CHAPTER 1

Solar Water Heating Overview

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1. SOLAR WATER HEATING OVERVIEW

1.1 Common types of solar water heaters

What this section is about

Solar water heaters are not a new technology. They have been developed, manufactured and used in Australia since the 1950s and more recently in New Zealand. Many improvements have taken place in that time. This section gives an overview of the various types of solar water heating systems for domestic hot water supply on the market in Australia and New Zealand. It will help the reader understand the basic differences between the types of systems covered.

Solar water heating systems consist of four basic components:

- a solar collector to collect the solar radiation and convert it to heat energy in a fluid
- a storage tank to store the collected heat energy for later use
- a circulation system to transfer the collected heat energy from the collector to the storage tank
- a supplementary or boost heater to further heat the water if solar radiation is inadequate to ensure sufficient hot water is available on demand.

The collector

The collector is the heart of the system. A collector may be in the shape of a flat plate or an array of evacuated tubes.

A **flat plate collector** consists of a darkened absorber plate encased inside a glass fronted box. The **solar radiation** is absorbed in the absorber plate, converted to heat energy and transferred to water in fluid passageways attached to the absorber plate. The glass-fronted box helps to increase the temperature inside the box using the greenhouse effect. Over the years, various improvements have been made to collector construction to improve their ability to collect and transfer heat energy to the water. This includes features such as anti-reflection surface treatment of the glass covers, '**selective' absorber surfaces** and **flooded plate absorber** design. Full details of flat plate collector construction and operation are presented in Chapter 3.

Photo: Courtesy Rinnai

Figure 1.1.1 – Flat plate collector

Evacuated tube collectors are formed from an array of evacuated tubes joined to a manifold, through which the heat transfer fluid flows. Tubes may have a heat pipe or have a means of taking the heat transfer fluid in a loop through the tube.

In flat plate collectors, heat is lost through the top surface of the collector. This heat loss increases as the water temperature in the collector gets hotter during the day. So while the collector is highly efficient at the beginning of the day (e.g. 70% efficiency), the efficiency decreases as the water circulating through the collector gets hotter. In evacuated tube systems, this heat loss is greatly reduced. This is because the space between the absorber and the glass outer tube is evacuated. There is little air to move and transfer heat by conduction and convection, so heat loss cannot easily take place. Each evacuated tube is a collector in itself with either a flat fin absorber attached to an inner tube or an inner cylindrical absorber surface. Tubes are connected in parallel to form banks of collectors (see Figure 1.1.2).

Evacuated tube collectors are used extensively in China, and are now being more commonly used in Australia and New Zealand.

Photo: Endless Solar

Figure 1.1.2 – Heat pipe evacuated tube system

Storage tank and heat transfer fluid circulation

Once the water has been heated in the collector, it is circulated to a storage tank by either:

- natural thermosiphon circulation where hot water is less dense and tends to rise – hence the tank must be above the collector (as in Figure 1.1.3 and Figure 1.1.4)
- forced circulation using a pump – hence the tank can be at ground level below the collector (see Figure 1.1.5).

The configuration of the collectors relative to the storage tank is used to categorise the system type. The storage tank can be located:

- close to and above the collectors – known as a close coupled, thermosiphon system (see Figure 1.1.4)
- in the roof and above the collectors – known as a remote storage, thermosiphon system (see Figure 1.1.3)
- below the collectors, normally on the floor or ground – known as a forced circulation, pumped storage system or commonly called a ‘split system’ (see Figure 1.1.5).

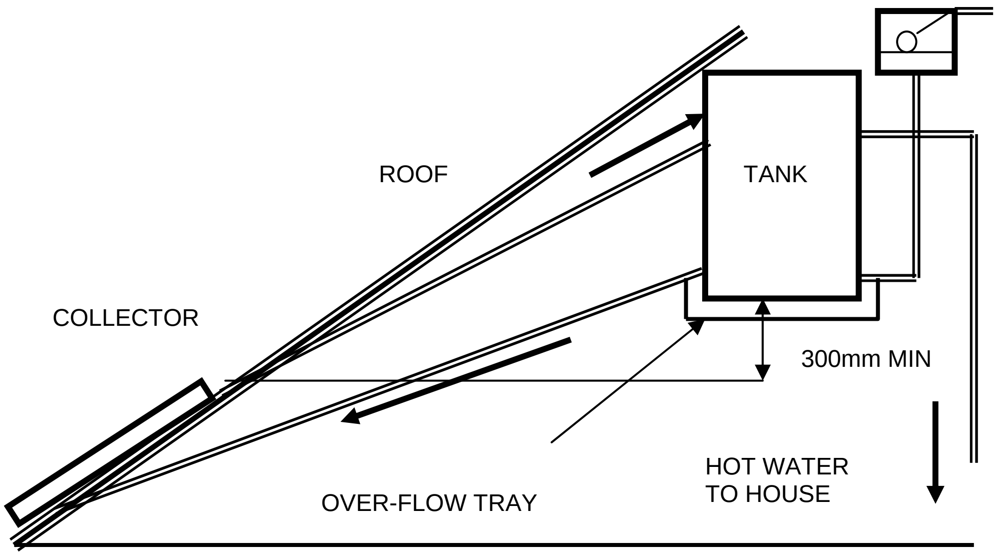

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Figure 1.1.3 – Remote storage, thermosiphon system

Most systems are pressurised by mains supply or pressure pumps. Remote storage, thermosiphon systems can be either low (gravity feed) or mains pressure systems. The tank is either above the collectors (as shown) or no lower than the collectors.

Integral systems incorporate the thermal collector and storage tank. These are used in markets such as the USA, but are not common in Australia or New Zealand.

The types of systems outlined here include:

- flat plate thermosiphon systems
- flat plate split or pumped storage systems
- evacuated tube split or pumped storage systems
- heat pump systems.

Flat plate collector systems

The greatest proportion of solar water heaters both produced and installed in Australia use flat plate collectors. Evacuated tube systems are becoming more common in Australia and have a growing share of the New Zealand market.

Figure 1.1.4 shows a typical **flat plate, thermosiphon, close-coupled system** where the tank is mounted just above the collector. The heated water flows naturally up to the tank. These are the most commonly sold systems in Australia due to their lower cost and ease of installation.

Photo: Trevor Berrill

Figure 1.1.4 – One of the authors beside a successful installation at Roadvale, Qld

Split or pumped storage systems have become increasingly popular due to their lower profile on the roof and hence more aesthetic appeal. This is because only the collector is roof-mounted. The tank is generally at ground level in a convenient location (see Figure 1.1.5) and a pump is used to circulate the heated water from the collectors to the storage tank. A differential temperature controller is used to control pump operation so that the pump only switches on when sufficient heat is available. The pump and controller make these systems a little more expensive.

