Large Scale Solar Thermal Systems Design Handbook

A joint publication between Master Plumbers' and Mechanical Services Association of Australia and Sustainability Victoria

PREFACE

This document was produced jointly by the Master Plumbers and Mechanical Services Association of Australia (MPMSAA) and Sustainability Victoria (SV).

SV promotes the sustainable use of resources and supports the increased deployment of low-emission, renewable technologies such as larger scale solar thermal systems.

Solar thermal systems are already commonly used for providing hot water in residential homes. Another promising application range for solar thermal systems is the utilisation of solar heat for commercial and small industrial applications such as hot water for hospitals, laundries, schools, multi-family houses, process heat or solar cooling applications.

This handbook aims to provide guidance in designing best practice, large-scale solar thermal systems and addresses common design issues, including flow rates, hydraulic configuration, control designs and collector arrangement.

This handbook does not cover large solar thermal systems for swimming pool applications.

The MPMSAA and SV acknowledge the review committee for their contributions to the development of this handbook:

Deakin University
Endless Solar
Energy Efficiency and Conservation Authority (EECA)
Rheem Australia
Solar Industries Association New Zealand
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DISCLAIMER

The information contained herein is provided as a guideline to the installation and maintenance of solar hot water and does not overrule existing OH&S legislation, Australian and State (Territory) standards and manufacturers' installation requirements, which should be adhered to at all times.

Due to the wide variety of products on the market, the technical diagrams illustrate the general principles of the technologies and may differ in appearance from actual products.

While every effort has been made to ensure that all available technologies and plumbing requirements have been covered, some omissions may have been made; however, sources of additional information have been provided.

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CHAPTER 1 INTRODUCTION

1.1 General

This handbook provides an overview of the technical and related issues relevant to the design, installation and use of large-scale solar thermal systems (LSTS). It covers commercial- and industrial-scale solar applications within the 60–120ºC temperature range and does not extend to swimming pool applications. The handbook has been written to ensure good practice is followed in all aspects of LSTS. This is vital in designing reliable and efficient systems and to avoid mistakes of past installations.

The structure of this handbook anticipates that designers already have a high level of understanding of good plumbing practice. Therefore, detailed information about some fundamental issues, such as pump selection, has not been included. In these instances, the reader is referred to the relevant Australian/New Zealand Standard or other building services engineering texts for information.

LSTS in Australia and New Zealand are not new. The first systems appeared in Australia in the late 1960s and were installed to supply hot water to hotels, colleges and hostels. LSTS for industrial process heating were constructed in the late 1970s and early 1980s, as a result of demonstration programs led by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) and some state energy bodies. Between 1976 and 1984, at least 16 large systems were installed in country and urban parts of Australia. Large quantities of hot water were supplied to various industries such as beer pasteurisation, hospitals, dairies and soft drink manufacturing. Rising energy prices and concerns about greenhouse gas emissions have led to new interest. In New Zealand, LSTS have principally been for municipal swimming pools and rest homes.

1.2 State of the art

The solar thermal market experienced 60% growth rates in Europe and 123% in Germany in 2008. Although most of the installations are domestic solar hot water systems, the market growth of LSTS installations is increasing significantly.

Most LSTS in Europe with more than 50 m² of collectors are used for domestic hot water applications in hotels and multi-family homes (refer to Chapter 7.1), as well as hospitals, nursing homes and sport halls. Other common applications are solar space heating and cooling. In Canada, Germany and Denmark, LSTS are used to provide solar heat for district space heating using underground seasonal storage systems (Meyer, 2009).

LSTS with more than 500 m² of collectors are mainly constructed in China (9000 systems), Turkey (320 systems) and India (200 systems).

The European Union (EU) promoted LSTS with collector areas of more than 30 m² in the housing industry, hotels and public buildings through the SOLARGE program, which ran from January 2005 to December 2007. Besides several national market studies and a common market report, a database with more than 111 good practice examples is accessible on their website (solarge.org). Two case studies from the SOLARGE project with additional details are included in this handbook (refer to Chapter 7).

The International Energy Agency (IEA) Solar Heating and Cooling Programme (SHC) Task 33 and the IEA Solar PACES Programme Task IV Solar Heat in Industrial Processes (SHIP) estimated the annual potential for LSTS to provide heat for industrial processes to be around 258 PJ in Europe (not including LSTS in the residential sector and commercial sector).

A recent project undertaken in Europe (www.stescos.org) has led to the development of software tools for the evaluation of Energy Service Companies (ESCo) solar water heating contracting opportunities.

For Victoria, a study for the Sustainable Energy Authority Victoria (SEAV, 2005) concluded that there is 36 PJ per annum of industrial and commercial sector end-use energy that could be technically replaced by solar thermal collectors. The economic potential is mainly in the commercial sector. A case study on a leisure centre on the central coast of NSW has been included in Chapter 7.

Some of the important operations and processes that are suitable for solar heating are shown in Table 1.1 below.

Table 1.1: Industrial operations and process suitable for solar

●: important; X: very important

Process	Food	Textile	Building material	Galvanising, electroplating	Fine chemicals	Pharmaceuticals and biochemical	Service industry	Paper industry	Automobile supply	Tanning	Painting	Wood and wood products
Cleaning	X	X	●	X	●	X	X		●	●	X	
Drying	X	X	●		●	X	X	●	●	X	X	X
Evaporation and distillation	X				●	X						
Pasteurisation	X					X						
Sterilisation	X					X						
Cooking	X											
General process heating	●	●	●	X	●	●	X		●			●
Boiler feed water preheating	X	X	●		●	●		●		●		
Heating of production halls	X	X		●	●	●	●		X	X	X	X
Solar absorption cooling	X			●		X	X					

Source: IEA (www.iea.org), 2004

CHAPTER 2 TECHNOLOGY OVERVIEW

2.1 Solar collectors

2.1.1 Collector types

There are two basic types of solar collectors and these are usually classified as concentrating and non-concentrating. The latter will be discussed first because their use is far more widespread.

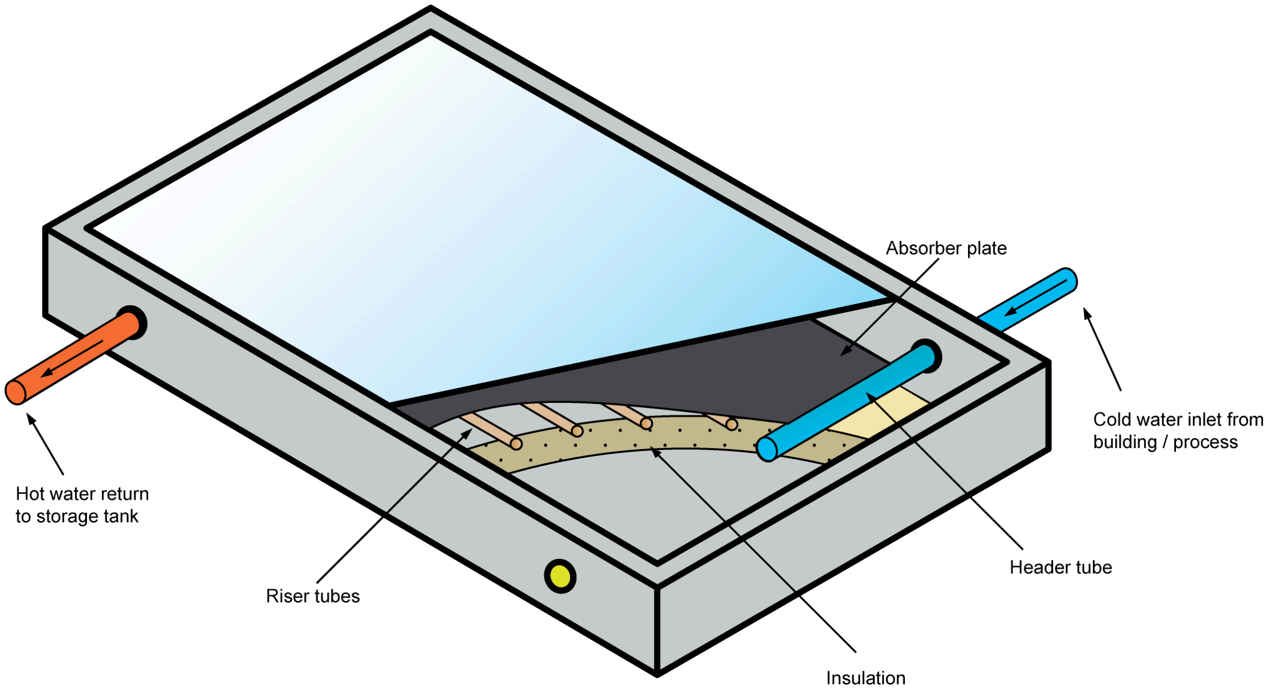
2.1.1.1 Non-concentrating collectors

There are two main types of non-concentrating collectors: flat plate and evacuated tube. In 2007, it was estimated that there were nearly 210 million square metres of solar thermal collectors in operation around the world with a capacity of nearly 147 GW_{th}. Flat plate and evacuated tube collectors provided 80% of this capacity (Weiss et al., 2009).

2.1.1.1.1 Flat plate collector

The flat plate collector is the most commonly used solar collector around the world. Although there are a number of variations possible in the design of the flat plate collector, the basic cross section is shown in Figure 2.1.

Figure 2.1: Typical cross-section through a conventional flat plate solar collector



An absorber plate, usually metal, is connected to a series of riser tubes (or pipes), which are in turn connected at the top and bottom to larger diameter pipes, called headers. The solar energy incident on the absorber plate is transferred to the fluid flowing through the riser tubes. Cool water enters at the bottom header and warmed water exits from the top header. The absorber is usually contained in an insulated box with a transparent cover. The temperature range of flat plate collectors is approximately 30–80°C.

Flat plate collectors can be constructed from a variety of materials and different construction methods are possible. As a result, they may have different performance and costs and be designed for different applications. For example, two layers of glazing are sometimes used to improve thermal performance. Some of the other variations are discussed below.

Unglazed collectors have no glazing or insulation, and usually consist of extruded polymer tubes. Their use in LSTS is rare, although they have been used in the horticultural sector for greenhouse heating and swimming pool heating where lower water temperatures are required. These collectors have the largest share of the flat plate solar collector market, particularly in Australia.

2.1.1.1.2 Evacuated tube collector

There are two common types of evacuated tube collectors: heat pipe and U-tube. Both collector types are formed from an array of evacuated tubes joined to a manifold through which the heat transfer liquid (water or water/glycol) flows.

The solar absorber is located inside a double glass tube with a vacuum between the two tubes, similar to an elongated thermos flask. The tubes are connected to a manifold through which the heat transfer fluid is passed (Figures 2.2 and 2.3). The inner glass tube has a selective surface facing outward to absorb the sun’s energy. The heat is transferred into the inner glass tube and removed by a heat pipe or a copper tube through which the heat transfer fluid flows. The loss of heat from the absorber by natural convection is eliminated by the vacuum and, as a result, high operating fluid temperatures of up to 120ºC can be achieved. The possibility of higher temperatures is of particular importance for solar industrial process heating application because it increases the number of applications where solar energy can be used.

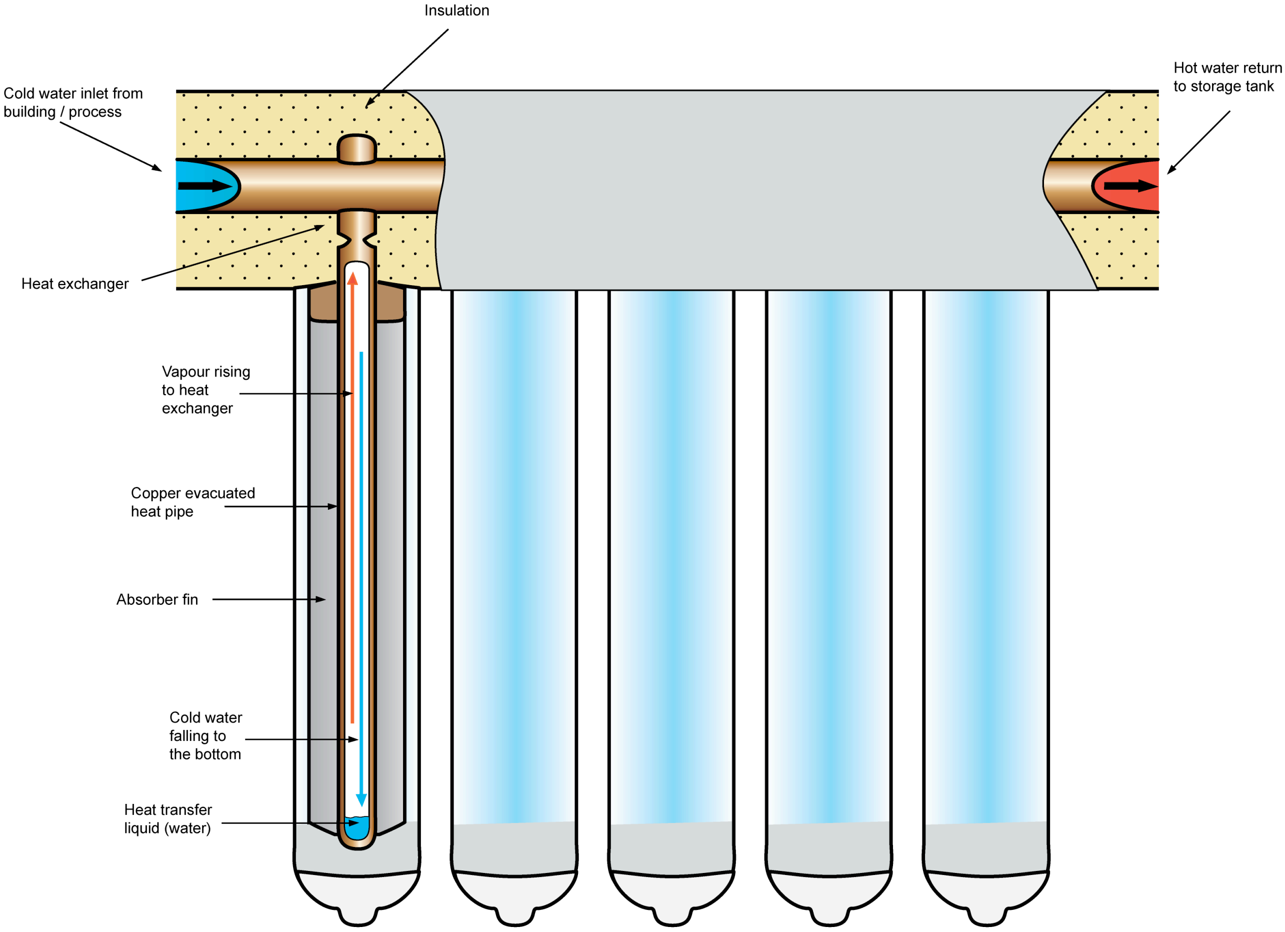
Heat pipe evacuated tube collector

A heat pipe evacuated tube collector uses heat pipes to transfer the collected solar heat from the tube into the fluid in the manifold. Heat pipes are made up of copper tubes which contain a very small amount of water in a partial vacuum. The heat pipe is encased in the inner glass tube.

As the heat pipe is heated, the small amount of water inside vaporises and rises to the top of the heat pipe into the heat exchanger in the manifold. The cold water is heated as it flows through the manifold and at the same time cools the vapour inside the heat pipe where it condenses and falls to the bottom of the heat pipe. The process is repeated, thus creating a highly effective method of transferring the sun's energy, which strikes the tubes into the fluid.

Heat pipe evacuated tube collectors are not suitable for horizontal installation, as inclination should be at least 25° to function.

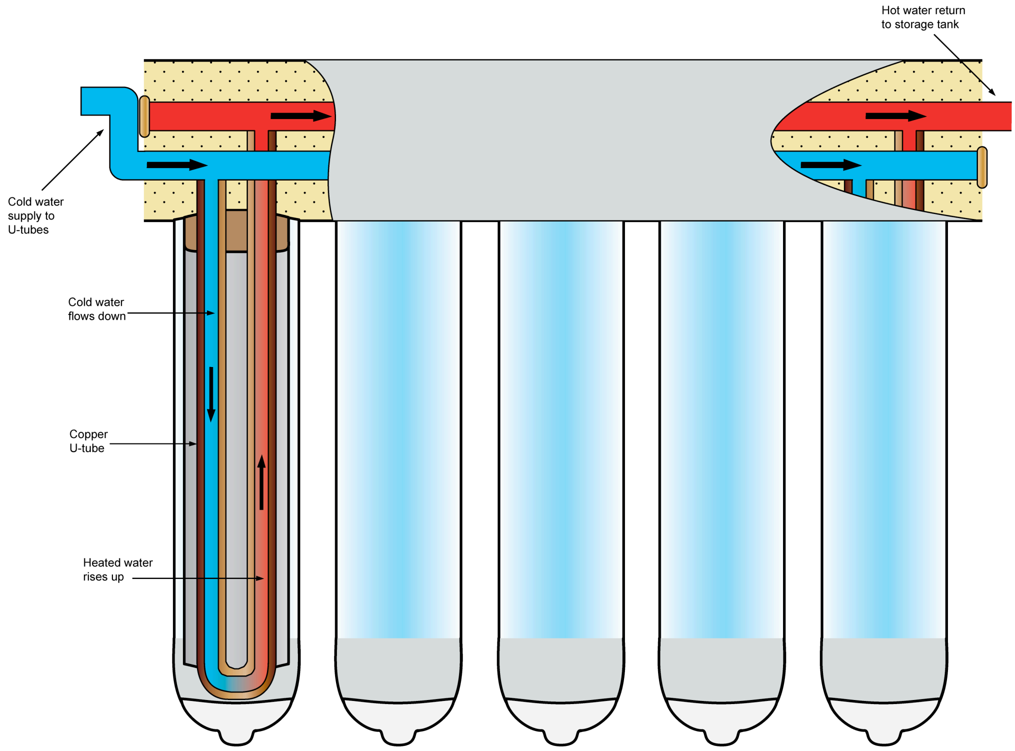
Figure 2.2: Typical heat pipe evacuated tube array



U-tube evacuated tube collector

Evacuated U-tube collectors have the fluid heated as it flows through a ‘U’ shaped copper pipe inside the glass tubes.

Figure 2.3: Typical evacuated U-tube array



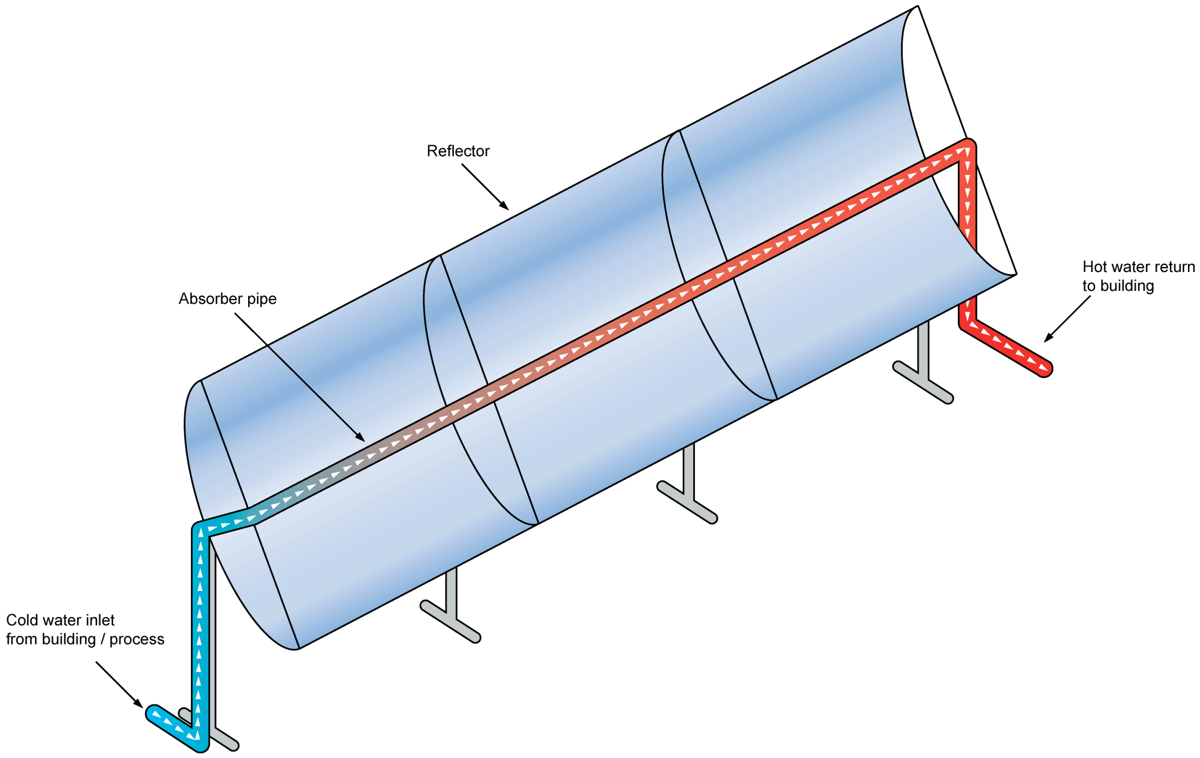
2.1.1.2 Concentrating collectors

Concentrating solar collectors use reflectors either as a trough (Figure 2.4) to focus on a line absorber or a dish to focus on a point absorber. They can reach far higher temperature levels than non-concentrating collectors. Concentrating collectors will collect only direct radiation (the solar energy coming directly from the sun) and consequently perform better in areas with predominantly clear sky (not cloudy) conditions.

The collectors are designed with either one or two axis tracking so that the concentrator can track the sun and the incident rays are always right-angled to the aperture areas. Common systems include the parabolic trough, linear Fresnel, parabolic dish and central receivers (solar tower). These collectors are typically used where temperatures above 100°C are needed, i.e. process heat or electricity generation.

Concentrating collectors are typically specified by their concentration ratio. The concentration ratio is the ratio of the area of the reflector to the absorber area. High concentration ratios are used for higher temperature collectors, but require more accurate tracking of the sun's path.

Figure 2.4: Typical concentrating collector



2.1.2 Collector performance comparison

Various types of solar collectors have been briefly described above. How do they compare with each other and what might be their areas of application? The standard method to evaluate the performance of solar collectors is to compare:

- instantaneous efficiency curve
- annual heat output.

When determining the annual heat output of a solar collector, the efficiency equation used must be consistent with the collector area used by the test laboratory to compute efficiency from the collector test results. It is distinguished between three collector areas:

- gross collector area
- aperture area
- absorber area.

The different collector areas for flat plate and evacuated tube collectors are shown in Figures 2.5, 2.6 and 2.7.

The gross collector area includes the outside dimensions of the product and defines the minimum amount of roof area of the collector.

The aperture area is the area that corresponds to the light entry area of the collector.

The absorber area is the area that receives solar energy. The absorber area of the heat pipe collector is the plan area of the array of tubes and does not include the gap between tubes. The area of tube arrays with a parabolic reflector behind the tubes is the area of parabolic reflector.

Figure 2.5: Cross-section of flat plate collector showing gross, aperture and absorber area

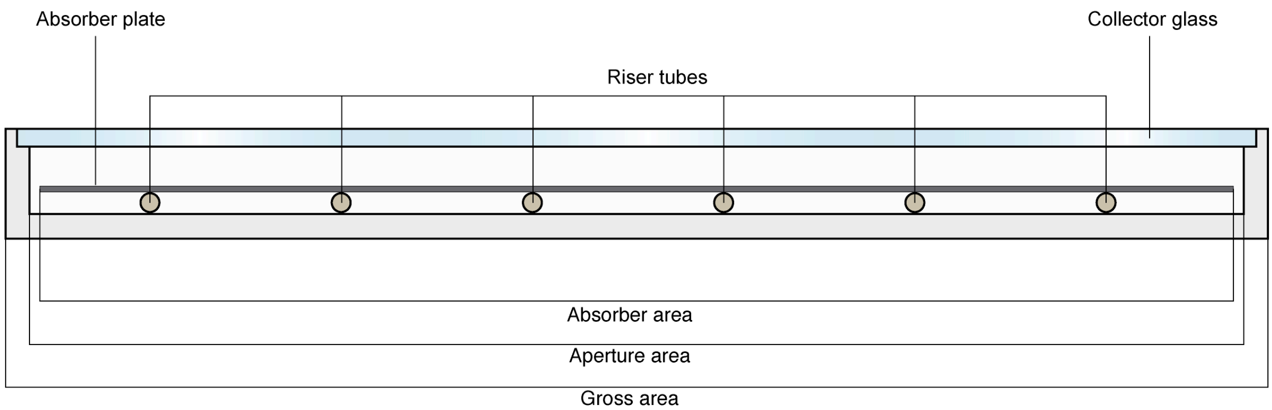


Figure 2.6: Cross-section of heat pipe evacuated tube collector without a backing reflector, showing gross, aperture and absorber area

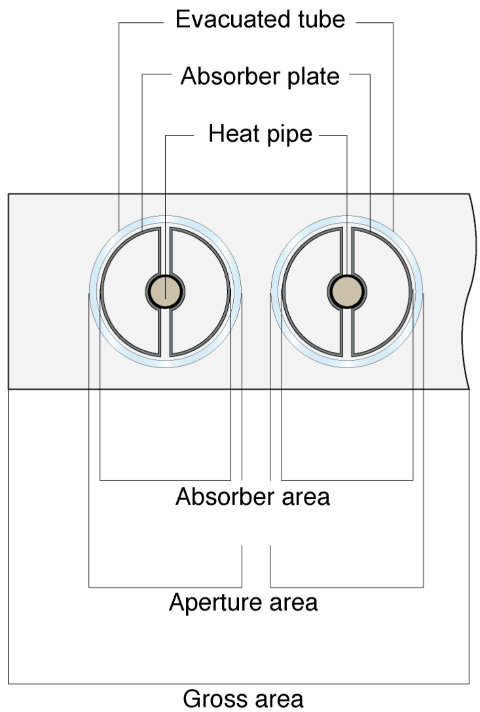
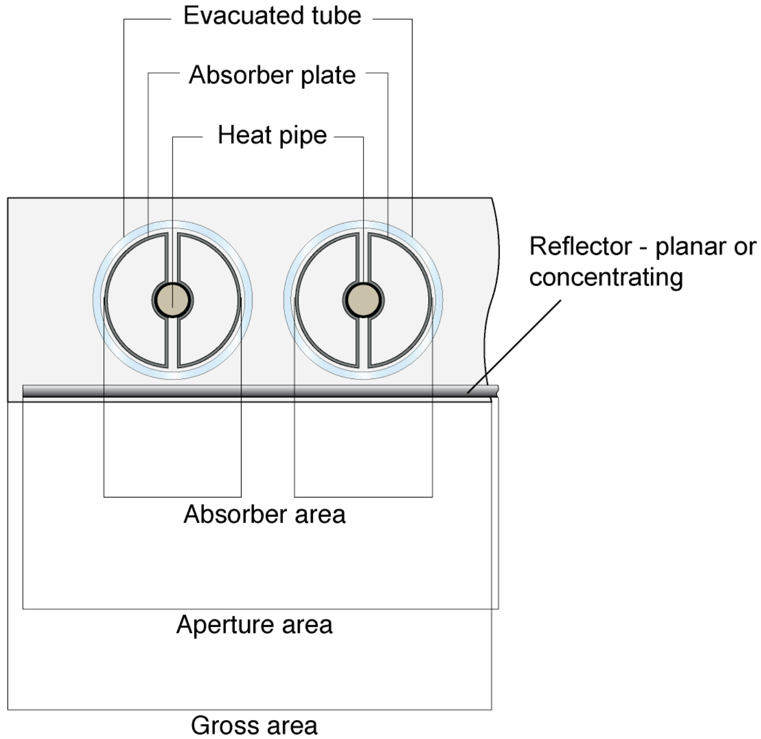


Figure 2.7: Cross-section of heat pipe evacuated tube collector with a backing reflector, showing gross, aperture and absorber area



The area basis for defining solar collector efficiency can be on the basis of gross, aperture or absorber area. If alternative solar collectors are compared on the basis of efficiency, care must be taken to use the efficiency with the collector area that was used by the test laboratory to compute the efficiency. Some test laboratories report all three alternative forms of collector efficiency.

Evacuated tube solar collectors that do not incorporate a reflector behind the tubes typically have efficiency reported on the basis of the aperture area. Such a report would imply a very high efficiency; however, it must be noted that the efficiency curve is based on a smaller area than an evacuated tube collector incorporating a reflector or a flat plate collector.

The choice of the appropriate pairs of values of efficiency and reference area has no effect on the computation of the energy delivery, as the product of efficiency times area is the same whether gross, aperture or absorber area is used.

To compare the heat output of different solar collectors, the product of efficiency times aperture area should be compared rather than efficiency alone due to the bias that can be introduced into efficiency specification by using the smallest area to define efficiency.

The most accurate way of comparing alternative solar collector performance is to determine the annual heat output for the range of inlet temperatures for the application and for the location of interest. This type of performance specification is referred to as a heat table (refer to Chapter 5).

The range of solar collector efficiency parameters for different product types can be compared on the basis of a linearised efficiency (equation 1) versus $(t_m - t_a)/G$ fit to the test data, as shown in Figure 2.10.

For the evaluation of the solar collector heat output, a three coefficient non-linear efficiency characteristic (equation 1) is required to accurately represent the high $(t_m\text{-}t_a)/G$ performance of glazed flat plate and evacuated tube collectors (refer to AS/NZS 2535).

$$\eta = \bar{\eta}_o - \bar{a}_1 \frac{t_m - t_a}{G} - \bar{a}_2 \frac{(t_m - t_a)^2}{G} \tag{1}$$

where $\bar{\eta}_0$ = optical efficiency

$\bar{a}_1$ and $\bar{a}_2$ = positive coefficients from AS/NZS 2535 normal efficiency tests

G = incident solar radiation on the slope of the collector (from climatic data file)

t_a = ambient temperature (from climatic data file)

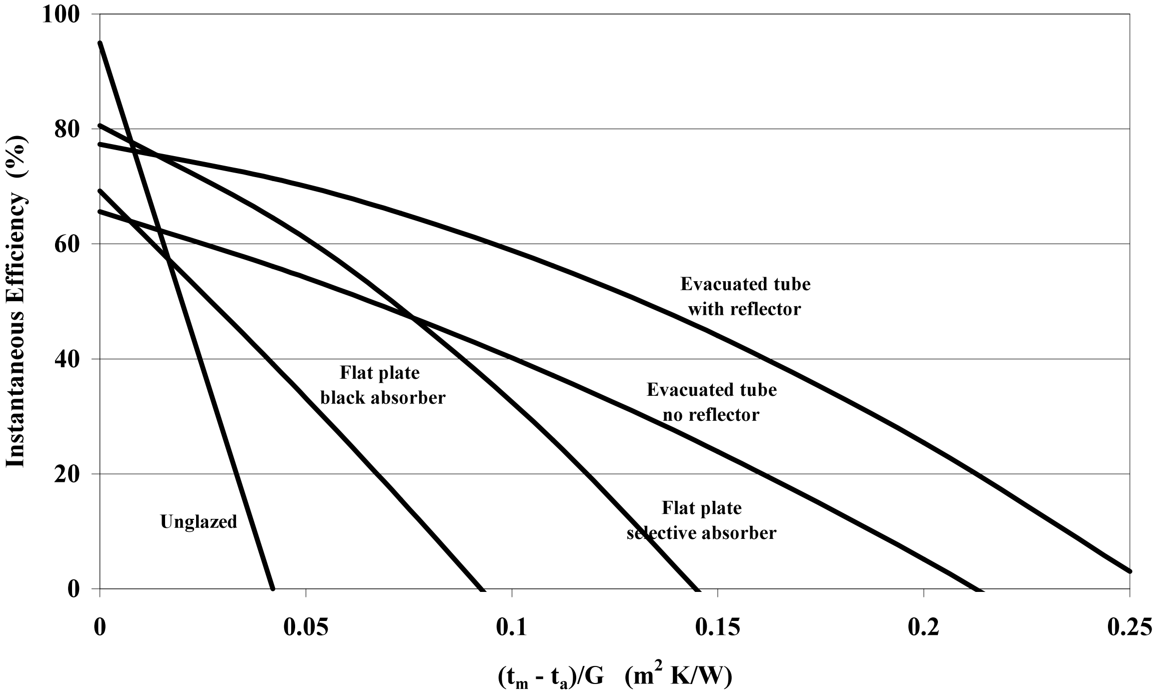
t_m = average fluid temperature in the collector

Typical normal incidence solar collector efficiency characteristics are shown in Figure 2.8.

The bottom axis, $(t_m - t_a)/G$, of the graph in Figure 2.8 represents the difference between the average fluid temperature in the collector (t_m) and the ambient air (t_a) divided by the incident solar radiation (G). Solar radiation under clear sky conditions is of the order of 1000 W/m^2. It can be seen that for a given value of solar radiation when the temperature difference is low, an unglazed flat plate collector performs better, i.e. has higher collection efficiency than a glazed flat plate or evacuated tube collector. As the value of $(t_m - t_a)/G$ increases, the glazed flat plate and the evacuated tube collectors perform better, i.e. have a higher efficiency. For high values of $(t_m - t_a)/G$, an evacuated tube collector with a backing reflector has the highest efficiency.

The implication of these observations is that if a solar collector is likely to be operating with a high $(t_m-t_a)/G$ value, then a collector with lower heat loss should be used. This is the case in many industrial applications where there is a closed process circuit loop and inlet temperature of the solar collector is always high. The exception to this general rule would be if the process circuit was open and significant amounts of cold make-up water were required to replace lost fluid. This would mean that the collector inlet temperature would be closer to ambient temperature and a less efficient collector might be adequate.

Figure 2.8: Instantaneous efficiency curves for various types of solar collectors



In addition to the normal incidence efficiency, the off-normal performance of a collector must also be considered. Typical off-normal performance of flat plate and evacuated tube collectors is shown in Figure 2.9. Flat plate collector performance decreases when the incident angle is not normal to the collector aperture due to reflection losses in the cover. Evacuated tube collectors normally show an increase in performance up to an incident angle of 60° due to the three-dimensional shape of the absorber and the losses at normal incidence due to the spacing of the tubes. The off-normal efficiency of a collector is given by equation 2 where $K_{\tau\alpha}$ is the incidence angle modifier.

$$\eta = \overline{\eta}_o K_{\tau\alpha} - \overline{a}_1 \frac{t_m - t_a}{G} - \overline{a}_2 \frac{(t_m - t_a)^2}{G} \qquad (2)$$

In the equation above:

- The $\acute{\eta}_0$ coefficient defines how a collector will perform when the ambient air temperature is the same as the mean collector temperature. Using this coefficient alone to calculate the efficiency can lead to inaccurate results.
- The $\bar{a}_1$ and $\bar{a}_2$ coefficients define how the collector will perform when the ambient air temperature is lower than the mean collector temperature. If a collector performs well in cold climates, or with high fluid temperatures, it will have very <u>low</u> $\bar{a}_1$ and $\bar{a}_2$ coefficient values.
- Evacuated tubes typically have very <u>low</u> $\bar{a}_1$ and $\bar{a}_2$ coefficients due to the vacuum layer that insulates the tubes against the ambient air temperature.
- Unglazed collectors typically have very <u>high</u> $\bar{a}_1$ and $\bar{a}_2$ coefficients, meaning that they lose efficiency when the ambient air temperature is below the mean collector temperature.

- $K_{\tau\alpha}$ defines how the collector will perform when the sun is not directly above the collector. For example, in the morning and afternoon (θ = 60°) an evacuated tube collector is operating at around 140% more than its rated $\acute{\eta}_0$ efficiency, and a flat plate collector is operating at around 90% of its rated $\acute{\eta}_0$ efficiency.

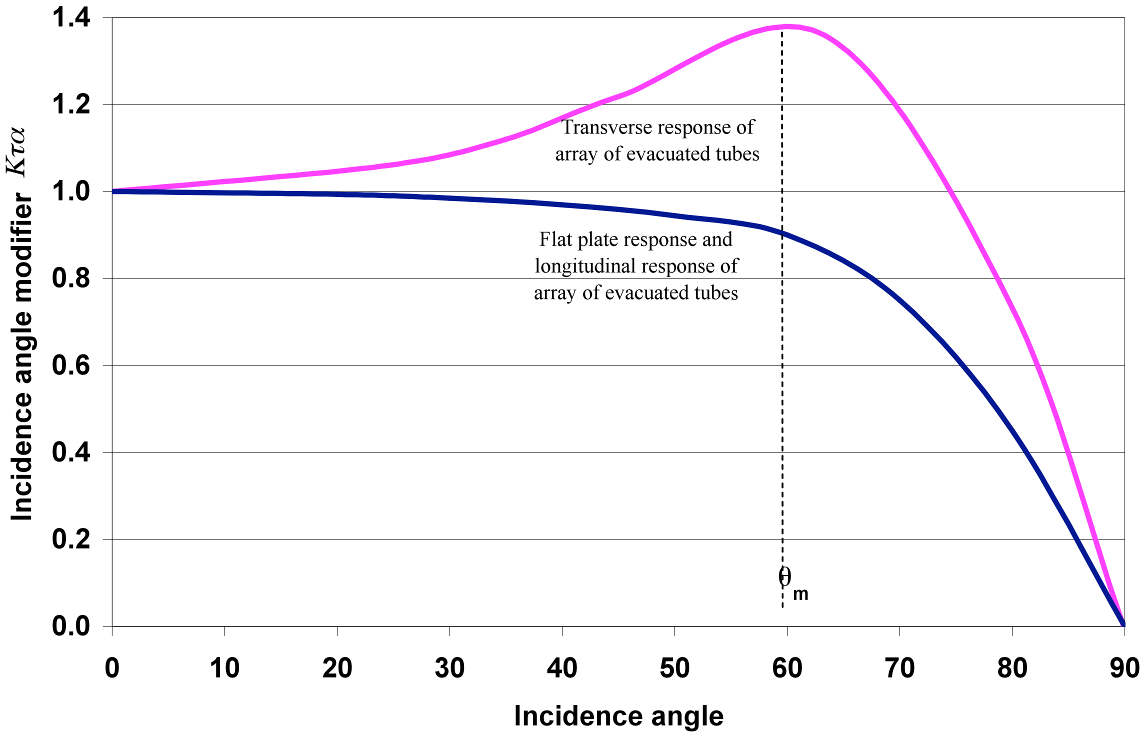
Note:

Care should be taken not to oversize the solar collectors. Systems with too much solar contribution can lead to prolonged stagnation conditions and very high temperatures (refer to Chapter 2.8).

If the hot water load is constant throughout the year, the collector area should be sized to meet the load during the period where the solar contribution is the highest – this usually occurs in summer when there are higher levels of solar radiation (refer to Chapter 3). The collectors should be sized to meet no more than 100% of the load requirements at any one time, right throughout the year.

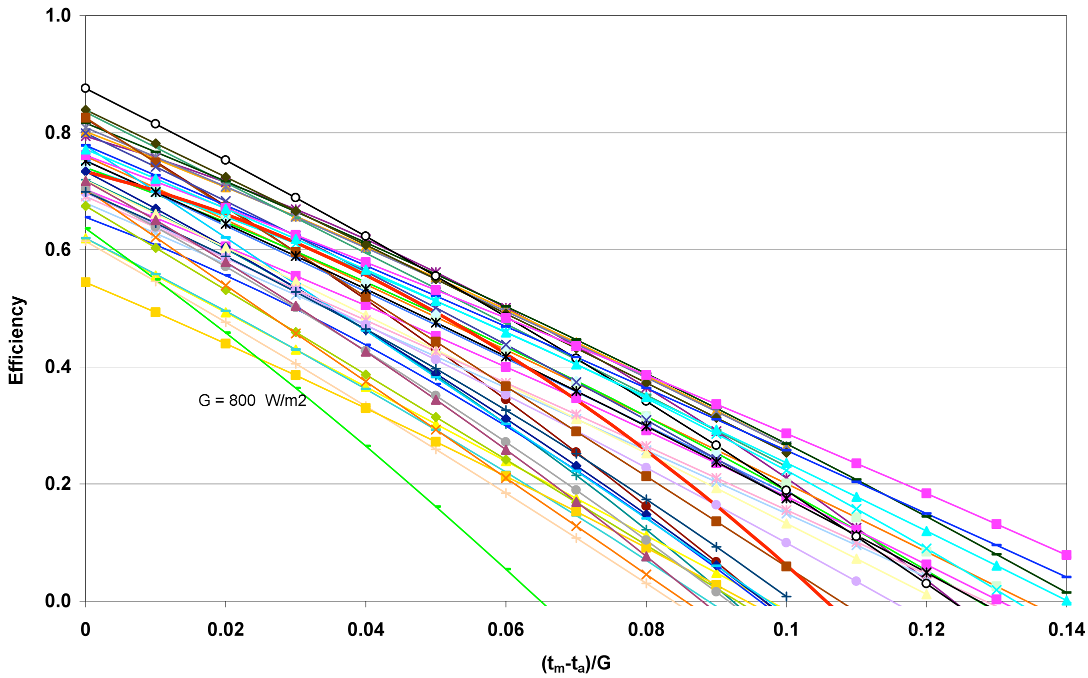
For LSTS with a non-constant load pattern, detailed analysis should be done to ensure that there are not long periods of time when there is no load placed on the collectors.

