Actions
Roof work	Confirm the collector orientation and tilt angle is as per design. Check the integrity and aesthetics of the roof and whether the mounting and piping has been installed properly. Ensure that the cold and hot sensors are positioned and connected properly. If the system has been filled successfully, remove covers that may have been placed over the solar collectors.
System piping	Ensure that all isolation/drain valves are closed. Confirm that all connections, piping, insulation, gauges and valves are installed as per the design.
Electrical wiring	Confirm that all system wiring is as per the schematics and has been terminated properly. Ensure sensor wiring is secure and UV protected.
Gas or electric booster	Confirm that the booster system and connections are as per the design.
Filling and turning on the system	Refer to steps below.
System control	Confirm the temperature and resistance of the sensors at the sensor location by using a thermometer and ohmmeter respectively. Confirm the control functions to ensure proper operation in the system. Confirm the pump operation and configuration.
Pressure test	Perform a pressure test with water or other working fluid. Check that the mains or working fluid pressure is within the operation range of the system. Check the operation of TPR valves.
Solar circuit	Calibrate the collector array or flow rate by using a balancing valve.

Filling and Turning on a SWH System

The steps for filling and turning on a typical **passive** SWH system are as follows:

1. Open all hot water taps in the building to allow air to be bled from the storage tank and collector.
2. Open the mains cold water inlet to the storage tank to fill the tank and collector.
3. Close the hot water tap when water freely flows after all air is expelled.
4. Check any leakage on the pipeline.
5. Open the hot water tap again to check that all air is purged from the system.
6. Turn on any boosting system that has been installed.

The steps for filling and turning on a typical **active** SWH system are as follows:

1. Follow the steps 1-4 of the passive system list to purge all air from the storage tank.
2. In an indirect system, the working fluid solution that is circulated may need to be filled in, depending on the type of system. Follow manufacturer's instructions for filling collector loop with glycol. This generally involves cracking a nut or a fitting at the highest point in the collector loop to allow air to escape while glycol is filled from a low point in the system. Glycol is filled either by a bucket connected via a hose and held at height over the system, or with specialised manual pumps.
3. Open the hot water tap again to check that all air has been purged from the system.
4. Plug in and activate the power to the solar controller and pump.
5. Turn on the heat booster system.

For an indirect system that uses a working fluid other than water, the manufacturer's instructions should be followed when filling the collector loop with the working fluid. Propylene Glycol is usually filled by a bucket connected via a hose at the height over the system or by the use of specialised manual pumps.

Note: The power supply to any solar water heater installation must not be switched on until the water heater is completely filled.

6.5.1 Leaving A SWH Unused For A Long Time

Leaving a SWH unused for a long period may result in excessive heating of the water and stagnation conditions. Build-up of pressure are relieved by the TPR valve and other pressure relief mechanisms.

At residences or schools where people are absent for weeks at a time, the booster heating should be turned off and the collectors covered.

At a new building site, where the system may not be used for some time, the system is best commissioned shortly before hand over. Collectors should remain covered until ready for use.

Follow the manufacturer's recommendations relating to how best to secure the system if it is to be unused for a long period.

6.5.2 Documentation For the Customer

Once the system has been commissioned the customer must be instructed regarding the operation and basic maintenance of the SWH. The following items should be provided to the customer:

- A Product User Manual.
- Documentation for the site and installation should be completed including the Installation certificate for compliance.
- Photos of the installation are highly recommended for future reference (Figure 30).

Figure 30: Sample Of A Post-Commissioning Photo Provided To the Customer

7. Maintenance and Troubleshooting of SWH systems

Proper troubleshooting and maintenance of SWH systems must be conducted to achieve good performance and longevity in the system. Although good installations usually reduce the possibility of system failure, problems due to manufacturing defects, improper installation, advancing age and environmental conditions may still occur.

The information provided in this section is of general nature, hence the manual and manufacturer's recommendation for the equipment's maintenance must be followed. Always follow the instructions provided by the manufacturer in order to maintain the warranty. As part of the manufacturer's requirements, all SWH system services may need to be performed by an authorized tradesperson.

7.1 Minor Service/Maintenance

Minor Service (which is typically every 6 months) includes:

- A visual inspection to ensure that there are no leaks in the system.
- Flushing of the TPR valve to ensure that this works correctly. Gently pull the lever outwards for a few seconds to release some water. To return it to its normal position, do not let it snap back as this may damage the valve seating. As this forms the primary protection mechanism, the TPR is very important for the safe operation of the SWH system.
- Cleaning of collectors should be done regularly to get rid of the dust and dirt build up to ensure that the best system yield can be achieved. Do this when the collectors are cool in the early morning to prevent thermal shock breaking the glass.
- Tree growth in the immediate vicinity of the SWH system can cause shading, so they should be trimmed regularly.
- Always read and follow the Manufacturer's Maintenance program.