Photo: Solahart

Figure 1.1.5 – Forced circulation (pumped) system

Heat pump systems

A heat pump system is a form of solar water heating system. It does not rely on direct or diffuse solar radiation to heat a fluid in a collector; instead, it uses the vapour compression, refrigeration cycle to transfer heat from the ambient air, generally outside the house, into the water in the storage tank. A compressor shifts a heat transfer fluid (typically refrigerant is the more environmentally benign R134a or R407c refrigerant gas) in a closed cycle between the evaporator fan coil (mounted in any convenient location outside, or on top of the storage tank) and the condenser coil (wrapped around or immersed in the hot water storage tank), and back again to the compressor.

Heat pump water heaters have become more popular because they reduce energy consumption to about one-third of a conventional electric water heater, hence reducing running costs and CO_2 emission. They can be ground mounted and are recommended where shading of collectors excludes the use of conventional solar water heaters. They work best in warm areas. Cost is comparable to most solar water heaters. Their running costs may be more or less than a conventional solar water heater, depending on the contribution of the solar collectors to the total hot water demand (this is called the solar fraction). Typical heat pumps are shown in Figure 1.1.6.

Photos: Courtesy Dux, Quantum, Solahart and Stiebel Eltron

Figure 1.1.6 – Heat pump water heating systems

All of the above systems are described in more detail in later chapters, including the operation of the systems, their advantages and disadvantages, and installation and maintenance requirements. It also includes discussion of their use as a pre-heater to existing hot water system, when the solar collectors provide less than 50% of the total hot water demand.

Key points

- Solar water heating systems consist of four parts:
    a. collectors
    b. storage tank
    c. circulation system
    d. supplementary or boost heater.
- In Australia the most common system type is that using roof-mounted, flat plate collectors closely coupled to a storage tank just above the collectors. This is due to the lower cost and ease of installation of these systems. In New Zealand the split (or forced flow) system is more common.
- Systems are classified by the location of the storage tank relative to the collectors:
    a. close coupled thermosiphon systems
    b. remote storage thermosiphon systems
    c. pumped storage or split systems.
- Collectors may be in the shape of a flat plate or an array of evacuated tubes. Evacuated tube collectors consist of banks of cylindrical glass tubes with a flat or cylindrical absorber inside. The space between the outer glass and the absorber is evacuated. This provides higher efficiency under low ambient temperatures and irradiation levels due to lower convection and conduction heat losses. This makes them well suited to higher latitude regions such as the southern parts of Australia and New Zealand.
- Heat pump systems extract heat from the ambient air surrounding them using the vapour compression refrigeration cycle. Heat is collected at the evaporator plates, transported by a compressor to a condenser and released at the condenser, which is wrapped around a hot water storage tank. Hence the heat is transferred from the outside air to the water in the tank.

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Section 1.1 questions

1. A solar water heater system is similar to an electric or gas storage water heater with some extra components. What are the four sections of a solar water heater system referred to above?

2. Some gas or electric hot water systems are instantaneous and don't require storage. They heat the water as it is required. Why must solar hot water systems have a hot water storage tank?

3. Transfer of hot water from the solar collectors to the storage tank can occur in either of two ways. What are these ways?

4. Why are evacuated tubes more effective than flat plate collectors in cold climates?

5. Heat pumps use refrigeration to heat water. The heat pump transfers heat into the water. From where does the heat come?

1.2 Economic benefits of solar water heating systems

What this section is about

Solar water heaters provide a financial return via reduced hot water energy bills. These savings help to pay for the extra cost of the solar water heater over its lifetime. This is because the owner doesn't have to pay for the sun's energy, just the boosting energy used on cloudy or rainy days. With careful use of hot water, even the boosting energy cost can be kept very low in most parts of Australia or New Zealand due to our sunny climates.

This section examines some of the factors of which customers should be made aware, so that they can maximise the financial return from their solar water heater investment. These factors include:

- the purchase or capital cost of solar water heaters
- the costs of solar water heaters compared with gas and electric systems
- the likely performance of solar water heaters in different areas of Australia and New Zealand
- the life expectancy of different water heating systems
- the effect of different patterns of hot water use on the performance of SWH systems
- the method and timing of use of supplementary heating, the size of tanks and setting of flow rates for split systems
- the influence of different electricity and gas tariffs.

Irradiation in Australasia

The amount of irradiation available for heating water differs throughout Australasia, depending on latitude and topography. Figure 4.1.1 in Chapter 4 shows the potential solar contribution available.

Relative installed and operating costs of water heaters

The customer will want to know the installed capital cost of the system after rebates (if applicable) and the likely yearly operating cost of the boosting energy and maintenance. The capital cost varies depending on the complexity of the system, the materials used, the size and efficiency of the system, and the installation costs. The cost of a Building Consent (New Zealand) should also be included.

The boost energy used and resulting cost savings depend on:

- collector positioning and inclination
- the quantity and temperature of hot water required
- climatic conditions of irradiation, air temperature and cold water temperature
- the size and efficiency of the collectors and tank
- the timing and efficiency of the booster
- how efficiently the system is managed by the users.

Yearly cost savings are of most interest to customers. These can be estimated roughly by the anticipated solar fraction for a given region. **Solar fraction or solar contribution factor** is a measure of the likely contribution from the solar collectors to the total hot water demand. Table 1.1 shows the anticipated solar fraction as a range of percentages for various sites in Australasia. This is for a three- to four-person household in Melbourne using about 200 litres of hot water per day and proportionally less in warmer climates. This assumes that the system is well designed, appropriately oriented and tilted to maximise the solar fraction. This standard load requires a recommended storage capacity and collector area, typically about 300 litres and $4m^2$ respectively.

Table 1.1 – Potential energy and cost savings at centres in Australia and New Zealand

Darwin	**Brisbane/ Cairns**	**Perth/ Sydney**	**Adelaide**	**Canberra/ Melbourne**	**Hobart**
92%–100%	76%–86%	72%–82%	69%–78%	62%–72%	60%–70%
Auckland	**Wellington**	**Christchurch**	**Invercargill**		
60%–70%	55%–65%	55%–65%	51%–61%		

Source: Adapted from Australian Standard AS NZS 3500.4

Table 1.2 shows a range of installed costs and annual operating costs for typical solar, electric and gas hot water systems. It also gives the projected total cost over five and 10 years, allowing for differing life expectancies of systems. The data assumes:

- a typical home of three to four people using about 170 (Brisbane) to 200 litres (Melbourne) of hot water per day (much of New Zealand is similar to Melbourne)
- a range of operating costs for Brisbane and Melbourne to reflect the difference in performance and costs across much of Australasia
- that solar water heaters and heat pumps can have a life of 15 to 20 years, whereas the electric storage and gas systems last about seven to 10 years
- that in Australia, solar water heaters earn Renewable Energy Certificates (RECs) from the Commonwealth Mandatory Renewable Energy Target (MRET), providing in effect a price discount of $700 for a system that is allocated 31 RECs at $23 each (NB. RECs vary in price depending on their supply and demand; and additional State Government rebates may be available in some states, which would further reduce the installed cost of solar water heaters)
- that in New Zealand grants and loan financing of $500 per installation are available for some systems supplied by accredited suppliers
- solar fractions ranging from 0.7 to 0.86 (Brisbane), and 0.55 to 0.7 (Melbourne and New Zealand).
- split systems include pump/controller running costs of $14 per year
- LPG costs about 2.5 times more than natural gas (though this can vary)
- heat pump coefficient of performance ranges from 2.0 to 5.0, depending on location and environmental conditions.