Figure 2.9: Incidence angle modifiers



The efficiency of different solar collector products depends on the product configuration and the methods used to limit heat loss. The range of efficiencies observed in commercially available flat plate collectors in Australia is shown in Figure 2.10. The low-efficiency products use black absorbers and low-transmission glass and as a result are less expensive compared to high-efficiency products that incorporate selective surface absorbers and high-transmission glass covers. The most appropriate solar collector is the one that can deliver the minimum energy cost over the life of the system at the required temperatures (refer to Chapter 5). In some cases, a low-efficiency product may be the most cost-effective solution.

Figure 2.10: Measured efficiency of flat plate solar collectors sold in Australia



2.1.3 Comparison of solar collectors on the basis of efficiency

To compare the heat output of different solar collectors, the product of aperture area times efficiency at the operating condition considered should be compared rather than efficiency alone due to the bias that can be introduced into efficiency specification by using the smallest area to define efficiency.

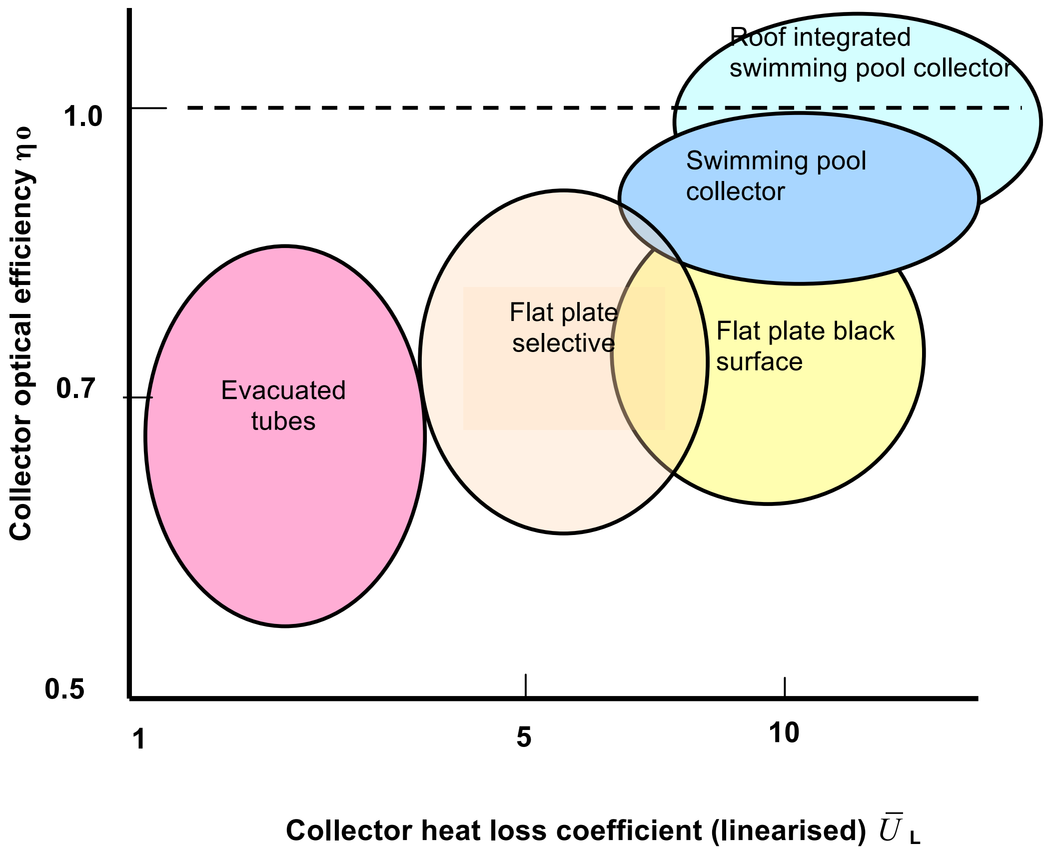
The most accurate way of comparing alternative solar collector performance is to determine the annual heat output for the range of inlet temperatures for the application and for the location of interest. This type of performance specification is referred to as a heat table (refer to Chapter 5).

The collector efficiency equation (equation 1) can be simplified into a linear equation (equation 3) that provides a reasonable approximation of the performance at low values of $(t_m - t_a)/G$. The range of linearised solar collector efficiency parameters for different product types is illustrated in Figure 2.11. The linearised equation is calculated by fitting collector test data to equation 3 to find the linearised heat loss coefficient (U_L) and the optical efficiency (η_0).

$$\eta = \bar{\eta}_o - \bar{U}_L \frac{t_m - t_a}{G} \qquad (3)$$

where $\bar{\eta}_0$ = optical efficiency
U_L = heat loss coefficient
G = solar radiation on the slope of the collector (from climatic data file)
t_a = ambient temperature (from climatic data file)
t_m = average fluid temperature in the collector

Figure 2.11: Solar collector efficiency parameters (linearised)



2.2 Storage tanks and heat exchangers

Temperature stratification in hot water storage tanks is the formation of layers of water of different temperatures within a storage tank. The hot water is at the top and gets cooler further down the tank. Temperature stratification can provide substantial operational performance benefits. Convection in the storage tank induced by collector loop or load side heat exchangers affects thermal stratification. Therefore, correct integration of the tank and heat exchangers in a low-flow system is essential.

Three configurations of heat exchangers are shown in Figures 2.12, 2.13 and 2.14. The degree of thermal stratification that can be achieved in tanks with collector loop heat exchangers depends on the location of the heat exchanger and the flow rate in the collector loop. Storage tanks with internal helical coil heat exchangers, either for a closed collector loop (Figure 2.12) or a load side heat exchanger (Figure 2.13), will have less stratification than storage tanks with an external heat exchanger based on low-flow design (Figure 2.14).

Figure 2.12: Tank with helical coil heat exchanger

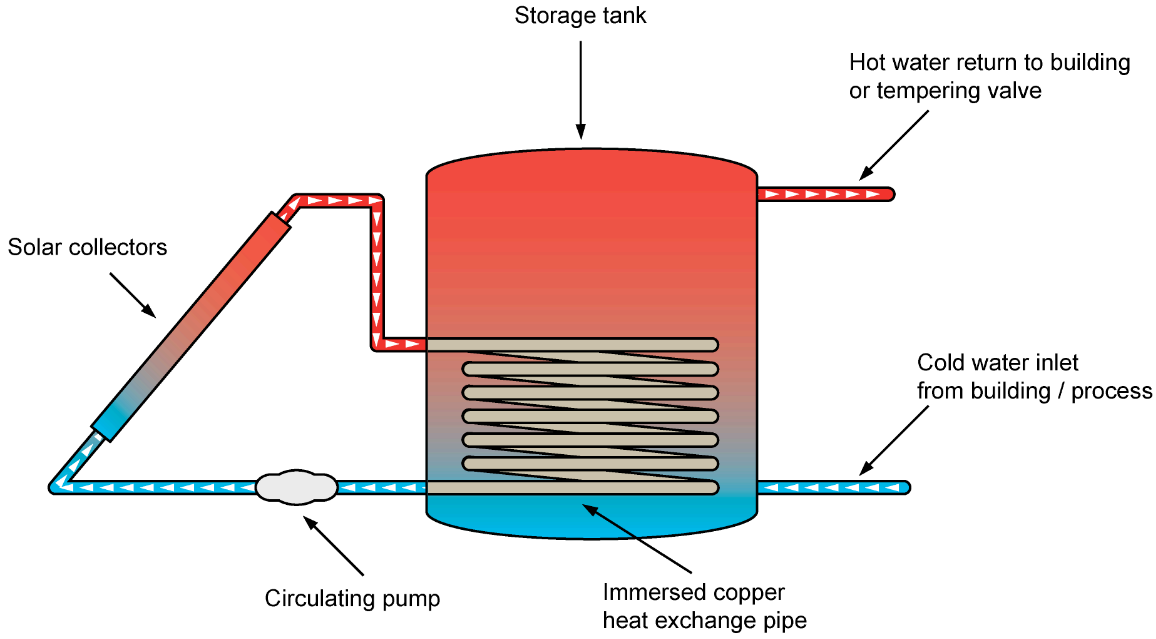


Figure 2.13: Load side heat exchanger tank

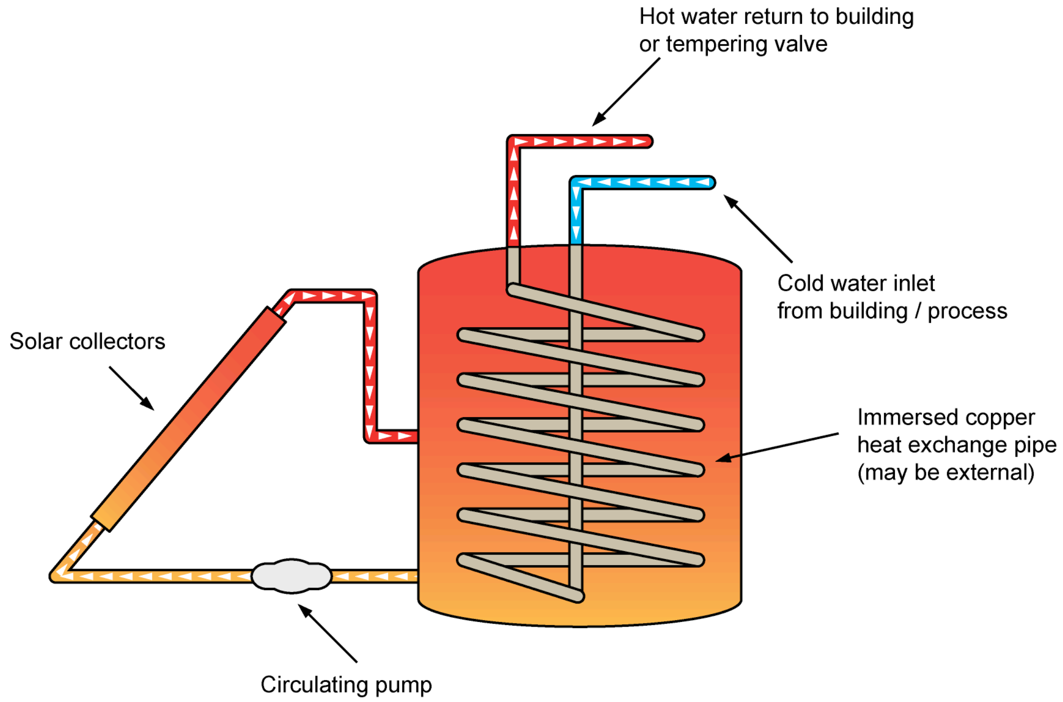
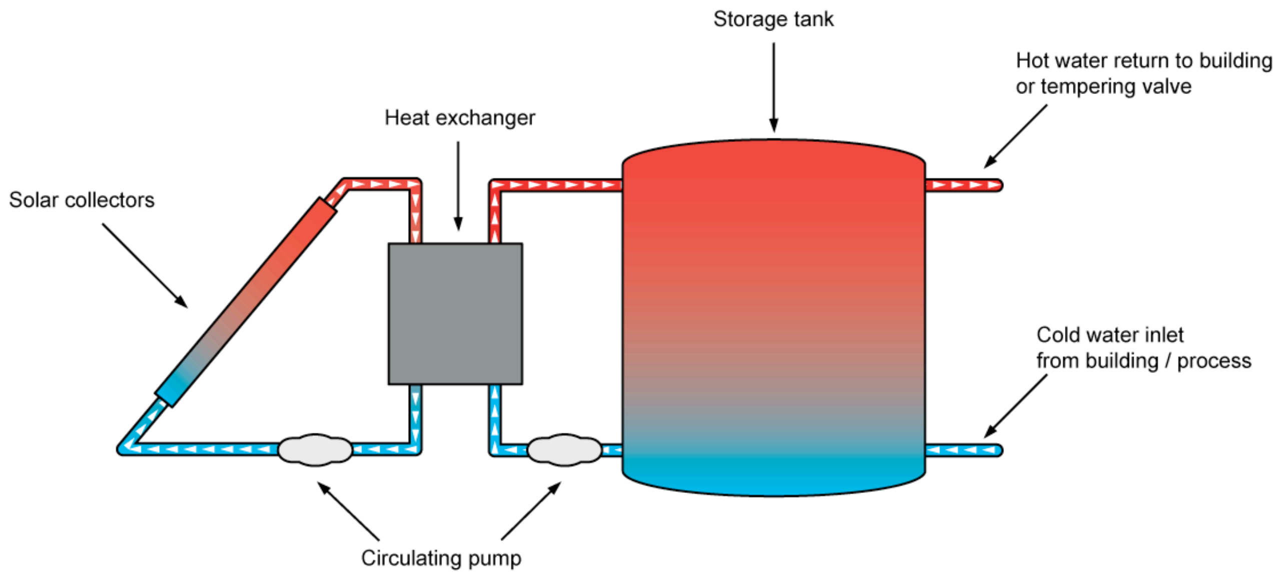


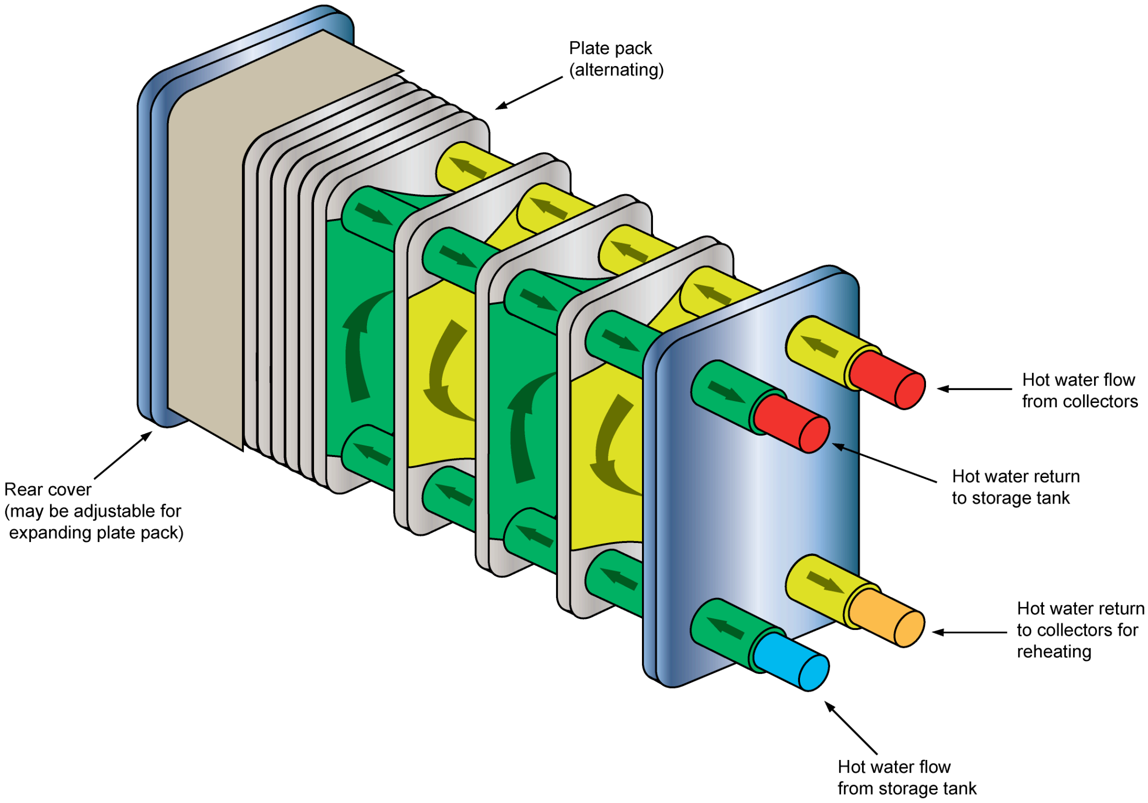
Figure 2.14: Tank with external heat exchanger



2.2.1 External heat exchanger configurations

External heat exchangers can be either plate or shell and tube heat exchanger configurations. Plate heat exchangers (Figure 2.15) operated in the counter flow mode have higher effectiveness and, as a result of a higher outlet temperature in the tank, loop flow can be configured to maximise thermal stratification in the tank.

Figure 2.15: Typical plate heat exchanger



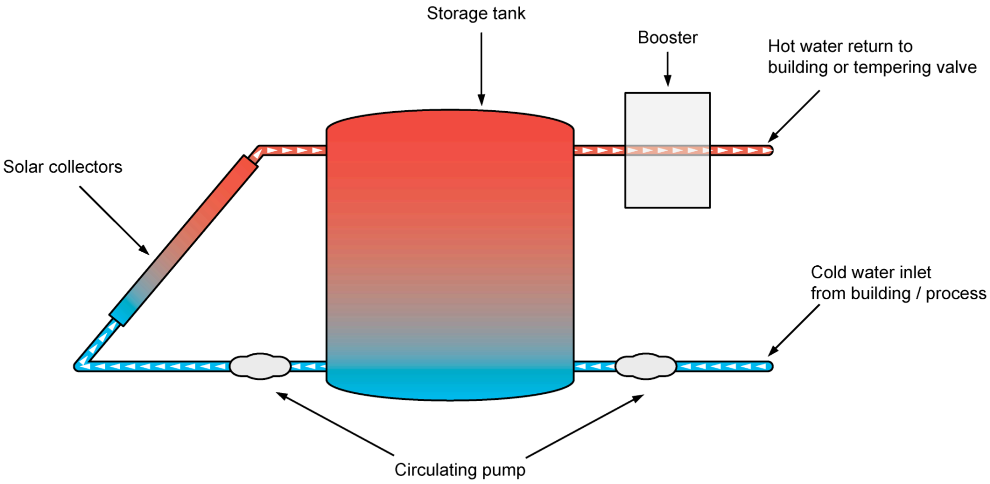
2.3 System layouts

There are two basic system layouts used in LSTS. These are the open and closed loop systems. The closed loop system is the most common one.

2.3.1 Open loop systems

In an open loop system, the sun directly heats the (potable) water and no heat exchanger is needed. The water is pumped from the storage tank to the collector array and then returned to the tank after it has been heated. The same water is taken from the tank to the process circuit (Figure 2.16).

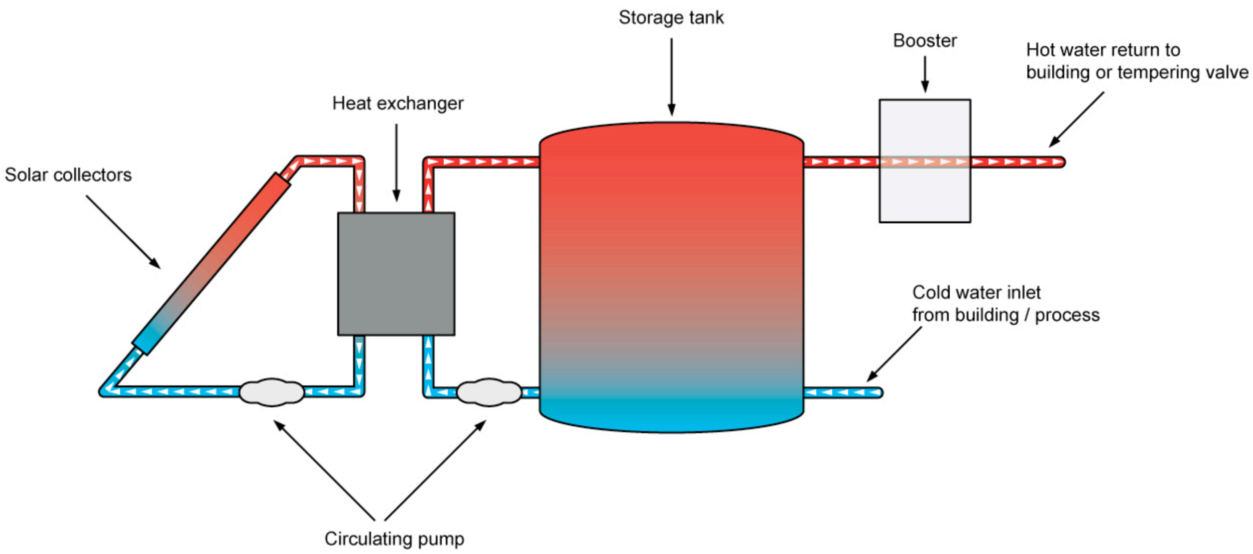
Figure 2.16: Typical open loop system



2.3.2 Closed loop systems

Closed loop systems use a heat exchanger to transfer the heat to a secondary circuit or thermal storage tank. The collector heat transfer fluid (water or water/glycol) remains in a sealed system. This configuration allows the use of non-potable water as the heat transfer fluid and anti-freezing agent may be added to the fluid in order to prevent damage from freezing (Figure 2.17).

Figure 2.17: Typical closed loop system



2.4 Collector loop design concepts

The most effective system design will depend on the selection of the most cost-effective solar collector for the application and careful system design. A system that is incorrectly configured may result in stagnation in some sections of the collector array and thus a significant reduction in heat output. The most common fault in designing LSTS is bad hydraulic design that results in uneven flow distribution or air locks in the collector array.

A high flow rate through a solar collector will maximise energy collection for a given collector inlet temperature, but the collector outlet temperature of the fluid may be too low to be useful. In addition, high flow rates require larger pumps and cause significant amounts of parasitic electrical energy. On the other hand, a flow rate that is too low will result in high fluid temperatures, high heat losses from the collector array and therefore a low heat collection efficiency.

The concepts that produce optimum heat output include:

- Design for thermal stratification in the storage which can be achieved by implementing the low-flow design concept (refer to Chapter 4.3).
- Balance the flow between parallel paths through the collector array which requires:
    1. equal friction (piping lengths) in all parallel paths in the collector array to ensure even flow – reverse return plumbing, also known as the Tichelmann principle
    2. all parallel flow paths are taken to the highest point in the array before entering the reverse return line.
- Incline all parallel flow paths in the collector array to the highest point for natural air lock clearance or fit air relief valves at all local high points in the plumbing.
- Optimise pump controller settings to avoid pump hunting (refer to Chapters 2.6 and 5.3).

2.4.1 Collector interconnection

LSTS require many collectors to be linked together. The objective of the collector arrangement is to achieve low pumping power requirements and a uniform heat production by all collector modules. The optimal collector configuration depends on:

- geometry of available collector installation area
- hydraulic characteristics of the collector modules.

Solar collectors may be connected together in series, parallel or a combination of series and parallel arrangements (Figures 2.18 and 2.19).

Figure 2.18 shows a series-connected collector array where all the heat transfer fluid passes through all of the collectors. In addition to the air relief valve at the collector outlet pipe, it may be necessary to install additional air relief valves at all local high points to avoid air locks. This depends on the system design (high or low flow) and pump selection.

In general, more electrical energy is required to pump the water through a series-connected array than a parallel-connected or multiple-parallel collector system because of the greater flow resistance from an equivalent number of collectors joined together in series.

Figure 2.18: Series-connected collector array

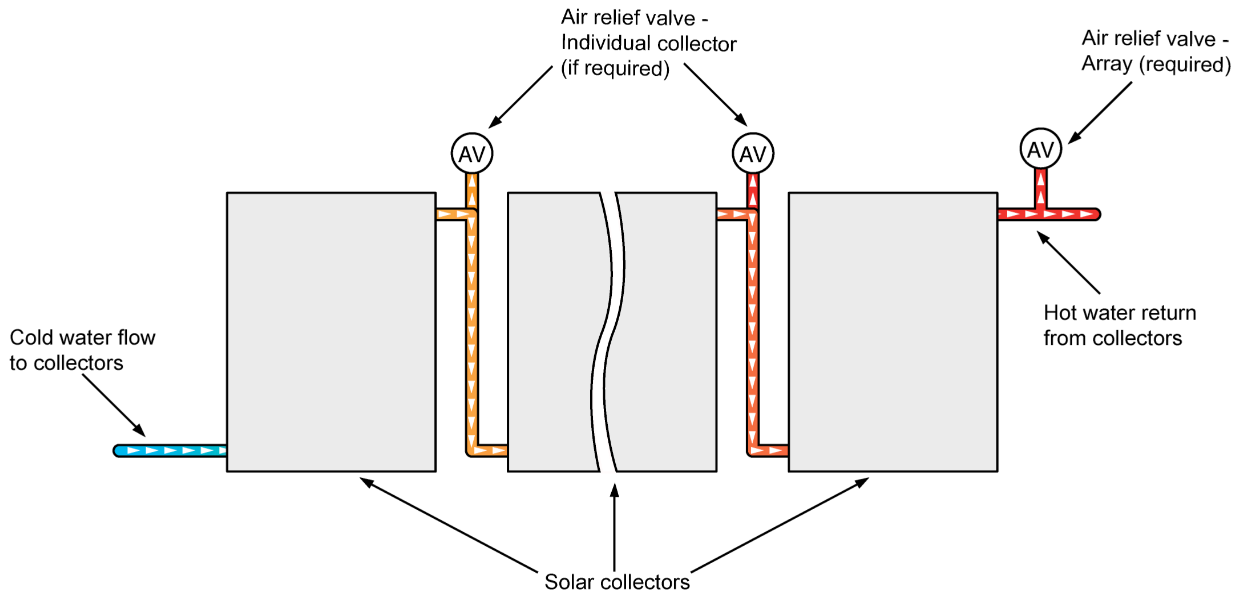


Figure 2.19 shows a parallel-connected collector array, where the flow of the heat transfer fluid is divided and a proportion goes through each collector. This collector arrangement only needs an air relief valve at the collector outlet pipe.

Figure 2.19: Parallel-connected collector array

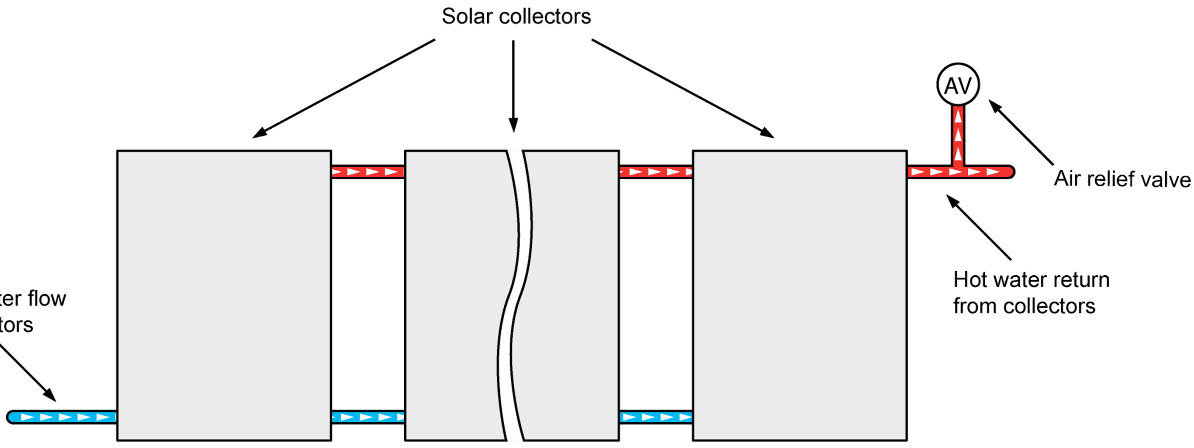
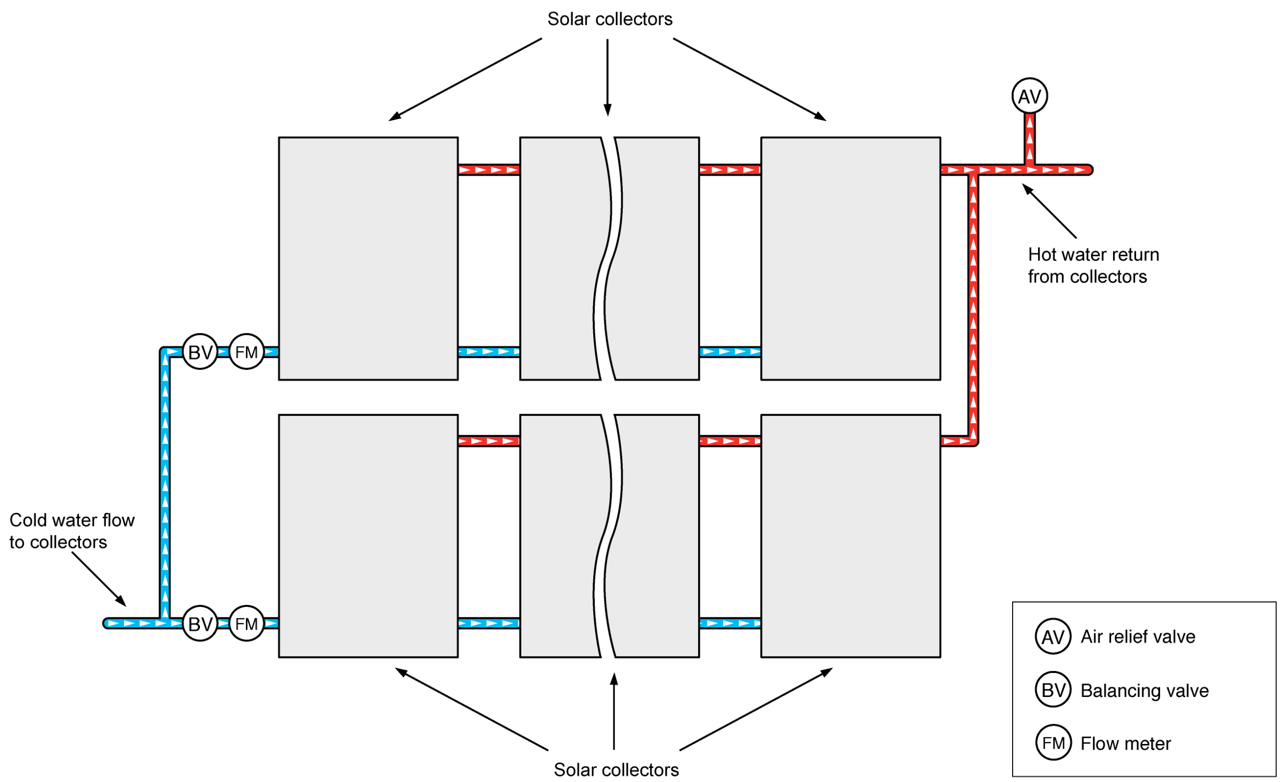


Figure 2.20 shows the recommended multiple-parallel collector arrangement, where a proportion of the heat transfer fluid goes through each group of collectors depending on how many rows are established. Collector groups connected in parallel should be plumbed such that the length of the flow and return paths are approximately the same for all flow paths through the array in order to achieve evenly distributed flows. If the number of collectors per row differs, balancing valves and flow meters are needed to be installed at the cold water flow pipes to ensure equal flows (refer to AS 3500). The air relief valve needs to be installed at the highest point after the different collector outlet pipes have been diverted together to avoid air locks.

Figure 2.20: Multiple-parallel collector array (recommended)



The optimal configuration depends on the geometry of the available area for collector mounting and the hydraulic characteristics of the collector modules. The objective of array layout is to achieve a low pumping power requirement and a uniform heat production by all collector modules.

Electricity consumption used for pumping is commonly known as the system's 'parasitic' energy. It is recommended that parasitic energy should not exceed 3% of the collected solar energy. If the parasitic energy is higher, it is an indication of poor hydraulic design.

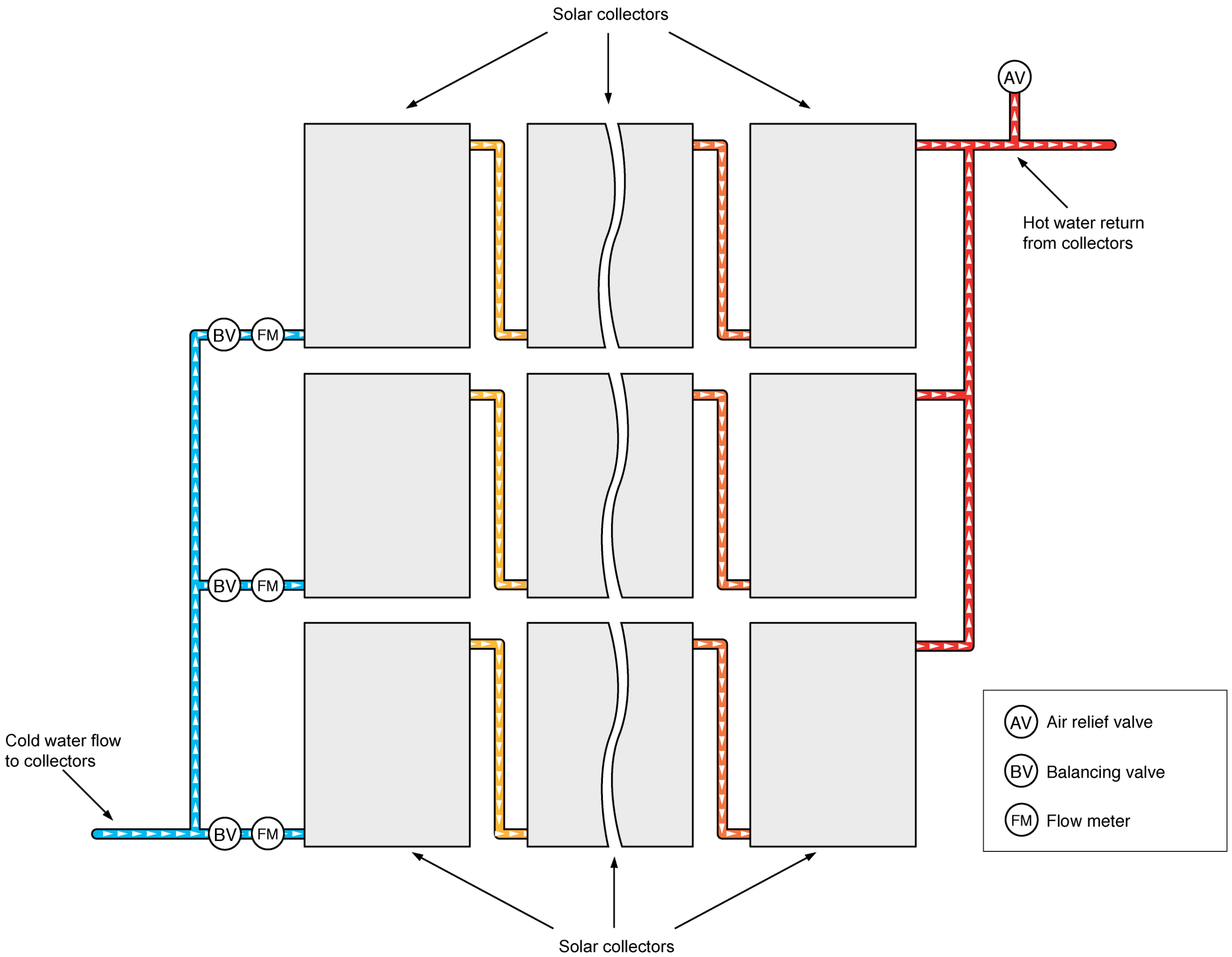
However, in large arrays, some collector modules may need to be connected in series so that the pressure drop in the header pipe does not exceed 10% of the pressure drop through a module in order to get uniform flow through parallel-connected collectors.

The starting point for optimising the collector arrangement is to aim for a high-irradiance temperature rise greater than 20 Kelvin through each series-connected collector group. This leads to a specific flow rate requirement of 0.2 to 0.4 L/(min.m^2 aperture area).

Connection of the flow and return lines to the same panel at one end of a parallel row will cause those panels at the near end to short circuit the flow, while those at the far end will receive less flow and suffer a reduction in performance. Such an arrangement should only be used where the pressure drop in the headers is much less than that in the fluid passages across the panels.

Multiple-parallel/series collector arrays as shown in Figure 2.21 should not be used, as one or more of the flow paths may air lock and significantly reduce the heat output of the collector array.

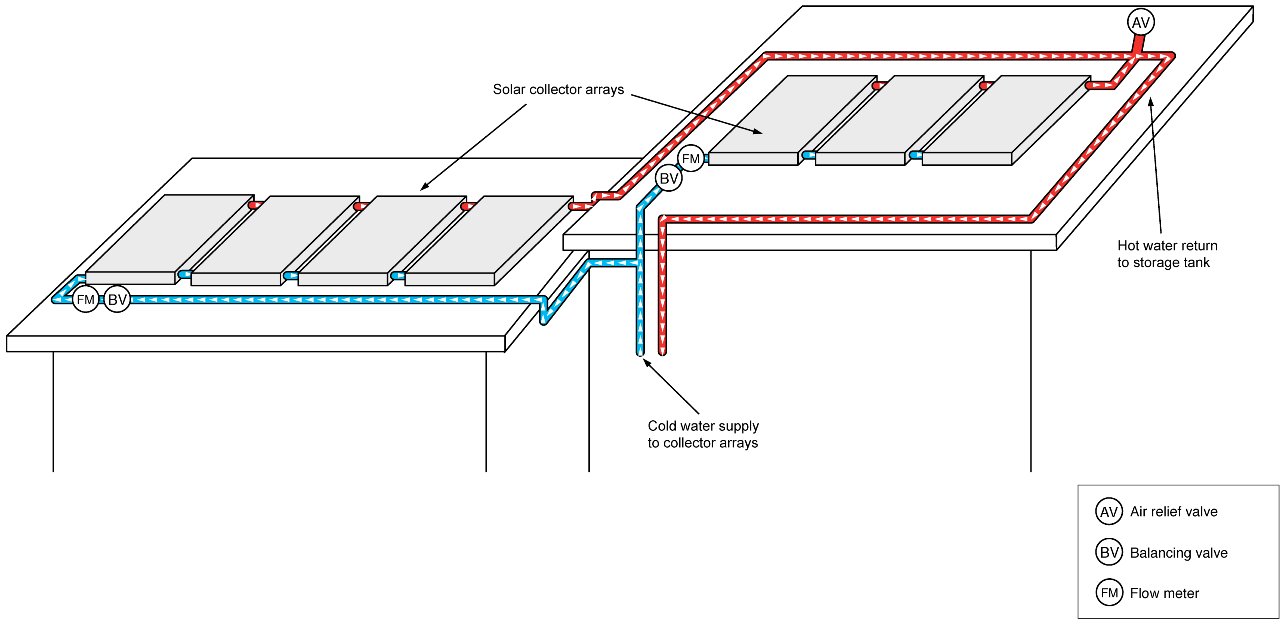
Figure 2.21: Multiple-parallel/series collector array (not recommended)



2.4.2 Collectors at different heights

Groups of collectors at different heights should be connected in such a way that they all receive water from the lowest point in the system and return it to the highest point. Figure 2.22 illustrates a system arranged in this way. The collector outlet pipe of the lower located collector array goes to the highest point in the system where it gets connected with the outlet pipe of the higher located collector array. Air trapped in the system gets relieved through an air relief valve at the main outlet pipe of the collector array. If the return lines do not come from a common height, flow through the different sections of the collector array may not be uniform, causing a reduction in performance. Flow meters and balancing valves at the collector inlet pipes are needed to ensure equal flows.

Figure 2.22: Collector array connections for collector panels at different elevations, illustrating common feed and return points at the lowest and highest points in the system



2.4.3 Sections of collector array with different orientation, slope or shading

If a collector array has sections with different orientation, slope or are subject to different shading effects, consideration should be given to independent control of the flow to each collector segment. This is to avoid heat loss from a section of the array receiving low radiation even though the overall mixed output flow may indicate positive output from the array. For such installations, the flow controller should monitor the outlet temperature of each collector segment and have the capability to isolate collector sections that have low output.

