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The Alternative Technology Association (ATA) is a not-for-profit organisation that has been promoting renewable energy, sustainable building and water conservation since 1980.

We do this through publications such as this booklet, as well as through our magazines, *ReNew: technology for a sustainable future* and *Sanctuary: modern green homes*, both of which are available through newsagents or by subscription.

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Introduction

As energy prices rise and the climate change consequences of our energy choices weigh on our minds, we all need to consider higher efficiency and lower emission appliances.

What we consider to be an efficient hot water system has changed a lot in the last ten years. Modern electric appliances can perform better than gas appliances, are cheaper to operate and can run entirely on renewable energy. And more Australian households have rooftop solar PV installations with at least some excess electricity available to help run the hot water system.

Water heating can account for around 21% of total energy use at a considerable financial cost each year (on average, according to *YourHome*) so efficiency is so important when choosing a system.

Replacing a conventional water heater with a heat pump, solar thermal (commonly referred to as solar hot water) or solar electric system will help save the most energy.

About the guide

This is a guide for the selection of higher efficiency hot water systems.

From an efficiency and environmental point of view the future of household energy is electric. The rise of rooftop solar PV and the availability of GreenPower means that households can use 100% renewable energy to run their appliances, including hot water systems.

We cover systems designed for household hot water that can run from renewable energy, including electricity, and ambient and solar thermal heat. These include heat pump, solar thermal, electric instantaneous and the newer kids on the block, PV diversion and direct PV water heating systems. Heat pump systems can be

designed for other purposes in the home such as pool heating or hydronic heating, but these are out of the scope of this guide.

We don't cover efficient gas hot water options such as gas instantaneous in this guide, although the solar thermal hot water systems listed do have gas boost options. Gas used to be seen as the cleaner energy choice, at least when compared with burning coal, but there are better non-gas appliances available to households now. And changes in the gas market mean gas prices are on the rise. Replacing a hot water system with a modern solar thermal or electric one is often the first step in disconnecting from the gas grid, and eliminating the associated costs and greenhouse gas emissions.

The energy used by any hot water system is influenced by factors such as its location, the water storage temperature, and insulation of pipes. These are discussed in the Installation section for each system type.

Of course, however it's heated, reducing the amount of hot water a home uses is a key aspect of

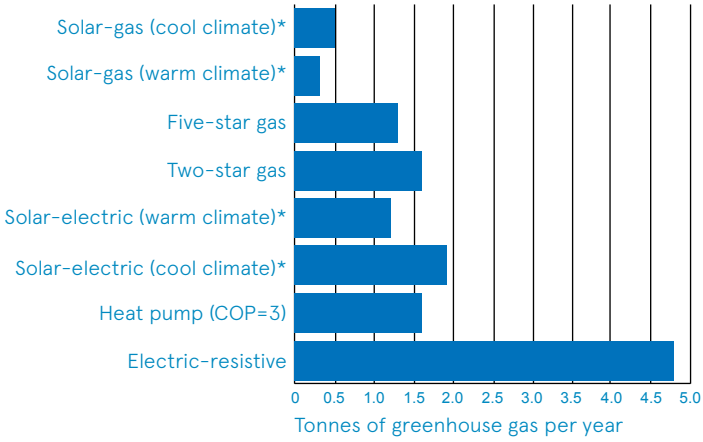

Figure 1.
Annual greenhouse gas emissions based on 200 litres daily hot water use and average power generation emissions. If using 100% GreenPower, solar-electric, heat pump and electric-resistive systems would have zero emissions.

*Warm climate receives 75 per cent solar contribution, for example, Brisbane.

lessening its environmental and financial impact. Water-efficient appliances are one way you can reduce energy use, for example, you could replace your 20 litre per minute shower head with the most efficient, which uses less than 5 L/min, saving 15 litres for each minute you shower. Demand-reduction measures such as low-flow shower heads are not addressed in this guide.

Benefits

Energy savings

Depending on the type of heat pump, energy reductions of up to almost 80 per cent can be achieved compared to resistive-electric storage water heaters.

Between 50 and 95 per cent of your household hot water demand can generally be supplied by a solar thermal hot water system. The percentage depends on where you live in Australia, ranging from 50–55 per cent in Hobart, to 90–95 per cent in Darwin (see Figure 5 p32). The shortfall is most commonly made up by electric or gas boosting.

A close-coupled heat pump system.

Rebates and STCs

Various government schemes exist to provide incentive for the adoption of high-efficiency hot water systems.