The most important thing that Table 1.2 shows is that, at the time of writing, solar water heaters take about 10 years in Australia and 10 to 15 years in New Zealand to pay for their extra capital cost. This can be seen by comparing the costs over 10 years shown in the right-hand column. After that time, all cost savings are tax-free earnings and are equivalent to having invested money and earning a tax-free interest rate of about 7% to 10%. This is more than most people earn with money in a bank term deposit at 6% per annum less tax.

Please note, however, that this table is a simplistic analysis as it makes no allowance for the changing value of money over time and the effects of inflation. It is also very likely that in coming years, a carbon cost will be added to the cost of all fossil fuels to account for their environmental and social costs due to air pollution and climate change. This will improve the cost competitiveness of solar systems.

Table 1.2 – Installed and operating costs of common size/type water heaters

System type	Installed cost*	Yearly operating cost	Five-year total cost	10-year total cost	Location
Solar (close coupled) 300 litres and two collectors (electric boost)	$3400 to $4000	$45 to $75 $115 to $175	$3625 to $4375 $3975 to $4875	$3850 to $4750 $4550 to $5750	Brisbane Melbourne
Solar (close coupled), 300 litres and two collectors (gas boost)	$4000 to $4800	$30 to $80 $60 to $95	$4150 to $4900 $4300 to $4970	$4300 to $5300 $4600 to $5450	Brisbane Melbourne
Solar (split system), 300 litre and two collectors (electric boost)	$4000 to $4800	$50 to $90 $130 to $190	$4250 to $5250 $4650 to $5750	$4500 to $5700 $5300 to $6700	Brisbane Melbourne
Electric heat pump	$4300 to $4650	$70 to $100 $150 to $225	$4650 to $5150 $5050 to $5775	$5000 to $5650 $5800 to $6900	Brisbane Melbourne
Natural gas storage, 5-Star, 170 litres	$1000 to $1200	$280 $235	$2400 to $2600 $2175 to $2375	$4800 to $5200 $4350 to $4750	Brisbane Melbourne
Natural gas instantaneous, 5-Star	$1200 to $1700	$210 $190	$2250 to $2750 $2150 to $2650	$4500 to $5500 $4300 to $5300	Brisbane Melbourne
LPG storage	$1000 to $1200	$700 $588	$4500 to $4700 $3938 to $4138	$9000 to $9400 $7875 to $8275	Brisbane Melbourne
Electric storage 315 litres (off-peak tariff)	$1000 to $1300	$267 $358	$2335 to $2635 $2790 to $3090	$4670 to $5270 $5580 to $6180	Brisbane Melbourne
Electric storage, 160 litres (general tariff)	$800 to $900	$480 $700	$3200 to $3300 $4300 to $4400	$6400 to $6600 $8600 to $8800	Brisbane Melbourne

*Costs are for base model only and do not include specific application additional costs.

Sources: Berrill – personal communication to System Suppliers (2006); GWA (2005); MEPS Reports (2004); MMA (2004), Energy Australia)

Cost of additional system features

Table 1.2 shows the typical installed cost range for systems. However, some models cost more than others. Additional costs to that for a base model solar system include the cost of pumps and controllers for split systems, frames, Building Consent (New Zealand), gas boosters, frost protection in colder climates and higher performance 'selectively' coated collectors.

The circulation pump, controller and additional valves for split systems add about an extra $500 cost as shown above. Gas boosting is more energy efficient and produces less pollutants and greenhouse gas emissions. However, it can add up to $1000 to the cost of a system.

Frost protection is required over much of Australasia, and this is done using a range of methods including heat exchange circuits between the collectors and storage tank, special valves or special collector design (see Chapter 5 and Annex 2.1 for more details on frost protection).

In colder regions, areas of lower solar radiation or very high hot water demand, higher-efficiency collectors are used. These have special 'selectively' treated collector surfaces that reduce re-radiation heat losses from the collector. These features are all described in detail in later chapters of this book. Table 1.3 shows the typical additional cost of other system features such as gas boosting, frost protection and selectively coated collectors.

Table 1.3 – Additional costs for solar water heaters (June 2006)

Additional system feature	**Additional cost**
Gas boosting – either in-tank or in-line after the storage tank	$700 to $1000
Boosting controller	$300 to 500
Frames	$380 to $540 (extra cost for reverse or side pitch, or frames for more than two collectors)
Building Consent (in New Zealand)	$125 to $350
Frost protection (dependent on the technology used)	$300 to $500
Selective surface (more efficient collector for colder climates or low solar radiation areas or very high hot water demand) – generally bonded chemically or electro-chemically, such as AMCRO coating, nickel, titanium or chromium oxide coatings (Black Chrome)	$300 to $700

Cost of Building Consent

In New Zealand nearly all applications require a Building Consent. The only exception is for installation of a closed-loop split system where a tank with a heat exchanger replaces an existing conventional electric tank, under the provision for replacing like-for-like without a consent. The closed-loop system itself, as long as the collector is under 20kg/m^2, does not require a consent.

Installation costs

Installation costs vary considerably depending on the complexity of the job. These costs can increase when:

- retrofitting existing houses as access may be restricted, safety equipment may not already be on site or the roof may need strengthening to take the added tank weight
- installing systems with the tank inside the roof rather than on the roof
- installations are at higher roof levels where more safety and expensive lifting equipment may be required
- new piping is required to be run in walls and roof cavities with difficult access
- tree pruning or removal may be necessary for good solar radiation access.

Factors affecting financial return

Life of systems

The expected life of a hot water system depends on many variables including construction quality and materials, water quality, temperature and pressure and system installation and maintenance.

Rule of Thumb 1.1 – System lifetimes

Solar water heating systems can have longer lifetimes than gas or electric hot water systems under the same conditions. This needs to be accounted for when comparing costs over their lifetime with alternative water heaters.

Available solar radiation (irradiation)

The daily average for each month of solar radiation (MJ/m^2) falling on the solar collectors is an important factor determining the system performance. This depends on latitude, local climate, tilt of the collectors to the horizontal and orientation to the equator. Lower latitudes (closer to the equator) have access to more irradiation, particularly in the winter months. Summer months are very similar at all latitudes in most regions. Winter performance can be improved by tilting the collectors at an angle equal to the latitude angle plus a bit more (e.g. latitude angle plus 10º to 15º). However, most solar collectors are tilted at the pitch angle of roofs for ease of installation and aesthetic considerations. This means that there is generally a small increase in the winter operating cost compared with the optimal orientation and tilt. This is offset by a lower installation costs as no special mounting frames are required.

Patterns of usage of hot water

The pattern of usage of hot water affects the efficiency of the solar collectors and therefore the boosting energy required to provide sufficient hot water. This in turn affects the operating cost. For example, reheating over-night with auxiliary electric or gas heaters can potentially reduce the efficiency of the solar collectors the next day if this hot water is not used before the collectors started heating. This is because the water entering the collector is already warm or hot and the collectors may add little extra heat to the water.