2.5 Energy conservation

The role of energy conservation in the design of LSTS is important and should not be underestimated for two reasons. Firstly, energy conservation reduces the energy consumption and saves scarce energy resources. Secondly, it is usually the most cost-effective way to reduce overall energy cost.

There are many energy-conservation measures in industrial process water heating processes that can be considered. These include:

- no-cost actions such as minimising the hot water storage temperatures
- simple and low-cost actions such as increasing insulation levels on pipework and storage tanks (discussed further below)
- complex and expensive actions such as the installation of more accurate control or heat recovery systems

Routine maintenance of boilers, thermostats, pumps and other components in a heat delivery system is also vital. There is little sense in installing an expensive LSTS to complement a poorly maintained conventional boiler and ancillary equipment. The second reason for reducing the demand for hot water for a particular process is that it will also mean that any LSTS installed subsequently can be either smaller or meet more of the demand than would have been the case prior to the conservation measures. In general, LSTS are capital intensive and any reduction in hot water demand will lead to a reduction in the size of the LSTS and a lower capital outlay.

It is critical that all pipework, fittings and storage tanks are optimally insulated. Failure to optimise the insulation level will either result in the unnecessary loss of collected solar heat (if there is too little insulation) or unnecessary expenditure (if there is too much insulation). The level of insulation on a storage tank and pipework in a conventional plant would normally be decided on the basis of an acceptable financial payback for the money spent on the insulation based on the annual energy savings.

When installing LSTS, the level of insulation on the storage tank, pipework and fittings should be increased to the point where the cost of the energy saved by the insulation is just less than the cost of the energy produced by adding more solar collectors to the system. In other words, the heat from the solar thermal system is cheaper than adopting further energy conservation measures.

If the low-flow optimum design approach is used, then a high level of insulation of the solar collector loop plumbing system (piping and fittings) is essential, as the collector outlet temperature will be high. However, as the piping diameter of the collector loop in low-flow designs is smaller than that of high-flow designs, a high degree of insulation can be achieved with less insulation thickness. The insulation material of pipework installed outside (e.g. between the collectors) should be weather and ultraviolet (UV) resistant and be able to withstand extreme temperatures (refer to Chapter 4.4).

2.6 Control systems

2.6.1 Pumps and controllers

LSTS require one or more pumps to circulate the heat transfer fluid around the system. In order to collect and deliver heat effectively and efficiently, an active control system is required to regulate the flow of the heat transfer fluid. Although it is possible to regulate pump operation using a time clock or photoelectric cell, these types of controllers are ineffective. The time clock cannot respond to variations in solar radiation and the photoelectric cell cannot respond to variations in storage temperature. As a result, differential or proportional controllers are used in LSTS.

A differential controller compares the difference between the collector inlet temperature, e.g. at the bottom of a storage tank, and the collector outlet temperature of the water at the top of the storage tank. If the difference is positive, then it is assumed that ‘useful’ heat may be collected and the pump is activated. If the solar radiation level falls below the level required to maintain a positive differential, then the pump is turned ‘off’. In order to avoid the problem of a pump turning ‘on’ and ‘off’ repeatedly over a short period of time – known as ‘hunting’ – the controller incorporates hysteresis and on/off temperature differences must be matched to the collector type, size of collector array and flow rate.

Controller temperature difference settings required for evacuated tubes are different to those required for flat plate collectors, as evacuated tubes can reach a high stagnation temperature even in dull conditions. However, the heat gain from the collector may not be sufficient to achieve a steady state temperature greater than the controller turn off condition unless the sky condition is very clear. This means the pump runs until the heat is removed from the collector and then turns off and waits for the collector to reheat. The effect of this is to shunt hot water from the collector to the return pipe, which then cools off while the controller waits for the collector to reheat.

Typical on/off settings for a differential thermostat (DT) controller for a low-flow system supplying water at temperatures above 50°C are:

- 10/2 for a flat plate collector
- 20/2 for an evacuated tube collector.

However, the optimum controller settings depend on the size and flow rate of the collector array and are also influenced by the collector efficiency (refer to Chapter 5.3).

In closed loop systems, a second temperature sensor in the tank above the heat exchanger may be used to switch the pump between low and high speed and hence provide some control of the return temperature to the tank heat exchanger without using a proportional controller.

A proportional controller varies the speed of the collector array pump in order to maintain a relatively constant water temperature at the collector array outlet. As the solar radiation level increases, the pump speed is increased and, conversely, as the solar radiation declines, pump speed is reduced. This control concept has only a minor effect in systems using the low-flow concept.

Controllers using these strategies can be integrated within computerised building management systems.

Programmable controllers that can sense the temperature distribution in the tank as well as the collector outlet temperature can be used to optimise the system performance. Controllers with time-of-day clocks can also be used to minimise auxiliary energy use for applications that have a repeated daily hot water demand pattern.

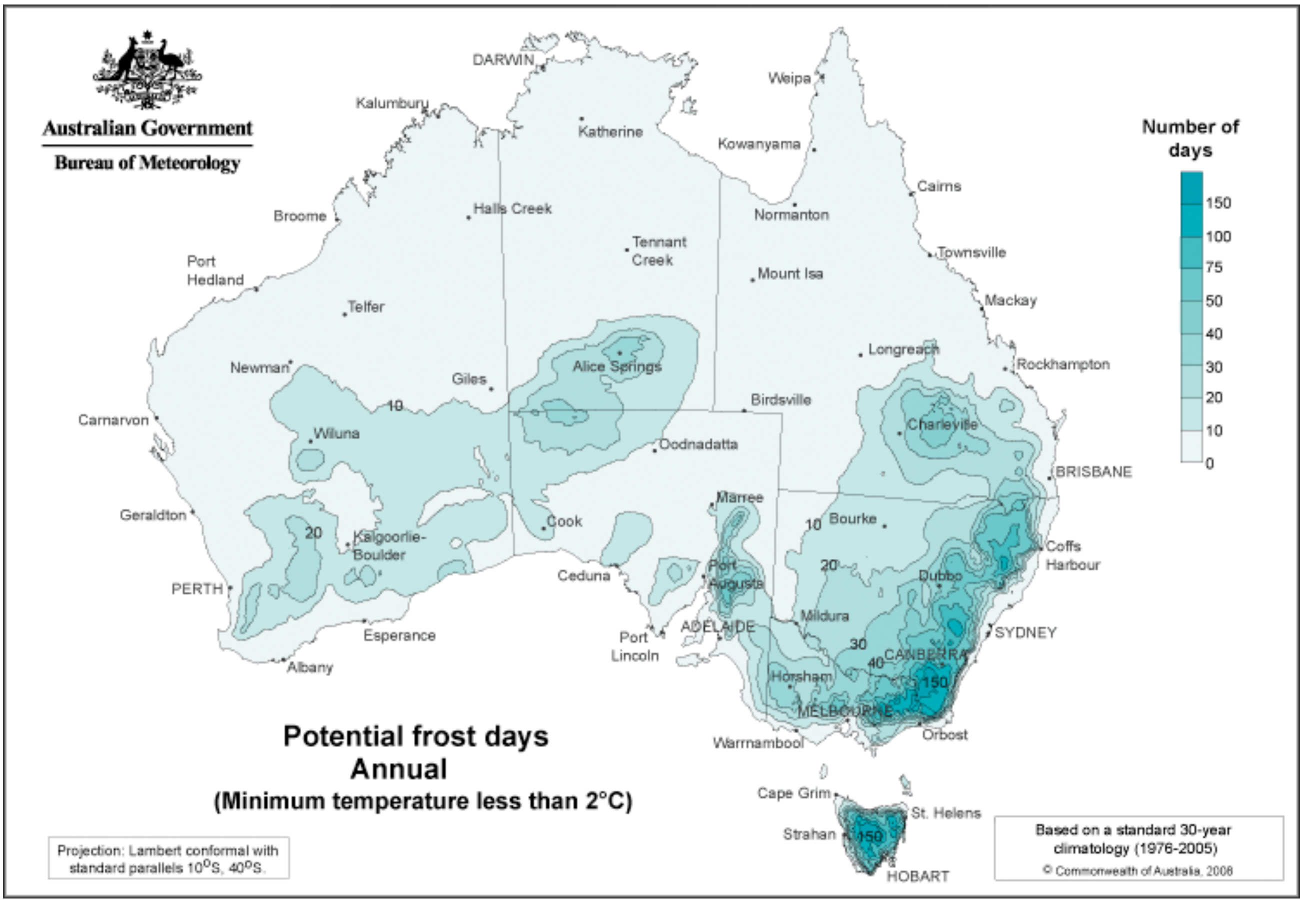
There are few low-power pumps suitable for drain back solar collector arrays, as low-power centrifugal pumps do not have sufficient static head to start drain back systems. In such cases, it may be necessary to use two pumps or a dual-speed pump. The high head pump mode is used to refill the collector loop and the system then switches to the low flow rate pump or mode of operation. Positive displacement pumps readily control flow rate but tend to be noisy and expensive.

2.7 Freezing

In some Australian locations and throughout most of New Zealand, there is a significant danger that cold overnight ambient temperatures will result in some freezing of fluid in the collector loop.

Figure 2.23 and Table 2.1 show the potential annual frost days for various locations in Australia.

Figure 2.23: Potential annual frost days with a minimum temperature of less than 2ºC



Source: Bureau of Meteorology: www.bom.gov.au

Table 2.1: Potential annual frost days of capital cities in Australia

City	Number of days
Adelaide	0–10
Alice Springs	30–40
Brisbane	0–10
Cairns	0–10
Canberra	100–150
Darwin	0–10
Hobart	150+
Melbourne	0–10
Perth	0–10
Sydney	0–10

Source: www.bom.gov.au

Table 2.2 below shows the number of potential frost days in areas throughout New Zealand.

Table 2.2: Potential annual frost days of various cities in New Zealand

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Kaitaia	0	0	0	0	0	0	0	0	0	0	0	0	1
Whangarei	0	0	0	0	1	3	4	2	1	0	0	0	11
Auckland	0	0	0	0	1	3	4	2	1	0	0	0	10
Tauranga	0	0	0	1	5	9	12	9	4	2	1	0	42
Rotorua	0	0	0	2	8	12	14	11	7	3	1	0	57
Taupo	1	1	1	3	8	12	16	14	9	7	3	1	69
Hamilton	0	0	1	3	8	11	14	11	7	3	1	0	63
New Plymouth	0	0	0	0	1	4	4	3	1	0	0	0	15
Masterton	0	0	1	2	8	11	13	12	8	5	2	1	60
Gisborne	0	0	0	0	3	8	9	8	3	1	0	0	33
Napier	0	0	0	0	3	7	7	7	3	1	0	0	29
Palmerston North	0	0	0	1	4	8	10	8	4	2	1	0	38
Wellington	0	0	0	0	1	2	3	3	2	0	0	0	10
Wanganui	0	0	0	0	0	1	3	2	0	0	0	0	7
Westport	0	0	0	0	2	6	8	6	2	0	0	0	26
Hokitika	0	0	0	2	5	12	15	12	5	2	1	0	54
Milford Sound	0	0	0	1	7	14	16	13	5	2	1	0	56
Nelson	0	0	1	4	12	18	21	17	10	4	1	0	88
Blenheim	0	0	0	1	6	15	16	13	6	2	0	0	60
Kaikoura	0	0	0	0	2	6	8	6	4	1	0	0	27
Mt Cook	1	1	3	9	19	22	24	23	14	8	3	1	140
Christchurch	0	0	0	2	9	16	16	15	9	3	1	0	70
Lake Tekapo	1	1	5	11	21	25	27	25	16	9	5	3	149
Timaru	0	0	2	5	12	21	23	19	12	5	3	0	100
Dunedin	0	0	0	2	6	13	16	12	7	3	1	0	58
Queenstown	0	0	1	5	12	21	24	21	14	7	3	0	107
Alexandra	1	2	3	10	19	26	27	26	19	12	6	2	148
Invercargill	1	2	3	6	9	16	18	16	11	6	4	2	94
Chatham Island	0	0	0	0	0	1	1	1	1	0	0	0	4

Source: Energy Efficiency and Conservation Authority (EECA)

In New Zealand, freeze protection should always be included in Zones B and C as defined in AS/NZS 3500.

In closed loop solar thermal systems there are five common strategies to prevent damage from freezing:

- **Polypropylene glycol**: glycol is an antifreeze solution mixed with the water.
- **Drain down**: a strategy that will overcome the danger of overnight freezing of water in the collector array is to allow the fluid in the collector to drain back to the storage tank at the end of the day, as described above. Using this scenario, freezing is avoided and energy loss is reduced (refer to Chapter 2.7.1).
- **Pump circulation**: another option to mitigate against freezing is to circulate tank water through the collector array at night if collector fluid temperatures fall to some critical level. This system relies heavily on the accuracy and reliability of the sensors used and may be an energy-intensive option.
- **Insulation of piping**: insulation reduces freezing in the flow and return pipes.
- **Collector selection**: some collectors and collector types are less prone to freezing due to a high grade of insulation, e.g. evacuated tube collectors.

2.7.1 Drain down

Large solar arrays can hold a considerable amount of water compared to a domestic-sized system. If heated water is allowed to remain in the collectors overnight, energy in the collectors at the end of the day is lost. In the case of a clear sky overnight, the system will start with a collector loop temperature that may be much colder than the make-up water temperature, which results in reduced performance. One strategy used to overcome this problem is to drain the collectors and collector loop piping back into the storage tank at the end of the day.

Drain-down systems require a low-pressure tank so that the water displaced from the collector loop can be retained. They typically have installed vacuum relief valves at the high point of the collector array. Once pumping has ceased at the end of the day or because the solar radiation level has fallen below the critical level, warmed water in the collector array is allowed to slowly return to the storage system.

Due to air entering the collector loop each time the system drains down, consideration must be given to minimising corrosion in the plumbing. This will normally require a full copper circuit.

2.8 Stagnation

The dangers of extreme high collector temperatures due to stagnation must also be considered. Extreme temperatures may be caused by pump failure, which either leads to an empty collector array or the loss of fluid flow. If the collector array is empty, very high absorber plate temperatures can be generated and this may result in physical damage of the collector. If the fluid flow stops, then boiling of the collector fluid may take place.

Stagnation can also occur during a period of low hot water demand, i.e. maintenance period of the industry process. In this case, the generation of hot water by the solar array exceeds demand. Damage to the solar thermal system could occur in either scenario.

Solar collectors tested to AS/NZS 2712 are tested to resist performance deterioration due to stagnation.

Pressure relief valves should be installed to allow for any unwanted increase in pressure, e.g. as a result of boiling.

The storage tank and piping should be able to withstand high operating temperatures, including high stagnation temperatures. Pipes will be subject to high temperatures if the pump starts up after the collector has been stagnating for a period during the day. The material must withstand the temperatures and pressures that could be developed. Furthermore, it is important to install pipework in a way that allows for expansion, e.g. flexible framework.

2.9 Typical potable hot water loads

The overall hot water consumption should be identified prior to designing LSTS. Table 2.3 gives some indication of hot water loads of different commercial applications. However, many system designs require further analysis to determine the exact hot water load, including daily, seasonal and other application-specific load patterns.

Table 2.3: Typical hot water loads for various commercial applications

Use	Typical water use (litres)
Apartments	
Peak period 60 minutes	
Bed-sitter	25
1 bedroom	40
2 bedroom	70
2 bedroom w/ensuite	75
3 bedroom	80
3 bedroom w/ensuite	90
4 bedroom	100
Penthouse	150
Nursing home	
Peak period 180 minutes	
Bedpan	2.5
Shower	25
Cleaning water/bed	10
Water per meal	5.5
Laundry peak period 300 minutes	
Laundry (1.2 kg per bed)	10 litres/kg
Laundry	
Laundromat peak period 180 minutes	
Water per machine/hr	70
Commercial laundry peak period 300 minutes	
Laundry (1.2 kg per bed)	10 litres/kg
Offices	
Office peak period 60 minutes	
Water per person	1.5
Area per person	10 m^2
Gymnasium peak period 30 minutes	
Water per person	25
Motel	
Motel peak period 60 minutes (2 people per room)	
Shower 1- and 2-star	25
Shower 3-star	20
Shower family/spa	100
Restaurants	
Restaurant peak period (per person)	
Bistro	5.0
Coffee shop	3.5
Auditorium	3.0
Restaurant	5.5
Takeaway shop	2.5
Café	3.0
Hotel kitchen	6.0

Source: Rheem Commercial Solar Hot Water Manual

Note: these are typical hot water loads. With many system designs, further analysis must be undertaken to determine the exact hot water load. With more efficient fittings and behavioural change, lower hot water loads than those shown can be achieved.

2.10 Temperature ranges

Traditionally, the temperature ranges for thermal energy are classified as low, medium and high. The low temperature range covers all thermal energy delivered below 100°C. The medium temperature range covers all heat delivered between 100°C and 400°C. Any heat delivered above 400°C is classified as high. Depending on the application, heat can be delivered by hot air or water, or steam. Some other heat transfer fluids such as oil are also used, usually in the medium to high temperature ranges, to overcome the problems associated with boiling water. Table 2.4 shows industrial sectors with processes in the low to medium temperature range.

Table 2.4: Industrial sectors with processes in the low to medium temperature range

Industrial sector	Process	Temperature range (°C)
Food and beverages	Drying	30–90
	Washing	40–80
	Pasteurising	80–110
	Boiling	95–105
	Sterilising	140–150
	Heat treatment	40–60
Textile industry	Washing	40–80
	Bleaching	60–100
	Dyeing	100–160
Chemical industry	Boiling	95–105
	Distilling	110–300
	Various chemical processes	120–180
All sectors	Preheating of boiler feed water	30–100
	Heating of production halls	30–80
	Hydronic heating	50–60
Personal use	Bathroom/laundry	50–60

Source: Adapted from IEA (www.iea.org), 2005

LSTS may require additional hot water boosting to reach consistent temperatures as needed for different applications.

CHAPTER 3 SOLAR CLIMATE

3.1 General

Solar radiation or irradiation is the energy emitted from the sun. The amount of irradiation arriving at ground level varies depending on the latitude of the location and the local climatic conditions.

Factors affecting available solar irradiation at the collector are:

- latitude/location
- shading
- orientation of solar collectors
- tilt angle of solar collectors.

3.2 Solar fraction

The relative solar fraction can be used as an indicative measurement of the relative energy performance benefit, greenhouse gas emission reduction and energy cost savings of LSTS.

The relative solar fraction is calculated as the proportion of the hot water energy demand provided by the solar collectors in relation to the boosting energy required to heat water to the required temperature in a conventional system.

Table 3.1 below shows the average anticipated solar fraction of a well-designed solar hot water system for low-temperature applications in the major capital cities of Australia and New Zealand.

Table 3.1: Anticipated relative solar fraction for potable water systems

City	Solar fraction
Adelaide	70–80%
Auckland	60–70%
Brisbane	80–90%
Canberra	60–70%
Christchurch	60–70%
Darwin	90%+
Hobart	60–70%
Invercargill	50–60%
Melbourne	60–70%
Perth	70–80%
Sydney	70–80%
Wellington	60–70%

Source: AS/NZS 3500

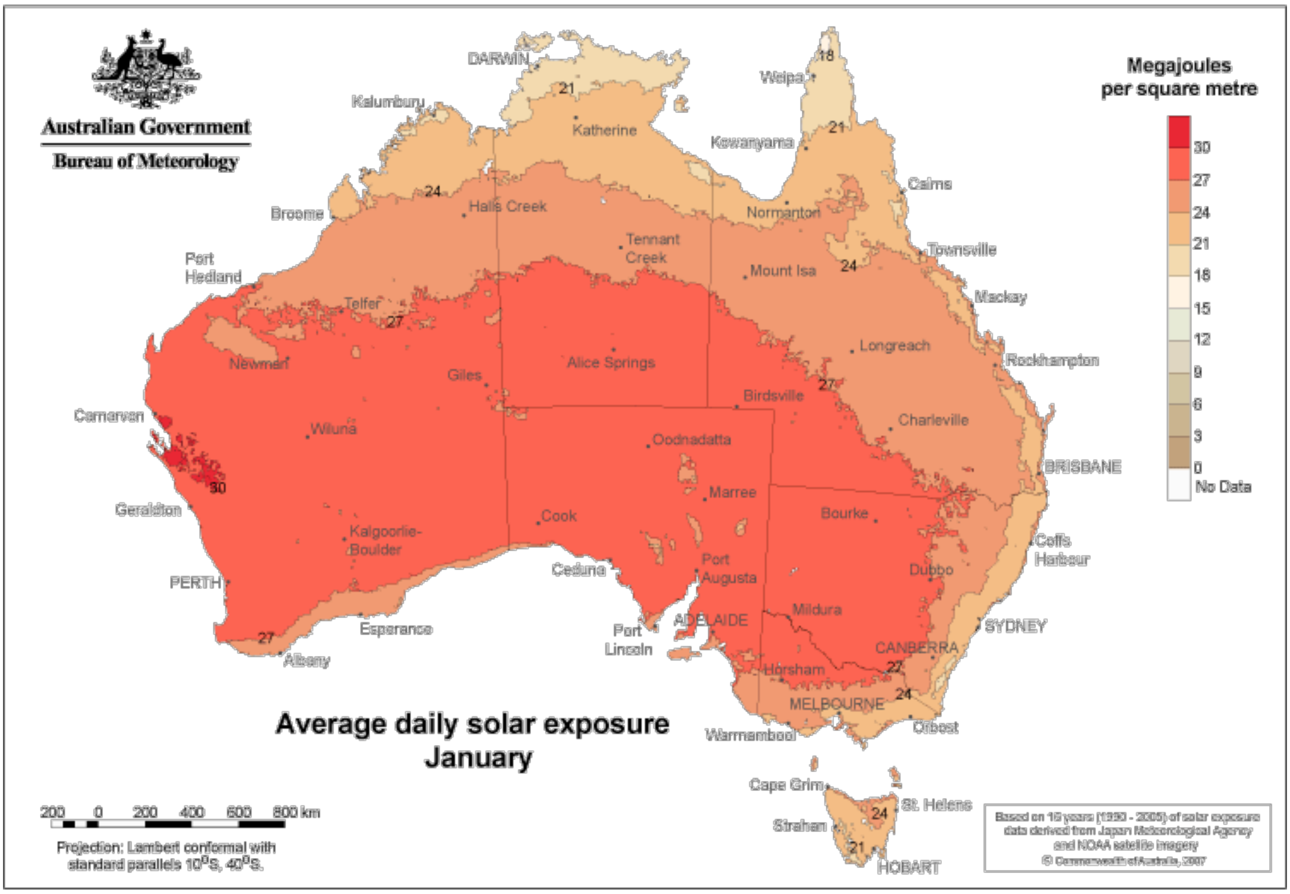
Other factors affecting the performance for different regions and installations are:

- amount of solar irradiation
- temperature of cold water at the inlet
- solar thermal system sizing
- hot water consumption
- ambient air temperature around tank, collector, solar flow and return
- pipework and tank insulation
- energy needed for boosting and circulating pump.

Detailed solar radiation data can be obtained from the *Australian Solar Radiation Data Handbook* published by the Australian and New Zealand Solar Energy Society. Refer to 'Appendix C.5' for additional information.

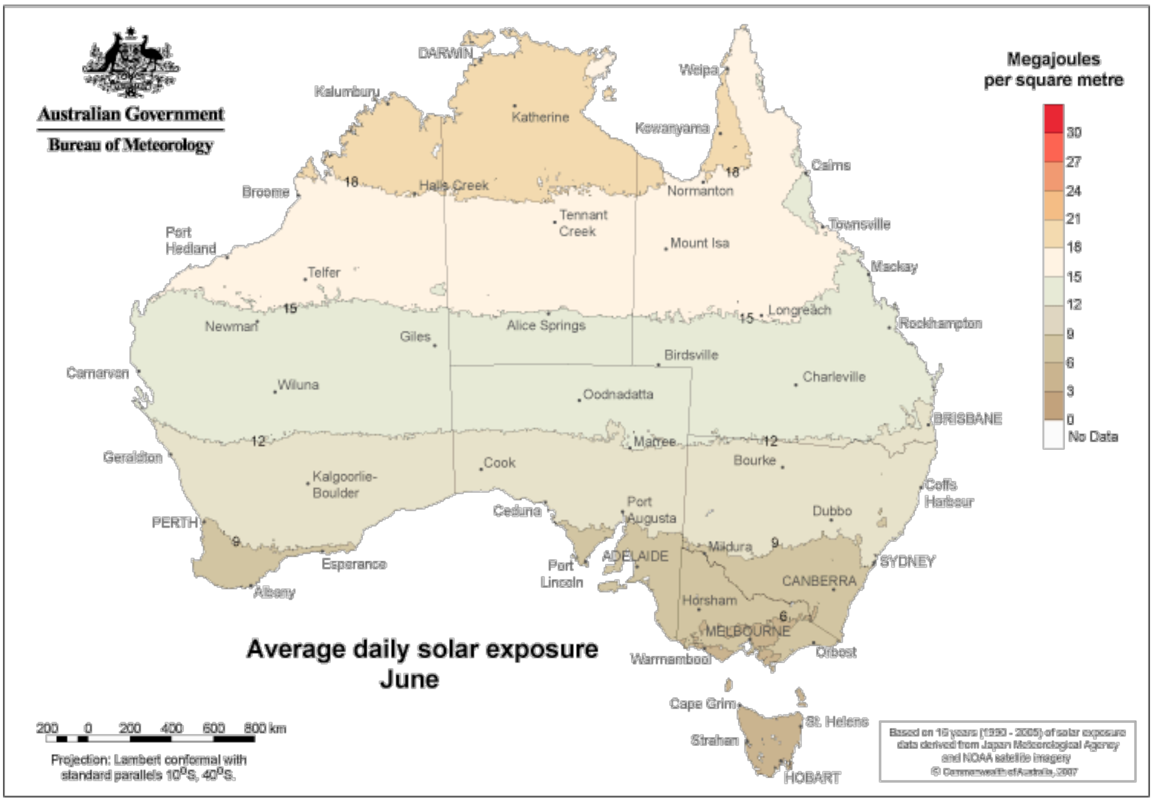
3.2.1 Global irradiation distribution in Australia

Figure 3.1: Daily average horizontal global radiation in January, MJ/(m^2·day)



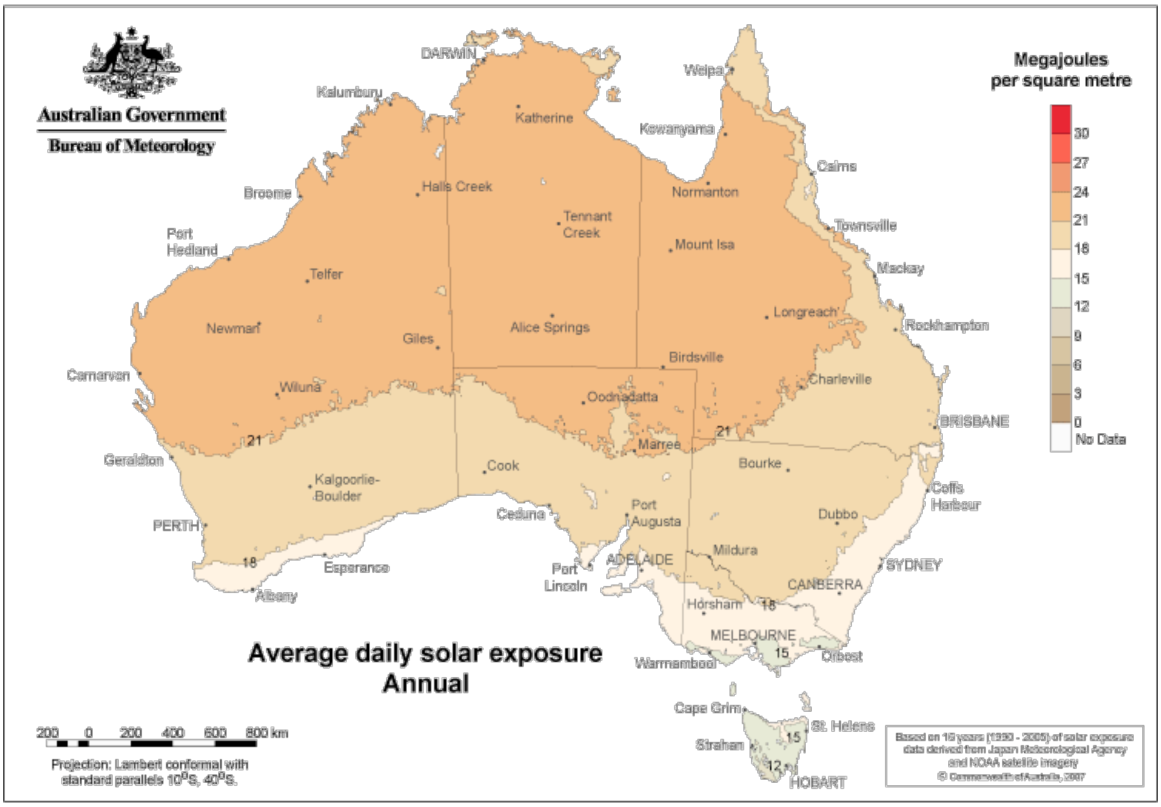
Source: Bureau of Meteorology www.bom.gov.au

Figure 3.2: Daily average horizontal global solar radiation in June, MJ/(m^2·day)



Source: Bureau of Meteorology www.bom.gov.au

Figure 3.3: Annual daily average global horizontal radiation, MJ/(m^2·day)



Source: Bureau of Meteorology www.bom.gov.au

3.2.2 Average solar radiation for Melbourne

The average global, diffuse and direct beam solar irradiation on a horizontal plane and the average irradiance on a north-facing plane inclined at latitude angle for Melbourne is shown in Tables 3.2 – 3.5 below.

Table 3.2: Average global hourly irradiance (W/m^2) and daily irradiation (MJ/m^2) on a horizontal plane in Melbourne

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
5	1										2	3	1
6	41	11	1						1	17	56	69	16
7	162	101	43	10	1			3	34	114	178	200	70
8	307	251	172	96	39	15	19	58	147	255	319	344	168
9	452	410	318	225	137	94	104	172	277	392	452	491	294
10	594	555	451	346	241	186	202	285	385	502	569	612	411
11	722	672	550	425	317	263	284	360	460	590	674	720	503
12	801	751	612	477	349	295	321	394	504	628	735	777	554
13	826	772	629	474	345	286	316	393	505	625	738	787	558
14	785	729	584	428	301	250	282	352	462	577	679	737	514
15	689	637	497	342	222	179	207	280	379	481	576	636	427
16	561	504	368	229	124	94	121	178	266	357	449	508	313
17	401	341	222	100	33	19	34	71	137	215	295	364	186
18	234	173	77	13	1		1	6	30	79	145	204	80
19	80	40	6							9	30	68	20
20	4											4	1
Daily	24.0	21.4	16.3	11.4	7.6	6.1	6.8	9.2	12.9	17.4	21.2	23.5	14.8

Source: Australian Solar Radiation Data Handbook

Table 3.3: Average diffuse hourly irradiance (W/m^2) and daily irradiation (MJ/m^2) on a horizontal plane in Melbourne

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
5	1										2	3	
6	30	9	1						1	12	38	46	11
7	90	62	30	8	1			3	24	70	98	104	41
8	145	119	89	57	28	12	15	40	86	129	154	158	86
9	191	163	137	108	80	60	64	96	137	179	201	198	135
10	224	191	174	145	120	101	108	139	180	217	237	230	172
11	237	212	198	173	146	129	137	168	212	239	255	254	197
12	241	221	212	184	159	143	152	185	224	249	263	253	207
13	238	219	210	184	158	144	155	186	219	245	254	245	205
14	227	209	199	170	145	131	142	171	204	227	236	231	191
15	207	189	177	145	118	102	114	142	173	197	208	208	165
16	175	162	146	110	76	61	73	102	130	156	171	178	128
17	140	130	105	60	24	15	24	48	78	107	128	139	83
18	101	85	48	10	1		1	5	21	48	75	97	41
19	48	30	6							4	17	42	12
20	4											3	1
Daily	8.3	7.2	6.2	4.9	3.8	3.2	3.5	4.6	6.1	7.5	8.4	8.6	6.0

Source: Australian Solar Radiation Data Handbook

Table 3.4: Average direct beam hourly irradiance (W/m²) and daily irradiation (MJ/m²) on a horizontal plane in Melbourne

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
5											1	1	
6	11	2								5	18	24	5
7	73	40	12	2					10	44	80	96	30
8	162	132	82	38	11	3	4	18	61	126	165	186	82
9	261	247	181	117	57	34	40	76	139	213	250	292	159
10	370	364	277	200	121	85	95	146	205	285	332	382	239
11	485	460	352	253	171	133	147	192	248	351	419	466	306
12	560	529	400	293	191	152	168	209	280	379	472	523	346
13	588	553	419	290	186	142	162	207	286	380	484	541	353
14	558	519	385	257	156	118	141	181	258	351	443	506	323
15	482	448	320	197	104	77	93	138	207	285	369	428	262
16	386	342	222	119	48	34	48	77	136	201	278	330	185
17	261	211	118	40	9	4	9	23	59	109	168	224	103
18	132	88	30	3	1			1	9	32	70	107	39
19	32	11	1							5	13	26	7
20	1											1	
Daily	15.7	14.2	10.1	6.5	3.8	2.8	3.3	4.6	6.8	10.0	12.8	14.9	8.8

Source: Australian Solar Radiation Data Handbook

Table 3.5: Average total hourly irradiance (W/m²) and daily irradiation (MJ/m²) on a north-facing plane inclined at latitude angle -37.8° (Melbourne)

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
5	1										2	3	
6	29	9	1						1	12	36	43	11
7	111	70	34	10	1			4	28	103	142	141	54
8	259	236	199	116	41	17	21	60	185	267	291	289	165
9	419	418	380	322	226	140	164	261	351	429	441	450	334
10	581	592	547	487	382	317	336	419	489	564	578	590	490
11	730	736	676	593	492	434	458	521	584	674	702	714	609
12	822	834	757	666	535	478	508	562	643	723	774	781	674
13	849	860	780	660	527	458	497	559	645	718	775	791	677
14	797	806	720	597	463	405	448	503	588	657	702	729	618
15	682	691	608	481	347	299	335	406	482	537	578	610	505
16	529	529	443	328	204	156	211	264	338	385	426	460	356
17	346	336	261	121	33	20	36	78	176	219	253	295	181
18	167	149	65	12	1		1	7	22	49	96	133	58
19	45	28	6							5	17	39	12
20	4											4	1
Daily	22.9	22.7	19.7	15.8	11.7	9.8	10.9	13.1	16.3	19.2	20.9	21.9	17.1

Source: Australian Solar Radiation Data Handbook

The global average daily solar radiation energy on a horizontal plane for various locations in Australia and New Zealand are shown in Tables 3.6 and 3.7 below.