7.2 Major Service/Maintenance

Major Service is typically every 3 – 7 years. Typical major service may include:

- All the connections should be inspected for leaks. The collector loop in an indirect system that uses propylene glycol should also be checked separately.
- The Inspection and replacement of the sacrificial anode should be done as part of the major service. This might need to be done more frequently depending on water quality.
- Replacement or top up of propylene glycol used with the indirect systems should be done as part of the major service.
- Since the TPR valves form the most important safety component of the SWH system they should be replaced as part of the major service.
- The solar collectors should be flushed and the air in them should be bled out so that the water flow can be made more uniform.
- A thorough check of the pump, controller and electric booster should be done as part of the major service.
- Always read and follow the manufacturer's maintenance program.

7.3 Troubleshooting of SWH Systems

There may be unexpected faults in the system therefore before going to troubleshoot a system, some questions should be asked of the user/customer to gather useful information that may assist in troubleshooting.

Some of these questions can be:

- Has it been cloudy outside? If it has, then the Solar Water Heating system may not generate enough hot water.
- Ask the customer whether extra hot water usage might have occurred on the previous night causing the tank to have been completely drained of heated water.
- Ask the customer about any power outage that would have occurred recently and as a result the booster element or circulation pump might not have operated. This can be of particular concern on days of a power outage with heavy cloud cover.
- Is the customer getting good water pressure out of the cold taps? If not and if there is a cold-water pressure pump, is it running?
- Before visiting the site, the customer should be asked about any shading on the collectors. Have trees grown up since the system was installed or has a structure been positioned nearby that is now shading the collectors at some time during the day?
- The customer should be asked about any obvious leaks in the system. If possible, the location of the leaks should be ascertained so that the technician/plumber can come prepared.
- Ask the customer if the TPR valve is running continually. Around a litre or two a day is normal but if it is around a bucket a day the TPR valve is requiring service or replacement.

7.4 Basic Troubleshooting Procedure

The product manual may contain a brief troubleshooting guide; however, the following could also be handy while troubleshooting. When a system is not working, the troubleshooting visit should occur during daylight hours, preferably a mostly clear day when there is enough sunshine to be able to test the output of the system and with sufficient day light hours available to allow a full investigation.

When on-site, check to check be sure that the information given by the customer is correct.
(Did they miss the obvious?)

- Check visually for leaks.
- For Active systems is the circulator pump operating? (feel for vibration in pipes)
- If the circulating pump is not working, is there a logical reason? (e.g. stagnation, insufficient vertical distance between the collector and tank in a thermosiphon system, power outage)
- Check to see if either of the temperature sensors is damaged. The sensors can be damaged by heat if they are installed too close to the collector pipes. In a worst-case scenario, they may have come loose or are not connected.
- Check if the pump and its controller is working correctly. Always refer to the User Manual for troubleshooting if the pump is not working or is functioning incorrectly.
- Do a visual inspection to check if any evacuated collector tubes are damaged physically. If damaged then these probably have lost their vacuum and their efficiency drastically reduced.
- Check the quality of the water supply. If the carbonate content is too high then scale build up may occur in the valves or the collector pipes and they may malfunction.
- Always check the manufacturer’s user manual for troubleshooting

8. Appendix 1: Solar Irradiationtion Data

Table showing Peak Sun Hours (PSH) for various Pacific Island sites and tilt angles

Alofi, Niue

Latitude: 19°04' South | Longitude: 169°55' West

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	6.47	6.2	5.67	4.81	4.26	3.86	4.01	4.61	5.35	6.02	6.53	6.46	5.34
19° Tilt[2]	6.43	5.88	5.7	5.2	4.96	4.46	4.75	5.14	5.53	5.81	5.98	6.47	5.53
34° Tilt[2]	6.06	5.39	5.47	5.24	5.24	4.78	5.08	5.29	5.41	5.41	5.35	6.15	5.41

Apia, Samoa

Latitude: 13°50' South | Longitude: 171°46' West

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.39	5.47	5.16	5.09	4.63	4.46	4.71	5.25	5.77	5.91	5.76	5.51	5.25
13° Tilt[2]	5.32	5.24	5.12	5.31	5.06	4.99	5.23	5.60	5.85	5.72	5.67	5.46	5.38
28° Tilt[2]	5.14	4.86	4.93	5.37	5.34	5.40	5.62	5.79	5.74	5.35	5.45	5.3	5.36