Efficient use of the solar system involves careful control of boosting and management of hot water usage. Generally, manufacturers suggest that the home owners use most hot water in the morning prior to 9am or 10am so that the hot water in the storage tank will have been consumed and the solar collectors can then reheat the tank efficiently. This is particularly important in higher latitudes but is not necessary closer to the equator (e.g. Brisbane and north) as winters are sunny, hot water demand lower and there is generally hot water left over for morning use from the previous day's heating.

Solar system tanks are generally larger than conventional electric tanks, so there is an opportunity to carry over solar heat gain from one day to another in case the second day is not as sunny.

Effect of tariffs

The structure and cost of tariffs for boosting energy from gas or electricity can affect the cost-effectiveness of solar hot water systems. When high solar fractions (e.g. greater than 80%) are achieved, the use of off-peak electricity tariffs with fixed monthly charges can reduce the cost savings, as the minimum fixed monthly charge may be incurred each month. To avoid paying this minimum charge, customers can be advised to swap to a general light and power tariff.

To avoid unnecessary boosting, it is advisable to have electric boosters controlled by timers or to use smart controllers provided by solar suppliers (see Boost Heating in Chapter 4 for more details).

Value adding to homes

Solar water heaters are now recognised as adding to your home's resale value. They also improve the energy star rating of homes.

Short-term versus long-term financial assessment

The economic worth of solar water heating systems can be compared with other systems using two methods:

- simple payback time
- net present value, using discounted cash flow analysis.

The simple payback time method compares the difference in installed capital costs with the difference in annual operating costs. This method is common but crude as it doesn't account accurately for different system lifetimes or the changing value of money over time (e.g. $100 will buy more now than in five years' time).

The best comparison method is the net present value method, which calculates the difference in the total present day values of each system over the lifetime of the solar system. This method accounts for inflation rates and market discount rates (equal to likely market interest rates) that change the value of money over time. It also accounts for replacement costs of alternative systems over the solar system's lifetime. More details of this method are shown in the Appendix.

Simple payback time

If the annual savings are divided into the extra total installed cost of a solar water heater (refer to Table 1.2), then the result will be the number of years that it will take the solar water heater to pay for itself. Example 1.1 – **Simple payback time calculation** uses information from Table 1.2 for installed and operating costs of solar, gas and electric water heaters. The example shows how the simple payback time is typically calculated as the difference in the installed capital costs divided by the difference in annual operating costs.

Example 1.1 – Simple payback time calculation

The installation cost of a gas-boosted solar water heater is $4800 after rebates and it has an operating cost (boosting energy) of $64 per annum. The corresponding sized electric water heater has an installed cost of $1200 and an operating cost of $362 per annum. Assume that both systems have similar lifetimes and maintenance costs. The extra cost for the solar water heater is:

$4800 – $1200 = $3600

The annual saving due to the solar water heater is:

$362 – $64 = $298

This will result in a simple payback time of:

$3600/$298 = 12 years

Calculations of this type are crude as they do not take into account the change in value of money over time. Nor do they take account of the comparative service lives of the alternative hot water systems. Example 1.1 **– Simple payback time calculation** shows how this difference in system lifetimes could be crudely accounted for.

Example 1.2 – Simple payback time adjusted for different system lifetimes

To adjust Example 1.1 **– Simple payback time calculation** for the longer life of a solar water heater compared with a gas or electric system, assume the solar system lasts 20 years instead of 12 years (i.e. 1.67 times longer).

This means that the capital cost of the electric water heater must be increased by 1.67 times to $2171.

Hence the simple payback time becomes:

($4800 – $2171)/$298 = 8.8 years

If you were to compare the simple payback times in Examples 1.1 and 1.2 with the actual payback time calculated using the net present value method, we would find that first estimate of the simple payback time as in Example 1.1

was wrong as it doesn't account for either the changing value of money over time or the service life differences. The actual payback time is about 8.5 years, similar to that calculated in Example 1.2 **– Simple payback time adjusted for different system life**.

Despite the approximate nature of simple payback method, it is often used because it is a relatively simple concept to grasp and gives the purchaser of a solar water heater a handy measure of how good a return their investment will give.

Computer modelling

The performance of solar water heating systems can be reasonably well modelled using programs such as Solahart's SCF program and Solwatt (F-chart-based programs) or TRNSYS (an hourly simulation package). These programs allow the user to optimise the system performance and cost.

Economic benefits to society

While solar water heaters provide financial benefits to the purchaser, they also provide economic and environmental benefits to society. These benefits include:

- Money is saved on fossil fuel energy use that in effect creates manufacturing and installation jobs.
- Money is saved by the user. This is a tax-free earning that can be spent on other products and services or invested.
- Pollution and climate change costs arte reduced.
- Costs to upgrade the electricity and gas generation and supply systems are deferred.

These factors may influence the decision of some solar system buyers.

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Section 1.2 questions

Refer to Table 1.1

1a. Darwin is in the north of Australia (latitude 12ºS). What proportion of the hot water can be supplied by the sun using a solar hot water system?

1b. Invercargill is the southernmost city in New Zealand (latitude 46ºS). What proportion of hot water can be supplied using a solar hot water system?

1c. Melbourne is in the south of Australia (latitude 37ºS). What proportion of hot water can be supplied using a solar hot water system?

1d. Why is there such variation between these places?

1e. Why is there such variation at any one place? (e.g. Darwin 92%–100%, Invercargill 51%–61%, Melbourne 62%–72%)

Refer to Table 1.2

The table shows two costs: installed cost and annual running cost (yearly operating cost).

2a. What type of hot water system is the cheapest to buy and have installed?

2b. What are the running costs per year for this unit?

2c. Suggest reasons why the running costs in Brisbane are lower than the running costs for the same unit in Melbourne.

2d. Now compare these annual running costs with the first solar hot water system on the top of the list. How much money would be saved each year by installing a solar hot water system with electric boosting rather than an electric hot water system (general tariff) in: (i) Brisbane and (ii) Melbourne?

2e. In order to make electric water heaters more attractive, electricity companies reduce the tariff for units that heat the water during off-peak times (night). How much would be saved by using a solar system (electric boost) rather than an electric hot water system on a night rate tariff in: (i) Brisbane and (ii) Melbourne?

2f. Over a 10-year period you will see that the costs of the solar system are lower than of a comparable gas or electric system. What influence will Rule of Thumb 1.1 have on this figure if a mains pressure gas or electric hot water system has a life of eight to 12 years?

3a. What is meant by 'payback time' when talking about a solar hot water system?

3b. Working on simple calculations, what is the payback time for a solar hot water system as shown in Example 1.1?

3c. What is the payback time for a system taking into account the longer life of the solar hot water system compared with a gas or electric system as in Example 1.2?

3d. What other factor was mentioned that results in a shortening of the payback time?

3e. Why would the payback time for an LP gas-boosted system be much shorter than for an LP gas hot water system without solar heating?