Table 3.6: Daily average global horizontal irradiation in Australia, MJ/(m^2·day)

Location	Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Adelaide	-35	28.2	25.3	19.7	14.2	9.6	7.7	8.4	11.6	16.1	21.2	25.3	26.7	17.8
Albany	-35	24.8	21.2	16.5	11.9	8.8	7.6	8.3	10.8	14.4	18.5	21.1	24.6	15.7
Alice Springs	-23.8	27.8	25.5	24.2	20.5	16.2	14.6	15.7	19.0	22.7	25.5	26.9	27.7	22.2
Brisbane	-27.4	24.0	20.9	19.1	15.0	11.9	11.4	12.2	15.4	19.6	21.2	22.9	24.1	18.1
Canberra	-35.3	26.8	23.7	19.2	13.8	9.8	7.9	9.0	11.9	16.5	21.5	24.7	26.9	17.7
Cairns	-16.8	22.4	18.9	19.8	17.5	16.5	14.8	15.9	18.2	22.0	24.0	23.4	22.2	19.6
Darwin	-12.4	19.3	18.8	20.0	21.2	20.0	19.2	19.9	21.5	22.6	23.5	22.9	21.1	20.8
Forrest	-30.8	28.7	24.9	21.2	16.8	12.7	11.0	11.8	14.9	19.3	24.0	26.7	29.0	20.1
Geraldton	-28.8	29.5	26.7	22.7	17.4	13.3	11.3	12.2	15.5	20.0	25.1	28.2	30.1	21.0
Halls Creek	-18.2	24.3	23.4	22.9	21.8	19.0	17.8	18.9	21.0	23.9	25.5	25.6	25.0	22.4
Hobart	-42.8	22.7	20.0	14.8	10.2	6.6	5.2	6.0	8.6	12.7	17.2	20.4	22.2	13.9
Kalgoorlie	-30.8	28.4	25.1	21.2	16.1	11.9	10.5	11.4	14.8	19.7	24.7	26.8	28.9	20.0
Launceston	-41.6	24.4	21.7	15.7	10.9	6.6	5.0	5.7	8.1	12.4	17.5	22.2	24.0	14.5
Laverton	-37.9	24.5	22.1	16.7	11.8	8.0	6.5	7.3	9.9	13.6	18.0	21.7	23.8	15.3
Longreach	-23.4	26.6	24.5	23.2	20.0	16.2	15.1	15.9	19.3	23.1	25.8	27.6	27.6	22.1
Melbourne	-37.8	24.0	21.4	16.3	11.4	7.6	6.1	6.8	9.2	12.9	17.4	21.2	23.5	14.8
Mildura	-34.2	28.3	25.4	21.2	15.5	10.6	8.6	9.5	12.7	17.0	22.0	26.0	28.4	18.8
Mt Gambier	-37.7	24.6	22.4	16.7	11.3	7.7	6.4	7.1	9.7	13.4	17.8	21.5	23.8	15.2
Oodnadatta	-27.6	28.8	26.3	23.8	18.9	14.8	12.8	13.9	16.8	20.9	25.3	28.0	29.7	21.6
Perth	-31.9	29.4	26.0	21.5	15.6	11.1	9.0	9.6	12.5	16.8	22.1	26.0	29.2	19.1
Port Headland	-20.4	27.3	25.5	24.1	21.0	17.2	15.9	17.2	20.3	24.4	27.7	29.2	29.1	23.2
Rockhampton	-23.4	23.4	21.3	20.9	17.6	14.6	13.6	14.4	17.0	20.6	22.7	24.3	24.5	19.6
Sale	-38.1	23.4	21.1	15.0	11.3	7.6	6.0	7.0	9.2	13.2	17.6	21.0	22.5	14.6
Sydney	-33.9	23.3	20.4	17.0	12.9	9.8	8.6	9.2	12.4	16.5	20.1	22.4	23.7	16.4
Tennant Creek	-19.6	25.9	24.0	24.3	22.0	19.2	17.3	18.3	21.2	23.8	25.0	25.6	25.9	22.7
Townsville	-19.2	22.3	21.1	20.5	17.3	14.5	14.2	15.0	17.6	21.8	23.5	23.7	24.7	19.7
Wagga Wagga	-35.2	27.3	24.4	20.2	14.9	9.8	7.6	8.4	11.3	15.9	20.8	25.6	27.6	17.8
Williamtown	-32.8	23.9	21.2	18.3	14.5	10.8	9.1	10.3	13.8	17.2	20.3	23.2	24.9	17.3

Source: Adapted from ACADS-BSG http://members.ozemail.com.au/~acadsbsg/

Table 3.7: Daily average global horizontal irradiation in New Zealand, MJ/(m^2·day)

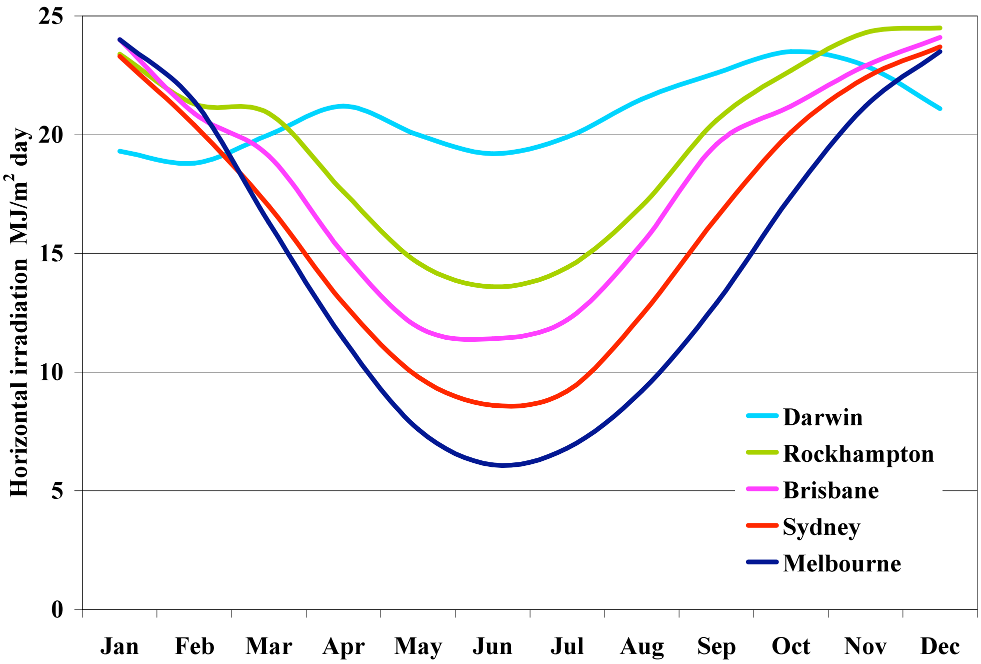
Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Kaitaia	21.7	19.4	16.4	11.6	8.5	7.0	7.7	10.1	13.5	16.9	19.9	22.1	14.6
Whangarei	20.8	18.4	15.5	11.3	8.4	7.1	7.4	10.3	13.7	16.9	18.8	20.4	13.8
Tauranga	23.0	20.2	16.4	11.4	8.1	7.0	7.1	9.8	13.7	17.2	20.4	22.6	14.6
Rotorua	22.5	19.6	16.0	11.1	8.0	6.3	6.7	9.4	12.9	16.6	19.5	21.6	14.1
Auckland	23.1	20.1	16.0	11.7	8.3	6.6	7.9	10.0	13.8	17.5	20.9	23.1	15.0
Hamilton	21.7	19.2	15.8	11.1	7.7	6.2	6.7	9.0	12.7	15.9	19.9	22.0	14.1
New Plymouth	23.2	20.9	16.3	10.8	7.6	6.1	6.7	9.7	13.0	16.7	20.9	22.6	14.7
Masterton	21.7	19.0	15.2	9.7	7.0	5.5	5.9	8.6	12.6	17.0	20.6	22.5	13.8
Gisborne	22.6	19.4	15.4	10.8	7.9	6.6	6.8	10.0	13.9	18.5	20.7	23.0	14.6
Napier	22.1	19.4	15.5	10.8	7.8	6.3	6.8	9.7	13.6	18.4	20.8	22.5	14.5
Palmerston North	21.9	19.2	14.7	10.1	6.8	5.2	5.9	8.4	11.8	15.7	19.0	20.9	13.6
Wellington	23.6	19.9	15.1	10.3	6.6	4.9	5.7	8.1	12.3	16.9	20.9	22.6	14.0
Wanganui	23.8	21.5	15.6	10.9	7.7	6.1	6.9	9.3	13.3	17.1	21.2	23.7	14.9
Westport	20.9	18.7	14.5	9.2	6.5	4.8	5.7	8.2	11.6	14.4	19.5	20.0	13.0
Hokitika	20.7	18.1	13.8	9.2	5.8	4.5	5.3	7.7	11.5	14.9	19.2	20.5	12.6
Nelson	23.4	20.5	15.6	11.2	7.6	5.7	6.2	8.8	13.2	17.2	21.0	22.9	14.4
Blenheim	23.1	19.8	15.9	11.1	7.5	5.8	6.5	9.0	12.9	17.5	20.8	22.5	14.3
Kaikoura	21.3	18.7	14.9	10.1	7.1	5.3	6.1	9.1	12.8	17.8	21.1	22.4	13.9
Christchurch	21.9	18.6	13.9	9.5	6.1	4.6	5.1	7.7	12.1	16.8	20.6	22.2	13.3
Timaru	20.0	17.3	14.4	9.3	6.2	5.5	6.2	8.9	13.0	16.7	20.4	21.2	13.2
Dunedin	18.5	17.2	12.3	8.1	4.9	3.6	4.5	6.8	11.0	14.3	17.1	18.9	11.4
Manapouri	21.4	18.5	13.6	8.4	5.0	3.7	4.2	7.2	11.4	15.8	19.9	22.5	12.7
Queenstown	23.9	20.8	15.5	10.2	6.3	4.7	5.7	8.6	13.0	18.0	21.7	24.3	14.4
Clyde	22.2	19.2	15.0	10.0	5.9	4.3	4.7	8.0	12.3	17.5	21.3	22.8	13.6
Invercargill	20.4	17.5	12.6	7.9	4.6	3.6	4.3	7.0	11.1	15.5	19.8	21.5	12.1
Chatham Island	20.0	16.9	12.8	8.6	5.1	4.0	4.7	7.2	10.9	15.2	18.9	20.7	12.3
Antarctica, Scott Base	25.4	13.7	4.5	0.4	0.0	0.0	0.0	0.1	2.5	11.2	23.3	29.3	9.2

Source: Energy Efficiency and Conservation Authority (EECA)

3.2.3 Monthly global solar irradiation in Australia

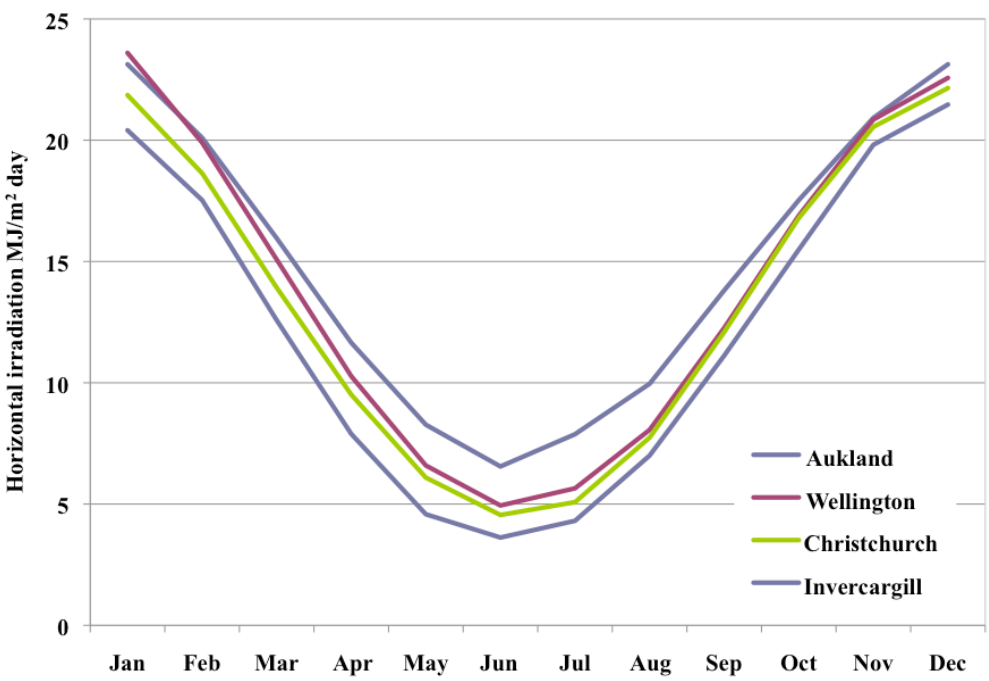
The variation over a year of global irradiation for some locations in Australia is shown in Figure 3.4 below.

Figure 3.4: Monthly global solar irradiation in Australia



The annual variation of global irradiation for some locations in New Zealand is shown in Figure 3.5 below.

Figure 3.5: Monthly global solar irradiation in New Zealand



3.2.4 Monthly solar irradiation on inclined surfaces in Victoria

The variation of solar radiation on inclined surfaces in Melbourne, Mildura and Sale is shown in Figures 3.6, 3.7 and 3.8 below. There is a substantial increase in energy available in winter on an inclined surface. The appropriate slope for a particular application depends on the seasonal energy demand pattern. The interaction of the energy seasonal demand pattern and the seasonal solar availability can be evaluated using the system performance simulation models described in Chapter 4.

Figure 3.6: Solar irradiation on inclined surfaces in Melbourne (south of the Great Dividing Range)

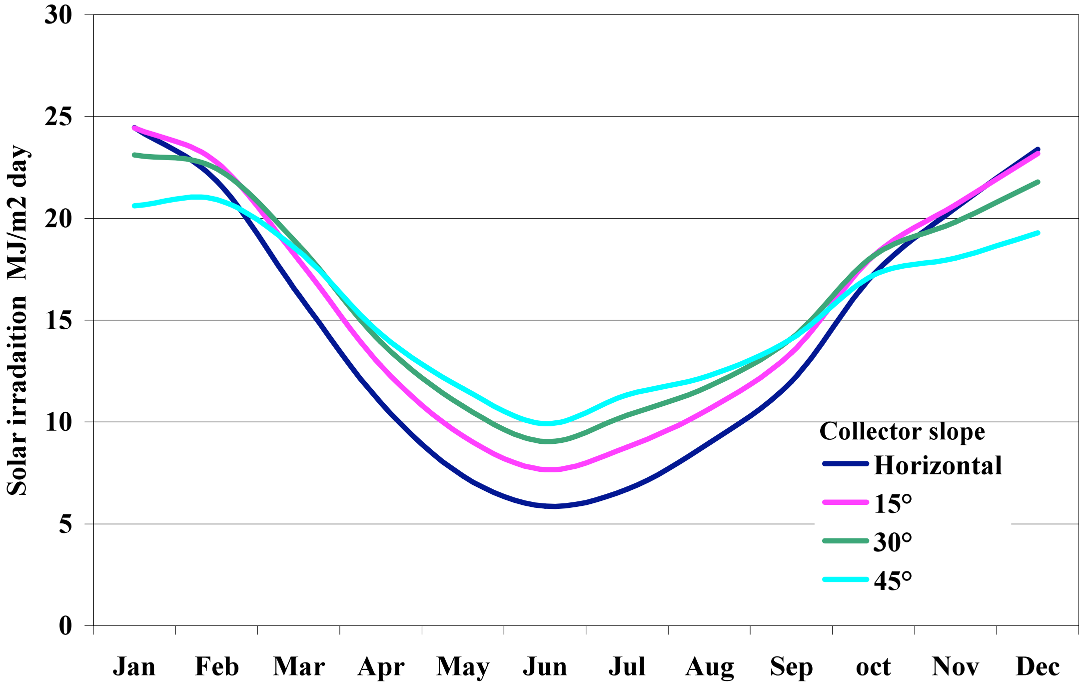


Figure 3.7: Solar irradiation on inclined surfaces in Mildura (north of the Great Dividing Range)

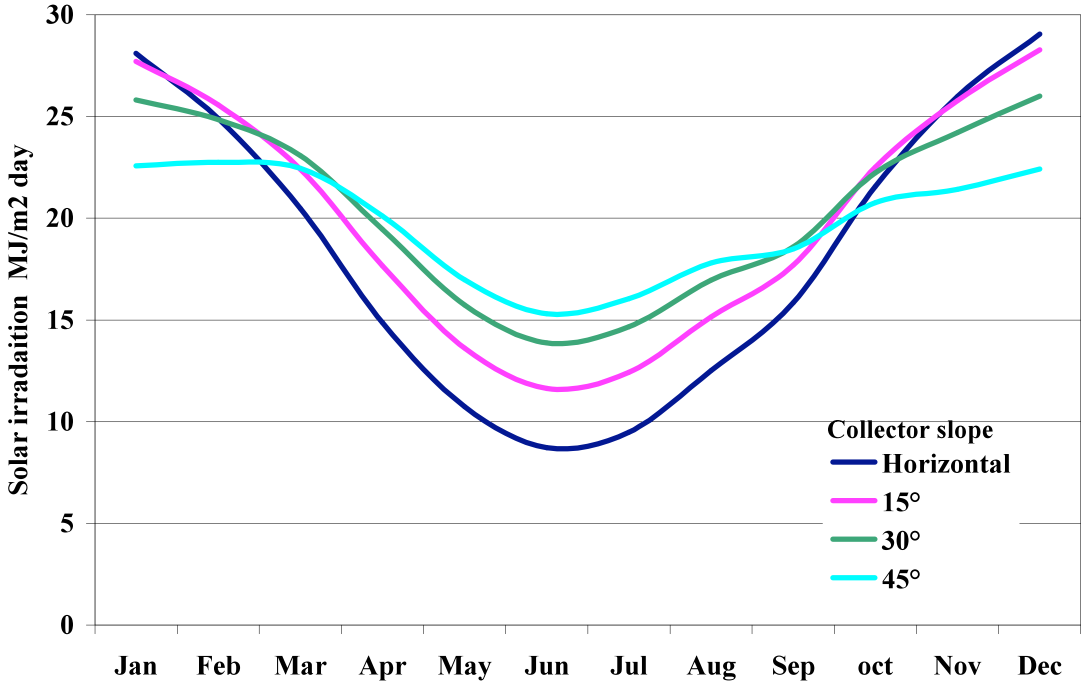
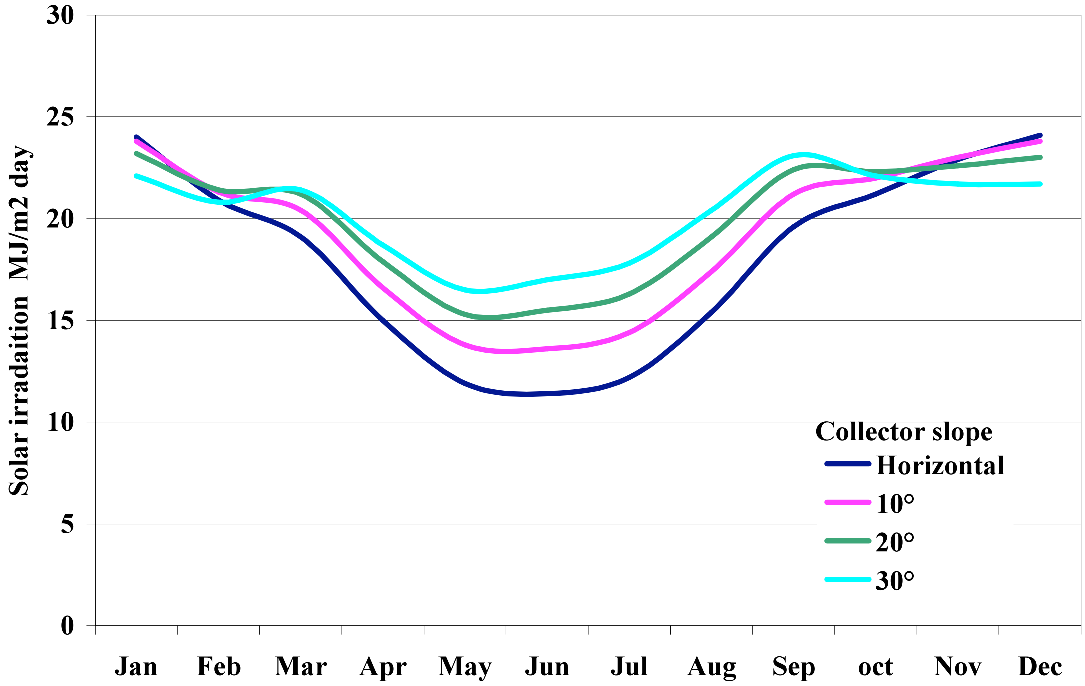


Figure 3.8: Solar irradiation on inclined surfaces in Brisbane



3.2.5 Factors governing LSTS performance

LSTS performance depends on the:

- system design
- product characteristics
- applied hot water loads
- inclination and orientation of the collector.

The variation of LSTS performance, due to non-ideal orientation and inclination of the collector, is a function of the radiation characteristics at the application site and the seasonal load pattern of the hot water use. Positioning the collectors so that they receive maximum annual radiation may not result in maximum solar contribution, as excess energy may be collected in summer when the hot water demand is low. The optimum collector inclination and orientation depends on the seasonal variation of solar input and the seasonal demand for output energy.

Analysis of the variation of solar contribution as a function of collector orientation and inclination needs to be determined for realistic seasonal load patterns and a mixing valve in the system to modulate the load volume in response to the wide range of temperatures that occur in a solar-heated tank. The range of collector orientations and inclinations that result in annual solar irradiation within 5% of the optimum is shown by the central zone of Figures 3.9, 3.10 and 3.11 for Melbourne, Mildura and Brisbane. Variation of annual solar irradiation is relatively insensitive to collector orientation (azimuth) within 45° of north for these locations. For arrays facing north, acceptable solar irradiation is obtained for inclinations within 15° of the latitude angle.

Although the annual incident irradiation is relatively constant for inclinations within 15° of the latitude angle and for orientations up to 45° of north, the seasonal pattern of incident irradiation varies significantly with inclination and orientation. Installations with a north-facing collector with an inclination of 15° or 55° in Melbourne (points A and B in Figure 3.8) both receive similar annual irradiation; however, the 55° installation (A) would receive significantly higher radiation in winter than the 15° installation (B). If the hot water seasonal energy demand pattern has a winter peak, then installation B may produce excess energy in summer that will have to be dumped and the system will underperform in winter. The combined effects of the seasonal radiation input and the seasonal hot water demand patterns need to be considered during the full system performance analysis (refer to Chapter 5.4).

Figure 3.9: Relative solar radiation as a function of orientation (azimuth) and inclination of the solar collector in Melbourne (south of the Great Dividing Range)

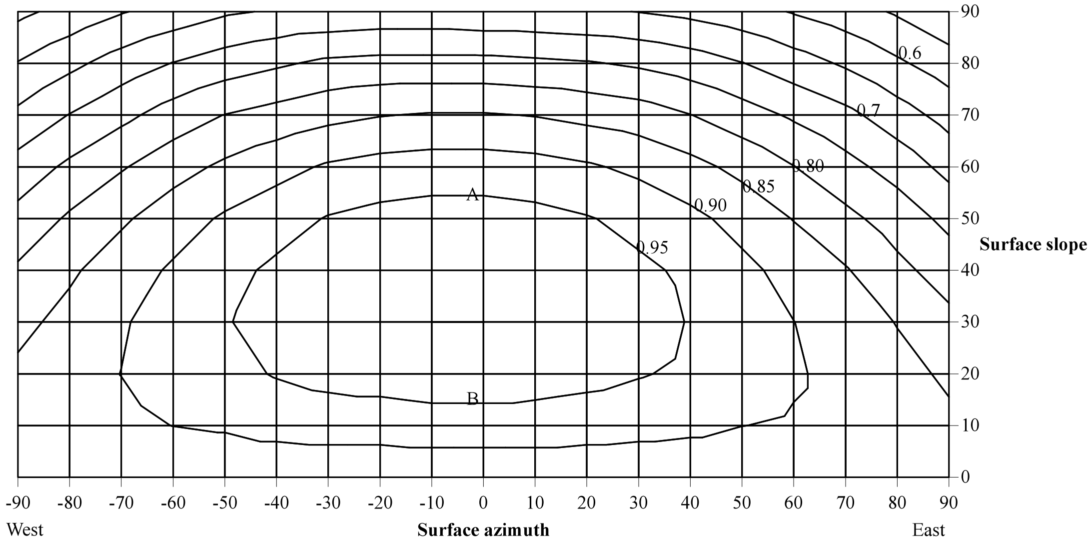


Figure 3.10: Relative solar radiation as a function of orientation (azimuth) and inclination of the solar collector in Mildura (north of the Great Dividing Range)

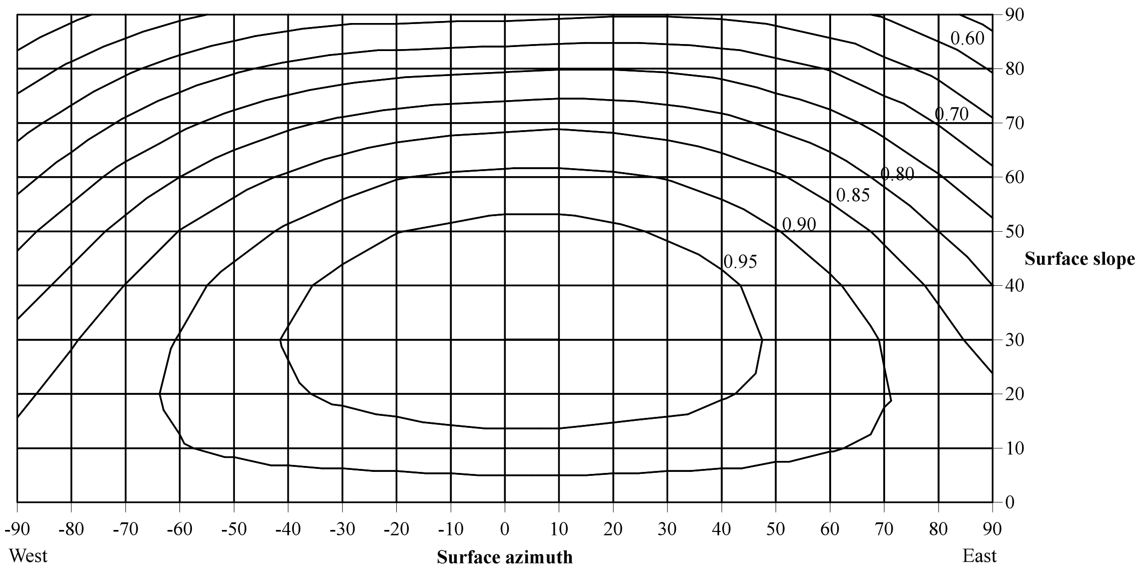
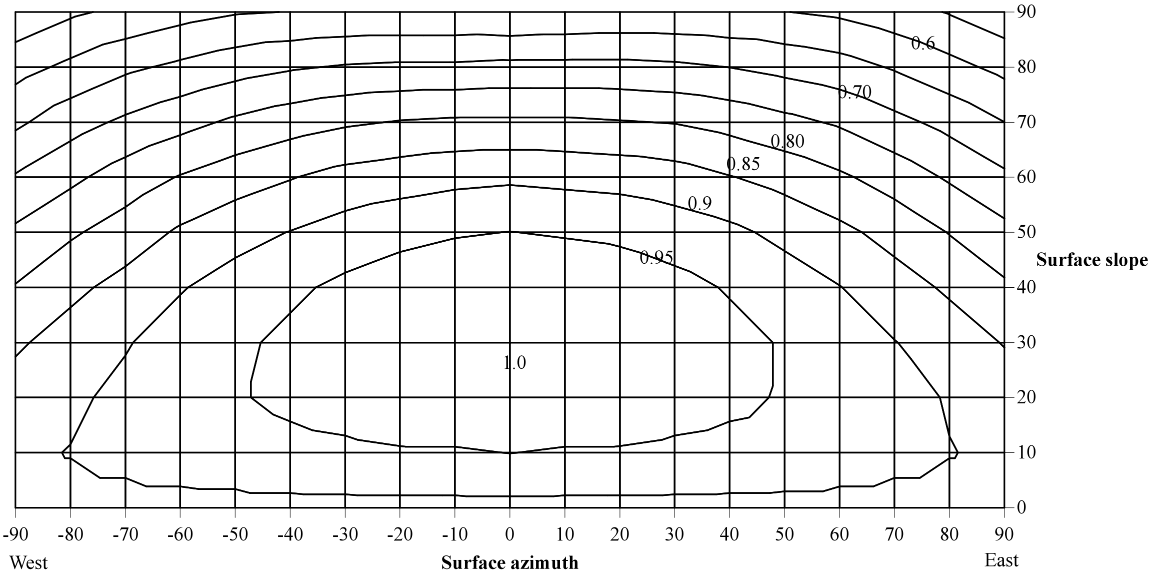


Figure 3.11: Relative solar radiation as a function of orientation (azimuth) and inclination of the solar collector in Brisbane



Tables 3.8 and 3.9 below show the effect on slope difference in solar irradiance on the collector at various inclinations in New Zealand cities. The red-shaded values are the highest for the particular month. The blue-shaded cells have the lowest values.

Table 3.8: Effect of slope on monthly solar radiation resource for Auckland (Zone 5)

	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
Jan	1.00	1.00	0.98	0.93	0.86	0.77	0.66	0.54	0.41	0.27
Feb	0.81	0.83	0.82	0.80	0.75	0.69	0.61	0.52	0.41	0.31
Mar	0.74	0.79	0.83	0.84	0.83	0.80	0.74	0.67	0.58	0.47
Apr	0.45	0.50	0.54	0.57	0.58	0.58	0.56	0.52	0.47	0.41
May	0.34	0.40	0.44	0.48	0.50	0.51	0.51	0.49	0.46	0.42
Jun	0.26	0.32	0.36	0.40	0.42	0.43	0.44	0.43	0.41	0.37
Jul	0.35	0.42	0.49	0.54	0.57	0.59	0.60	0.58	0.55	0.51
Aug	0.46	0.53	0.58	0.63	0.65	0.65	0.64	0.61	0.57	0.51
Sep	0.57	0.62	0.65	0.67	0.66	0.64	0.61	0.56	0.49	0.41
Oct	0.78	0.82	0.83	0.81	0.78	0.73	0.65	0.56	0.46	0.35
Nov	0.89	0.89	0.88	0.84	0.78	0.71	0.61	0.51	0.39	0.27
Dec	0.98	0.97	0.94	0.89	0.81	0.72	0.61	0.49	0.37	0.24
Total	0.91	0.96	1.00	1.00	0.98	0.93	0.86	0.77	0.66	0.54

Source: Energy Efficiency and Conservation Authority (EECA)

To determine the total solar radiation each month, multiply each value in the table by 198 kWh/m^2. Multiplying by 1662 kWh/m^2 provides the annual solar radiation at each slope.

Table 3.9: Effect of slope on monthly solar radiation on resource for Dunedin (Zone 6)

	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
Jan	1.00	1.00	0.98	0.93	0.86	0.77	0.66	0.54	0.41	0.27
Feb	0.81	0.83	0.82	0.80	0.75	0.69	0.61	0.52	0.41	0.31
Mar	0.74	0.79	0.83	0.84	0.83	0.80	0.74	0.67	0.58	0.47
Apr	0.45	0.50	0.54	0.57	0.58	0.58	0.56	0.52	0.47	0.41
May	0.34	0.40	0.44	0.48	0.50	0.51	0.51	0.49	0.46	0.42
Jun	0.26	0.32	0.36	0.40	0.42	0.43	0.44	0.43	0.41	0.37
Jul	0.35	0.42	0.49	0.54	0.57	0.59	0.60	0.58	0.55	0.51
Aug	0.46	0.53	0.58	0.63	0.65	0.65	0.64	0.61	0.57	0.51
Sep	0.57	0.62	0.65	0.67	0.66	0.64	0.61	0.56	0.49	0.41
Oct	0.78	0.82	0.83	0.81	0.78	0.73	0.65	0.56	0.46	0.35
Nov	0.89	0.89	0.88	0.84	0.78	0.71	0.61	0.51	0.39	0.27
Dec	0.98	0.97	0.94	0.89	0.81	0.72	0.61	0.49	0.37	0.24
Total	0.91	0.96	1.00	1.00	0.98	0.93	0.86	0.77	0.66	0.54

Source: Energy Efficiency and Conservation Authority (EECA)

To determine the total solar radiation each month, multiply each value in the table by 165 kWh/m^2. Multiplying by 1338 kWh/m^2 provides the annual solar radiation at each slope.

CHAPTER 4 DESIGN OF COMMERCIAL SOLAR WATER HEATERS

4.1 System configurations

Typical LSTS are shown in Figures 4.1 – 4.5 below. The system configurations shown are:

- open loop system with no heat exchanger
- closed loop system with immersed heat exchanger in storage tank
- closed loop system with external heat exchanger between collector and tank
- closed loop system for multi-level solar hot water delivery
- closed loop system with ring main solar hot water delivery.

The pump is controlled by sensing the solar collector outlet temperature and temperatures in the storage tank. The simplest controller is a differential thermostat (DT) controller that senses the temperature difference between the collector output and the temperature in the bottom of the storage tank as shown in the figures below. More advanced controllers sense the temperature gradients in the tank and availability of auxiliary energy and make decisions regarding the solar collector pump and auxiliary booster operation depending on the time of day, solar radiation level, hot water capacity of the tank and anticipated user demand.

Figure 4.1: Open loop system with no heat exchanger

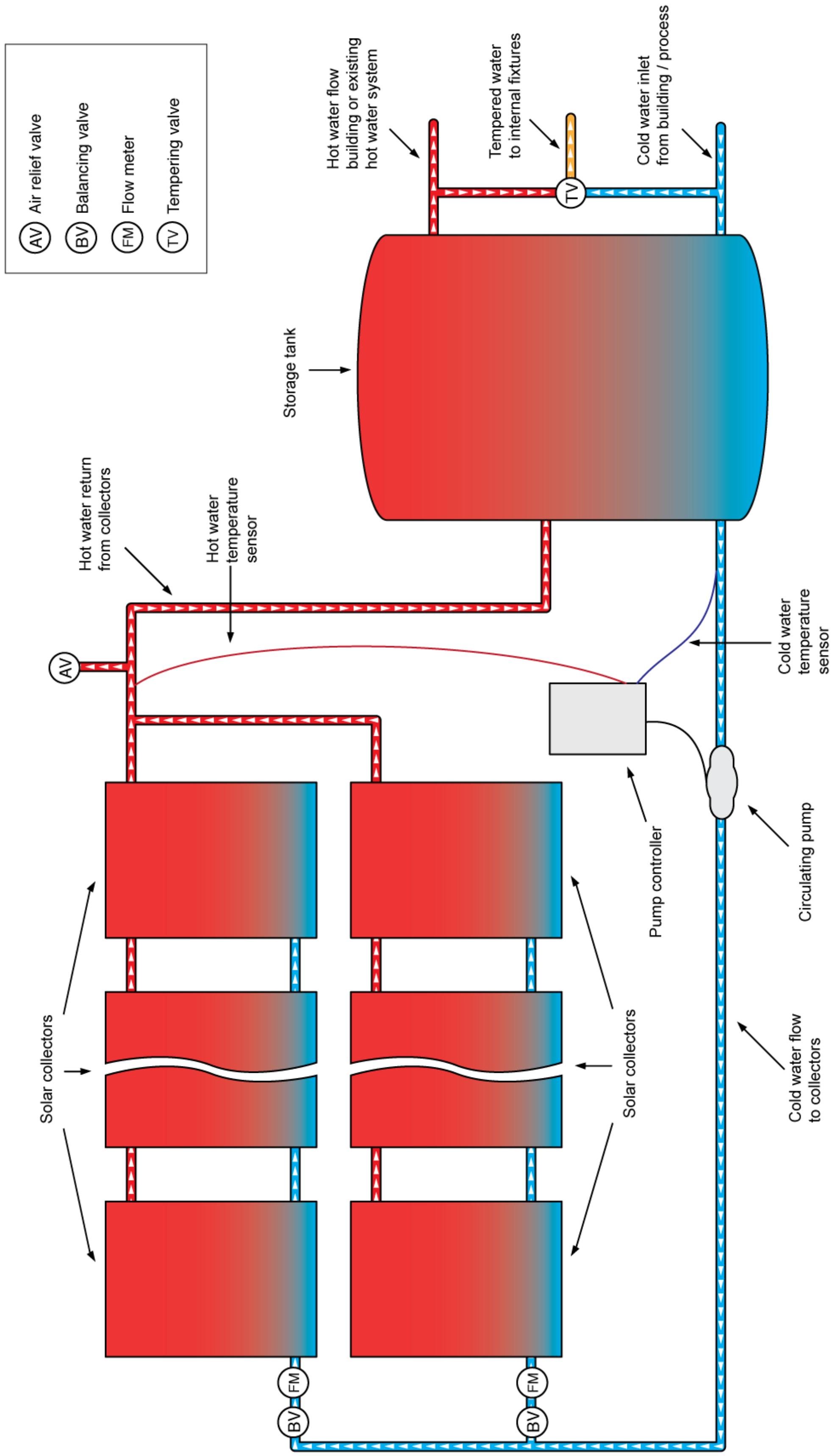


Figure 4.2: Closed loop system with immersed heat exchanger in storage tank

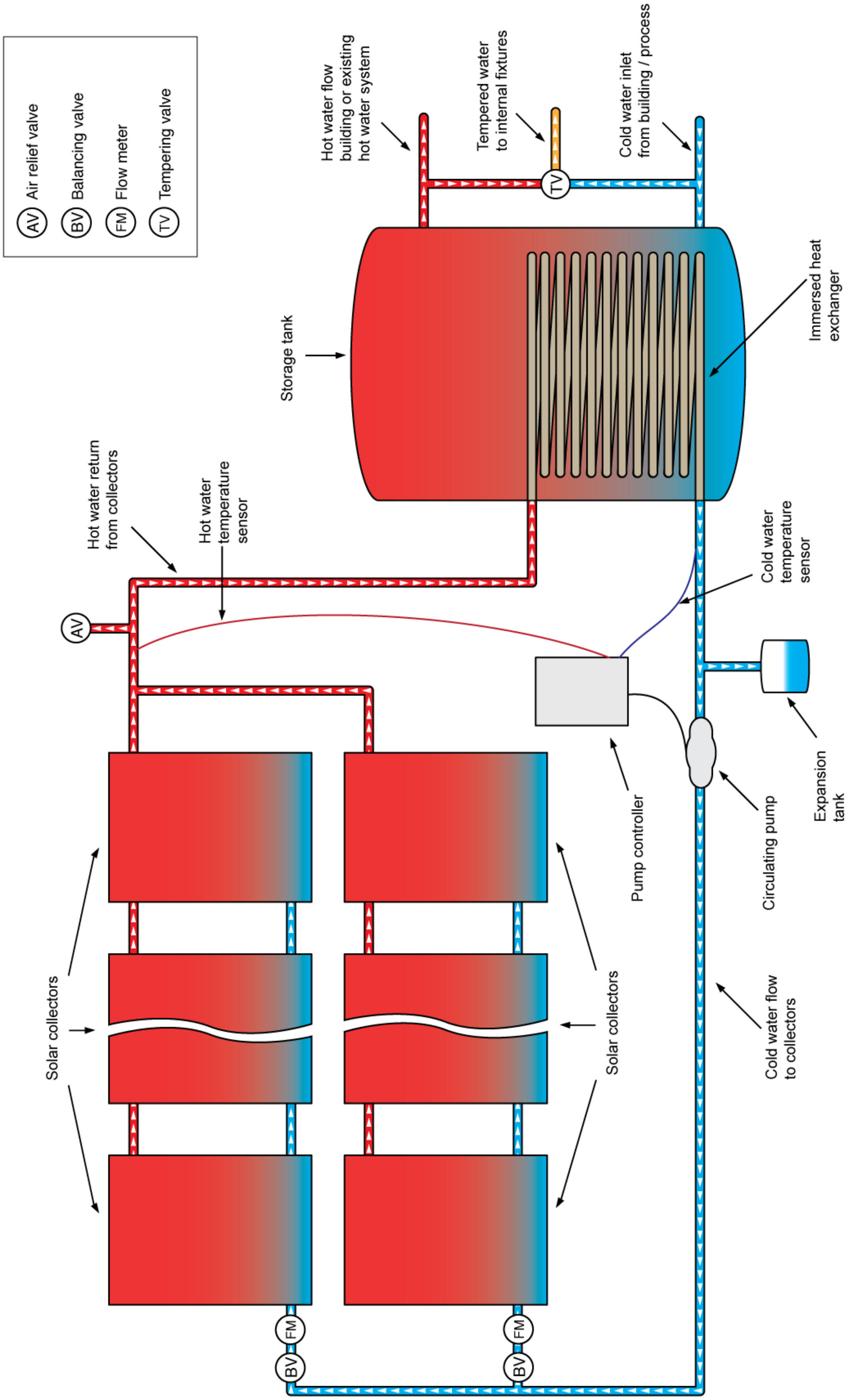


Figure 4.3: Closed loop system with external heat exchanger between collector and tank

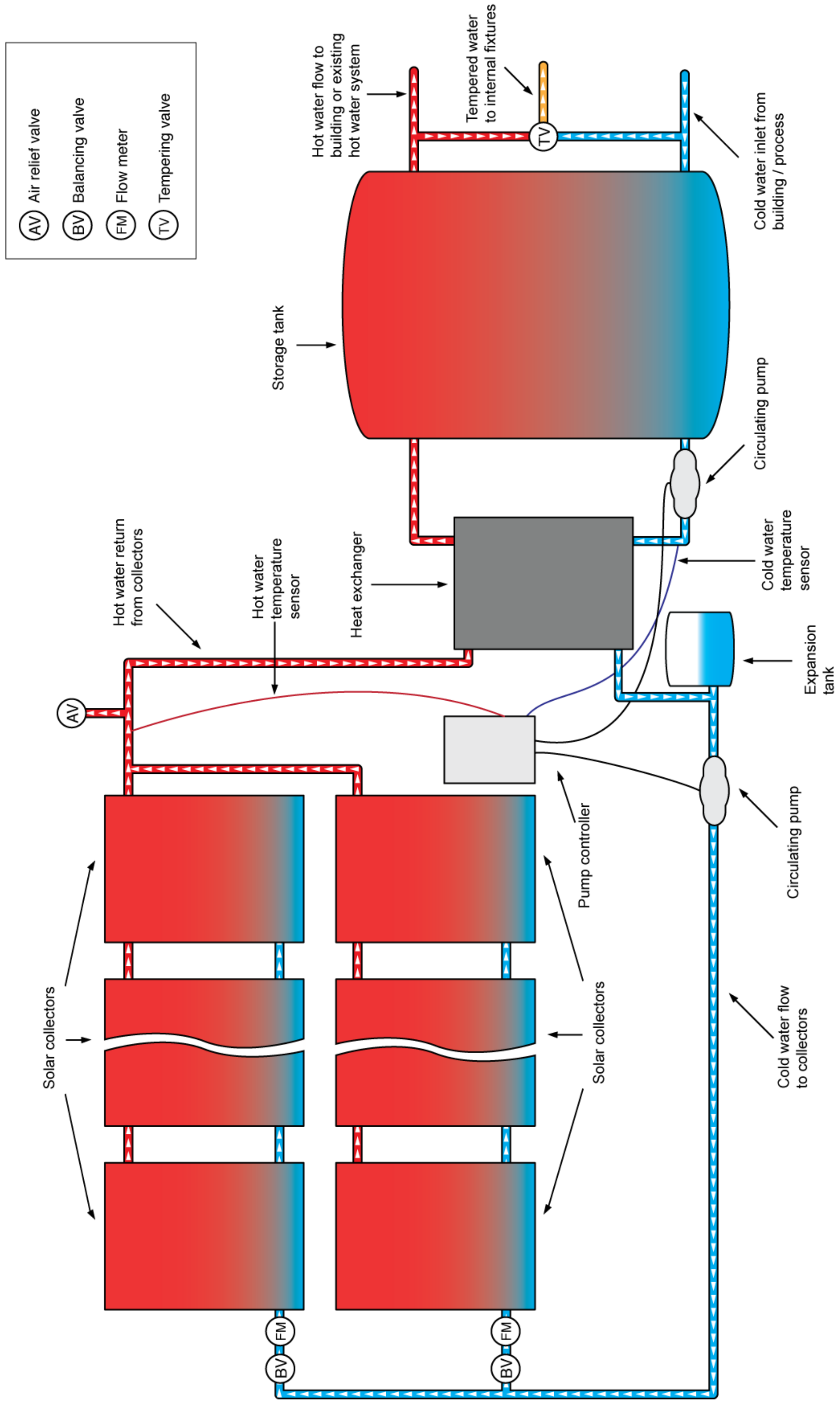


Figure 4.4: Closed loop system for typical ring main solar hot water delivery design (tempered hot water delivery)