Hagåtña, Guam

Latitude: 13°28' North | Longitude: 144°45' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.33	5.87	6.73	7.12	7.04	6.44	6	5.3	5.42	5.46	5.16	5.05	5.9
13° Tilt[2]	5.94	6.27	6.85	6.88	6.97	6.43	5.95	5.17	5.38	5.7	5.66	5.69	6.07
28° Tilt[2]	6.40	6.48	6.75	6.39	6.71	6.27	5.77	4.90	5.18	5.77	6.00	6.19	6.06

Honiara, Solomon Islands

Latitude: 09°27' South | Longitude: 159°57' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.99	5.55	5.61	5.41	4.76	4.59	4.45	5.19	5.81	6.26	6.4	6.22	5.52
9° Tilt[2]	5.98	5.47	5.54	5.52	5.00	4.90	4.69	5.36	5.81	6.15	6.38	6.24	5.59
24° Tilt[2]	5.92	5.29	5.34	5.58	5.26	5.28	4.98	5.52	5.71	5.88	6.29	6.22	5.61

Koror, Palau

Latitude: 07°20' North | Longitude: 134°28' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.19	5.59	6.18	6.3	5.71	5.01	5.12	5.2	5.56	5.39	5.26	4.93	5.45
7° Tilt[2]	5.4	5.7	6.16	6.22	5.7	5.01	5.11	5.15	5.49	5.45	5.44	5.16	5.5
22° Tilt[2]	5.74	5.85	6.06	6.01	5.67	5.03	5.11	5.03	5.3	5.3	5.73	5.53	5.55

Lae, Papau New Guinea

Latitude: 06°44' South | Longitude: 147°00' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.13	4.85	5.03	4.85	4.58	4.29	4.17	4.51	4.97	5.27	5.35	5.13	4.84
6° Tilt[2]	5.2	4.88	5.03	4.93	4.73	4.47	4.32	4.61	5	5.28	5.41	5.21	4.92
21° Tilt[2]	5.2	4.77	4.86	4.97	4.96	4.77	4.55	4.72	4.91	5.12	5.39	5.25	4.96

Majuro, Marshall Islands

Latitude: 7°12' North | Longitude: 171°06' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.26	5.86	6.11	5.89	5.66	5.31	5.35	5.63	5.42	5.15	4.88	4.84	5.44
7° Tilt[2]	5.47	5.98	6.09	5.81	5.65	5.32	5.35	5.58	5.35	5.2	5.03	5.05	5.49
22° Tilt[2]	5.83	6.16	5.99	5.62	5.62	5.35	5.35	5.46	5.16	5.24	5.27	5.4	5.53

Nauru

Latitude: 0°32' South | Longitude: 166°56' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.77	6.24	6.27	6.04	5.99	5.75	5.85	6.25	6.7	6.5	6.12	5.5	6.07
15° Tilt[2]	5.94	6.26	6.08	6.05	6.28	6.15	6.20	6.39	6.51	6.46	6.28	5.69	6.19

Noumea, New Caledonia

Latitude: 22°16' South | Longitude: 166°27' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	7.31	6.7	5.73	4.97	3.94	3.47	3.91	4.73	6.05	7.09	7.41	7.6	5.73
22° Tilt[2]	6.61	6.34	5.83	5.55	4.75	4.19	4.69	5.50	6.44	6.88	6.77	7.54	5.92
37° Tilt[2]	5.74	5.8	5.59	5.62	5.02	4.48	4.99	5.69	6.32	6.37	5.94	7.03	5.72

Nuku'alofa, Tongatapu, Tonga

Latitude: 21°08' South | Longitude: 175°12' West

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	6.69	6.3	5.62	4.65	4.04	3.58	3.78	4.43	5.23	6.28	6.69	6.7	5.32
21° Tilt[2]	6.1	5.96	5.69	5.1	4.81	4.25	4.41	5.03	5.46	6.07	6.16	6.65	5.47
36° Tilt[2]	5.35	5.47	5.45	5.14	5.08	4.55	4.67	5.18	5.34	5.64	5.45	6.25	5.3