3f. All sorts of extras are possible with some solar systems: mounting frames, frost protection, over-temperature protection, high-performance collectors, gas boosting, etc. These extra features may improve the performance of the solar hot water system, but they also increase the installed cost. What will happen to the payback time if the installed cost of the system is increased significantly?

4. How could energy (gas and electricity) companies make solar water heating less attractive by altering their tariffs?

5. Governments offer rebates to reduce the cost of solar hot water systems. Why do they do this?

1.3 Environmental benefits of solar water heating systems

What this section is about

Environmental issues are often part of the reason people purchase solar water heaters. This section outlines environmental benefits of solar water heaters and some non-technical issues that have slowed their uptake in the marketplace. This information will assist you to inform customers of the benefits of solar water heaters. It will also assist you to inform local policy makers about these benefits so that there is support for policies and initiatives that increase the uptake of solar water heaters in your area.

What are the environmental issues on which solar water heaters have an influence?

Some of the most serious environmental impacts faced by society are those associated with the combustion of fossil fuels to provide electricity. These impacts may include:

- acid rain damage to buildings or forests
- respiratory illness due to tiny particles or gases we breathe in as polluted air
- changes to the Earth's climate system due to increasing greenhouse gas emissions.

What is the link with water heating? On average, about 27% of energy used in Australian homes (and 36% in New Zealand) is for water heating. Overall in Australia, most homes use electric storage water heaters, and coal is the main fuel burnt to make the electricity. Less coal but proportionally more gas is used in New Zealand to produce electricity. To a lesser extent (though the usage may be higher in certain regions or states), natural gas, LPG, solid fuel and oil are used. The combustion of these fuels produces waste gases. These include:

- carbon dioxide (CO_2)
- carbon monoxide (CO)
- nitrous oxides (NO_x)
- sulphur oxides (SO_x)
- methane (CH_4)
- ozone (O_3)
- polycyclic aromatic hydrocarbons.

They also produce small airborne particles that we breathe in and that are trapped deep in the lungs.

Some of these fuels are less polluting than others. For example, natural gas and LPG water heaters produce substantially less air pollutants and greenhouse gases than electric water heaters (where the electricity is produced from burning coal). Solar water heaters are generally less polluting again as they further reduce the amount of pollution and greenhouse gas emissions from fossil fuels by displacing their use. The environmental impacts of burning fossil fuels and the benefits of using solar water heaters are discussed in more detail below.

Air pollutants

Air pollutants are having harmful effects for an increasing number of people globally. In Australia our cities suffer significant levels of air pollution from the use of fossil fuels – particularly coal, diesel and petrol. This, in turn, has contributed to significant levels of respiratory diseases such as asthma and, in serious cases, death (Simpson 1989).

In some countries, acid rain is a major problem. Nitrogen and sulphur oxides in the atmosphere can be dissolved in water vapour, which ultimately falls as rain. When dissolved in water these oxides form nitric and sulphuric acids. Rain that includes these acids is called ‘acid rain’. Acid rain can damage forests, buildings and people’s respiratory systems.

Climate change and the enhanced greenhouse effect

The most significant effect of air emissions from burning fossil fuels is the change to the earth’s climate systems due to increase in the greenhouse effect. The greenhouse effect is essential to life on earth as it is the process that maintains the earth's temperature at a level suitable for life, an average temperature over the earth of about 14.5°C. The process works as follows.

We are all familiar with how hot it gets inside a closed car sitting in the sun or inside a garden greenhouse. This is exactly the same process, except that the earth’s atmosphere acts like the glass. The solar radiation entering the earth's atmosphere consists of a range of shorter wavelengths made up of electro-magnetic radiation in the visible (50%), infrared (40%) and ultraviolet (10%) parts of the spectrum. The atmosphere is relatively transparent (like a glass window) to these wavelengths, hence they pass through the atmosphere and are absorbed by the earth’s surface.

This absorbed energy is converted to heat in the part of the surface that it strikes (land, water, buildings, people etc). It is re-radiated from the surface of the earth as longer wavelengths (longer-wave infrared). This re-radiated energy is partly absorbed by the carbon dioxide (CO_2) and water vapour in the atmosphere and again converted to heat, warming the atmosphere. Eventually this heat energy is re-radiated back to space from the upper layers of the atmosphere. This process slows the rate at which heat is lost back to outer space. As a result, the global average temperature is much higher than if this energy were re-radiated immediately back to space from the earth’s surface. A small amount of heating is also due to the earth’s internal heat.

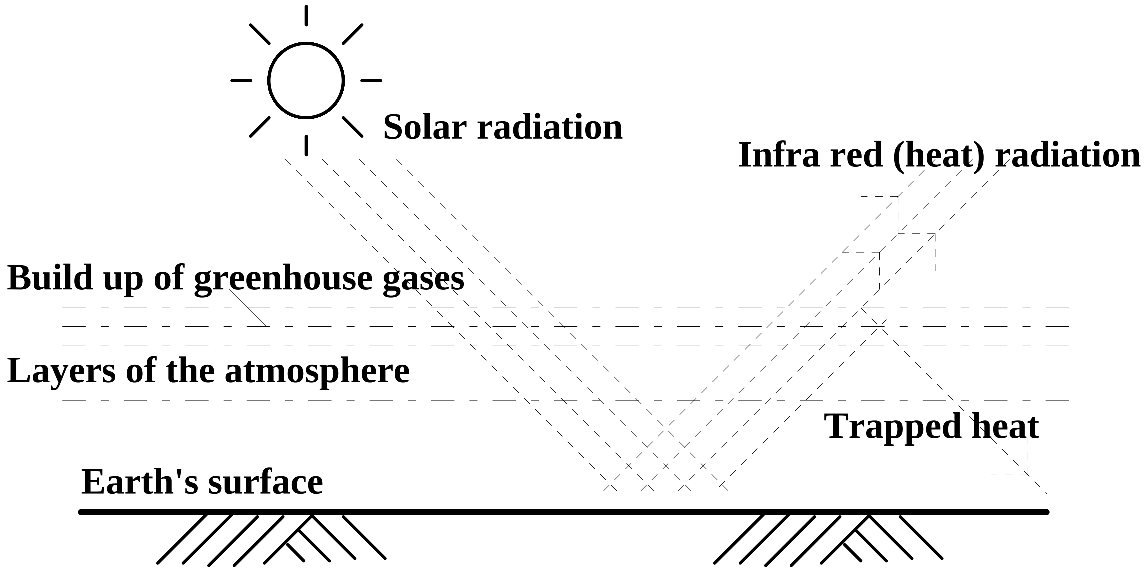


Figure 1.3.1 – The greenhouse effect

Life as we know it on earth exists because of a balance between the rate of solar energy gained by the earth and the rate of heat lost back to space, and the resulting average surface temperature. The use of fossil fuels is changing this balance. This burning of fossil fuels releases large quantities of additional carbon dioxide and methane (the principal greenhouse gases) into the atmosphere, increasing the amount of heat trapped in the atmosphere and increasing the earth's average temperature.