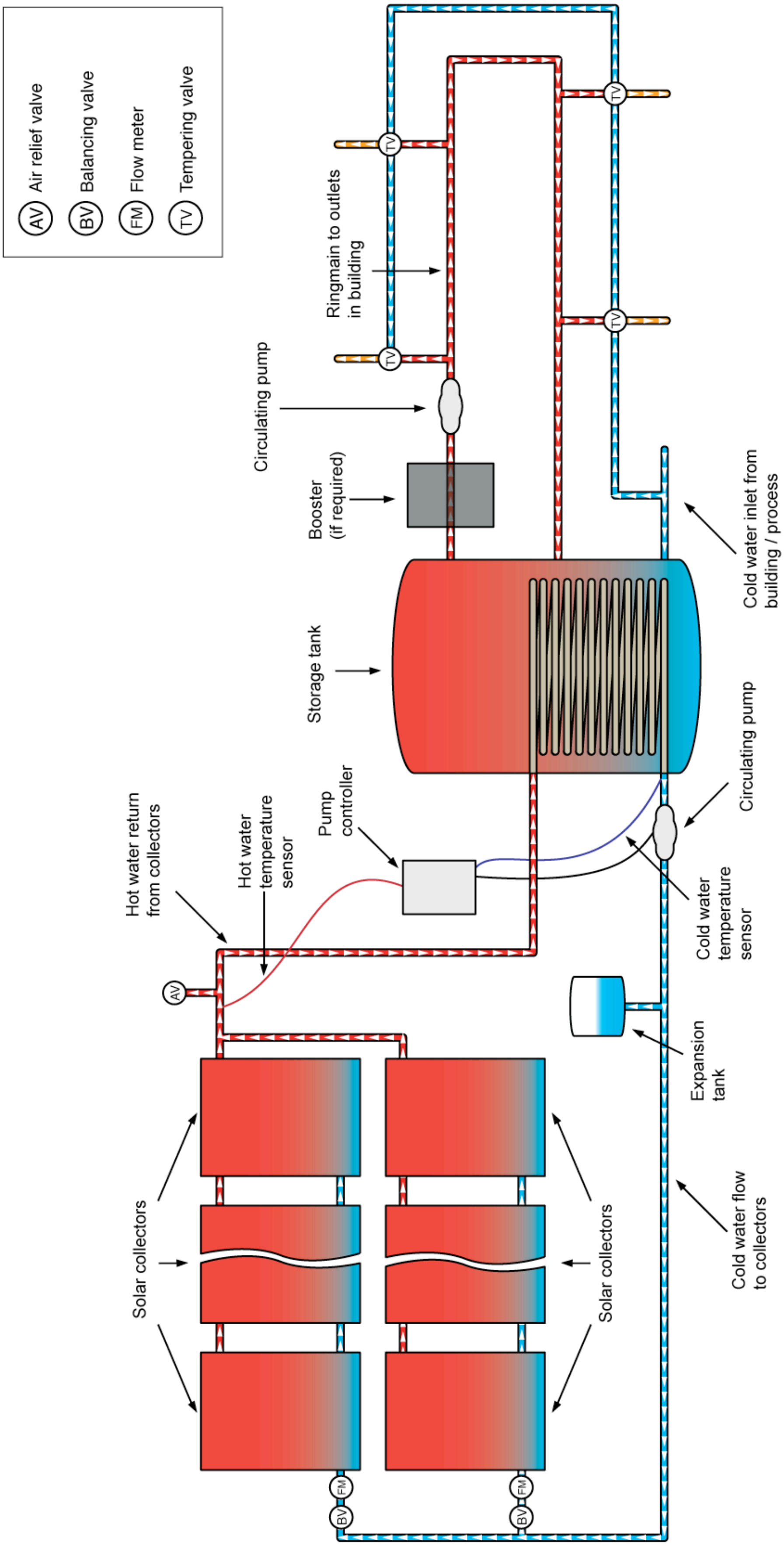
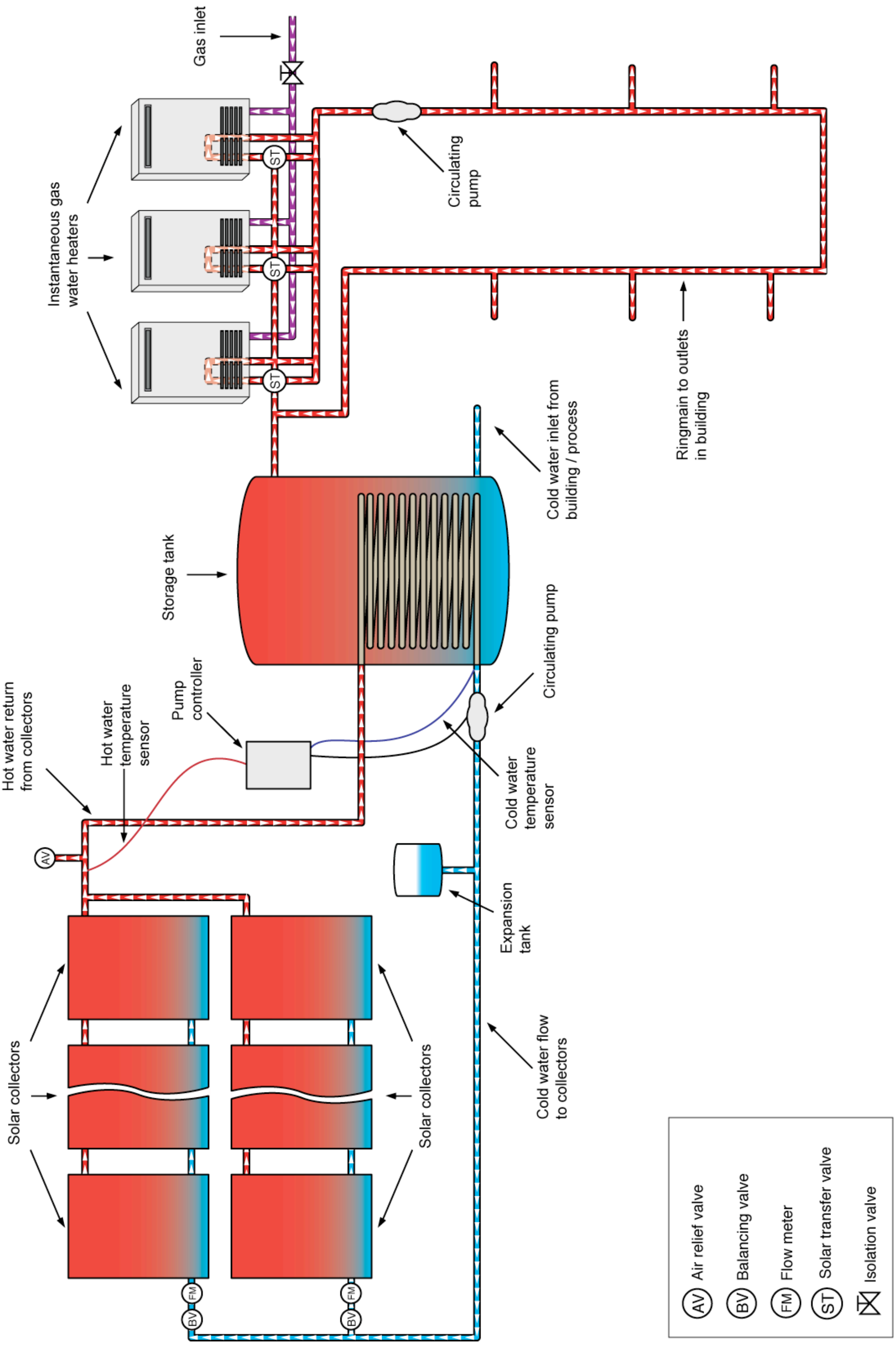


Figure 4.5: Typical ring main solar hot water delivery design



4.2 Flow rates

The flow rate used in the solar collector loop has a major effect on the system performance for both open and closed loop systems. In classic text books, a high flow rate is recommended in order to maintain low collector temperatures and maximise the internal heat transfer coefficient in the collector. The disadvantage of high flow rates is that thermal stratification in the storage tank is disturbed, even if a heat exchanger is used between the collector and the tank. For copper piping, the pipe sizes and flow rate used should ensure that the maximum velocity is 3 m/sec. Refer to 'AS/NZS 3500' for flow rates and performance charts for pipe sizing.

There are also LSTS that keep the heat transfer fluid (water, preferably without any heat exchanger) in the collector until it reaches the desired temperature, e.g. Paradigma XL-Solar with AquaSystem®. These systems typically use collectors with low heat loss, e.g. evacuated tube. Once the heat transfer fluid reaches the desired temperature, the pump controller transfers the heated fluid into the tank, replacing it with cold fluid. Using this method, pump energy and tank stratification is optimised.

4.3 Low-flow collector loop design

If the system performance is considered rather than just the collector as an isolated element, it is found that the solar contribution can be increased if a low collector loop flow rate is used, as this will promote a thermally stratified tank. Low flow rates, combined with appropriate positioning of the return flows to the tank, are necessary for maximum benefit.

High-flow systems can have some degree of stratification if carefully designed flow diffusers are used in the tank and also depending on whether there are heat exchangers in the collector loop or the load flow stream. Heat exchangers such as internal coils, full-height mantles or external spiral tubing on the wall of the tank minimise mixing in the tank but only produce minor stratification.

Maximum performance benefits can be gained through a fully integrated low-flow system design. The low-flow design approach influences both system capital cost and operating costs. The benefits of low-flow design are:

- Smaller, low-power pumps can be used.
- Piping to the collectors can be a smaller diameter and perhaps flexible, easier to install, and less expensive.
- Smaller tubes lower the thickness and cost of pipe insulation because the R-value is dependent on the ratio of the outer diameter to inner diameter and not the absolute thickness of the insulation.

Maximum benefit will be achieved in a low-flow system if the following load-matching principles are incorporated (Gordon, 2001):

- flow in the collector loop in the range 0.2 to 0.4 L/(min·m^2 aperture area)
- flow into the storage tank is controlled to minimise mixing
- total daily flow through the collector on average matches the daily load flow, i.e. a once-through concept
- optimisation of collector hydraulic design and supply piping to minimise pumping power.

4.4 Pipework

4.4.1 Insulation

Insulation is required to prevent heat loss through pipework. If the low-flow system design concept is adopted, then pipe diameters can be minimised and the cost of insulation reduced. The optimum insulation level can be determined for a given energy delivery to the storage tank by balancing the cost of increased insulation against savings due to reduced collector array area for the required energy delivery.

4.4.1.1 Minimum insulation requirements

4.4.1.2 Climate region

The climate region where LSTS installation is located will determine the minimum R-value for insulation. Table 4.1 below shows the climate region for major capital cities in Australia. Refer to 'AN/NZS 3500.4 Section 8' for detailed climate maps of Australia.

Table 4.1: Climate regions for major capital cities

City	Climate region
Adelaide	A
Brisbane	A
Canberra	C
Darwin	A
Hobart	C
Melbourne	B
Perth	A
Sydney	A

Source: Adapted from AS/NZS 3500.4

Table 4.2 below outlines the minimum R-value for the different climate regions in Australia.

Table 4.2: Minimum insulation R-value for Australian climate zones

Climate region	Internal locations		External locations	
	Pipes	Valves	Pipes	Valves
A	0.3	0.2	0.3	0.2
B	0.3	0.2	0.3	0.2
C (Non-alpine areas)	0.3	0.2	0.6[1]	0.2
C (Alpine areas[2])	0.3	0.2	1.0[1]	0.2

Source: Adapted from AS/NZS 3500.4

Notes:

1. If the pipe length is greater than 1 m, then the R-value needs to increase to 1.0.
2. An alpine area is defined as an area in New South Wales, Australian Capital Territory or Victoria with an elevation of 1200 m above sea level and 900 m above sea level in Tasmania.

4.4.1.3 Minimum insulation diameter

The minimum diameter of insulation can be determined by using the R-value from Table 4.2 above and finding the corresponding diameter in Table 4.3 below.

Table 4.3: Minimum insulation diameter (mm) required to achieve R-value

R-value	Insulation diameter (thickness)
0.2	9 mm
0.3	13 mm
0.6	25 mm
1.0	38 mm

Source: Adapted from AS/NZS 3500.4

Note: the insulation diameters specified in Table 4.3 are the minimum requirements under AS/NZS 3500.4. Insulation can be higher depending on the system design and cost effectiveness (refer to Chapter 2.5).

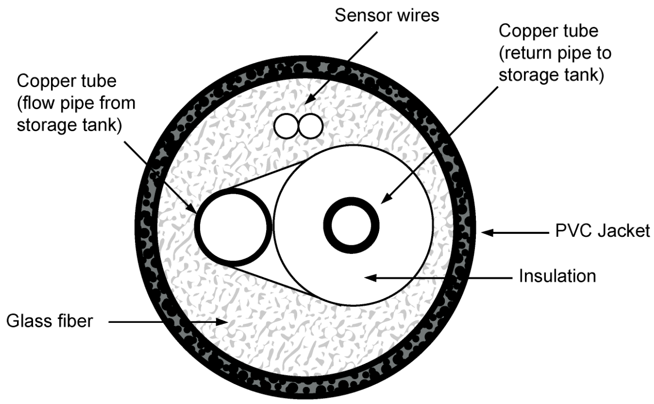
4.4.1.4 Insulation construction

Insulation should be made of closed-cell polymer, with a UV-resistant and water-resistant coating surrounding the polymer. Insulation should also be able to withstand the temperature that it may be subjected to.

4.4.2 Bundled piping systems

Low-flow systems can use smaller diameter collector loop piping and, as a result, flexible non-metallic or annealed copper tubes may be used. If flexible tubing is used it is possible to combine the two flow tubes and the collector temperature transducer lead into one insulated bundle for easy installation, as shown in Figure 4.6 below.

Figure 4.6: Bundled collector piping – Canadian 'LifeLine' system



The piping diameter required for low flow rates is typically half the diameter needed for high flow rates. The benefits of bundled tubing systems are:

- reduction of installation cost, as only one tube bundle has to be fitted between the collector and the tank
- reduction of heat loss by a factor of two due to smaller tube diameter and combining of the insulation of the hot and cold tubing
- easy handling and delivery of tubing.

CHAPTER 5 DESIGN TOOLS

5.1 General

The design of large solar collector arrays requires consideration of:

- quantification of user hot water volume or energy demand level and demand patterns
- selection of alternative solar collectors prior to full system design
- specification of pump and controller to achieve thermal stratification in the storage tank
- full system performance evaluation for local climatic conditions.

A range of software tools to assist the design process are outlined below.

Refer to ‘Appendix A’ for a comprehensive listing of design considerations.

5.2 Comparison of alternative solar collectors

The annual energy delivery of alternative solar collectors can be evaluated prior to full system design and system performance evaluation by computing the solar collector heat output for anticipated operating temperatures. The energy delivery for a given inlet temperature can be determined by combining the measured solar collector efficiency characteristic with measured hourly radiation, ambient temperature and wind velocity data for the location of interest. The output from such an analysis is referred to as a heat table.

5.2.1 Solar collector annual energy delivery – heat table

The monthly energy delivered by a solar collector operating with a fixed inlet temperature can be determined from the collector efficiency test results (normal incidence test conditions AS/NZS 2535). The extended solar collector efficiency functions for unglazed and glazed solar collectors specified in AS/NZS 2535 appendix ZC are used in the heat table analysis described here.

$$\eta = a\,K_{\tau\alpha} - (b + cV)\frac{(\bar{T} - T_a)}{G} - d\,\frac{(\bar{T} - T_a)^2}{G} \qquad (4)$$

where *a, b,* c and *d* are positive coefficients from AS/NZS 2535 normal efficiency tests
G = solar radiation on the slope of the collector (from climatic data file)
T_a = ambient temperature (from climatic data file)
$\bar{T}$ = average collector temperature (computed by heat table software)
V = wind speed (for glazed solar collectors, *c* is very small and is usually neglected)
$K_{\tau\alpha}$ = incidence angle modifier

For flat plate collector, the incidence angle modifier $K_{\tau\alpha}$ is given by:

$$K_{\tau a} = \left[1 - e\left(\frac{1}{\cos\theta} - 1\right)\right] \qquad (5)$$

where *e* is a coefficient evaluated through AS/NZS 2535 testing
θ = incidence angle of the solar beam to the collector normal (computed by heat table software)

Hourly data for *G,* T_a and V are read from a typical methodological year (TMY) weather data file for the location of interest.

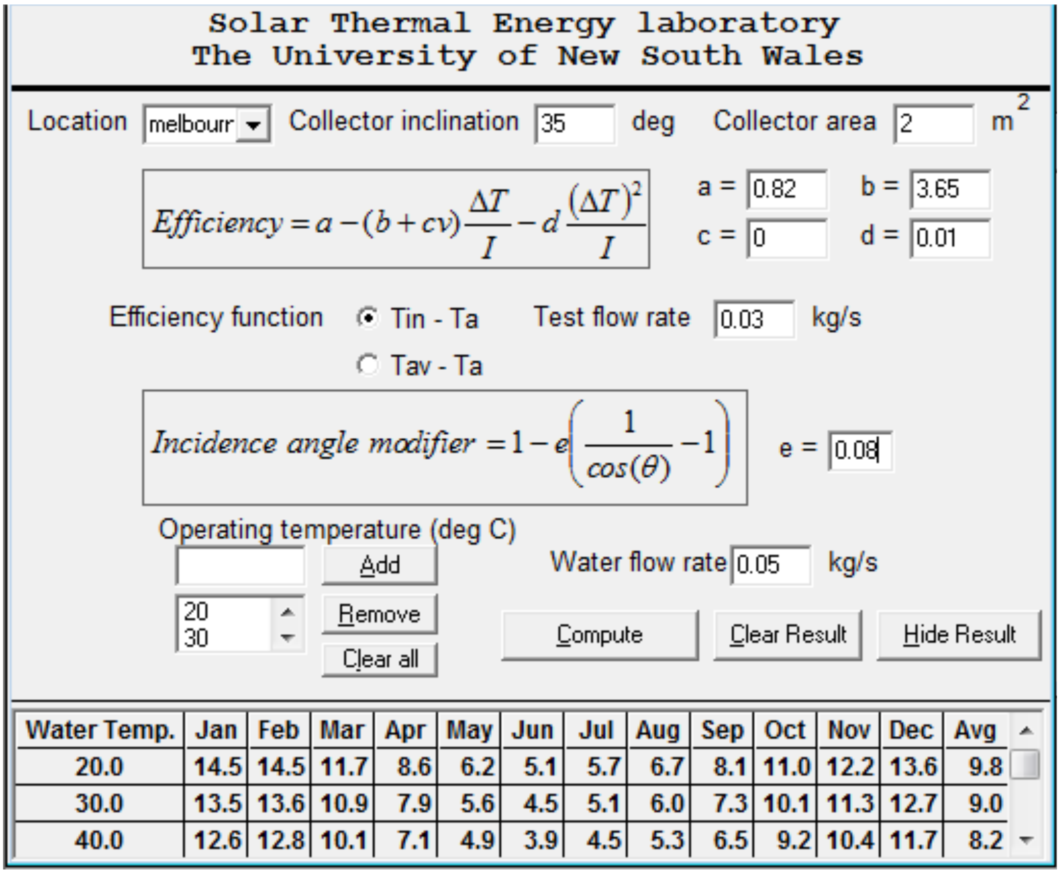
The heat table program carries out an hour-by-hour analysis of the collector output over one year, for a fixed inlet temperature as follows:

- corrects the coefficients in the efficiency equation to account for any difference between the test flow rate and the operational flow rate if $T_{in} - T_a$ correlation function is used
- reads hourly data for *G*, T_a and *V* from a TMY weather data file
- computes hourly radiation on the specified collector slope
- computes hourly useful energy output for specified inlet temperature and flow rate
- integrates energy output over each month (only positive energy output is considered)
- repeats the analysis for each specified inlet temperature.

Heat tables can be generated using commercially available software such as TRNSYS. A software package (Solar Collector Annual Energy Delivery, or SCAED) with a graphical user interface for generating heat tables is available from UNSW Global)[1]. The user interface for SCAED is shown in Figure 5.1 below. The output is monthly energy delivered for the specified list of inlet temperatures.

The solar collector efficiency equation used to specify the collector characteristic in this program is a combination of the unglazed and glazed functions specified in AS/NZS 2535. For unglazed solar collectors, efficiency coefficients a, b and c are required (d = 0); for glazed flat plate collectors and evacuated tube collectors, efficiency coefficients a, b and d are required (c = 0).

Figure 5.1: User interface for generating heat tables



Source: UNSW Global SCAED software and weather data mechlab@unsw.edu.au

[1] UNSW Global mechlab@unsw.edu.au[2] www.stescos.org

5.2.2 Heat table output

The heat table program can be used to compare the monthly and annual energy delivery of different solar collectors for given operating temperatures as shown in the following tables.

Table 5.1: Average daily heat production for Melbourne, MJ/(m²·day) – typical selective absorber flat plate collector

Inlet temp ºC	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
20	16.9	17.3	13.9	10.2	7.2	5.8	6.5	7.8	9.4	12.8	14.2	15.8	11.5
30	15.4	15.9	12.5	9	6.2	4.9	5.5	6.6	8.1	11.4	12.8	14.3	10.2
40	14	14.5	11.2	7.8	5.2	3.9	4.6	5.6	6.9	10.1	11.4	12.9	9
50	12.5	13.1	9.8	6.6	4.3	3.2	3.8	4.6	5.7	8.8	10.1	11.5	7.8
60	11.1	11.7	8.6	5.6	3.6	2.5	3	3.8	4.7	7.6	8.8	10.1	6.7
70	9.8	10.4	7.4	4.6	2.9	1.9	2.3	3	3.8	6.5	7.5	8.8	5.7
80	8.5	9.1	6.3	3.8	2.3	1.5	1.7	2.3	3	5.5	6.4	7.6	4.8

Collector efficiency = $0.82^* K_{\tau\alpha} - 3.65(\overline{T} - T_a)/G - 0.01(\overline{T} - T_a)^2/G$

$K_{\tau\alpha}$ = $1 - 0.08^*(1/\cos(\theta) - 1)$

Collector inclination = 35°

Table 5.2: Average daily heat production for Melbourne, MJ/(m²·day) – typical low-cost black absorber flat plate collector

Inlet temp ºC	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
20	14.7	15.5	12.0	8.6	5.7	4.4	4.9	6.1	7.5	10.6	12.0	13.6	9.6
30	12.2	13.1	9.7	6.6	4.1	2.9	3.4	4.3	5.5	8.3	9.7	11.1	7.6
40	9.8	10.8	7.6	4.8	2.9	1.9	2.2	2.9	3.8	6.4	7.6	8.9	5.8
50	7.7	8.7	5.7	3.4	1.9	1.2	1.3	1.9	2.5	4.7	5.7	6.9	4.3
60	5.8	6.7	4.2	2.3	1.1	0.6	0.7	1.1	1.6	3.3	4.2	5.1	3.0
70	4.1	5.0	2.9	1.4	0.6	0.3	0.2	0.5	0.9	2.1	2.8	3.5	2.0

Collector efficiency = $0.72^* K_{\tau\alpha} - 6.5(\overline{T} - T_a)/G - 0.02(\overline{T} - T_a)^2/G$

$K_{\tau\alpha}$ = $1 - 0.08^*(1/\cos(\theta) - 1)$

Collector inclination = 35°

Table 5.3: Average daily heat production for Melbourne, MJ/(m²·day) – typical evacuated tube collector

Inlet temp ºC	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
20	14.5	14.5	11.7	8.6	6.2	5.1	5.7	6.7	8.1	11	12.2	13.6	9.8
30	13.5	13.6	10.9	7.9	5.6	4.5	5.1	6.0	7.3	10.1	11.3	12.7	9.0
40	12.6	12.8	10.1	7.1	4.9	3.9	4.5	5.3	6.5	9.2	10.4	11.7	8.2
50	11.7	11.9	9.2	6.4	4.3	3.4	3.9	4.7	5.7	8.4	9.5	10.8	7.5
60	10.8	11	8.4	5.7	3.8	2.9	3.4	4.1	5.0	7.6	8.6	9.9	6.7
70	9.9	10.2	7.6	5.0	3.3	2.4	2.9	3.5	4.3	6.8	7.8	9.0	6.0

Collector efficiency = $0.65^* K_{\tau\alpha} - 2.06(\overline{T} - T_a)/G - 0.006(\overline{T} - T_a)^2/G$

$K_{\tau\alpha}$ = bi-axial optical incidence map

Collector inclination = 35°

5.3 Evaluation of impact of pump flow rate and controller set points

The most common pump controller is the fixed differential thermostat (DT) with hysteresis, which compares the collector outlet temperature and the temperature in the bottom of the tank. Selection of the controller turn on and turn off temperature differences and the pump flow rate can have a significant effect on the performance of a pumped system. If the pump controller temperature difference settings are close, e.g. 8/6, then the pump may turn on/off most of the time, except in very clear conditions (refer to Chapter 2.6). A software design tool is described that can display a map of the collector loop (collector piping and collector array) operating conditions for a wide range of solar radiation and water inlet temperatures.

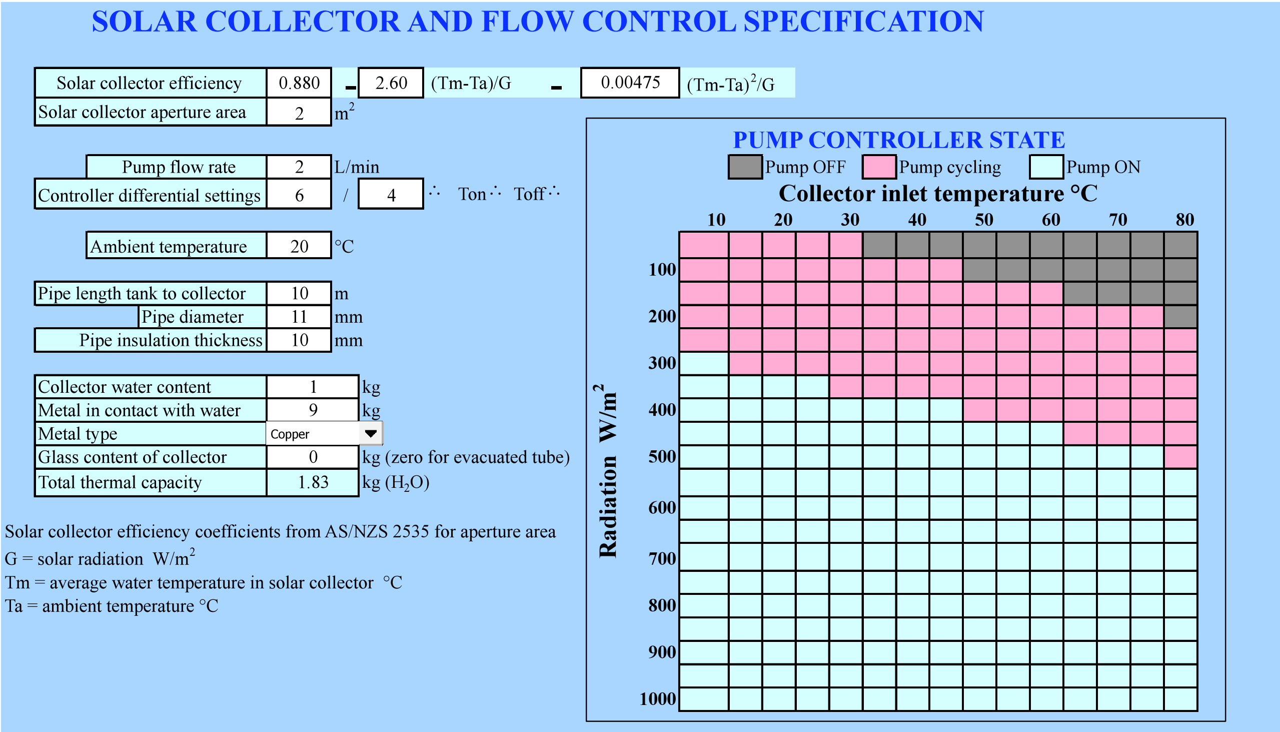
Optimum specification of the controller temperature difference settings depends on the type of solar collector used, the collector array area and the flow rate. Evacuated tubes have a high stagnation temperature and hence can reach the turn on temperature difference even in dull conditions; however, the heat gain from the collector may not be sufficient to achieve a steady-state temperature rise equal to the turn off temperature difference unless the sky condition is very clear. Consequently, the pump may run only for short periods until the heat is removed from the collector and then turns off and until the collector heats up. The hot water from the collector may be left in the return pipe little hot water is delivered to the tank.

5.3.1 PCL Design tool

The PCL Design software provides a window into the factors affecting pumped solar collector loop operation. The primary feature of PCL Design is the display of each factor in a matrix of inlet temperatures and solar radiation intensity so that the operation of the collector loop for all operating conditions can be seen in one output map. This allows design trade-offs to be made between the conflicting factors influencing optimum solar collector loop performance.

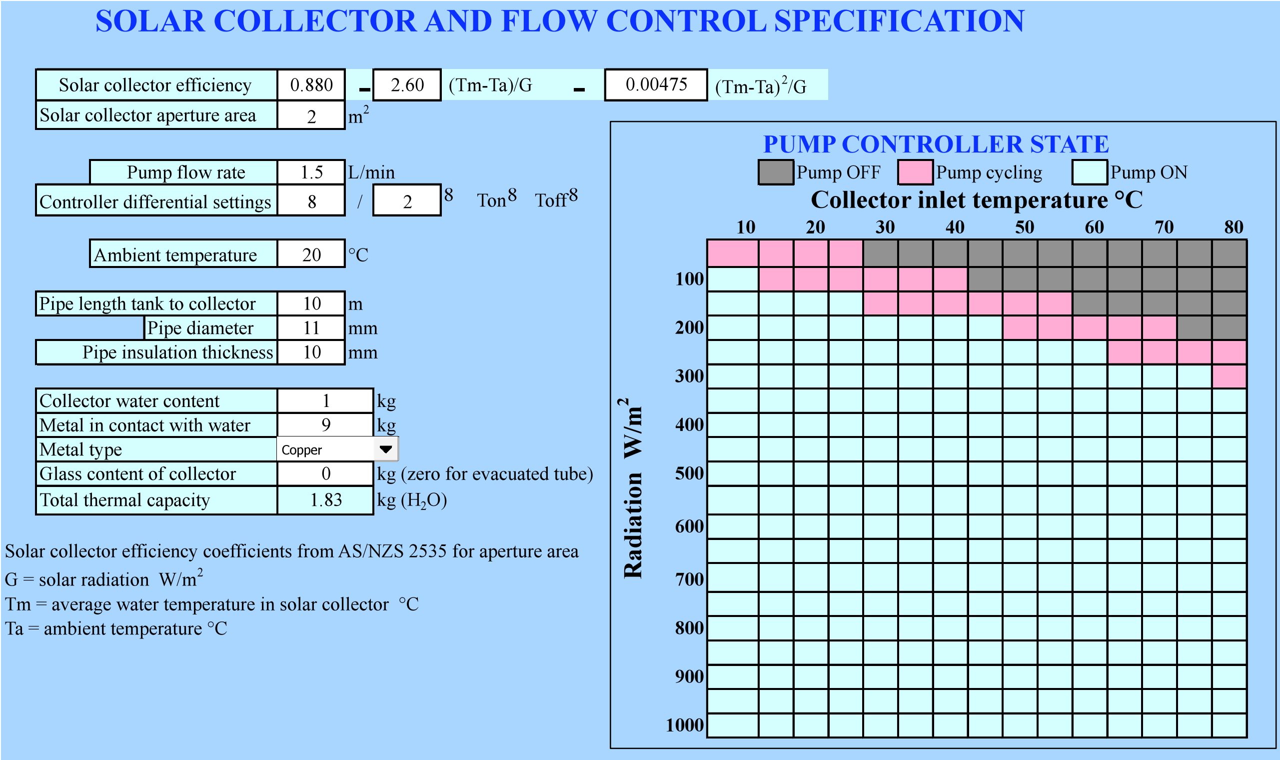
In the controller performance map shown in Figure 5.2 below, the green area shows operating conditions (radiation intensity and collector inlet temperature) when the output of the collector is sufficient to achieve a steady temperature rise of more than 4 K so the pump stays on. The red zone shows conditions where the pump is turning on/off and there are increased losses as a result. The dark area shows operating conditions where the pump is off.

Figure 5.2: Collector loop specification interface and pump controller state in terms of radiation level and collector inlet temperature



The range of operating conditions where the controller is turning on/off can be reduced by lowering the turn off temperature difference and/or by reducing the flow rate. The controller operation map for the same collector array but with controller settings of 8 on/2 off and reduced flow rate is shown in Figure 5.3. The region of unstable pump operation is significantly reduced.

Figure 5.3: Collector loop stability with optimised controller and pump flow rate



Further reduction of the unstable zone is possible by reducing the turn off difference setting; however, if the turn off temperature difference is very small, then there is the possibility of the pump running when the heat gain from the solar collector is less than the heat loss from the pipes connecting the solar collector to the tank. This can occur even though there is a positive temperature difference between the collector outlet and the bottom of the tank. For a controller turn off setting of 2, the net energy gain to the tank (collector heat output minus pipe losses) is shown in Figure 5.4.

A small zone of operation that results in net heat loss from the collector loop is circled in Figure 5.4. Reducing the turn off differential temperature setting further could result in some of the negative net heat gain areas moving into the stable pump controller zone.

Figure 5.4: Net heat delivered to tank when pump is running (collector output – pipe losses)

COLLECTOR LOOP HEAT OUTPUT WHEN PUMP IS RUNNING
Watts

Pump OFF, heat output not achieved
Pump cycling (heat losses due to transient operation)
Pump ON, heat output available

Pump flow rate 1.5 L/min
Controller differential settir 8 ON 2.0 OFF
Ambient temperatur 20 °C

Collector inlet temperature °C

Radiation W/m²	10		20		30		40		50		60		70		80
	174	129	84	39	-7	-54	-100	-100	-195	-243	-291	-340	-389	-438	-488
100	258	213	168	123	77	30	-16	-16	-111	-159	-207	-256	-305	-355	-405
	342	297	252	207	161	114	68	68	-27	-75	-124	-172	-222	-271	-321
200	426	381	336	290	245	198	151	151	57	9	-40	-89	-138	-188	-238
	510	465	420	374	328	282	235	235	140	92	44	-5	-54	-104	-154
300	594	549	504	458	412	366	319	319	224	176	128	79	29	-20	-71
	678	633	588	542	496	450	403	403	308	260	211	162	113	63	13
400	762	717	672	626	580	534	487	487	392	343	295	246	197	147	97
	846	801	756	710	664	618	571	571	475	427	379	330	280	230	180
500	930	885	840	794	748	701	654	654	559	511	462	413	364	314	264
	1014	969	924	878	832	785	738	738	643	595	546	497	447	397	347
600	1098	1053	1008	962	916	869	822	822	727	678	630	581	531	481	431
	1182	1137	1092	1046	1000	953	906	906	810	762	713	664	615	565	514
700	1267	1221	1176	1130	1084	1037	990	990	894	846	797	748	698	648	598
	1351	1305	1260	1214	1168	1121	1074	1074	978	929	881	831	782	732	681
800	1435	1389	1344	1298	1251	1205	1157	1157	1062	1013	964	915	865	815	765
	1519	1473	1428	1382	1335	1288	1241	1241	1145	1097	1048	999	949	899	848
900	1603	1557	1512	1466	1419	1372	1325	1325	1229	1181	1132	1082	1032	982	932
	1687	1641	1596	1550	1503	1456	1409	1409	1313	1264	1215	1166	1116	1066	1015
1000	1771	1725	1680	1633	1587	1540	1493	1493	1397	1348	1299	1249	1200	1149	1099

5.3.2 Pump flow rate and tank stratification

The temperature rise achieved between the bottom of the tank and the flow returned to the tank governs the thermal stratification that can be achieved in the tank. Increased thermal stratification results in improved system performance. The collector loop temperature rise (temperature rise across the collector minus temperature drop along the connecting pipes) is an indication of the possible thermal stratification in the tank. A collector loop temperature rise of more than 20 K under clear sky conditions (low-flow concept) has been shown to produce improved system performance as a result of thermal stratification in the tank. For the original controller specifications of 6/4 and a flow rate of 2 L/min (Figure 5.2), the collector loop temperature rise shown in Figure 5.5 is small and optimum stratification would not be achieved in the tank with the specified array area and flow rate.

Figure 5.5: Collector loop temperature rise

COLLECTOR LOOP TEMPERATURE RISE WHEN PUMP IS RUNNING (K)

Pump OFF, heat output not achieved
Pump cycling (heat losses due to transient operation)
Pump ON, heat output available

Pump flow rate 2 L/min
Controller differential settir 6 ON 4.0 OFF
Ambient temperatur 20 °C

Collector inlet temperature °C

Radiation W/m²	10		20		30		40		50		60		70		80
	1.3	0.9	0.6	0.3	-0.1	-0.4	-0.7	-1.1	-1.4	-1.8	-2.1	-2.5	-2.8	-3.2	-3.6
100	1.9	1.5	1.2	0.9	0.6	0.2	-0.1	-0.5	-0.8	-1.2	-1.5	-1.9	-2.2	-2.6	-3.0
	2.5	2.2	1.8	1.5	1.2	0.8	0.5	0.1	-0.2	-0.6	-0.9	-1.3	-1.6	-2.0	-2.3
200	3.1	2.8	2.4	2.1	1.8	1.4	1.1	0.8	0.4	0.1	-0.3	-0.7	-1.0	-1.4	-1.7
	3.7	3.4	3.1	2.7	2.4	2.0	1.7	1.4	1.0	0.7	0.3	0.0	-0.4	-0.8	-1.1
300	4.3	4.0	3.7	3.3	3.0	2.7	2.3	2.0	1.6	1.3	0.9	0.6	0.2	-0.2	-0.5
	4.9	4.6	4.3	3.9	3.6	3.3	2.9	2.6	2.2	1.9	1.5	1.2	0.8	0.4	0.1
400	5.5	5.2	4.9	4.5	4.2	3.9	3.5	3.2	2.8	2.5	2.1	1.8	1.4	1.1	0.7
	6.1	5.8	5.5	5.2	4.8	4.5	4.1	3.8	3.5	3.1	2.7	2.4	2.0	1.7	1.3
500	6.8	6.4	6.1	5.8	5.4	5.1	4.8	4.4	4.1	3.7	3.4	3.0	2.6	2.3	1.9
	7.4	7.0	6.7	6.4	6.0	5.7	5.4	5.0	4.7	4.3	4.0	3.6	3.2	2.9	2.5
600	8.0	7.7	7.3	7.0	6.7	6.3	6.0	5.6	5.3	4.9	4.6	4.2	3.9	3.5	3.1
	8.6	8.3	7.9	7.6	7.3	6.9	6.6	6.2	5.9	5.5	5.2	4.8	4.5	4.1	3.7
700	9.2	8.9	8.5	8.2	7.9	7.5	7.2	6.8	6.5	6.1	5.8	5.4	5.1	4.7	4.3
	9.8	9.5	9.2	8.8	8.5	8.1	7.8	7.5	7.1	6.8	6.4	6.0	5.7	5.3	4.9
800	10.4	10.1	9.8	9.4	9.1	8.8	8.4	8.1	7.7	7.4	7.0	6.6	6.3	5.9	5.6
	11.0	10.7	10.4	10.0	9.7	9.4	9.0	8.7	8.3	8.0	7.6	7.3	6.9	6.5	6.2
900	11.6	11.3	11.0	10.6	10.3	10.0	9.6	9.3	8.9	8.6	8.2	7.9	7.5	7.1	6.8
	12.3	11.9	11.6	11.3	10.9	10.6	10.2	9.9	9.5	9.2	8.8	8.5	8.1	7.7	7.4
1000	12.9	12.5	12.2	11.9	11.5	11.2	10.8	10.5	10.1	9.8	9.4	9.1	8.7	8.4	8.0

5.4 System simulation software

To optimise the components of a design, including seasonal energy delivery requirements and seasonal variation of solar input, a detailed, short time step simulation is necessary. Software packages suitable for annual performance optimisation include TRNSYS, Tsol and Polysun.

5.4.1 TRNSYS

TRNSYS is a commercially available Transient Energy System Simulation program designed to simulate the transient performance of thermal energy systems and is now the most widely used solar thermal system and building energy modelling package. A designer is able to build a model of the solar and conventional heating components in a unique system configuration without the need to develop computer code. The components in the system and the flow, temperature and control links between components are defined through an input data file. Due to the modular nature of the program, the designer is not restricted in the range or configuration of systems that can be analysed. The modular or object-oriented approach also reduces the complexity of formulating system simulation models by converting a large simulation task into a number of small problems, each of which can be more easily solved independently. The large existing library of components available in TRNSYS greatly reduces the time and effort involved in modelling a new system.