Pago Pago, American Samoa

Latitude: 14°16' South | Longitude: 170°42' West

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.87	5.93	5.54	5.18	4.63	4.4	4.59	5.2	5.78	6.05	6.11	5.93	5.43
14° Tilt[2]	5.79	5.66	5.51	5.43	5.11	4.98	5.14	5.59	5.87	5.84	6.01	5.87	5.57
29° Tilt[2]	5.57	5.22	5.29	5.48	5.4	5.39	5.51	5.77	5.76	5.45	5.75	5.69	5.53

Palikir, Pohnpei FSM

Latitude: 6°54' North | Longitude: 158°13' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	4.97	5.57	5.91	5.79	5.44	5.33	5.51	5.54	5.66	5.29	5.03	4.83	5.4
6° Tilt[2]	5.11	5.65	5.88	5.72	5.42	5.34	5.51	5.49	5.59	5.32	5.15	4.99	5.43
21° Tilt[2]	5.42	5.81	5.79	5.55	5.41	5.39	5.54	5.40	5.40	5.38	5.42	5.34	5.49

Port Moresby, Papua New Guinea

Latitude: 9°29' South | Longitude: 147°9' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.71	5.14	5.32	5.33	4.98	4.67	4.75	5.29	5.95	6.42	6.51	6.04	5.51
9° Tilt[2]	5.81	5.15	5.33	5.5	5.29	5.03	5.09	5.53	6.03	6.4	6.61	6.17	5.66
24° Tilt[2]	5.72	4.96	5.12	5.55	5.58	5.43	5.43	5.69	5.91	6.1	6.5	6.13	5.68

Port Vila, Vanuatu

Latitude: 17°44' South | Longitude: 168°19' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	6.68	6.2	5.76	4.98	4.2	3.79	4.04	4.75	5.65	6.47	6.67	6.93	5.5
17° Tilt[2]	6.69	5.89	5.77	5.32	4.75	4.41	4.65	5.21	5.82	6.25	6.47	7.01	5.69
32° Tilt[2]	6.38	5.42	5.55	5.38	5.01	4.74	4.97	5.37	5.7	5.82	6.08	6.74	5.6

Rarotonga, Cook Island

Latitude: 21°12' South | Longitude: 159°47' West

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	6.45	6.14	5.78	4.59	3.86	3.54	3.73	4.46	5.16	5.94	6.63	6.56	5.23
21° Tilt[2]	5.9	5.82	5.86	5.04	4.56	4.2	4.34	5.07	5.38	5.74	6.11	6.51	5.38
36° Tilt[2]	5.19	5.34	5.62	5.08	4.8	4.48	4.6	5.22	5.26	5.34	5.41	6.11	5.2

Suva, Fiji

Latitude: 18°08' South | Longitude: 178°25' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	6.29	6.2	5.54	4.67	4.05	3.72	3.89	4.44	5.08	6.04	6.32	6.38	5.21
18° Tilt[2]	6.27	5.88	5.55	4.99	4.61	4.38	4.51	4.88	5.21	5.83	6.1	6.41	5.38
33° Tilt[2]	5.95	5.4	5.33	5.03	4.84	4.7	4.8	5	5.1	5.43	5.71	6.13	5.28

Tarawa, Kiribati

Latitude: 01°28' North | Longitude: 173°02' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.58	5.98	5.99	5.87	5.82	5.7	5.87	6.15	6.52	6.4	6.1	5.5	5.95
16° Tilt[2]	5.9	6.1	5.83	5.79	5.95	5.93	6.06	6.17	6.28	6.45	6.43	5.88	6.06

Vaiaku, Tuvalu

Latitude: 8°31' South | Longitude: 179°13' East

Peak Sunlight Hours (kWh/m²/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0° Tilt[1]	5.16	5.27	5.33	5.29	4.93	4.66	4.76	5.3	5.72	5.8	5.57	5.23	5.25
8° Tilt[2]	5.14	5.2	5.26	5.37	5.14	4.92	4.99	5.45	5.71	5.71	5.55	5.23	5.31
23° Tilt[2]	5.09	5.05	5.08	5.43	5.41	5.29	5.32	5.61	5.61	5.49	5.48	5.21	5.34

[1] *Monthly Averaged Insolation Incident On A Horizontal Surface (kWh/m²/day)*

[2] *Monthly Averaged Radiation Irradiance for Equator Facing Tilted surface tilted at an angle equal to the latitude of the location and at an angle equal to the latitude of the location plus 15 degrees (kWh/m²/day)*

These data were obtained from the NASA Langley Research Center (LaRC) POWER Project funded through the NASA Earth Science/Applied Science Program. (https://power.larc.nasa.gov/)