There is now general acceptance by scientists (and most politicians) that the increase in the average global temperature of 0.6ºC recorded in the past 100 years is largely attributable to human burning of fossil fuels. The extent of the global warming is difficult to predict precisely, but scientists' modelling of the atmosphere suggests a 2°C to 6°C average global temperature rise within the next 100 years. This doesn't seem like a significant increase, but when it is put in the context of the temperature rise since the last ice age, it is alarming.

During the last ice age (about 20,000 years ago) the average global temperature was only 5°C lower than it is today. Life on earth has gradually adapted to such a temperature change over a period of 20,000 years. Now we may be forcing the same temperature change in 100 years. Questions are being raised about the ability of life on earth, as we know it, to survive such a change. Some predicted affected areas are:

- Water resources – changes in rainfall patterns, water availability and demand and increased conflict over access to water. This is already happening in Australia with all eastern states and the southwest of Western Australia receiving less rainfall.
- Oceans – rising sea levels, flooding and more frequent and violent cyclones. Coastal areas and island nations are most affected. (Most Australians live close to the sea!)
- Agriculture – changes in crop yields with reduced yields in many areas due to less water and more frequent and severe droughts and floods.

- Health – more extreme weather patterns and periods of very hot or very cold temperatures leading to more temperature-related deaths, particularly of older people who do not cope well with such extremes. The spread of infectious diseases is likely to increase as warming environments allow insects and other disease-carriers to increase their range.
- Natural environment – changes to forest cover and composition will occur. Displacement of species and loss of species will increase as their habitats change too quickly for them to adapt.
- Weather – changes in weather patterns, more extreme events and associated environmental damage. Refugees and economic losses.

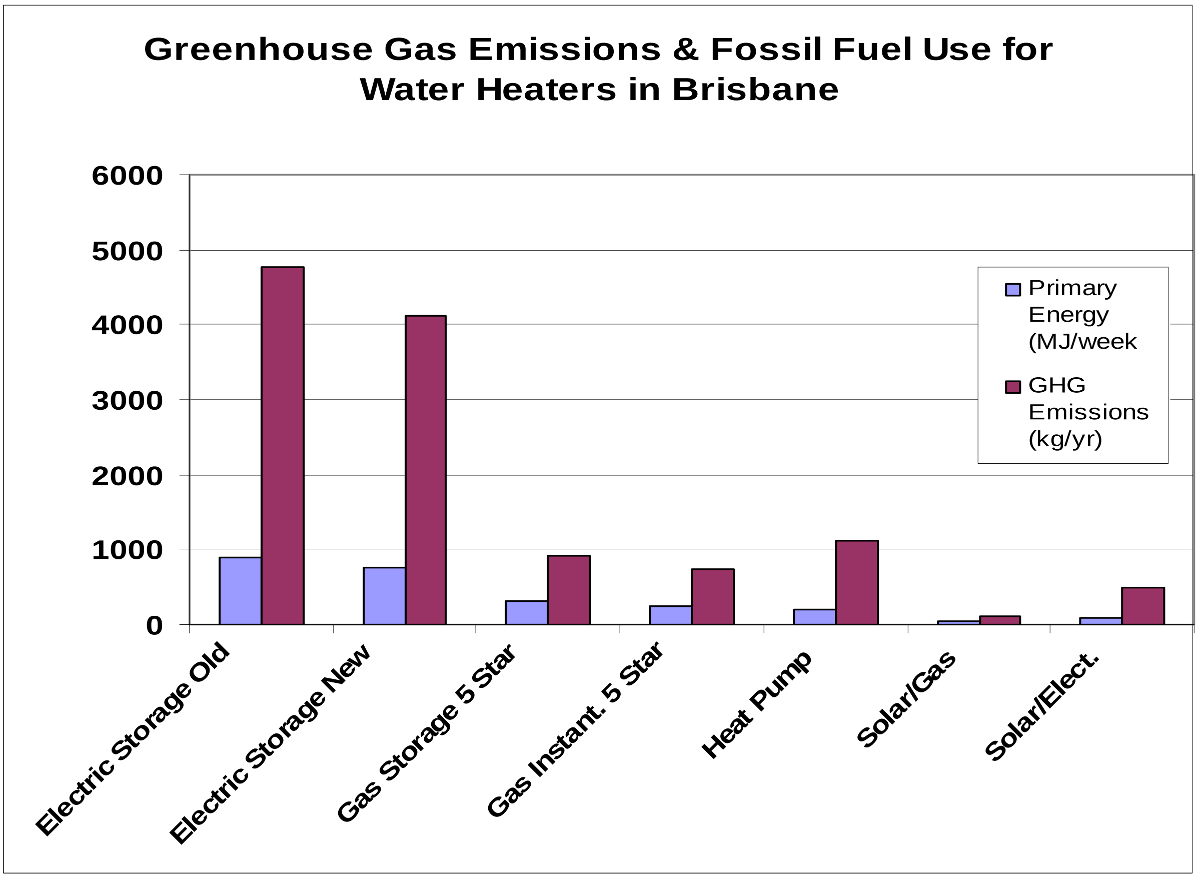
How can solar water heaters reduce the environmental impact?

The environmental impact of producing energy to heat water is reduced with the installation of a solar unit because it uses less fossil fuel to heat the water. A solar water heater will need some form of booster (or auxiliary heater) in all but the hottest of climates. This is because the collector may not be able to raise the temperature of the water sufficiently during rainy or cold cloudy periods. Northern parts of Western Australia, the Northern Territory and Queensland may not need any boost heating.

The exact contribution from solar water heaters towards environmental issues depends on:

- the quantity and temperature of hot water required
- climatic conditions of sunshine (irradiation), air temperature and cold water temperature
- the efficiency of the solar collector and storage tank
- the efficiency of the booster
- how efficiently the system is managed by the users
- the energy embodied in the construction of the complete system
- the annual boosting energy required and the energy source used.