TRNSYS is the most widely used detailed modelling package for transient thermal simulation and is able to simulate the dynamics of a wide range of solar and conventional energy systems (Table 5.4.) It is also used to calculate eligible Renewable Energy Certificates (RECs) of solar hot water systems under the Mandatory Renewable Energy Target (MRET). Hourly irradiation data and other weather parameters are required as inputs for TRNSYS. Hence, detailed studies are limited to locations where TMY data files are available.

Table 5.4: Library components for TRNSYS simulation program

Utility Components
Data Reader
Time-Dependent Forcing Function
Algebraic Operation
Radiation Processor
Quantity Integrator
Psychometrics Thermal Storage Wall
Load Profile Sequencer
Collector Array Shading
Convergence Promoter
Weather Data Generator

Solar Collectors
Linear Thermal Efficiency Data
Detailed Performance Map
Single or Bi-Axial Incidence Angle Modifier
Theoretical Flat-Plate
Theoretical CPC

Thermal Storage
Stratified Liquid Storage (finite-difference)
Algebraic Tank (plug flow)
Rockbed

Equipment
On/Off Auxiliary Heater
Absorption Air Conditioner
Dual Source Heat Pump
Conditioning Equipment
Cooling Coil Economics
Cooling Tower
Chiller

Utility Subroutines
Data Interpolation
First Order Differential Equations
View Factors
Matrix Inversion
Least Squares Curve Fitting
Psychrometric Calculations

Building Loads and Structures
Energy/(Degree-Hour) House
Detailed Zone (transfer function)
Roof and Attic
Overhang and Wingwall Shading
Window
Attached Sunspace
Multi-Zone Building
Thermal Storage Wall

Fluid flow control
Pump/Fan
Flow Diverter/Mixing Value/Tee Price
Pressure Relief Valve
Pipe

Controllers
Differential Controller with Hysteresis
Three-Stage Room Thermostat
Microprocessor Controller

Heat Exchangers
Heat Exchanger
Waste Heat Recovery

Output
Printer
Plotter
Histogram Plotter
Simulation Summariser
Economics

User-Contributed Components
PV/Thermal Collector
Storage Battery
Regulator/Inverter
Electrical Subsystem
Large concentrators
Rankine Power Cycles with Solar Input

Combined Subsystems
Liquid Collector Storage
Air Collector Storage System
Domestic Hot Water
Thermosyphon Solar Water Heater

There are many third-party suppliers of model extensions for TRNSYS.

5.4.2 Using TRNSYS

5.4.2.1 Required TRNSYS input data

Climatic data

- TMY weather data file or statistically generated hourly model based on monthly average weather data

Measured component performance

- solar collector efficiency to AS/NZS 2535
- storage tank heat loss

Hydraulic design

- collector loop flow rate (intersection of pump head characteristic and piping friction pressure drop characteristic)
- pump power at above flow rate

Product configuration

- direct circulation
- collector loop heat exchanger
- load side heat exchanger

Auxiliary boosting

- electric in tank
- electric series boost tank
- gas instantaneous
- gas series boost tank

Controller

- controller logic map

Product details

- ***solar array***
  - solar module area (AS/NZS 2535)
  - number of collectors in array
  - efficiency coefficients (AS/NZS 2535)
  - collector inclination
  - collector orientation
  - flow rate through each collector

- ***collector to tank piping***
  - diameter of collector inlet/outlet pipes
  - thickness of insulation on connecting pipes
  - inlet pipe length
  - outlet pipe length
  - thermal conductivity of insulation

- ***solar or preheat tank***
  - tank volume
  - tank diameter
  - volume of water above the collector return level
  - volume of water above the auxiliary element (if installed)
  - volume of water above the thermostat (if installed)

- ***auxiliary boost tank***
    - set temperature
    - thermostat dead band
    - auxiliary power
    - height of cold inlet above bottom of tank
    - heat loss from tank
    - thickness of inner tank wall (m)
    - thermal conductivity of inner tank wall

- ***pump***
    - pump flow rate
    - maximum tank temperature for pump operation
    - pump power input
    - pump controller turn on difference
    - pump controller turn off difference.

A TRNSYS input file is constructed for the particular product configuration. Example files (TRNSYS deck) are provided with AS/NZS 4234.

5.4.2.2 TRNSYS outputs

TRNSYS can be used to produce continuous time trace outputs to evaluate transient design features such as controller operation, capacity of the auxiliary system on cloudy days or over temperature effects on clear days with low loads etc. Integrated values of daily or monthly energy flows can also be generated for system performance calculation. Design sensitivity studies of the impact of collector array size, tank size etc. on seasonal and annual performance can be determined. Examples of the real-time outputs of solar collector and tank temperatures from a TRNSYS simulation are shown in Figure 5.6 and Table 5.5. The user can specify the output details in both the runtime plot and the performance data file.

Figure 5.6: TRNSYS runtime output

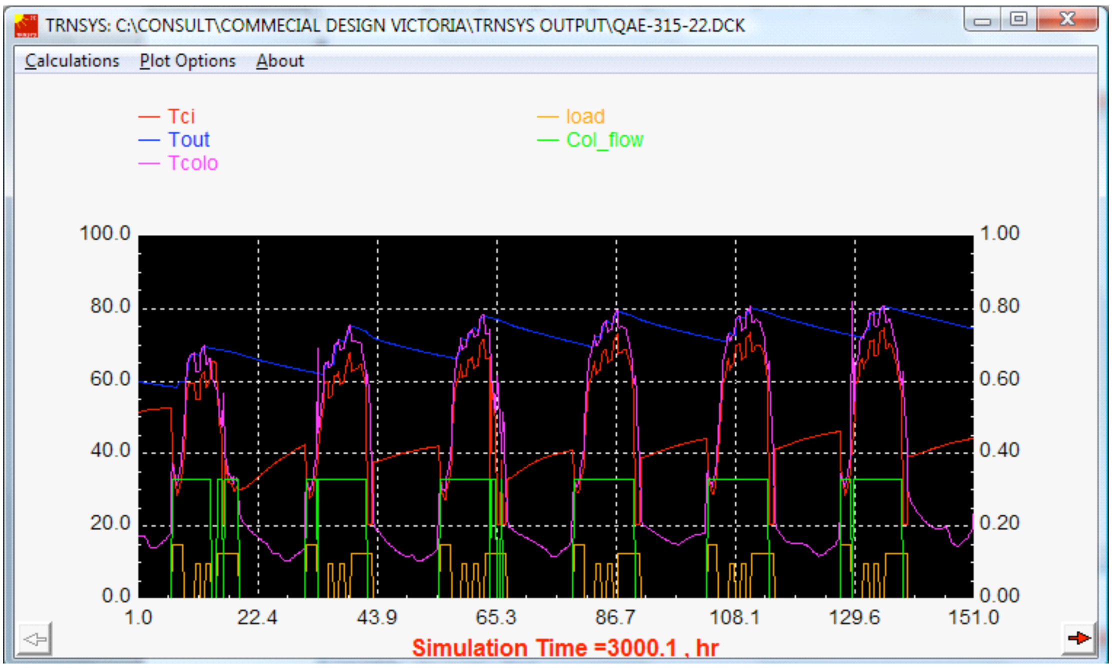


Table 5.5: Example TRYNSYS performance output

SIMULATION SUMMARY FOR TIME = 1.000 TO 8760.000IN INTERVALS OF 1 MONTH

MONTH	TIME	GI	TA	Auxtop	Auxbot
JAN	744.000	8.989E+05	2.076E+01	2.000E+05	0.000E+00
FEB	1416.000	7.563E+05	2.147E+01	1.717E+05	0.000E+00
MAR	2160.000	6.716E+05	1.886E+01	3.796E+05	0.000E+00
APR	2880.000	4.784E+05	1.673E+01	6.156E+05	0.000E+00
MAY	3624.000	3.637E+05	1.422E+01	8.801E+05	0.000E+00
JUN	4344.000	3.258E+05	1.034E+01	1.001E+06	0.000E+00
JUL	5088.000	3.128E+05	9.790E+00	1.183E+06	0.000E+00
AUG	5832.000	3.946E+05	1.182E+01	1.086E+06	0.000E+00
SEP	6552.000	5.290E+05	1.227E+01	8.161E+05	0.000E+00
OCT	7296.000	7.020E+05	1.536E+01	6.117E+05	0.000E+00
NOV	8016.000	7.339E+05	1.814E+01	4.479E+05	0.000E+00
DEC	8760.000	8.023E+05	2.053E+01	3.147E+05	0.000E+00
SUM	8760.000	6.969E+06	1.903E+02	7.707E+06	0.000E+00

MONTH	TIME	Vol	energy	aux	Tout1	Qut
JAN	744.000	3.810E+03	8.549E+05	2.000E+05	7.422E+01	9.500E+05
FEB	1416.000	3.361E+03	7.722E+05	1.717E+05	7.576E+01	8.071E+05
MAR	2160.000	4.294E+03	8.302E+05	3.796E+05	6.771E+01	6.951E+05
APR	2880.000	4.797E+03	8.874E+05	6.156E+05	6.311E+01	4.977E+05
MAY	3624.000	5.429E+03	9.914E+05	8.801E+05	6.042E+01	3.338E+05
JUN	4344.000	5.446E+03	1.043E+06	1.001E+06	6.005E+01	2.823E+05
JUL	5088.000	5.860E+03	1.215E+06	1.183E+06	5.993E+01	2.800E+05
AUG	5832.000	5.837E+03	1.239E+06	1.086E+06	6.059E+01	3.965E+05
SEP	6552.000	5.398E+03	1.127E+06	8.161E+05	6.178E+01	5.554E+05
OCT	7296.000	5.123E+03	1.153E+06	6.117E+05	6.609E+01	7.842E+05
NOV	8016.000	4.707E+03	1.007E+06	4.479E+05	6.655E+01	8.032E+05
DEC	8760.000	4.212E+03	9.417E+05	3.147E+05	7.162E+01	8.664E+05
SUM	8760.000	5.827E+04	1.206E+07	7.707E+06	6.483E+01	7.252E+06

MONTH	TIME	Tloss	Ploss	de	auxp	edump
JAN	744.000	2.676E+05	5.488E+04	3.024E+04	2.642E+04	0.000E+00
FEB	1416.000	2.425E+05	4.704E+04	-3.349E+04	2.310E+04	0.000E+00
MAR	2160.000	2.453E+05	4.345E+04	1.716E+03	2.202E+04	0.000E+00
APR	2880.000	2.250E+05	3.166E+04	3.210E+03	1.803E+04	0.000E+00
MAY	3624.000	2.317E+05	2.648E+04	-6.634E+03	1.537E+04	0.000E+00
JUN	4344.000	2.422E+05	2.539E+04	1.421E+02	1.325E+04	0.000E+00
JUL	5088.000	2.508E+05	2.124E+04	-4.248E+02	1.436E+04	0.000E+00
AUG	5832.000	2.425E+05	2.391E+04	3.025E+03	1.695E+04	0.000E+00
SEP	6552.000	2.401E+05	3.218E+04	6.409E+03	2.019E+04	0.000E+00
OCT	7296.000	2.516E+05	3.952E+04	-5.681E+03	2.383E+04	0.000E+00
NOV	8016.000	2.333E+05	4.041E+04	1.277E+04	2.420E+04	0.000E+00
DEC	8760.000	2.542E+05	4.623E+04	-1.215E+04	2.530E+04	0.000E+00
SUM	8760.000	2.927E+06	4.324E+05	-8.784E+02	2.430E+05	0.000E+00

ENERGY BALANCE 1: Qut +aux –energy -Tloss -de -edump

		ENERGY BALANCE 1	
MONTH	TIME	VALUE	PERCENT
JAN	744.000	-2.710E+03	0.24
FEB	1416.000	-2.447E+03	0.24
MAR	2160.000	-2.528E+03	0.23
APR	2880.000	-2.321E+03	0.21
MAY	3624.000	-2.523E+03	0.21
JUN	4344.000	-2.569E+03	0.20
JUL	5088.000	-2.581E+03	0.18
AUG	5832.000	-2.538E+03	0.17
SEP	6552.000	-2.472E+03	0.18
OCT	7296.000	-2.470E+03	0.18
NOV	8016.000	-2.407E+03	0.19
DEC	8760.000	-2.595E+03	0.22
SUM	8760.000	-3.016E+04	0.20

5.4.3 ST-ESCo

A recent project undertaken in Europe has led to the development of software tools for the evaluation of Energy Service Companies (ESCo) solar water heating contracting opportunities.

The ST-ESCo is a software tool developed in the framework of the ST-ESCo project[2], financed by the European Union. The tool has been developed with two objectives:

1. Develop and distribute an easy and friendly, but also precise, tool for the prediction of the energy output of solar thermal plants.
2. Use the output of the previous objective to evaluate the economical viability of solar thermal projects for ESCo.

The software is available free from the 'Solar Thermal Energy Service Companies (ST-ESCOs)' website[3].

The tool is a simulation tool based on TRNSYS and is structured in two main modules; one for the simulation of the solar thermal systems (energy module) and another for the economical evaluation of the systems (economical module).

The transient simulation tool allows the user to obtain an estimation of the likely solar energy production. Once the simulation is finished, the user may want to evaluate the economical benefits of the system through the economical module.

The input data includes:

- project data – general information about the project
- model input data – data relating to investment costs, operation and maintenance costs of the system, consumption and conventional energy system
- contract data – billing method implemented in the contract.

The user can use the economical module to evaluate the financial viability of the project visualised in graphical and table form. There is also the possibility for the user to study different billing methods and undertake simplified sensitivity analysis by changing the parameters of the project and calculating how this change would affect the financial viability of the project.

5.4.4 RETScreen

The RETScreen Clean Energy Project Analysis Software is a decision-support tool developed in Canada. The software, provided free of charge, can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of renewable-energy and energy-efficient technologies (RETs). The software also includes product, project, hydrology and climate databases, a detailed user manual, and a case study based college/university-level training course, including an engineering e-textbook.

5.4.5 SolSimNZ

The Solar Industries Association has a free-access simulation tool for commercial-scale systems on their website (www.solarindustries.org.nz). SolSimNZ is based on TRNSYS and allows the most common solar water heating systems to be modelled for 16 areas in New Zealand.

[3] http://www.stescos.org/downloads/_Software.doc

CHAPTER 6 PROJECT FEASIBILITY AND MANAGEMENT

6.1 Preparatory checklist

It is good practice to investigate and understand the opportunities, limitations, options and available solutions for a large-scale solar thermal project. Undertake a feasibility study of potential solutions and communicate your findings to all involved.

- ☐ **Client expectations:** understand exactly what is required of the project and the expectations of the client. There are generally four key drivers for installing a large-scale solar thermal system – financial, environmental, energy saving and legislative.

- ☐ **Review of current processes:** if your project involves the retrofit of an existing system, it is good practice to review and monitor the existing system. Look for ways to improve outputs, performance and efficiency. Evaluate how best to implement the chosen technology.

- ☐ **Application:** solar thermal systems can have a range of applications, such as potable and non-potable hot water, solar-sourced heating and cooling, industrial heat, steam generation, agriculture, sterilisation, swimming pools, power generation, desalination or other applications where heat is required.

  Be aware that each solar application has specific load requirements, and will have inherent requirements for quality, quantity and consistency of heat, as well as specific times of operation. However, a potential project can go through progressive phases of development from being a possibility to commissioning and operation. At the beginning, little may be known about the heat loads and size of system etc. To scope out the project, it is often useful to use one of the software tools in Chapter 5. Coarse heat load assumptions can initially be made and a 'back of the envelope' analysis undertaken. This will give an idea of whether the project is likely to be commercially feasible. If, from the initial analysis, the project looks attractive, then 'real data' collection can start.

  Data collection can be expensive, so it is worth getting a feel of a project to see if it may be feasible before incurring the cost of installing data collection equipment.

  Only after real data is collected can the scope of the project be crystallised.

- ☐ **Regulations:** understand the local and national regulations that will affect your project obligations, such as regulatory requirements, Australian Standards, OH&S requirements, local codes and zoning regulations.

- ☐ **Project restrictions:** be familiar with any restrictions that may influence the path that the project may take, such as construction methods, aesthetics, vandalism, access, water quality, noise, environmental, legislative, logistics, health and safety, available space, weight, structural integrity, clearances, wind loads, access and plant space.

- ☐ **Environmental, climatic and geographic restrictions:** solar technologies are dependent on climatic conditions and geographic location.

- ☐ **Technology review:** investigate technology, tools and resources available to you

  - ☐ Review the risks and considerations for each technology. Discern whether the technology is suitable for the application and whether it will satisfy the needs of the end user.

  - ☐ Investigate whether the technology has been successfully implemented before as a solution to the particular application.

  - ☐ Ensure that the chosen technology carries the appropriate approvals in Australia.

- ☐ Identify lifetime costs of the technology such as maintenance, warranty, servicing, and replacement costs. These should be included in the financial analysis.
- ☐ Consider the energy consumption of any standby, integrated, supplementary or backup energy consumption and the effect that this will have on purchased energy, peak loads and energy tariffs.
- ☐ Investigate the complexity of the installation, and the associated costs of installing the technology.
- ☐ Check the materials and build quality, ensuring that it is suitable for the application and the environment.
- ☐ Investigate the effect of climate and geographic location on the operation of each technology. The technology that you choose should be appropriate for the project environment, climatic conditions and geographic location.
- ☐ Review the performance, savings and financial evaluation for each technology in relation to the application and the environment, climate and geographic location.
- ☐ Review how the technology is supported in Australia.
- ☐ Seek expert advice if needed.

☐ **Resources:** identify the resources available to you to implement the technology successfully, such as consulting, labour, equipment, suppliers and materials. Large-scale solar thermal systems may require the assistance of industry professionals to guide you in correctly sizing, designing and installing a system. Manufacturers supplying commercial-grade systems are also a good source of information and should provide you with technical specifications of their products.

☐ **Potential risks:** identify potential project risks and environmental impacts. Some risks may be technology-specific or project-specific, and others will be common across the broader solar thermal category. Talk with other industry professionals about their experiences.

☐ **Compatibility:** ensure that the system design and control systems can be integrated effectively, are compatible and that the design strategies are aligned with the project goals. For example, some solar thermal control systems may be required to connect to the building management system.

☐ **Accountability:** define the accountability of people involved in the project, the system design and installation.

☐ **Testing and simulation**: on large or unique projects, a smaller scale prototype or computer model should be developed to help remove design uncertainty and other risks.

☐ **Financial incentives**: investigate the potential for adding value to the project through government grants, rebates, or Renewable Energy Certificates (RECs). There is also the potential for energy providers to subsidise a project based on the reduction of peak loads.

6.2 Project implementation plan

Document a clear definition of the project, scope of works and reach an agreement with the client on the objectives and deliverables of the project.

- **Define the scope**
  - boundaries of the project
  - tasks, activities and interactions with parties outside of your project
  - dependencies and limitations
  - outcomes and deliverables
  - timeframe and schedule
  - available options for delivering agreed objectives.

- **Resources:** outline how resources will be allocated and coordinated.

- **Financial:** identify project costs, allocate budgets and confirm payment terms.

- **Risks:** outline risks and methods to mitigate risks
  - environmental
  - financial
  - delays
  - OH&S
  - assumptions made during the design process
  - project and technology variables
  - project variances
  - insurances.

- **Communication:** define clear strategies for communicating between those directly involved in your project and those involved in interrelated projects.

- **Procurement:** outline a procurement strategy for equipment and services sourced from manufacturers and other third-party suppliers. Take into consideration lead time, costs and payment terms, delivery schedule, ownership and accountability.

- **Measurable quality:** identify measurable targets, controls and evaluation criteria. Outline key milestones that both you and your client agree on. These are typically related to the design and installation stages, as well as tied to overall delivery of key objectives in a timely manner.

- **Approvals:** ensure that all necessary approvals have been obtained and that your suppliers have the proper product certifications.

6.3 Execution

Execute the processes outlined in the planning stage. Use the measurable criteria and key milestones to periodically monitor and evaluate the outputs, and identify changes or potential risks.

Once completed, a full review of the deliverables is conducted, identifying any corrective actions needed.

6.4 Commissioning

- ☐ Thoroughly test all of the installed components over a wide range of operating conditions.
- ☐ Test flow rates and set balancing valves to equalise flows through different collector arrays.
- ☐ Test controller transducers and controller operation.
- ☐ Test the system whilst operating under realistic load and climate conditions.
- ☐ Document the ‘as installed’ performance, including flow rates through each collector bank, balancing vales setting etc.

6.5 Handover

Once the project is commissioned, acceptance by the client is sought and the project is brought to a conclusion.

Solar thermal applications may be eligible for Government grants and RECs. The appropriate paperwork should be completed.

The client should be provided with full documentation supporting the system, including operating instructions, a maintenance schedule and any other documentation that is necessary to support the product.

CHAPTER 7 CASE STUDIES

7.1 Case study: Vertix – solar thermal systems in multi-family house

7.1.1 Description

Location: Sant Cugat del Vallés (Barcelona) – Spain
Source: www.solarge.org/index.php?id=1261


All pictures: Vertix

This is a new residential building composed of 39 apartments across five floors. A 61m^2 flat-plate solar thermal collector (gross area) on a flat roof is installed.

This building was the first Vertix building where a solar thermal system was installed for hot water generation. The main reason for installing the LSTS was the solar ordinance of San Cugat del Vallès. This municipal ordinance mandates the installation of solar thermal systems for hot water generation in new buildings, with a minimum solar fraction of 60%. Vertix was satisfied with the realised solution and will apply more systems of this kind in the future.

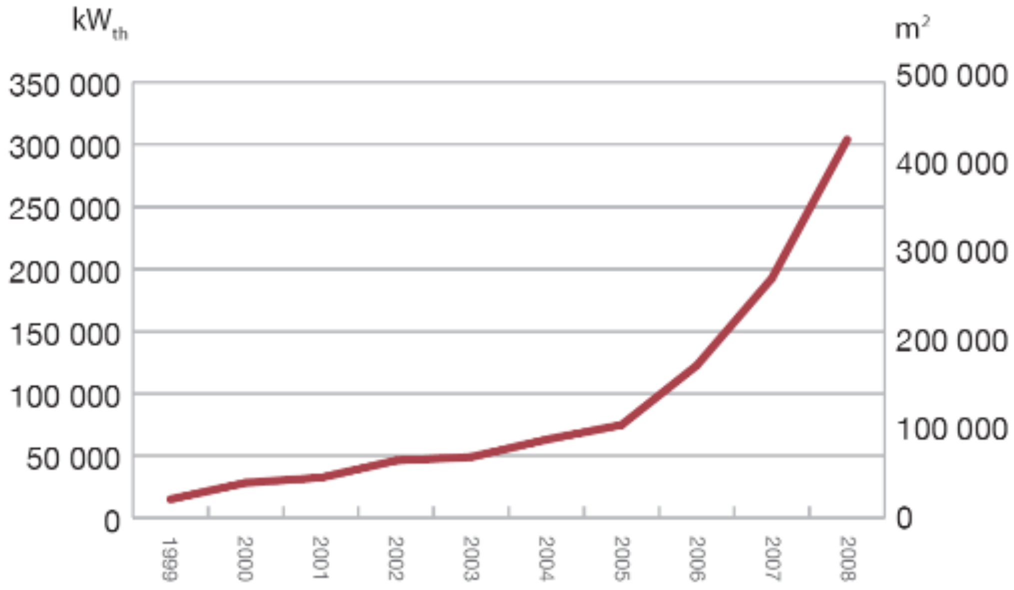
7.1.1.1 National objectives and regulation in Spain

The updated Plan for Renewable Energies in Spain 2005–2010 (PER) has set a goal for solar thermal to 4.2 million m² (additional collector surface in 2005–2010), reaching a total accumulated collector surface of 4.9 million m² in 2010, and a ratio of installed collector surface of 108–110 m² per 1000 inhabitants, depending on the population growth.

7.1.1.2 Current market in Spain

With a growth of 58% in 2008, Spain became the second largest market for solar thermal in Europe (European Solar Thermal Industry Federation, 2009). Over 300 MW_{th} were newly installed last year (434,000 m^2) bringing the total capacity in operation to 988 MW_{th} (1.4 mil m^2). While the solar obligation for new buildings provides a solid support framework, the overall construction market situation will likely result in lower growth in 2009. Nevertheless, interest in solar thermal technologies remains very high, as can be seen at the major solar and heating, ventilation and airconditioning (HVAC) events in Spain.

Figure 7.1: Current market trends in Spain



7.1.1.3 LSTS strategy measures

Regulatory measures

The existing regulatory measures in Spain are applied on different levels:

- **National level – CTE**
  The existing building code 'Código Técnico de la Edificación' (CTE) has been updated according to the European Energy Performance Building Directive (EPBD) and came into force in 2006. Among the basic quality requirements for buildings, the CTE established the DB-HE, which aims to save energy and apply thermal isolation in buildings. It is applicable for all new buildings and integral renovation projects (>1000 m²). The DB-HE chapter is divided into five parts:
  - Limitation on energy demand (HE1)
  - Efficiency of thermal installations (HE2)
  - Efficiency of lighting installations (HE3)
  - Application of solar thermal systems for hot water preparation (HE4)
  - Application of solar photovoltaic installations (HE5).

  The HE2 and HE4 chapters contain relevant information regarding the implementation of solar thermal installations: HE2 defines all procedures in order to ensure the efficiency of thermal installations (including solar thermal) and HE4 enforces the application of solar thermal systems to partially cover the hot water demand for domestic purposes and water heating for indoor swimming pools.

  In the HE4 chapter it is stated that for all new buildings and renovations, a minimum solar fraction from 30 to 70% is required (depending on climate zone, hot water demand and energy source for backup heating) at a reference temperature of 60ºC. The values established by the CTE are minimum values to cover the basic demand on a national level.

- **Regional level – decree of ecoefficiency in Catalonia**
  There is an existing decree in the Catalonian region (Decret d'Ecoeficiència de la Generalitat de Catalunya, Catalan government, 2006) which enforces the use of solar thermal and solar fractions required according to the Catalonian climate zones. The baseline calculations for hot water demand and solar fraction are not harmonised with the CTE.

- **Local level – solar ordinances**
  The objective of the solar ordinances is to regulate the incorporation of solar thermal systems of low temperature for the production of sanitary hot water in new and existing buildings (rehabilitation). Up to date, 71 of 8108 municipalities have a solar ordinance in place for SWH and seven municipalities are processing them. These municipalities represent 10.5 million Spanish inhabitants (24%). In contrast to the CTE, usually higher solar fractions are required in the solar ordinances. The baseline calculations are not always in line with the CTE.

  If there is a decree and/or a municipal solar ordinance in force, one should comply with all regulations, meaning the highest solar fraction should be met.

Link to solar ordinance of Barcelona

The first solar ordinance in Spain came successfully into force in 2000 in the city of Barcelona. This model has been used as a standard for almost all local solar ordinances that have been established to date. The Barcelona model also triggered and served as a base for the regional and national obligation.

Links: www.solarordinances.eu/STODatabase/tabid/60/Default.aspx?data_id=38
www.barcelonaenergia.cat/eng/operations/ost.htm

Table 7.1: Building characteristics

Year of construction	2004/05
Type of building	Multi-family house
Number of users	195
Number of dwellings	39
Number of floors	5

7.1.2 Energy consumption

Table 7.2: Heat consumption

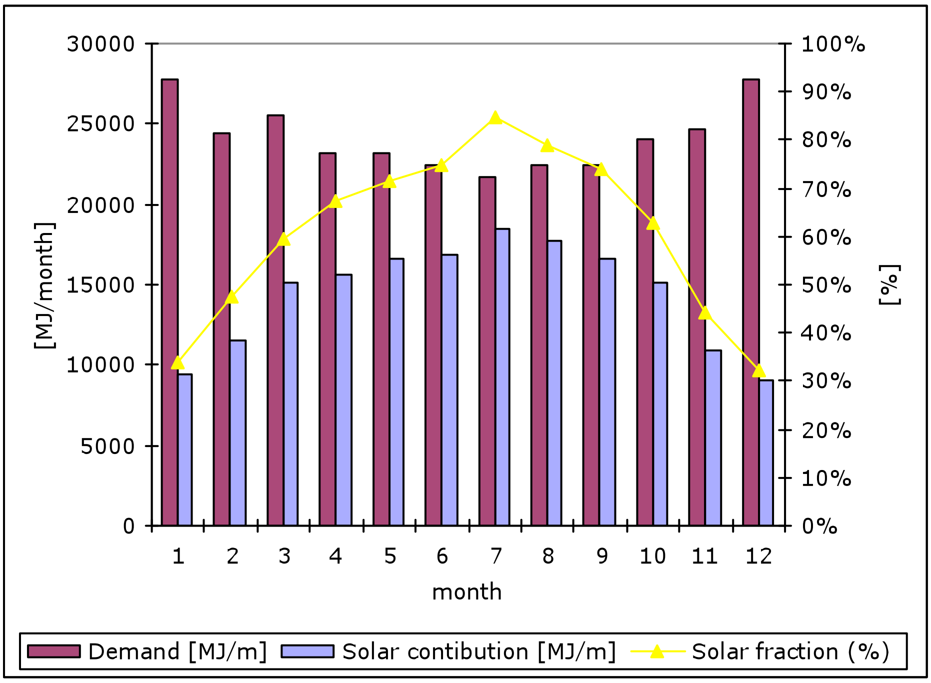
Whole energy consumption for hot water purposes after LSTS implementation	41,851 kWh/yr
Origin of data	Estimated, from official key numbers
Whole final energy consumption for heating purposes before LSTS implementation[4]	101,616 kWh/yr

[4] Based on an efficiency of the back-up heater of 80%

Table 7.3: Hot water consumption

Hot tap water consumption (calculated)	2135	m^3/yr
In Spain, real numbers for hot water consumption are very rare. Therefore, in all Spanish legislation, key numbers are defined for hot water consumption depending on the building type. For dwellings, a distinction is made between single-family and multi-family houses. Single-family houses: 30 L/p.day (60ºC) Multi-family houses: 22 L/p.day (60ºC)	Daily[5] D(60°) = 22 L/day*person[6] D(45°) = D(60°).(60° – 15°)/(45° – 15°) D(45°) = 33 L/p.day Person for dwellings: 4 each Dwellings: 39 DTOT = 39.4 person.33 L/(day.person) = 5,148 L/day = 5.15	m^3/day
	weekly	m^3/week
	Peak consumption	
Hot tap water temperature	45°C	
Cold water temperature	12°C	

Figure 7.2: Monthly energy usage



[5] The Solar Ordinance of San Cugat del Vallès does not give specific definitions for hot water daily demand, so we refer to CTE (national legislation) application of solar thermal systems for hot water preparation (HE4).
[6] According to the table of hot water daily demand for multi-family house inside CTE (national legislation) for an out temperature of 60° and the formulation

$$D_i(T) = D_i(60^{\circ}C)x\left(\frac{60 - T_i}{T - T_i}\right)$$

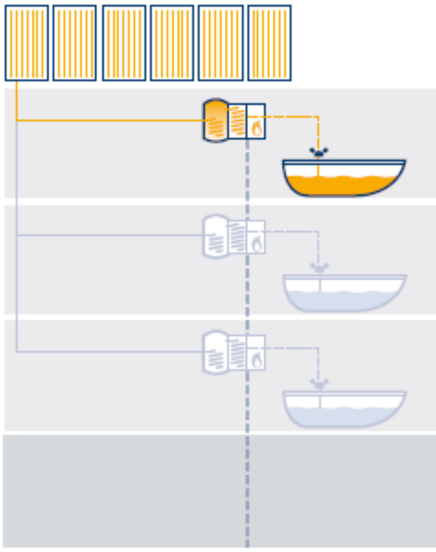
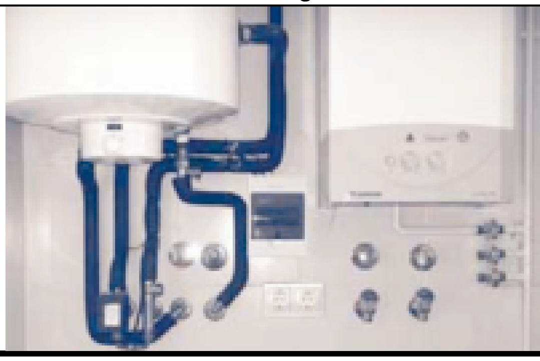
Where :
D_i (T) = water hot daily demand at a specific Temperature T
T_i = cold water average temperature

7.1.3 Design of the solar hot water system

The design objective of the project was to comply with the local obligation (solar ordinance) to install solar thermal systems in all new buildings in the municipality of Sant Cugat del Vallès. This was the only reason to install the LSTS.

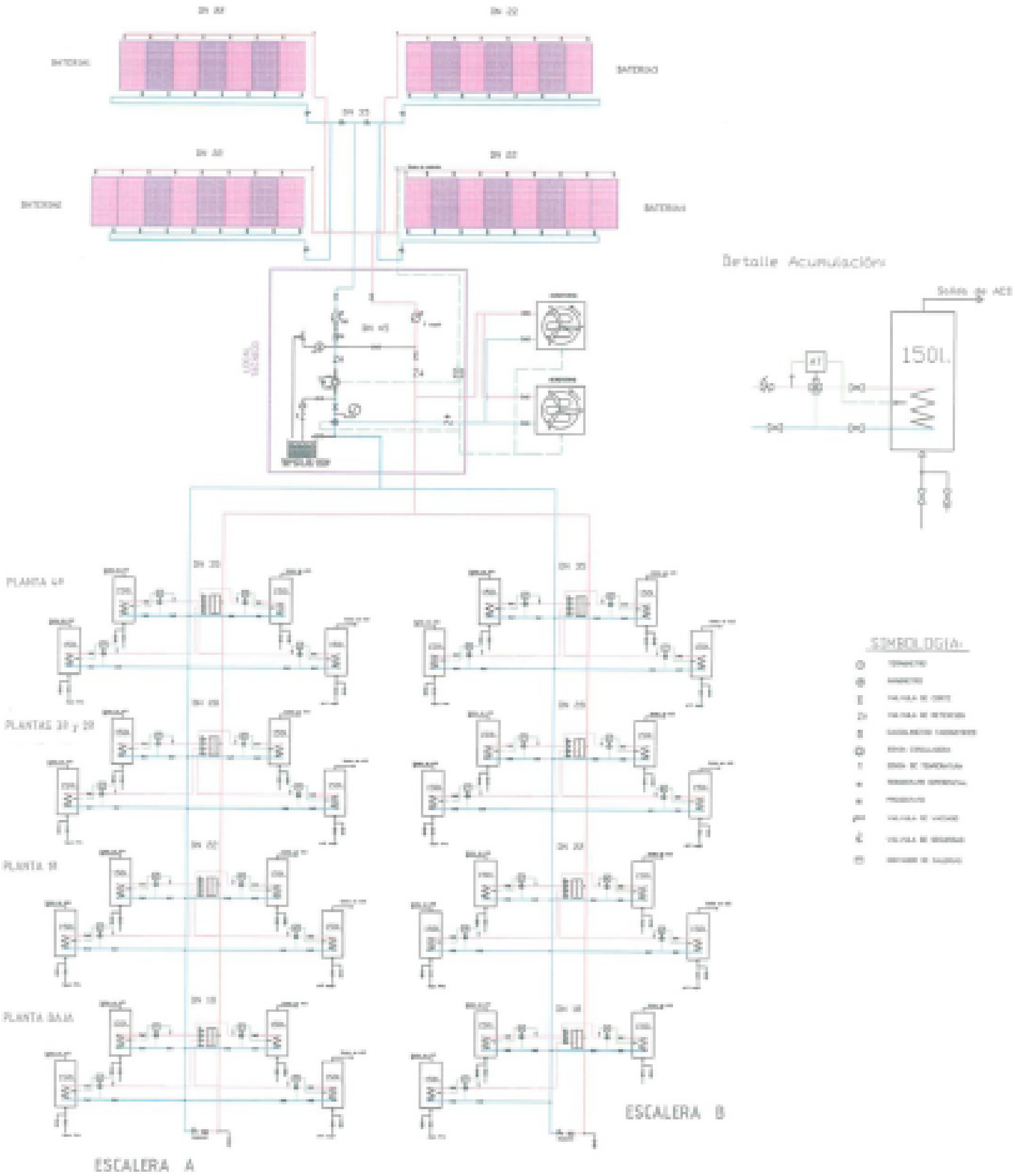
Table 7.4: System design specifications

General system information	
Year of LSTS construction	2005
Energy use of LSTS for	Hot tap water heating
Collector area per apartment	1.5 m^2
Control of backup system/LSTS	Separated control
Images of one of the four collector fields	 
Solar collector specifications	
Type of collectors	Flat plate collectors
Type of assembly	On flat roof
Orientation of collectors	South-east (-20°)
Inclination angle to horizontal	45°
Thermal power	42 kW_{th}
Gross area of collectors	60.9 m^2
Aperture area of collectors	60 m^2
Freezing protection	Glycol
Overheating protection	Expansion vessel, fan coil

Storage tank specifications	
Solar buffer storage	Total volume: 5.85 m^3 (39 × 150 L) The system consists of 39 individual storage tanks of 150 L
Operation mode	Low flow
Hot tap water storage	n/a
Hot tap water system	
Type of hot water heating	Decentralised
The solar storage devices (tanks) are distributed in a decentralised manner and are connected in series to a modulated combination boiler (for space heating and hot water generation)	
Space heating system	
Type of heating system	Decentralised
Number of boilers	39
Total capacity (power output) of boilers	936 = 39*24 kW
Capacity of each boiler (and the year of construction)	all: 24 kW (2005)
Energy source	Natural gas
Solar heat storages and backup heaters: auxiliary heating unit and control unit are located in each apartment Type of boiler system: standard	
Control and monitoring of the system	
Operator of the LSTS system	Self-operation
LSTS monitoring	No
Data accessible via internet	No
Scientific monitoring/follow-up	No
Maintenance contract	Yes, twice a year
Visualisation of the solar heat output	No
Type of heating system	Decentralised

7.1.4 Layout of the solar hot water system

Figure 7.3: Vertix system schematic



Source: www.solarge.org/uploads/media/santcugat_scheme.pdf

7.1.4.1 Collector field (central)

The collector field is composed of 30 collectors and divided into four batteries (2 x 7 and 2 x 8). The four batteries are connected in parallel. Within the batteries, the collectors are connected according the so-called Tichelmann principle, whereby all collectors are exposed to the same pressure losses and the flow rates adjust themselves in the collectors.

7.1.4.2 Solar storage (de-central)

Each apartment is equipped with a solar storage of 150 litres. This storage is connected to the gas-fired backup boiler (a combined boiler for hot water and space heating). The distribution of the solar heat to the storages is in parallel and divided into two main strings (16 and 15 apartments). Each solar storage is connected to the distribution system with a ΔT control in such a way that the heat exchangers of the solar storage will be connected to the distribution system if the temperature in the distribution system is higher than the temperature in the solar storage.

7.1.5 System performance

7.1.5.1 Technical system performance

Table 7.5: Yield of LSTS plant and reduction of final energy

Output of solar heat	47,812 kWh/yr
Origin of data	Design (calculated)
Reduction of final energy[7] (replaced energy source natural gas)	59,765 kWh/yr
Origin of data	Calculation made with the POLISUN software
Solar performance guarantee	No

Table 7.6: Energy and emissions assessment

Fossil energy savings by the LSTS	59,765 kWh/yr
Greenhouse gas emissions avoided	14.13 t CO_2/yr

It was estimated that a 60% reduction of final energy consumption for building hot water consumption using solar thermal energy was achieved.

Some issues reported from system use:

- The LSTS is running well even though at the beginning there were some complaints because of the noise of one pump. This pump was changed and no more problems were reported.
- In the beginning there were reported problems with the collector fluid. There were some small leaks in the circuit, which caused pressure drops. Leaks were detected and repaired and the circuit was filled again.
- Minor problems related to the use of the system by tenants were detected, but these problems were solved during maintenance.
- It was reported that one of the tenants disconnected two out of the three valves of the system in order to gain more hot water than the rest of the tenants. Restricting access to the system in order to diminish possible manipulation of the installation provided a solution for this problem.

For the rest, the system works properly.