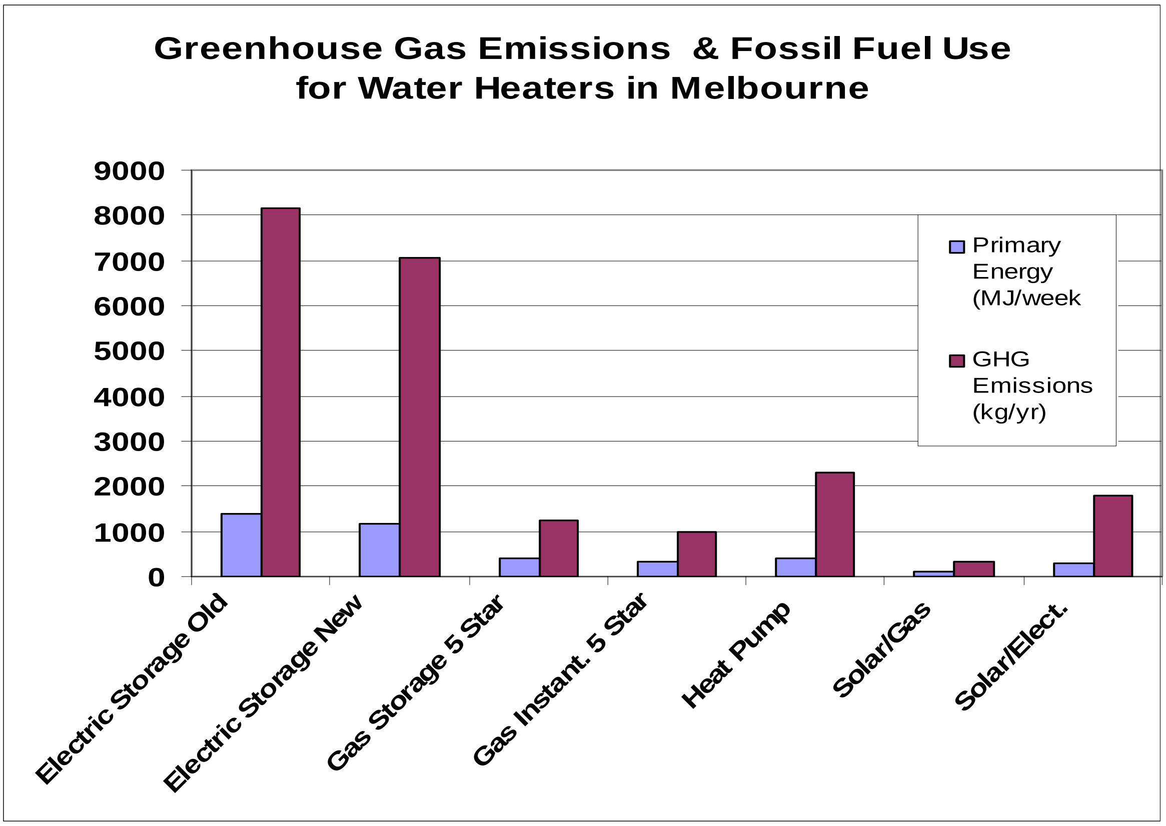
The **solar fraction (SF)** or solar contribution factor (SCF) can be used to indicate the relative energy performance benefit of solar water heaters. It can be used to estimate the environmental benefits such as reduced greenhouse gas emissions and the cost savings of solar water heaters compared with other water heaters. The solar fraction is the proportion of your hot water energy demand at the outlet of the water heater that is provided by the solar collectors, compared with the supplementary or boosting energy that is required to keep the water at a set temperature, typically 60ºC. It varies between households and regions. For example, if a solar water heater is efficient and correctly sized for demand, hot water is used efficiently and the heater is well managed by the users, then a solar water heater in Brisbane can provide almost all of your hot water (e.g. greater than 85%). By comparison, if water from a solar water heating system is not managed well in Melbourne for example, then a large part of the water in the storage tank will be re-heated overnight using the fossil fuel booster. The contribution of the solar collectors may be much lower in this case (less than 50%). The greenhouse gas emissions from different types of water heaters are shown in Figures 1.3.2 and 1.3.3 for Brisbane and Melbourne respectively.



Source: Berrill (2006)

Figure 1.3.2 – Contribution of various water heaters to greenhouse gas emissions (Brisbane)

These figures will vary depending on the factors listed above. In this case the figures are for a common brand solar system versus electric storage, gas and heat-pump systems providing about 170 litres of hot water at 60ºC each day. The solar fraction for Brisbane is taken as an average of 0.86 (or 86%), whereas that for Melbourne is 0.68. The results show that solar water heaters boosted by gas give potentially large savings in greenhouse gas emissions (and other air pollutants) in all regions of Australia, compared with other water heaters. Solar water heaters with electric boosting from fossil-fuelled power stations still give worthwhile savings even in southern parts of Australia. In mid to northern parts of Australia, solar systems substantially outperform gas and heat-pump systems. If the boosting energy from fossil fuel power stations is replaced by renewable energy purchased through ‘green power’ schemes from electricity suppliers, then the emission reductions for solar water heaters and heat pumps are even greater.



Source: Berrill (2006)

Figure 1.3.3 – Contribution of various water heaters to greenhouse gas emissions (Melbourne)

Note that the greenhouse emissions from water heaters in Figure 1.3.2 and Figure 1.3.3 are calculated using greenhouse gas emission intensity factors for the current mix of power stations in Queensland and Victoria respectively. The intensity factor is higher for Victoria due to the use of brown coal. The figures are not adjusted to take account of reductions in emissions that may occur in the future due to improved technology (Australian Greenhouse Office 'Greenhouse Gas Emissions Workbook – 2005').

Energy required to manufacture the components of a SWH

One of the myths commonly heard about solar water heaters is that they never repay their **embodied** or **capital energy**. This is the energy used to manufacture a water heater. This energy at the moment comes primarily from fossil fuels such as coal-fired electricity, natural gas for heat or electricity, and oil for transport. The energy required to manufacture and run any water heater needs to be considered if the full environmental impact of water heaters is to be fully assessed. We need to compare the total energy consumed over the lifetime of any water heater. This includes processing of raw materials, manufacturing of components, energy to transport materials and systems, energy use to heat the water and maintain the system during its operation, and energy to dismantle, recycle or dispose of the system. Researchers have quantified this for solar water heaters in Australia. Most studies examine the capital, operation and maintenance energy only as these are usually the greatest portion.

The results of one such study are shown in Table 1.3.1. It compares solar water heaters and electric water heaters providing about 170 litres of hot water per day at different locations in Australia.

Table 1.4 – Comparison of life cycle energy consumption of solar vs electric storage water heaters

City	Collector area (m^2)	Solar fraction	Capital energy (kWh)	Ambient water temp. (ºC)	Solar system life cycle energy (kWh)	Electric system life cycle energy (kWh)	Ratio
Darwin	3	0.97	2796	27.1	6286	100,504	16.0
Brisbane	4	0.81	3728	21.7	29,252	118,505	4.1
Sydney	4	0.76	3728	19.0	40,423	135,950	3.4
Melbourne	5	0.67	4660	15.2	63,497	160,078	2.5

Based on Jolly and O'Sullivan methodology

The table shows the recommended collector area and likely solar fraction for various cities according to Australian New Zealand Standard AS/NZS 3500.4. The capital energy is the energy to manufacture typical solar collectors. The life cycle energy includes the capital and operating energy. The operating energy is the energy required to heat the water. For the solar system, this is the energy required for boosting. The analysis is over 15 years. The **energy payback time** can be calculated as the capital energy divided by the annual energy savings from the solar system. The energy payback time for solar water heaters in Brisbane and Melbourne is about 0.6 and 0.7 years respectively. It decreases as the solar fraction increases.

Impact of solar water heaters on electricity demand

Solar water heaters have the potential to reduce both energy demand and peak power demand on the electric grid. This has substantial benefits to electricity supply and transmission companies (and society) including:

- reduced system energy losses at peak times
- reduced need for expensive upgrades on transmission lines or additional peaking plant
- reduced greenhouse gas and other polluting emissions.

Energy demand reductions occur simply because the solar water heater is displacing the use of fossil fuels. Peak power reductions can occur if the boosting of solar water heaters is done with:

- controlled tariff heating (off-peak type, separately metered tariffs) as supplied by electricity utilities – these tariffs restrict operation of controlled loads to hours outside peak periods, typically to between 9pm and 6am
- alternative fuels such as gas or wood

- smart controllers that control boost heating times but restrict the quantity of water heated, as well as the time of heating, more accurately by using a number of temperature sensors in the storage tank.

However, unless care is taken with the use of electric boosting, peak power reduction and energy savings may be limited. These issues are discussed in more detail later (Chapter 4).

Nuclear energy – is this the solution?

Nuclear powered electricity generation is often suggested as a possible future clean energy source to replace base-load coal-fired power stations. The electricity could be used to heat water. While this might sound acceptable, a close examination needs to be made of the complex environmental, political, social and economic issues involved. These include:

- the need for extremely long-term (thousands of years), stable storage of radioactive wastes, as well as safe handling and transport of radioactive materials
- ensuring no terrorist access to nuclear materials to make weapons
- avoiding the use of nuclear weapons by governments
- identifying the full cost of this form of electricity generation, including the military cost to restrict terrorist access, and the full life cycle costs such as decommissioning/dismantling power plants at the end of their life and waste disposal and storage costs.

Finally, it makes little sense from a thermodynamic, engineering point of view as the overall thermal efficiency to heat water to 60ºC with nuclear power is very low. The reader is advised to research this topic from all perspectives.

Non-technical barriers to solar water heating

In an average Australian household, 27% of the household energy is used to heat water (36% in New Zealand). Since this is a large proportion of the annual energy consumption and energy bill, and Australasia has lots of sunshine (‘solar resource’) and an established solar water heater industry, it might be expected that solar water heaters would be a very attractive alternative to electric or gas hot water systems. However, this is not always the case. There are many non-technical issues that have slowed the uptake of solar hot water systems in Australasia. These include:

- market issues
- energy prices that do not include the negative effects of burning fossil fuels
- low off-peak prices that reduce incentives for energy efficiency
- marketing of conventional water heaters that provide lower initial costs, but higher operating costs
- limited installation experience and skills for tradespeople due to solar water heaters being a small industry
- objections to the ‘look’ of a solar water heater
- difficulty in replacing conventional water heaters with solar due to complicated planning processes.

A more comprehensive and detailed analysis of these issues, with references, can be found in Annex 1.1.

These issues will not be examined in this book in detail. The authors encourage readers to investigate these institutional, political, economic and social barriers to the adoption of solar water heaters using the references listed in the bibliography. It is often these issues that prevent the uptake of a new technology, not the technical success or otherwise of the product.

Finally, an understanding of these non-technical issues will assist prospective industry people to be able to actively educate the general public and policy makers to achieve better policy for a truly environmentally sustainable future.

Key points

- Solar water heaters can provide substantial environmental benefits to society through the reduction in greenhouse gases and other pollutants from the burning of fossil fuels.
- Solar water heaters generally pay for the energy to manufacture them in less than one year.
- Solar water heaters, when well managed and with appropriately controlled boosters, can help to reduce the peak electricity demand.
- A range of non-technical barriers has slowed the sales of solar water heaters in Australasia. They include market distortions, off-peak electricity tariffs, aggressive marketing by competitors and lack of access to impartial information about solar water heaters for the general public.
- Nuclear power has been suggested as an alternative ‘clean’ fuel for electricity generation. This could provide energy for water heating. Besides being a very thermodynamically inefficient way to produce hot water, the issues of long-term radioactive waste storage, terrorist access to nuclear materials and the economics of nuclear power are complex and the reader is advised to carefully research these issues from all perspectives.

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Section 1.3 questions

1. Many purchasers of solar hot water systems buy them because they believe that they represent an environmental benefit. Suggest ways in which the use of a solar hot water system is of benefit to the environment.

2. Most Australian electricity is produced from ‘fossil fuels’.

   a. What does this mean?

   b. How does the replacement of electrically produced hot water with solar heated water reduce the production of atmospheric carbon dioxide?

3. Figure 1.3.2 shows annual greenhouse gas released for different types of hot water systems in Brisbane. Compare electricity storage new and solar/electric.

   a. Electric storage emissions are 4100kg/year. How many kg/year are produced by a solar/electric system?

   b. What does the vertical axis of the graph indicate?

   c. What proportion of the energy in a solar/electric comes from the sun?

4. Look at the graph for Melbourne (Figure 1.3.3).

   a. Electric Storage emissions are 7100 kg/year. This is nearly double the figure for Brisbane. How many kg/year are produced by a Solar/Electric system?

   b. What proportion of the energy in a Solar (electric boost) comes from the sun?

5. Now look at the Melbourne graph again (Figure 1.3.3). Look at gas storage 5-Star and compare it with solar/gas.

   a. Gas storage 5-Star emissions are 1200 kg/year. How many kg/year are produced by a solar/gas system?

   b. What proportion of the energy in a solar/gas comes from the sun? This is written as a fraction or as a percentage figure; e.g. 1 = 100%, 0.5 = 50%, 0.1 = 10%. Written as a fraction it is called a ‘solar fraction’.

   c. Is the difference between the solar/gas (66%) and the solar/electric (69%) water heaters significant?

6. Make a comparison between Brisbane and Melbourne and complete the following table showing the MJ/week.

	Electric storage	Gas storage 5-Star	Heat pump	Solar gas	Solar electric
Brisbane	MJ/wk	MJ/wk	MJ/wk	MJ/wk	MJ/wk
Melbourne	MJ/wk	MJ/wk	MJ/wk	MJ/wk	MJ/wk

a. Electricity is measured in kWh (kilowatt hours). Gas is measured in MJ (mega joules). There are 3.6 MJ in one kWh. Why is the unit for MJ not given as MJ hours?

b. Looking at the chart that you have completed you can see that Melbourne uses more energy to produce hot water than Brisbane does. How much more is not easy to work out from our figures because they are not accurate enough, but in all cases the figure is greater for Melbourne than Brisbane. Why?

c. What might the 'solar fraction' be in Hobart or even further south in Invercargill in New Zealand? You will have to guess as we do not have the figures; but in Table 1.1 we have figures for approximate cost savings. This will probably be the same as the 'solar fraction'. Take a guess before looking up the table.

d. If you do not know your geography of New Zealand, would you say that Invercargill was north or south of Auckland (simply using Table 1.1)?

7. What do you notice on the Table 1.4 about the number of solar collectors required to produce this quantity of hot water?

8. There are various arguments that people use to discourage the use of solar water heating systems. These are discussed earlier in the section, 'Non-technical barriers to solar water heating'. Who would be keen to discourage any one from installing a solar water heater, and why would they do this?

9. Table 1.4 shows a column labelled 'Capital energy'. This is the energy that is required to make/manufacture a solar hot water system. Why is more energy required to make a solar hot water system suitable for use in Melbourne than a system suited to Darwin?

10. A solar hot water system saves energy. How long might it take to save the energy that was required to make (manufacture) the system? Will this vary for different parts of Australia?