[7] considering a boiler efficiency of 0.8

7.1.5.2 Financial system performance

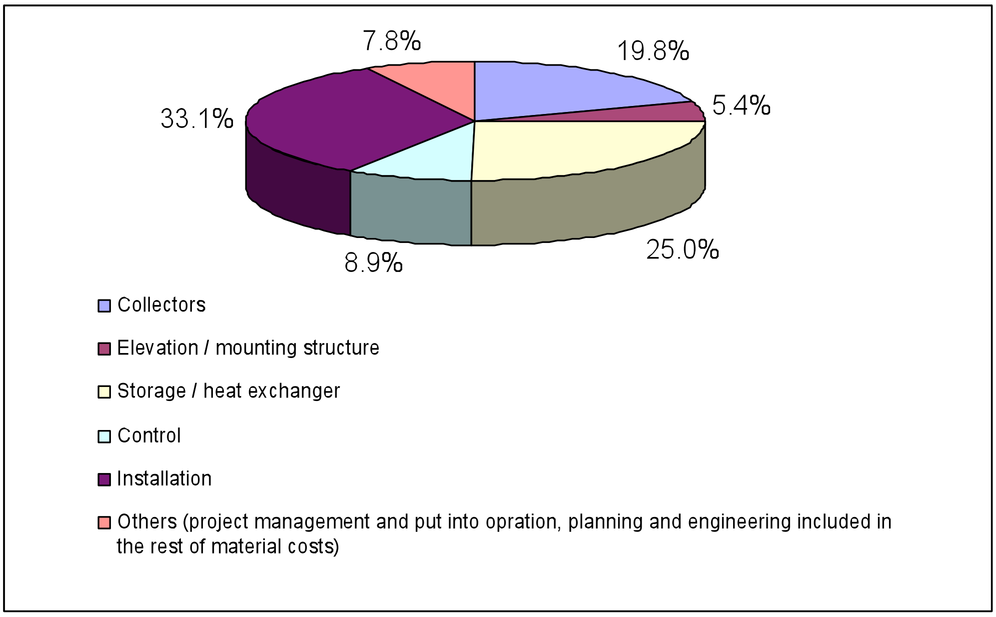
The project developers, Vertix, financed the LSTS installation without applying for a subsidy or special loans, although at the time the LSTS was built, subsidies were available. Vertix was informed by the installers about this possibility, but it was not interested.

The costs of the LSTS were incorporated into the final cost of the dwellings. This means the tenants paid for the system, of course with lower operational costs for hot water preparation.

Table 7.7: System cost breakdown

Costs of solar materials	**€**	**€/m²**
Investment costs per apartment[8]	2,285	-
Total cost of solar thermal system[9]	89,133	1636
Collectors	17,650	294
Elevation/mounting structure	4800	80
Storage/heat exchanger	22,341	372
Backup heater	not incl.	-
Control	7,900	132
Installation	29,559	493
Planning/engineering	incl. in rest	-
Others (project management and put into operation, planning and engineering included in the rest of material costs)	7000	117

Figure 7.4: Cost distribution



[8] without consideration of subsidies
[9] costs without conventional heating system

7.1.5.3 Economic assessment

Because of the lack of a monitoring system, it is hard to evaluate if the system is profitable in the way it was estimated. Although with increased energy (gas) prices, the LSTS will become more and more profitable. While Vertix was aware of this, the main reason for them to install the solar thermal system was because of legal obligation. According to Vertix, the payback time of this installation is estimated between 10 and 13 years.

7.1.5.4 Comments by owner

"The LSTS installation on San Cugat Vallès was the first one completed by Vertix. However, the implementation of the system was mandated by the municipality's solar ordinance. It was also taken on as a challenge by the project developer to comply with this obligation. The favourable results of the installation and the lack of major problems gave Vertix the confidence to invest in solar thermal systems in their future buildings."

7.2 Case study: CONTANK – Castellbisbal (Industrial)

7.2.1 Description

Location: Castellbisbal – Barcelona – Spain
Source: www.solarge.org/index.php?id=1600

All pictures: Aiguasol Enginyeria

Castellbisbal's parking service is a new building where the LSTS (Collective Solar Thermal System) was proposed at the design stage. Thus, the roof structure and the distance between the rafters was set according to the weight and the size of solar collectors and the total available roof space was taken into account.

In this facility, liquid freight goods' transportation containers from trucks and railways are cleaned. Part of the cleaning process requires hot water vapour. The daily consumption is about 80 m^3 at 70–80º. The LSTS produces 429 MWh (840 kWh/ $m^2 \cdot a$) which covers 21% of the total hot water demand. The installation has a monitoring system that allows detection of system incidents. The system was designed and built under the supervision of, and is monitored by, Aiguasol Enginyeria.

Table 7.8: Building characteristics

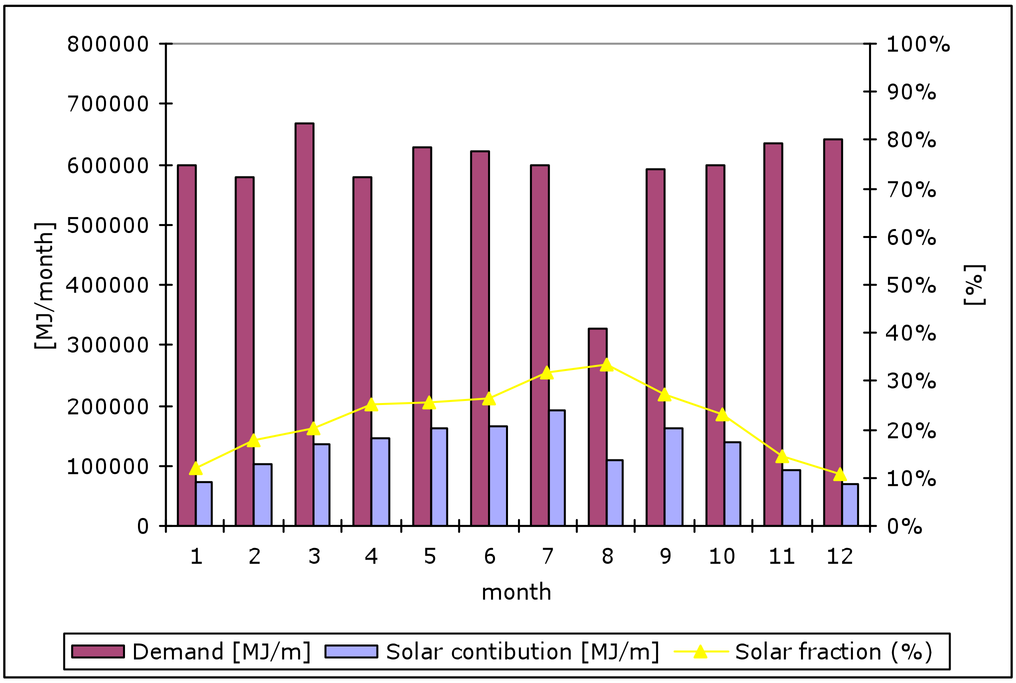
Year of construction	2005
Type of building	Industry – parking service

7.2.2 Energy consumption

Table 7.9: Hot water consumption

Hot tap water consumption (calculated)	22,880 m^3/yr
	80 m^3/day
	440 (considering 5.5 day/week) m^3/week
	Peak consumption n/a
Hot tap water temperature	70°C
Cold water temperature	15°C

Figure 7.5: Monthly energy usage



7.2.3 Design of solar hot water system

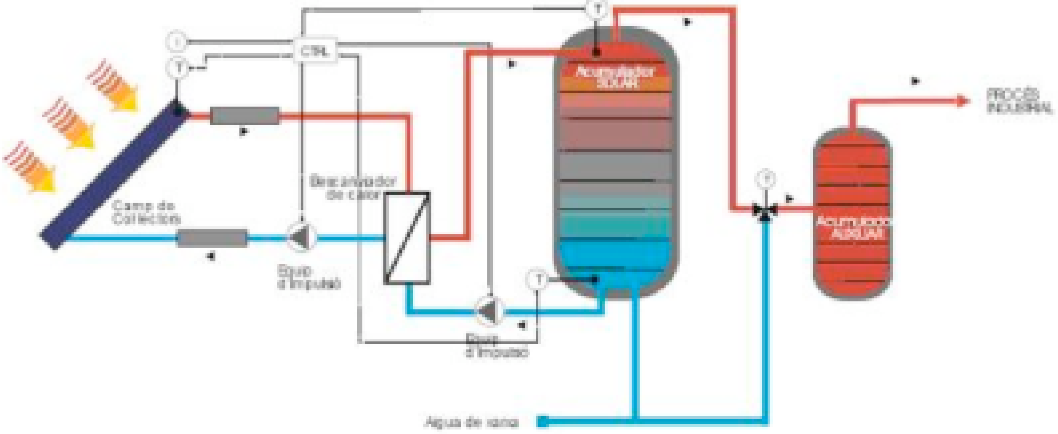
The containers to be cleaned in the Castellbisbal parking service can contain polluting liquids. In order to diminish the polluting effects to the environment, it was decided to install a solar thermal plant. Planning of the LSTS was optimised by the use of TRNSYS, which allowed the future performance of the installation to be accurately estimated.

The LSTS consists of:

- nine rows of solar collectors connected in parallel, where four of the rows have eight collectors and five of the rows have 12 collectors; the used collectors have a total area of 6 m^2; the row capacity is 910 L/h, summing up a total capacity of 8189 L/h
- one heat exchanger and a 40 m^3 solar storage tank, with a nominal solar thermal gradient of 36.6 K
- two primary pumps SEDICAL SIP 50/150.3-2.2/H (rodet 150) = 8.8 kW
- two secondary pumps SEDICAL SAP 50/9T (rodet 95)

Table 7.10: System design specifications

Generic information of the LSTS	
Year of construction of LSTS	2005
Energy use of LSTS for	Industrial cleaning process
Technical characteristics	
The solar thermal system is composed of a pressurised primary loop filled with antifreeze heat transfer fluid (30% glycol), a heat exchanger, and a secondary non-pressurised loop of decalcified and pre-processed water for industrial container washing. The solar collector field, placed with an azimuth 24° east and 25° of slope, is composed of two fields at different levels, with a total absorber surface of 510 m^2. Solar collectors are connected so that there is a low flow rate of 17 kg/h.m^2. Collector rows were installed with foreseen distances of the initial architecture project design. A 40 m^3 atmospheric stainless steel solar water storage tank supplies preheated water to the process.	



Plant scheme – solar storage in serial connection with storage for auxiliary heating

A thermostatic valve was installed, which was not considered in the initial project, to ensure that the process water temperature is not higher than 55°C.
In the case of the CONTANK system, the auxiliary energy is not delivered in the auxiliary tanks but through a tubular heat exchanger which provides energy from a steam boiler. Therefore, the energy is instantaneously given to the water for the cleaning process.
TRNSYS simulations (through the TRANSOL tool) were run for the optimisation of the solar thermal system and heat production estimation.

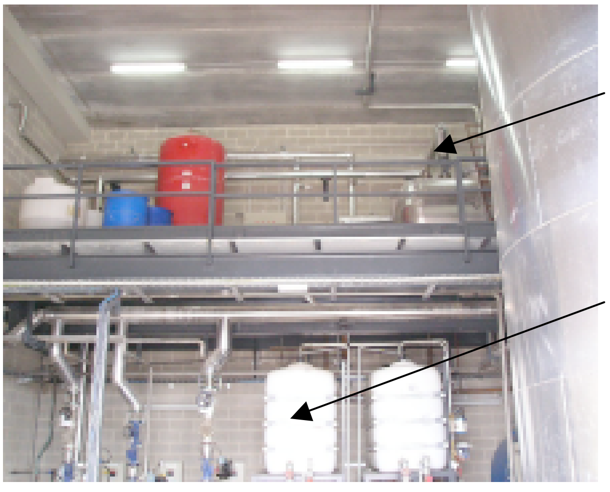
Solar collectors	
Type of collectors	Flat plate collector
Type of assembly	On flat roof
Orientation of collectors	South-east (-24°)
 Lightweight support structure (aluminium profile, inclination 20º)	 Inclination angle to horizon 25°
Thermal power	360 kW_{th}
Gross area of collectors	570 m^2
Aperture area of collectors	510 m^2

Solar collector characteristics	
Trademark collector	SONNENNKRAFT GK6
Manufacturer	Sonnenkraft GmbH
Technology	Flat plate
Area (total, active)	6.2, 5.54 m²

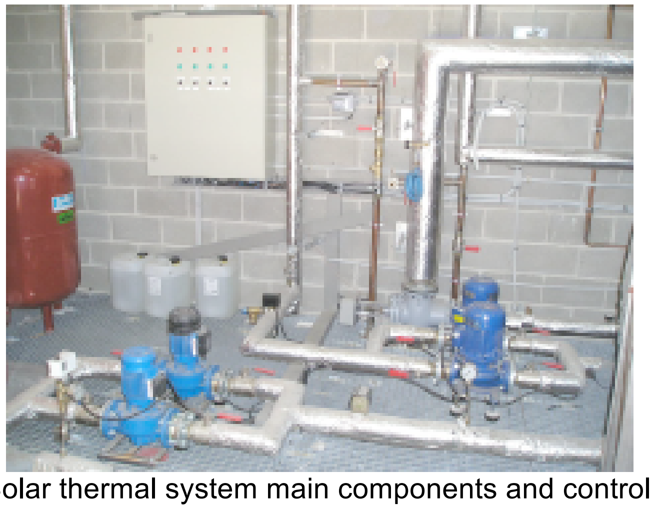
Heat and optical loss coefficients	
Optical conversion	h0 = 0.798
Thermal transmittance, linear	Uloss = 3.283 W/m²K
Thermal transmittance, quadratic	0.01870 W/m²K²
Freezing protection	Primary propenglycol 30%
Overheating protection	Expansion vessel 2000 L, safety valve
Image of solar collector	

Storage tank	
Solar buffer storage	Total volume: 40 m^3 (1 × 40 m^3) The system consists of one storage
Image of solar storage tank	
Hot tap water storage	Total volume: 6 m^3 (2 × 3 m^3) The system consists of two storages
Operation mode	Low flow

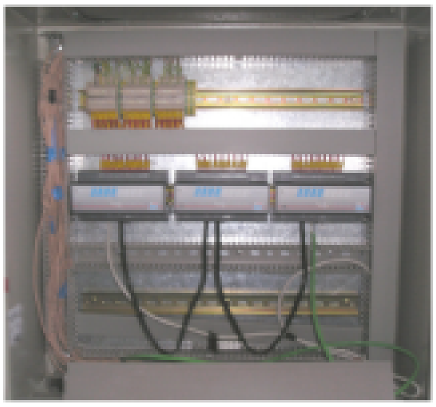
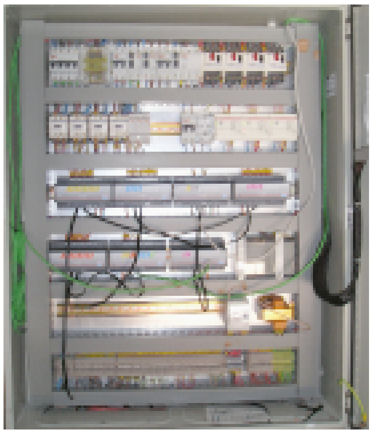
Hot tap water system	
Type of hot water heating	Centralised
Recirculation system	Yes
Separated backup heater/boiler for hot tap water heating only	Yes
Auxiliary energy source	Natural gas



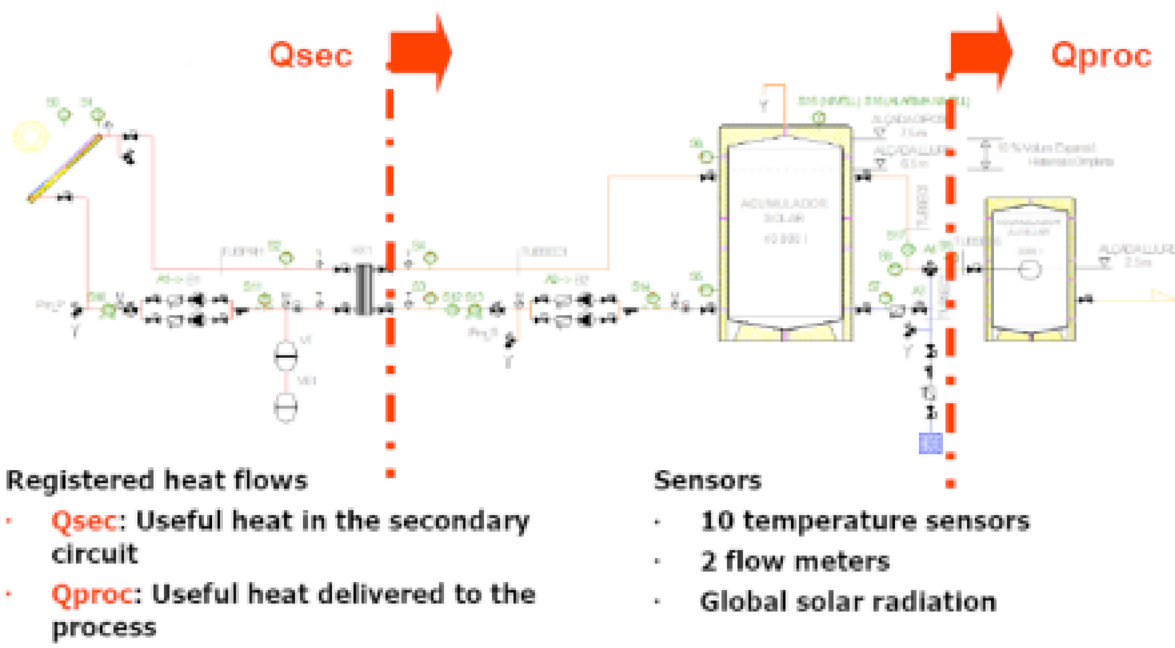
Solar field expansion vessel (2000 L) and temperature vessel



Solar thermal system main components and control panel

Control and monitoring of the system	
Operator of the LSTS system	Self-operation
LSTS monitoring	Solar radiation Output of solar heat Total water consumption
Scientific monitoring/follow-up	No
Maintenance contract	Yes, every three months
Visualisation of the solar heat output	No
Type of data observation (monitoring)	Grupo de Abastecimiento Energetico (GAE) supervises the data
 Solar thermal field panel	 Main control panel

System for tele-monitoring and tele-control



7.2.4 Layout of the collector field

Figure 7.6: Collector field schematic

7.2.5 System performance

7.2.5.1 Technical system performance

Table 7.11: Yield of LSTS plant and reduction of final energy

Output of solar heat	429,000 kWh/yr
Origin of data	Design (calculated)
Gross area of collectors	570
Reduction of final energy	613,470 kWh/yr
Origin of data	Estimated
Solar performance guarantee	No

Some issues reported from use:

- The LSTS is running properly. The best experience gained in this project was the application of a solar thermal technology in industrial processes and the use of non-pressurised storages. The engineering company Aiguasol has recommended adding heat recovery and variable flow pumps to ameliorate the installation. This project is a benchmark in Aiguasol activities due to the of coupling solar thermal technologies and industrial processes, an innovative application of solar thermal in Spain.
- The LSTS performance can be improved by the use of components such as non-pressurised storages and large collectors.
- The demand is not constant. However, the installation works very well and has good performance.
- Some broken solar collectors were the only problem faced in the system.

7.2.5.2 Monitoring results and operation experience

Monitoring results

A detailed monitoring system was installed and has been in full operation since July 2006. Data obtained from January to September 2006 (except from April to June) has provided the opportunity to check the real system operation, its real performance and real input data, such as demand profiles or local global radiation used, in order to validate the used TRNSYS model.

Global incident radiation monitoring results

The real global incident radiation monitoring results on the collector surface evaluated from July to September 2006 was 6.4% higher than the global radiation used in the simulations for the same period.

Consumption

The real consumption evaluated from January to March and from July to September 2006 was 55.7% lower than estimated at design stage. There are mainly two factors involved in this mismatch between the real consumption and the estimated one:

- Nominal working conditions were not achieved (80–100 m^3.day; 5.5 day/week).
- The percentage of cold water in the cleaning process was higher than expected.
- The reduction of the consumption involves a reduction of the performance of the solar thermal system, as well as a decrease in the expected energy delivered to consumption.

Simulation model validation

In order to validate the TRANSOL simulation model used for the forecast of the system operation and its performance, new simulations with the updated data obtained from the monitoring were necessary.

The monitoring data used for the new simulations included:

- real consumption load profile
- cold water temperature monthly average values
- global radiation on tilted surface, which was not used due to the small period in which the data was obtained (only three months).

Taking into account the new data obtained by the monitoring scheme, new simulations were developed in order to check the TRNSYS model.

Energy delivered to the solar tank

In the new simulations, the real amount of energy delivered to the solar tank evaluated from January to March and from July to September 2006 was 8.4% higher than the simulations for the same period. Considering that the real global incident radiation upon the collector surface evaluated during the same period was 6.4% higher than the global radiation used in the simulations, the obtained results fit mostly to the real system operation and performance.

Energy delivered to the auxiliary tanks

The energy delivered to the auxiliary tanks was 14.6% lower than the results obtained in the updated simulations for the same period. This reduction could be caused by the applied night cooling strategy, which was not considered in the design TRANSOL simulations.

Operation experience

During the first year and a half, the CONTANK solar thermal system was not working at full operational conditions. A lower consumption was forced during potential stagnation periods to apply delaying stagnation measures, such as night cooling of the solar tank.

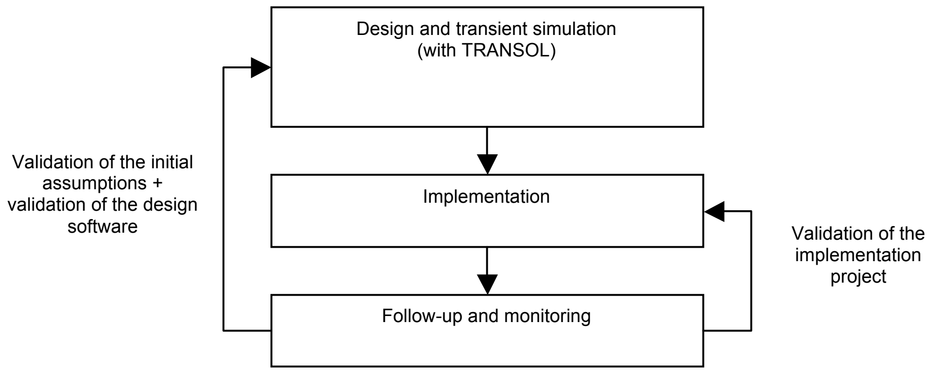
Incidents

No solar thermal system is exempt from incidents during its first years of operation. This is the main reason for the continuous follow-up by Aiguasol in the CONTANK factory, which has helped them anticipate and solve most of the incidents that occur with such a complex system.

Conclusion

Aiguasol has followed a three-step feedback methodology, which ensures the correct operation of the systems.

Figure 7.7: Aiguasol's three-step methodology



The TRANSOL model, simulated with the real actual working conditions, approaches nicely to the behaviour of the solar thermal system.

Monitoring results are the key to validate the design tools used, to review the initial demand assumptions and to check the real system operation and performance. Monitoring data also demonstrates a lower consumption than the initial estimation, mainly due to a lower use of the cleaning plant, which implements night cooling measures in order to soften stagnation conditions.

7.2.5.3 Financial system performance

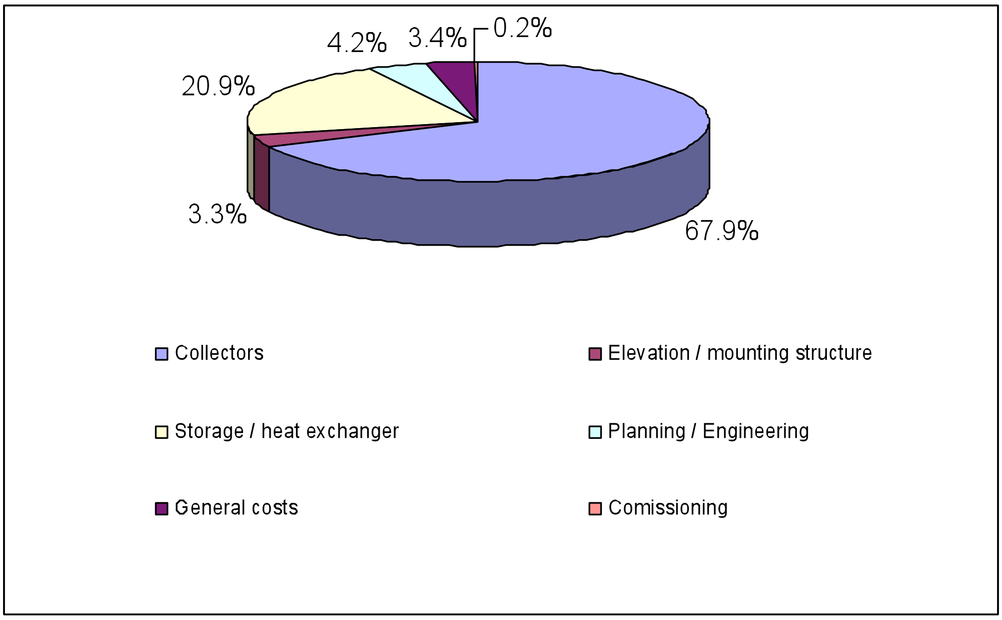
The 48% left was paid with direct subsidies granted by the Institute for Energy Diversification and Saving (IDAE), the Catalonian Institute of Energy (ICAEN) and the Ministry of Industry and Mining, a tax reduction and a low interest rate.

The total investment was 268.546 €, with IDAE and ICAEN contributing a total amount of 130.000 € (about 50%, including a tax reduction and a financing scheme with a low interest rate).

Table 7.12: Cost breakdown

Financing of LSTS		
Form of financing	51% self-financing 37.9% subsidies 11.1% bonus granted	
Costs of solar materials		
	€ (excl. VAT)	**€ / m²**
Total cost of solar thermal system[10]	268,546	471
Collectors	182,412	320
Elevation/mounting structure	8,855	16
Storage/heat exchanger	56,256	99
Control	Included in storage/heat exchanger	-
Installation	Included in collectors	-
Planning/engineering	11,167	20
Others costs: Commissioning (1) General costs (2)	630 (1) 9,223 (2)	1 (1) 16 (2)

Figure 7.8: Cost distribution



7.2.5.4 Economic assessment

The annual savings estimated are 13,050 € (maintenance and operation costs already deducted), resulting in a payback time of 10–12 years.

[10] costs without conventional heating system

7.3 Case study: Endless Solar – small leisure centre

7.3.1 Description

Location: Central Coast, New South Wales, Australia


All pictures: Endless Solar

Application

Leisure centre, including surf club, kiosk, club and bar

System type

Endless Solar Evacuated Tube System (www.endless-solar.com)

Constructed

New construction – 2009

Additional requirements

Customised system design modelled to be eligible for Renewable Energy Certificates (RECs).

Background

A local council on the NSW central coast operates a number of leisure centres and surf clubs. The facilities are used as a base for the local surf lifesavers, while also providing additional facilities for beach goers and the local community. The centre was the second of two clubs built in 2009, with energy efficiency and sustainability as a key motivator in the building design.

Due to the relatively high projected use of hot water at the centre, the heating of water was identified in the early stages of the design as a major contributor to running costs and greenhouse gas emissions. As natural gas was not available at the site, a highly efficient solar hot water system was vital to minimise the club's running costs.

Consequently, the centre and other council-owned facilities have been equipped with customised Endless Solar Evacuated Tube hot water systems.

Building characteristics

The two-storey leisure centre includes showers that are predominately used by the surf club members throughout the warmer months of the year. The centre also has a public bar, commercial kitchen, auditorium, restaurant and kiosk that operate all year round.

7.3.2 Energy consumption

7.3.2.1 Peak hot water load

The hot water at the leisure centre is delivered to both the showers (at 45ºC) and the commercial kitchen (at 72ºC).

Table 7.13 below shows the anticipated hot water usage in the peak of summer.

Table 7.13: Hot water usage at leisure centre

Showers	Number of showers per day	40
	Average length per showers (minutes)	4
	Flow rate (L/min)	6.5
	Total hot water usage (L/day at 45ºC)	1040
	Cold water supply temperature (ºC summer)	20
	Peak daily energy usage (MJ/day)	108.8
Commercial kitchen	Number of restaurant meals per day	50
	Litres per meal (at 72ºC)	5.5
	Number of kiosk meals per day	50
	Litres per meal (at 72ºC)	3
	Total litres per day (at 72ºC) = (50 x 5.5) + (50 x 3)	425
	Peak daily energy usage (MJ/day)	92.5
Total	Peak load (MJ/day)	~200

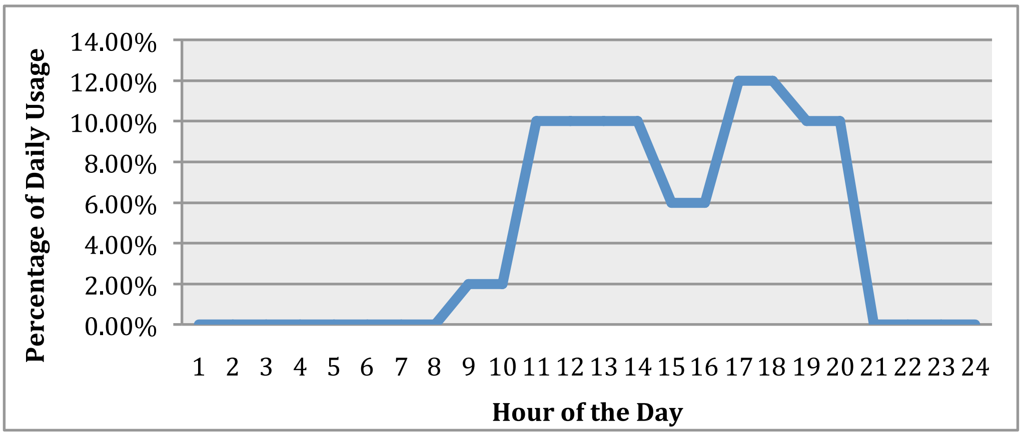
7.3.2.2 Usage patterns

The design of the system was equally influenced by the usage pattern as it was by the peak load.

7.3.2.3 Daily usage

The usage pattern varies throughout the day; usage will peak during the lunchtime period, at 5:00pm due to the shift changeover times for surf lifesaving staff and in the early evening due to restaurant usage.

Figure 7.9: Anticipated daily hot water usage pattern



7.3.2.4 Seasonal usage

The use of the building varies throughout the year as the popularity of the beach environment peaks in summer and drops off in the winter months. Consequently, hot water usage will peak between November and March and drop off between May and August.

This seasonal usage pattern is extremely convenient for a solar hot water system, as it maps closely with the available solar radiation levels.

Figure 7.10: Hot water usage pattern and solar radiation over an annual period

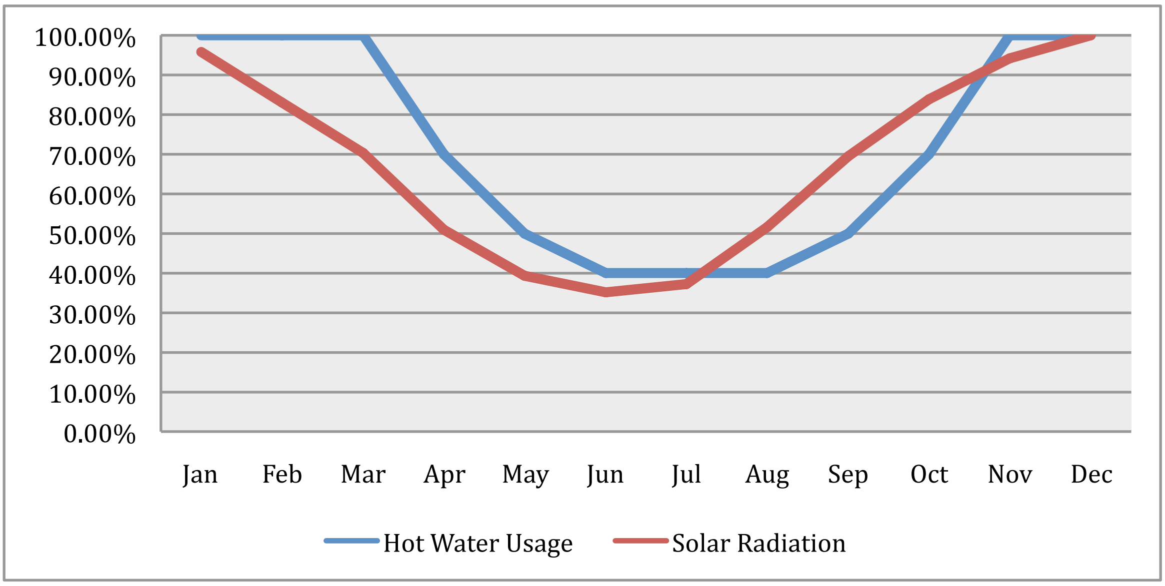


Table 7.14: Annual energy requirements

Month	Percentage of peak	Number of days	Total energy load (MJ)
January	100.00%	31	6200
February	100.00%	28	5600
March	100.00%	31	6200
April	70.00%	30	4200
May	50.00%	31	3100
June	40.00%	30	2400
July	40.00%	31	2480
August	40.00%	31	2480
September	50.00%	30	3000
October	70.00%	31	4340
November	100.00%	30	6000
December	100.00%	31	6200
Annual total (MJ)			52,200

7.3.3 Design of the solar hot water system

The system was custom designed for the client by Endless Solar to provide the hot water needs of the leisure centre in the most precise, energy-efficient and environmentally friendly way. Once the initial design was completed, Endless Solar modelled the system using the TRNSYS simulation software and submitted the results to the Office of Renewable Energy Regulator (ORER) to register the system to be eligible to create Renewable Energy Certificates (RECs).

Table 7.15: System design specifications

General system information				
Year of construction	2009			
Location	Central Coast, NSW, Australia			
Manufacturer	Endless Solar			
Model number	GB-1260-180-0-500LPG			
RECs	Zone 1	Zone 2	Zone 3	Zone 4
	142	133	142	124

The size and installation pitch of the solar collector array was specifically selected to complement the unique load profile of the leisure centre.

Under 'normal' load profiles, with a peak load of 200 MJ/day, eight evacuated tube collectors might have been selected and pitched at 34º to the horizontal to provide an even, year-round performance.

As the hot water requirements at the leisure centre are reduced significantly during winter, the collectors were mounted at 15º to the horizontal, allowing for maximum contribution during the summer months. The reduced pitch, coupled with the advanced optical properties of Endless Solar's evacuated tubes, provided four key benefits:

- Only six Endless Solar collectors were required, significantly reducing the cost of the system.
- The potential for the system to stagnate when the club is not in use (winter months) was reduced, as the collectors receive less solar radiation during this time.
- The aesthetics of the building were preserved by allowing the collectors to sit flush against an east-facing roof.
- The high performance of evacuated tubes in cold conditions enabled good solar contribution during the winter months.

Solar collector specifications	
Images of solar collectors	
Type of collectors	Endless Solar Evacuated Tube Collectors
Number of tubes	180 (6 x 30-tube)
Brand of collector	Endless Solar
Type of assembly	Flush mounted on low-pitched roof
Orientation of collectors	East
Inclination angle to horizontal	15°
Gross area of collectors	30 m^2
Aperture area of collectors	17 m^2
Freezing protection – collectors	Evacuated tubes are naturally frost tolerant
Freezing protection – pipework	Thermostatically driven pump

Storage tank specifications	
Image of solar storage	
Solar storage	Total volume: 1.26 m^3 (4 × 315 L) The system consists of four marine-grade stainless steel storage tanks of 315 L
Model number	ES 32GasCom315

High-quality, marine-grade stainless steel storage tanks were selected to ensure a long system lifetime. The solar storage has been sized to approximately match the expected daily hot water usage.

Solar circulating pump specifications	
Pump power	66 W (3 speed)
Operation mode	Low flow
Flow control method	Variable orifice valve with built-in flow rate display

As the system is pressurised, a low-wattage circulating pump was selected. The flow rate through the system is controlled to ensure maximum efficiency from the system.

Boosting system specifications	
Image of boosting system	
Boosting fuel	Liquid petroleum gas (LPG)
Thermal capacity	500 MJ/hr (2 x Bosch 250MJ/hr)
Hot water delivery	64 L/min (25ºC temperature rise)

The boosting system was designed to be capable of delivering the prescribed load assuming no contribution from the solar collectors. Redundancy has been built into the system to cater for any sporadic increases in hot water usage.

Control system specifications	
Operator of the system	Endless Solar Controller ESCi (microprocessor-based differential controller)
Monitoring	No
Data accessible via internet	No
Scientific monitoring/follow-up	No
Error warning	Yes
Operation visualisation	Yes
Temperature rating	300+°C
A simple, yet robust control system was selected, as no data logging or off-site monitoring capabilities were requested by the client.	

7.3.4 Layout of the solar hot water system

7.3.4.1 External components

Collector field

The collector field is composed of six collectors divided into two parallel arrays of three collectors connected in series; thereby all collectors are exposed to the same resistance to achieve balanced flow conditions.

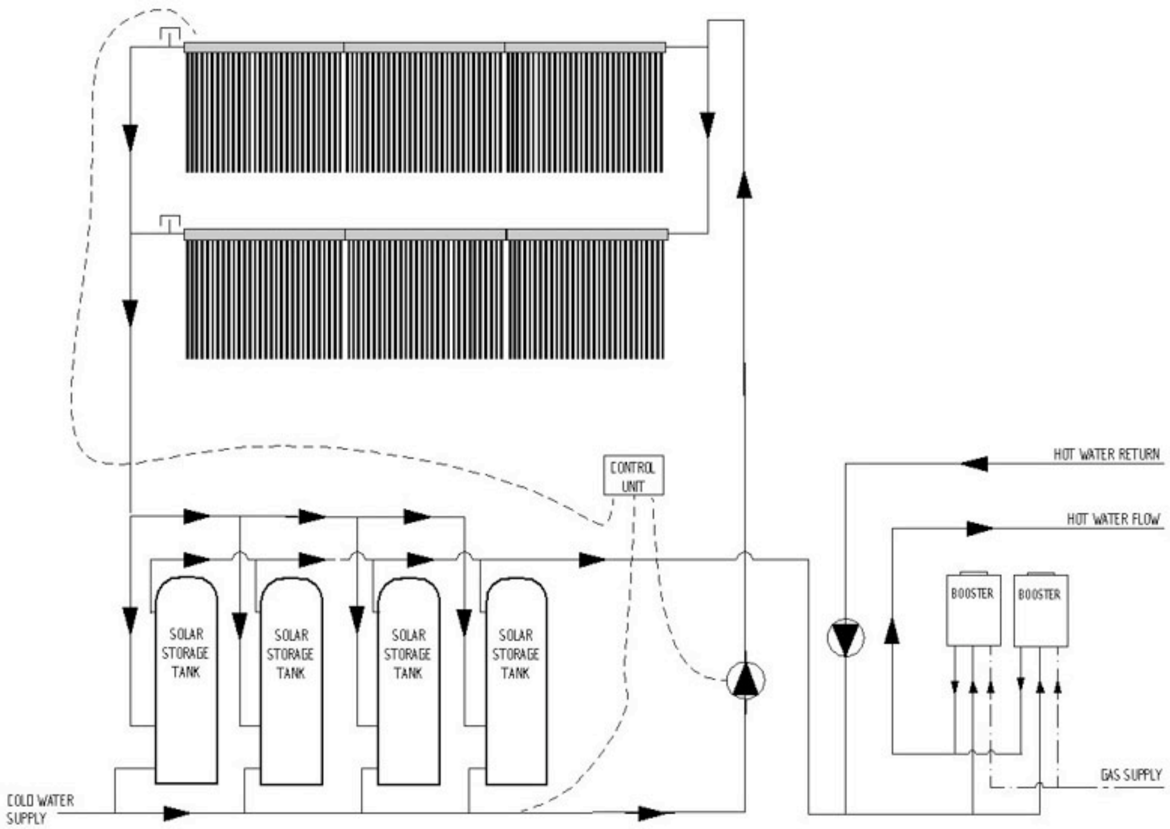
Solar storage

The four solar storage tanks are connected to achieve balanced flow conditions.

7.3.4.2 Internal components

The gas burners, control system and circulating pump are all installed internally to protect the components from the possibility of vandalism.

Figure 7.11: Layout of hot water components



7.3.5 System performance

7.3.5.1 TRNSYS modelling

The system was modelled using the TRNSYS simulation software to ensure it would operate as expected. The software was set up to simulate the system described above using the discussed load profile. Note: the methodology used here differed to the methodology used to calculate the RECs, the key difference being the customised load profile.

A second simulation was run to measure the energy used by a conventional hot water unit, the results of which were used as a reference to determine the energy savings gained through the installation of the solar hot water system.

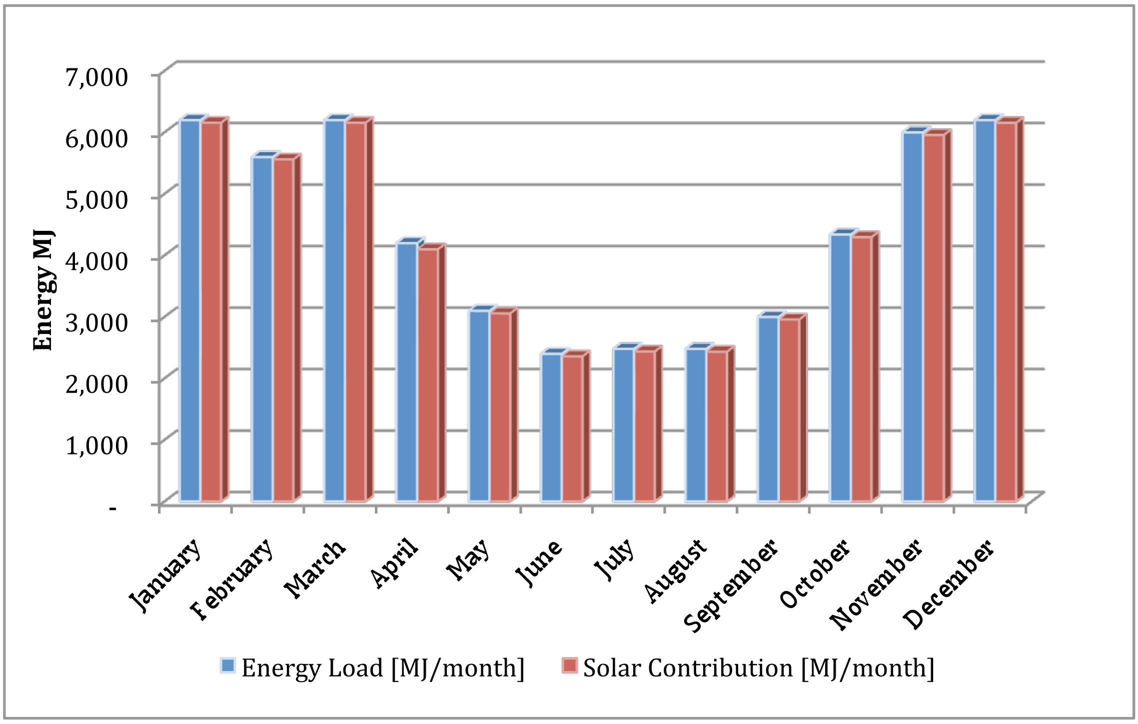
7.3.5.2 Calculated energy usage

The TRNSYS simulation produced the expected energy usage of both the solar hot water system and the reference system. The calculated energy usage presented here includes the electrical energy used to run the solar circulating pump and control system, the electrical energy used by the LPG burners and the efficiency of the LPG burner.

Table 7.16: Calculated energy usage

Month	Energy delivered to the load (MJ/day)	Calculated energy used by reference heater (MJ/day)	Calculated energy used by solar hot water system (MJ/day)
January	200	335.20	2.30
February	200	335.18	2.30
March	200	335.13	2.32
April	140	236.38	5.64
May	100	170.58	2.34
June	80	137.80	2.35
July	80	138.12	2.36
August	80	138.17	2.52
September	100	170.99	2.34
October	140	236.93	2.32
November	200	335.63	2.34
December	200	335.40	2.41

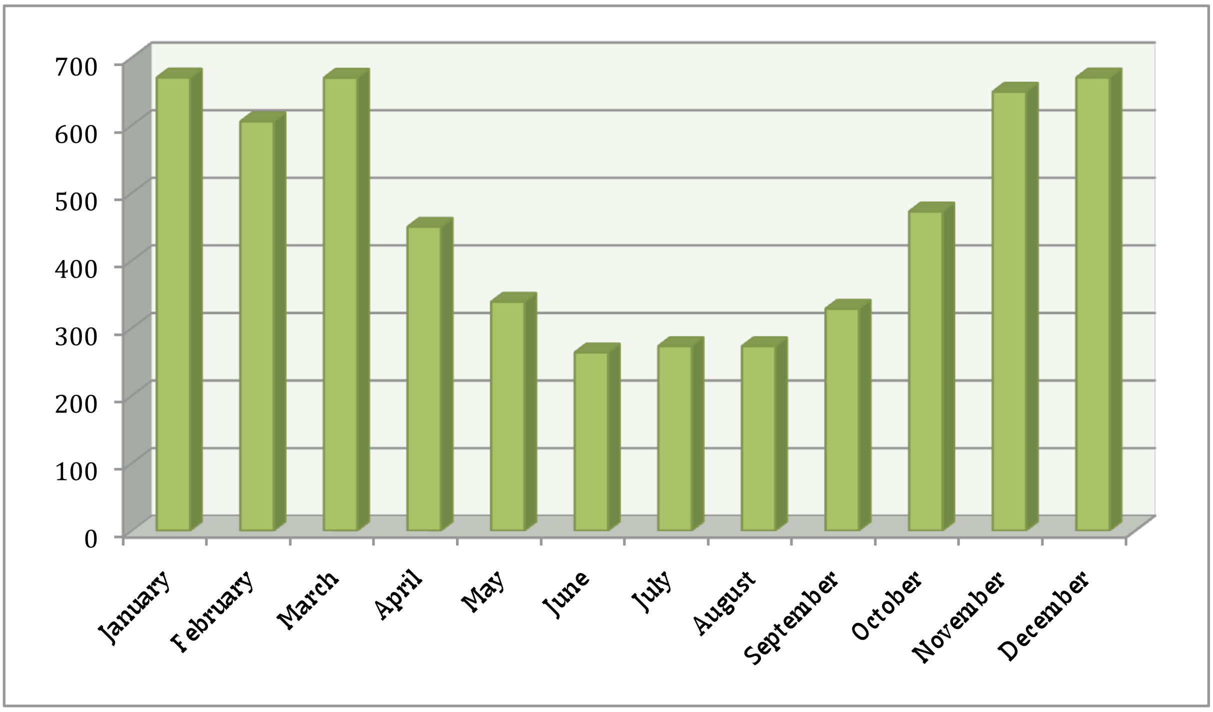
Figure 7.12: Solar contribution and energy load



7.3.5.3 Reduction in greenhouse gas emissions

The annual reduction in greenhouse gas emissions has been calculated using the assumption that each MJ of energy gained from burning LPG gas generates 0.065 kg of greenhouse gases.

Figure 7.13: Reduction in greenhouse gas emissions (kg/month)

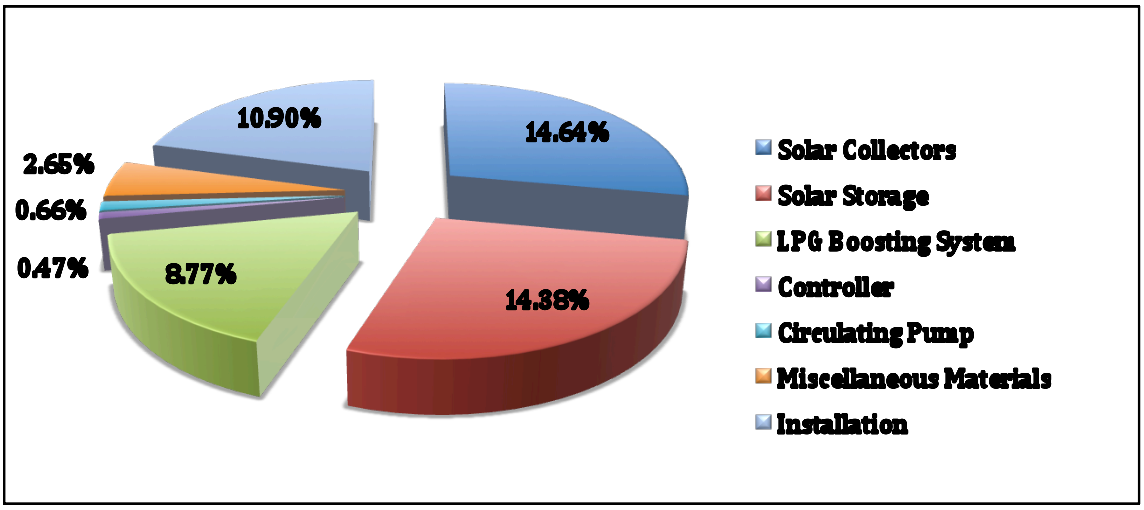


7.3.5.4 Financial system performance

Table 7.17: System cost breakdown

Component	Cost	Cost/m^2 (gross area)
Endless Solar Evacuated Tube Collectors	$11,076	$369
Solar storage	$8548	$285
LPG boosting system	$7335	$245
Controller unit	$362	$12
Circulating pump	$500	$17
Miscellaneous materials	$2000	$67
Installation	$8000	$267
System total	**$37,821**	**$1261**
Less RECs (142 @ $36)	-$5112	-$170
Total	**$32,709**	**$1090**

Figure 7.14: Cost distribution



CHAPTER 8 NOMENCLATURE

α	Absorptance or absorption factor
a, b, c, d	Correlation coefficients for solar collector efficiency from AS/NZS 2535
C	Celcius
D_i	Daily hot water demand
E	Coefficient evaluated through AS/NZS 2535 efficiency test
G	Incident solar radiation
GW_{th}	Gigawatt (thermal)
kWh	Kilowatt hours
K	Kelvin – measure of temperature
$K_{\tau\alpha}$	Incidence angle modifier for flat plate collector
L	Litres
min	Minute
MJ	Megajoules
Ŋ	Efficiency of solar collector heat output
η_o	Optical efficiency of collector
θ	Incidence angle relative to the collector aperture (degree)
PJ	Petajoules
τ	Transmittance
t_i	Cold water average temperature
t_a	Ambient temperature
t_m or $\overline{T}$	Average temperature in collector (collector inlet temperature plus collector outlet temperature divided by 2)
t_{in}	Inlet temperature in collector
U_i	Collector heat loss coefficient
V	Wind speed
W	Watt

CHAPTER 9 GLOSSARY OF TERMS

The following list of terms has been provided to assist in the clear use of terms and definitions that are currently used within the plumbing and water industry (AS/NZS 3500.1–2003). Not all terms listed are used in this publication, but are included for information regarding related plumbing activities.

Absorber area	The net area of absorber receiving solar energy. With a heat pipe collector the absorber area is the plan area of the array of tubes and does not include the gap between tubes. The area of tube arrays with a parabolic reflector behind the tubes is the area of parabolic reflector.
Absorptance (α)	A measure of the fraction of solar energy falling on a surface that is absorbed into the surface and converted to heat. Typical absorption factor for absorber plates = 0.9 to 0.95 (i.e. 90 to 95%). The maximum value is 1.0 or 100%.
Altitude angle	The vertical angle between the horizontal plane and the sun's position in the sky, or points along the top of any object that may cause shading on a collector.
Antifreeze solution	Adding ethylene glycol or propylene glycol to water lowers the temperature at which the water freezes. By adding sufficient glycol to the water in the solar collectors the damage that can be caused by frost is prevented, because freezing is prevented. This is exactly the same technique used in motor cars to prevent damage due to freezing.
Aperture area	The area that corresponds to the light entry area of the collector.
Azimuth angle	The horizontal angle between true north and the sun's direction measured clockwise on the horizontal plane.
Boost energy	Energy that is used to boost the temperature in the tank when solar energy is not available.
Closed loop system	A system where the heat transfer fluid flows in a closed loop from the collector to a heat exchanger in the tank and then back to the collector to be heated again. As the water in the storage tank is not heated directly, this system is also referred to as an indirect solar water heating system.
Collector area	See 'gross surface area'.
Commissioning	The process of ensuring that all component parts of a total system function as they should and that the system is adjusted for optimum performance under all normal operating conditions. Commissioning is the last part of an installation prior to handover to the owner.
Conduction	Conduction is the transfer of heat via atomic particles vibrating within a material and bumping into one another, giving some of their vibrational energy to neighbouring particles. The hotter the material, the faster the particles vibrate. It is the main way heat moves through solids and, to some extent, in liquids. Heat does not easily move through gases by conduction, as the molecules are spread far apart compared with solids or liquids.

Convection	Convection is the transmission of heat within a liquid or gas due to the bulk motion of the fluid. The rising of hot water from the bottom to the top of a saucepan as it is heated is one example. This occurs because the particles of water bump against one another more vigorously as they are heated and push themselves further apart, making the water less dense and hence lighter.
Corrosion	Deterioration of metal. The metal combines with other elements to form a salt of the metal. Rust is the corrosion product that results from the combination of iron (steel) and oxygen to form iron oxide.
Corrosion inhibitor	A chemical that can be added to water to prevent metals being corroded, such as rusting of steel. A corrosion inhibitor will also prevent the corrosion caused by dissimilar metals being in contact with each other.
Cross pitch stand or frame	A steel frame used on an east- or west-facing roof on which to mount a solar thermal system to face the collector to the north.
Diffuse radiation	The component of incoming solar radiation which is scattered by clouds and other gases or particles in the atmosphere.
Direct radiation	The component of solar radiation that comes direct from the sun as parallel rays.
Direct system	See open loop system.
Efficiency of collector	A measure of the fraction or percentage of energy in the heated fluid leaving a collector compared to the incoming incident solar radiation falling on the collector surface area.
Emittance	A measure of the fraction or percentage of heat re-radiated from the absorber surface.
Flow rate	The flow rate of the collector fluid per aperture area.
Freezing temperature of water	Water changes state between 4ºC and 0ºC. It changes from a liquid to a solid and, with that change, it increases in volume (expands).
Frost damage	The damage that occurs as the result of water expanding when it freezes.
Frost protection	Techniques used to prevent damage to solar water heaters caused by the expansion of water as it freezes.
Global radiation (see also irradiance)	A measure of the solar power at any instant on a surface. It is made up of both direct and diffuse radiation falling on the surface.
Gross surface area or collector area	The collector area with the outside dimensions of the product which defines the minimum amount of roof area of the collector.
Heat exchanger	A device to transfer heat from one fluid to another without the two fluids mixing. In solar water heaters, a heat exchanger transfers heat from the heat transfer fluid to the water in the storage tank. Note that it is the heat that is transferred, and there is no mixing of the two fluids.
Heat pipe	A fluid with a low boiling temperature is turned to a vapour by a heat source (the sun). The vapour rises up the heat pipe and gives off its heat to the heat transfer fluid at a lower temperature and changes back to a liquid.

Heat transfer liquid/fluid	A fluid that carries (transfers) heat from one place to another. In solar water heaters, it is the water itself or an antifreeze solution that does this job. The fluid in a heat pipe does the same thing.
Hysteresis	The difference between the switch-on and switch-off temperatures of a relay which is often found in differential thermostat (DT) controllers.
Inclination or tilt angle	A measure of the inclination angle of the collector to the horizontal plane.
Insolation	See irradiation.
Incident angle modifier	Accounts for off-normal incident effects that cause reflected rays to be scattered or to miss the absorber tube.
Insulation	Material that reduces the transfer of heat. In the case of insulated pipes, the insulation material may be rubber or plastic wrapped around the pipe. Felt fibre material was commonly used and is still available, but nitrile rubber products like ultraviolet-treated Armaflex are now recommended. Insulation comes in long rolls and can be wrapped around the pipe. Insulation is important in reducing heat losses from hot water pipes. Hot water storage tanks are also insulated to reduce loss of heat from the tank.
Irradiance	A measure of the solar power per square metre of surface area at any instant (International System of units [SI] is: kilowatts per square metre – kW/m^2).
Irradiation	A measure of the radiant solar energy per unit of surface area (SI unit: megajoules per square metre – MJ/m^2). The term ‘insolation’ was formerly used but is no longer preferred.
Legionnaire’s disease	A disease caused by the presence of Legionella bacteria that breeds in warm water (40°C) systems or cooling towers and airconditioning plant. It can be fatal to humans.
Megawatt hour (MWh)	The amount of energy generated or used over one hour where power output or demand is one megawatt (MW). Equivalent to 1000 kilowatt hours (kWh).
Open loop system	A system where potable water is directly heated in the collector and pumped to the storage tank. Without using a heat exchanger the same water is taken for the process circuit. These systems are not very common.
Optical efficiency	The efficiency of the collector at the point where the average collector temperature is equal to the ambient temperature.
Orientation angle	The angle between the direction the collector faces and true north (not magnetic north as read by a compass).
Pipework	In this guide, the word pipe can mean pipe or tube. Strictly speaking, pipe is measured internally and tube is measured externally. To be technically correct, we should not speak about copper pipe, but rather copper tube because it is the outside diameter which determines its size. Steel pipe and most plastic pipes are measured according to the internal hole size and so are pipes, not tubes.

Pipe friction	The force or drag of water on the walls of pipes that slows the flow of water through pipes, reducing the rate of flow. Pipe friction is increased by increased rate of water flow, reduced pipe size and the length of the pipe.
Potable water	Water classified under Australian Standards as suitable for drinking.
Pump circulation frost protection	By pumping water from the storage tank through the collectors, freezing of water in the collectors can be prevented if the water in the storage tank is warm.
Radiation	The transfer of heat by its conversion to electromagnetic waves or photons (tiny packets of energy).
Reflection factor (ρ)	A measure of the fraction of solar radiation that is reflected.
Renewable Energy Certificates (RECs)	Certificates issued under the Australian Government's Mandatory Renewable Energy Target (MRET) scheme that represent 1 MWh of renewable energy electricity generation or 1 MWh of electricity saved through the use of solar water heaters.
Ring main	A pipe that runs around all the hot water delivery points and has hot water circulating through it so that whenever a tap is turned on, hot water is instantly available.
Scale	The name given to the build-up of mineral deposits within a water heater that is using 'hard water'. It occurs on electric elements, the walls of storage tanks and solar collectors. It is usually calcium carbonate (limestone) and can be dissolved with acid such as hydrochloric acid.
Selective surfaces	Special coating applied to the surface of the absorber plate to increase its absorptance of solar radiation and, more importantly, reduce the re-radiated energy from the surface as it heats up.
Sequential freezing	The principle of having freezing occur in sequence in different parts of a collector. First – freezing occurs in the centre of the risers in a solar collector. Second – freezing occurs in the top and bottom of the risers. Third – freezing occurs in the headers. This varies for different manufacturers.
Solar constant	The average power intensity of solar energy outside the Earth's atmosphere, equal to 1367 W/m^2.
Solar fraction	The proportion of hot water energy demand that is provided by the solar collectors, compared to the supplementary or boosting energy that is required to keep the water at a set temperature.
Solar radiation (see also irradiance or irradiation)	The spectrum of radiant energy emitted from the outer layers of the sun. It consists of a range of wavelengths of electromagnetic radiation from ultraviolet to visible light and infrared radiation.
Stratification	The formation of layers of water of different temperatures within a storage tank; hot water at the top and getting cooler further down the tank.
Supplementary energy	Energy that is used to boost the water temperature when solar energy is not available (also referred to as boost energy).
Storage tank	Also referred to as a hot water cylinder or container.

Tichelmann principle	A collector array is arranged according to the Tichelmann principle if all flow paths through the collector array have the same flow resistance or, in other words, they have the same length and cross-sections.
Tilt angle	See inclination angle.
Transmittance factor (τ)	A measure of the fraction of solar radiation that passes through a transparent cover such as glass. Typical transmittance factor for low-iron glass is 0.92 or 92% and for window glass is 0.87 or 87%. The maximum value is 1.0 or 100%.
True north vs magnetic north	True north is the direction to the north pole. In most places, this is a little different to magnetic north, being either to the east or west of magnetic north.
Tube	In this guide, the word pipe can mean pipe or tube. Strictly speaking, pipe is measured internally and tube is measured externally. To be technically correct, we should not speak about copper pipe, but rather copper tube because it is the outside diameter which determines its size. Steel pipe and most plastic pipes are measured according to the internal hole size and so are pipes, not tubes.
Valve	A device for controlling the flow of fluid, having an aperture that can be wholly or partially closed by the movement relative to the seating of a component in the form of a plate or disc, door or gate, piston, plug or ball, or flexing of a diaphragm.
air relief valve	1. An automatic valve for the discharge of air from, or the admission of air to, a water main, each containing a buoyant ball that seats itself to close an orifice. 2. A manually operated valve used to release air from a water pipe or fitting.
cold water shut off valve	A spring-loaded terminator valve that closes the cold water supply if water leaks and fills the safe tray.
combination valve	A valve that combines the features of two valves generally used in mains pressure storage hot water services (e.g. temperature and pressure relief valves).
expansion control valve	A pressure-activated valve that opens in response to an increase in pressure caused by the expansion of water during the normal heating cycle of the water heater, and which is designed for installation on the cold water supply to the water heater.
float valve	A valve for controlling the flow of a liquid into a cistern or other vessel, which is operated by the movement of a float.
frost dump valve	A valve that opens at low temperatures (about 4ºC) to allow water to run through the collectors to prevent freezing.
instantaneous hot water system bypass valve	A valve that cuts off hot water supply if the temperature exceeds a set temperature to prevent scalding hot water being delivered to a hot tap. This type of valve is used in some instantaneous hot water systems.
isolating valve	Any valve for the purpose of isolating part of a water system from the remainder.
line strainer	Filters out small particles from the water supply.

non-return valve	A valve to prevent reverse flow from the downstream section of a pipe to the section of pipe upstream of the valve.
pressure limiting valve	A valve that limits the outlet pressure to the set pressure, within specified limits only, at inlet pressures above the set pressure.
pressure ratio valve	A valve that automatically reduces outlet water pressure to a specified ratio of its inlet pressure.
pressure-reducing valve	A valve that automatically reduces the pressure to below a predetermined value on the downstream side of the valve.
pressure and temperature-relief (PTR) valve	A spring-loaded automatic valve limiting the pressure and temperature by means of discharge, and designed for installation on the hot side of a storage water heater.
temperature-relief valve	A temperature-actuated valve that automatically discharges fluid at a specified set temperature. It is fitted to a water heater to prevent the temperature in the container exceeding a predetermined temperature, in the event that energy-input controls fail to function.
tempering valve	A mixing valve that is temperature actuated and is used to temper a hot water supply with cold water to provide hot water at a lower temperature (e.g. 50°C) at one or more outlet fixtures.
thermostatic mixing valve	A mixing valve in which the temperature from the mixed water outlet is automatically controlled by a thermostatic element/sensor to a preselected temperature.
vacuum-relief valve	A pressure-actuated valve that automatically opens to relieve vacuum conditions.

CHAPTER 10 AUSTRALIAN STANDARDS AND GUIDELINES

The following standards all have relevance to this guide, some to a greater extent than others. As standards are updated periodically, the current applicable Australasian Standard may have superseded the number shown.

ABCB Building Code of Australia

Australian Standards

- AS 1056 Storage water heaters
- AS 1056.1 Storage water heaters – General requirements
- AS 1056.2 Storage water heaters – Specific requirements for water heaters with single shells
- AS 1357 Water supply – Valves for use with unvented water heaters
- AS 1357.1 Water supply – Valves for use with unvented water heaters – Protection valves
- AS 1357.2 Water supply – Valves for use with unvented water heaters – Control valves
- AS 1361 Electric heat-exchange water heaters – For domestic applications
- AS 1375 Industrial fuel-fired appliances (SAA Industrial Fuel-Fired Appliances Code)
- AS/NZS 1571 Copper – Seamless tubes for airconditioning and refrigeration
- AS/NZS 2535.1 Test methods for solar collectors – 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 (Australia/New Zealand Wiring Rules)
- AS 3142 Approval and test specification – Electric water heaters (superseded)
- AS/NZS 3500 National Plumbing and Drainage Code
- AS/NZS 3500.0 Plumbing and drainage – Glossary of terms
- AS/NZS 3500.1 Plumbing and drainage – Water services
- AS/NZS 3500.4 Plumbing and drainage – Hot water supply systems
- AS 3565 Meters for water supply
- AS 3666 Air handling and water systems of buildings
- AS/NZS 3666.1 Air-handling and water systems of buildings – Microbial control – Design, installation and commissioning
- AS/NZS 3666 Air-handling and water systems of buildings – Microbial control – Operation and maintenance
- AS/NZS 4234 Heated water systems – Calculation of energy consumption
- HB 263 Heated water systems – Handbook
- AS 5601 Gas installations
- AS 3498 Authorization requirements for plumbing products – Water heaters and hot-water storage tanks
- AS 4032.3 Water supply – Valves for the control of hot water supply temperatures
- SMP 52 Manual of authorization procedures for plumbing and drainage products
- AS 4552 Gas fired water heaters for hot water supply and/or central heating
- AS/NZS 4692.1 Electric water heaters – Energy consumption, performance and general requirements
- AS/NZS 4692.2 Electric water heaters – Minimum Energy Performance Standard (MEPS) requirements and energy labelling
- AS 3814 Industrial and commercial gas fired appliances
- HB 9 Occupational personal protection
- AS 1470 Health and safety at work – Principles and practices

CHAPTER 11 REFERENCES AND FURTHER READING

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Software tools

POLYSUN – Solar Thermal Simulation – www.spf.ch/spf.php?lang=en&fam=41&tab=1

RETScreen – Clean Energy Project Analysis Software – www.retscreen.net/ang/home.php

SolSimNZ – New Zealand specific commercial scale simulation software – www.solarindustries.org.nz/solarinfo.asp#designtool

ST-ESCo – Software tools for the evaluation of Energy Service Companies (ESCo) – www.stescos.org/downloads/_Software.doc

TSOL – Solar Simulation and System Design – www.valentin.de/index_en

TRNSYS – Transient Energy System Simulation Tool – www.trnsys.com/

APPENDIX A DESIGN CHECKLIST

- ☐ **Hot water load**
  - ☐ Quantification of hot water load
  - ☐ Demand patterns e.g. daily, seasonal, etc.
- ☐ **Climatic data**
  - ☐ Typical meteorological year weather data file or statistically generated hourly model based on
  - ☐ Monthly average weather data
- ☐ **Measured component performance**
  - ☐ Solar collector efficiency to AS/NZS 2535
  - ☐ Storage tank heat loss
- ☐ **Hydraulic design**
  - ☐ Collector loop flow rate (intersection of pump head characteristic and piping friction pressure drop characteristic)
  - ☐ Pump power at above flow rate
- ☐ **Product configuration**
  - ☐ Open loop no heat exchanger
  - ☐ Closed loop with collector loop heat exchanger
  - ☐ Closed loop with load side heat exchanger
- ☐ **Auxiliary boosting**
  - ☐ Electric in tank
  - ☐ Electric series boost tank
  - ☐ Gas instantaneous
  - ☐ Gas series boost tank
- ☐ **Controller**
  - ☐ Controller logic map
- ☐ **Product details**
  - ☐ ***Solar array***
    - ☐ Solar module area (AS/NZS 2535)
    - ☐ Number of collectors in array
    - ☐ Efficiency coefficients (AS/NZS 2535)

- ☐ Collector inclination
- ☐ Collector orientation
- ☐ Flow rate through each collector

☐ ***Collector to tank piping***
- ☐ Diameter of collector inlet/outlet pipes
- ☐ Thickness of insulation on connecting pipes
- ☐ Inlet pipe length
- ☐ Outlet pipe length
- ☐ Thermal conductivity of insulation

☐ ***Solar preheat tank***
- ☐ Tank volume
- ☐
- ☐ Tank diameter
- ☐
- ☐ Volume of water above the auxiliary element
- ☐
- ☐ Volume of water above the thermostat
- ☐
- ☐ Volume of water above the collector return level

☐ ***Auxiliary boost tank***
- ☐ Set temperature
- ☐ Thermostat dead band
- ☐ Auxiliary power
- ☐ Height of cold inlet above bottom of tank
- ☐ Heat loss from tank
- ☐ Thickness of inner tank wall (m)
- ☐ Thermal conductivity of inner tank wall

☐ ***Pump***
- ☐ Pump flow rate
- ☐ Maximum tank temperature for pump operation
- ☐ Pump power input
- ☐ Pump controller turn on difference
- ☐ Pump controller turn off difference

APPENDIX B INSTALLATION AND COMMISSIONING CHECKLIST

B.1 Installation and commissioning

The installation of LSTS shall be undertaken as per design. However, the following checklist gives valuable information on the correct installation of LSTS.

Environment

- ☐ Water quality is suitable for contact with components
- ☐ Components and materials chosen will not react to other materials in contact (e.g. galvanic reaction)
- ☐ All components are suitable for the environment and climatic conditions
- ☐ There are no known impacts to the environment by this installation

Solar collectors

- ☐ Collector is pitched and oriented to achieve good solar gain
- ☐ The collector is positioned to avoid shading right throughout the year
- ☐ Collectors connected in parallel are plumbed for balanced flow conditions (if applicable)
- ☐ Collectors are installed to roof structure as per the manufacturer’s recommendations

Storage tank

- ☐ Pressure and temperature relief valve installed on water storage tanks (if applicable)
- ☐ Tanks connected in parallel are plumbed for balanced flow conditions (if applicable)
- ☐ Tanks are installed in a way to promote effective stratification (if applicable)
- ☐ Adequate access is allowed for maintenance
- ☐ If tank is to be roof-mounted, is the roof structurally strong enough to carry the weight of the full tank
- ☐ Storage tank is full of water before turning the system on

Flow and return pipe work

- ☐ Suitable pipework sizes for solar flow and return have been installed as per design
- ☐ No plastic components or pipework is used on the solar flow and return
- ☐ A high-quality, temperature-rated, ultraviolet-protected and weather-protected thermal insulation has been installed on solar flow and return pipes

Valves and fittings

- ☐ Air relief valves installed at highest points of collector array (if applicable)
- ☐ Low meter installed (if applicable)
- ☐ Balancing valves before collector rows installed (if applicable)
- ☐ Pressure limiting device installed (if applicable)
- ☐ Temperature limiting device installed to prevent scalding
- ☐ Non-return valve installed (if applicable)
- ☐ Expansion control valve installed (if applicable)
- ☐ Freeze protection device installed (if applicable)
- ☐ Stagnation or overheating protection device has been installed (if applicable)
- ☐ Thermal sensor cables are not in contact with the flow and return lines

High temperature/pressure

- ☐ Consideration has been given to the expansion and contraction of materials under high temperature conditions
- ☐ All materials, fittings, connection points and components are suitable for use under the expected temperature and pressure conditions

Regulatory

- ☐ All collector attachment points meet regulatory requirements
- ☐ Installation meets the requirements of AS/NZS 3500.4 and other applicable Standards covering the work completed
- ☐ All components have been installed to meet regulatory requirements and have been approved for use in Australia

Boosting

- ☐ The auxiliary boosting option is functional and is connected to the correct fuel or energy tariff (if applicable)
- ☐ A timer has been installed on the auxiliary boost and is operational (if applicable)

Pump controller

- ☐ The temperature sensors have been installed to the correct outlets and the leads connected to the controller
- ☐ The electricity supply has been connected and the unit switched on to ensure it operates

Commissioning

- ☐ All the installed components have been thoroughly tested over a wide range of operating conditions
- ☐ Flow rates have been tested and balancing valves set to equalise flows through different collector arrays
- ☐ Controller transducers and controller operation have been tested
- ☐ The system has been tested whilst operating under realistic load and climate conditions
- ☐ The ‘as installed’ performance has been documented, including flow rates through each collector bank, balancing vales setting etc.

General

- ☐ Proper clearances have been observed and there are provisions for future maintenance
- ☐ All components have been installed to manufacturers’ specifications
- ☐ The system has been tested, is operational and has been checked for leaks
- ☐ Descriptive labels have been applied to pipe work and components
- ☐ The site is neat and tidy. A full risk assessment of the site has been conducted
- ☐ All paper work has been completed
- ☐ Client has been provided with all necessary documentation and operating instructions

B.2 Troubleshooting

The manufacturer’s product information should be consulted for specific troubleshooting. Table B.1 below is a guideline for general problems.

Table B.1: Troubleshooting guidelines for general problems

Problem	Possible causes/areas of investigation
No hot water	Most solar hot water systems have a boosting mechanism to ensure hot water in times of low solar contribution. 1. Is the booster switched on and operational? 2. Has the booster failed? 3. Is the supply water pressure suitable for booster operation? 4. Is the flow rate suitable for booster operation? 5. Are there obstructions to the inlet or outlet of the booster?
Solar is not working effectively	Solar technologies depend on a suitable range of climatic conditions to operate effectively. 1. Is there enough solar radiation (cloudy/rainy weather)? 2. Is there excessive shading throughout the day (trees/mountains/buildings and other structures)? 3. Is the collector dirty? 4. Is the collector oriented and pitched correctly? 5. Is the system big enough to meet the load? 6. Is the system losing heat through uninsulated pipework? 7. Is there a leak? a. Is there a leak in pipework, connections and fittings? b. Are valves and components excessively discharging water? (pressure and temperature-relief valve, expansion control valve) 8. Is the flow rate suitable for the collector area? 9. Is cold weather or other climatic effects causing a reduction in performance? 10. Is the circulator operating at times of low solar gain, or at night? Check the controller to ensure controller sensors are located correctly and are not damaged.
Solar is not working at all	1. Circulator or controller not working a. Is the power connected and operational? b. Are the controller sensors damaged or broken? c. Has the controller or pump failed? 2. Is there an air lock in solar flow/return loop? 3. Is the collector damaged?
Using too much energy for boosting	1. Is the load larger than thought? 2. Is there enough solar contribution to meet load? 3. Is auxiliary boosting interfering with the effective operation of the solar operation? 4. Is there a leak? 5. Is there a circulating loop around the building?
Multiple collectors and tanks	1. Is there an unbalanced distribution of hot water? a. Check configuration to ensure balanced flow conditions and avoid master and slave effect.

Problem	Possible causes/areas of investigation
Other common problems	1. Expansion and contraction of materials under high temperature 2. Controller set points not right for application 3. Incorrect pump sizing 4. Incorrect flow rates 5. Incorrect thermostat setting 6. Unwanted thermosiphon effect 7. Unwanted mixing in a stratified tank 8. Hot water where it shouldn't be 9. Loud noises 10. Fluid expansion 11. Steam and air pressure problems 12. Scale formation (1) Bubbling in tank – steam unable to be vented b. Check air vents c. Check water pressure (2) Excessive corrosion or leaks d. Check water quality e. Check supply pressure 13. Stagnation and overheating problems 14. Slow recovery 15. Water loss 16. Milky or cloudy water 17. Adequate storage 18. Proper clearances

APPENDIX C SOLAR RADIATION DATA SOURCES FOR AUSTRALIA

C.1 General

Long-term hourly global solar irradiation data is available for 28 sites in Australia. The data elements available are:

- dry bulb temperature
- absolute moisture content
- atmospheric pressure
- wind speed
- wind direction
- total cloud cover
- global solar irradiance on a horizontal plane
- diffuse solar irradiance on a horizontal plane
- direct solar irradiance on a plane normal to the beam
- solar altitude
- solar azimuth

C.2 Solar irradiation data – user requirements

Solar energy system performance can be determined by detailed simulation or by correlation models. Detailed simulation of system performance usually requires short time-interval (<1 hr) data for the following parameters:

- global horizontal irradiation
- beam irradiation
- dry and wet bulb temperatures
- wind speed

Although the existing Bureau of Meteorology data consists of 15 to 20 years of records for 28 locations, the data files are very large because they contain additional meteorological data such as rainfall, cloud structure etc. This additional data is of interest to researchers, but is not needed for solar design applications.

Figure C.1: Solar radiation monitoring locations in Australia

C.3 Condensed solar radiation data sets

Solar radiation and meteorology data must be measured for many years in order to obtain representative data on long-term conditions. Once long data records are available, the long-term average performance of a solar energy system can be determined by simulating the system performance over the full length of data. To reduce the time taken to evaluate long-term performance, 'typical meteorological year' (TMY) weather data records have been developed. TMY data files have the following features:

- Radiation, ambient temperature and wind speed should have frequency distributions that are close to the long-term distributions.
- The sequence of daily data should be like the sequences registered at the location.
- Relationships among the different parameters in the data set should be like the relationships observed in nature.

C.4 Australian TMY data sets

Long-term hourly records for Australia are available from ACADS-BSG. TMY data files for the locations shown in Table C.1 have been developed from this data (Morrison and Litvak, 1999). These files are available from UNSW Global.

Table C.1: Australian typical meteorological weather data sites

Site	Latitude ° south	Longitude ° west	Deviation from local meridian	Elevation (m)	Time zone	Time zone longitude
New South Wales					14	150°E
Sydney	33.93	208.83	1.17	32		
Wagga	35.17	212.53	-2.53	224		
Williamtown	32.82	208.17	1.83	12		
Northern Territory					14.5	142.5°E
Alice Springs	23.82	226.1	-8.6	547		
Darwin	12.42	229.13	-11.63	35		
Queensland					14	150°E
Brisbane	27.42	206.92	3.08	6		
Longreach	23.43	215.73	-5.73	195		
Rockhampton	23.38	209.52	0.48	8		
South Australia					14.5	142.5°E
Adelaide	34.97	221.47	-3.97	11		
Mt Gambier	37.75	219.22	-1.72	63		
Oodnadatta	27.57	224.58	-7.08	113		
Woomera	31.15	223.50	-6.00	165		
Tasmania					14	150°E
Hobart	42.83	212.5	-2.5	8		
Victoria					14	150°E
Laverton	37.88	215.25	-5.25	14		
Melbourne	37.83	215.03	-5.03	123		
Mildura	34.25	217.92	-7.92	53		
West Australia					16	120°E
Albany	34.95	242.2	-2.2	71		
Forrest	30.83	231.88	8.12	157		
Geraldton	28.8	245.22	5.22	35		
Halls Creek	18.23	232.33	7.67	423		
Kalgoorlie	30.78	238.50	1.5	360		
Perth	31.93	244.03	-4.03	360		
Port Headland	20.38	241.38	-1.38	11		
ACT					14	150°E
Canberra	35.32	210.8	-0.8	8		

Note: Data records for Sydney are in Eastern Standard Time.
Data records for other locations are in Mean Solar Time.
The time stamp for Adelaide, Brisbane, Canberra and Sydney is the end of the solar integration period; the time stamp for all other locations is the midpoint of the solar integration period.

C.5 Australian Solar Radiation Data Handbook and AUSOLRAD

The *Australian Solar Radiation Data Handbook* (ASRDH) and an updated version developed by the Australian Solar Energy Society (AuSES) is a compilation of the average solar irradiation characteristics of the 28 radiation monitoring locations in Australia. The raw data comes from the Bureau of Meteorology real-time sets of half-hourly global and diffuse irradiation measurements. This was processed to give climatic means for time of day and time of year for a wide range of surface orientations and inclinations.

Included are single axis and double axis sun-tracking surfaces and direct beam and diffuse (sky and cloud scattered) and ground-reflected radiation components. There is also extensive tabulation of probability and frequency distributions of irradiation falling below given levels for particular durations, which is needed by designers of storage capacities, particularly for standalone solar thermal systems.

The hinterlands of the eight capital cities are also mapped with spatial and seasonal variation of irradiation shown in a series of isorad (contour) maps based on recent data collected from satellite observations of radiation being reflected back to space from the Earth's surface. This is particularly helpful in refining a design remote from the metropolitan areas.

AUSOLRAD and associated electronic data files for 28 Australian locations is available for users who want to know irradiation on surface orientations and slopes that are not tabulated in the ASRDH. AUSOLRAD allows for any geometry of the receiving surface (or window) and includes allowance for overhangs above windows and any reflection (albedo) off the 'ground' in front of the receiving surface.

C.6 New Zealand solar radiation data

Solar irradiation data is available in New Zealand from the 'Energy Efficiency and Conservation Authority' website (www.eeca.govt.nz).