Under the federal government's Small Scale Renewable Energy Scheme (SRES), eligible systems qualify for small-scale technology certificates (STCs), which are exchanged for a rebate at the time of purchase.

STCs can save you a great deal on the cost of a new heat pump or solar thermal hot water system. The rebates and STCs are

A close-coupled evacuated-tube solar water heater. The steep mounting frame is designed for placement on the ground or a flat roof.

usually arranged by the supplier so you don't need to do any paperwork to receive the discount. The price will probably still be higher than a similarly sized conventional water heater but savings on running costs can pay for this difference in 5 to 10 years in most cases.

Awarding of STCs is based on performance testing. The number of STCs a system receives relates directly to the amount of energy saved relative to a reference conventional hot water system used in the same location. The number of STCs for which a system qualifies is probably the best benchmark of comparative performance.

The government-maintained register of qualified solar and heat pump systems is publicly available on the Clean Energy Regulator's website: bit.ly/2s1oDz2.

Aside from providing a useful table of all qualified systems and their rated performance, the register provides a simple procedure for determining the number of STCs a system will earn when installed in any location.

Currently only SA and Victoria offer state government rebates for solar thermal and heat pump water heaters; ask your supplier for details.

Hot water tips

Households can use 100% renewable energy to run their appliances, including hot water systems.

Reduce hot water use to lessen the environmental and financial impact of any hot water system.

Rebates and STCs are usually arranged by the supplier so you don't need to do any paperwork to receive the discount.

The number of STCs a system qualifies for is probably the best benchmark of comparative performance.

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Heat Pump Systems

Heat pump water heaters are incredibly efficient, and can be powered by solar.

Hot water heat pumps are electric systems based on the same technology used in refrigerators and reverse-cycle air conditioners. They work by extracting low-grade heat from the air, concentrating it and dumping it into the water in a storage tank.

Heat pumps do not need direct solar energy to operate, although their efficiency is better with higher ambient temperature. They can heat in any weather so do not require a separate electric or gas booster, unlike solar water heaters.

They are much more efficient than conventional resistive electric water heaters. In comparison they can reduce year-round energy requirements for hot water by at least 50%, and by as much as 78% depending on the climate, brand and model.

The most common systems are air-source heat pumps where heat is extracted from the air. Ground-source heat pumps (which use buried coils to take heat from the ground) are even more efficient than air-source heat pumps and might be an option if you're considering both water and space heating systems. They are a great deal more expensive than air-source heat pumps, though, so often aren't viable. We looked at

ground-source heat pumps in *ReNew 112*.

Heat pump features and considerations

To split or not

Like solar systems, heat pump hot water systems are generally configured as either one-piece (integrated) or split. In an integrated system, the evaporator and fan are mounted on top of or beside the tank and integrated into a single unit. In a split system, the heat pump mechanism is housed in a separate unit plumbed to the tank at installation time. Depending on the design, the pipes between the tank and the external unit will carry either refrigerant or water.

An integrated unit has the benefit of simplicity of installation and compactness, whereas a

Do heat pumps provide solar energy?

The marketing of some heat pump devices describes them as providing solar energy around the clock. At one level this is clearly incorrect since the devices do not have a solar collector and are not directly dependent upon solar radiation for their operation. However, claims like this can be considered valid, since:

- the energy extracted comes from the ambient environment, and the electrical energy is principally used to pump the ambient energy;
- the ambient heat is renewable in a very real sense; and
- that heat ultimately originates from solar energy.

The testing and rating regime for heat pump hot water systems explicitly treats such systems as providing renewable energy and they earn STCs (a type of renewable energy credit) in a way comparable to solar thermal hot water systems.

split-system unit allows greater flexibility in locating the two components. For example, you could locate the tank indoors and the heat pump mechanism outside on a wall. Integrated heat pumps weigh more so could take two people to move or install.

Keep in mind that the tank or compressor can be fixed or replaced separately on a split system, whereas that might not be possible with an integrated unit.

Performance

Heat pumps are much more efficient than conventional resistive electric water heaters. Typical heat pumps have a coefficient of performance (COP) of around three, although many go to four and one new unit on the market has a COP of 5. A unit with a COP of three is three times as efficient as a resistive unit;

Close-coupled and split heat pump systems.

for every unit of electricity used, they move three times this much energy into the water.

However, it should be noted that COP varies with ambient conditions; when the air temperature is higher, the heat pump can more easily draw the heat energy from it. The way COP is measured and reported is often not consistent, so currently the best objective performance indicator is the number of STCs the system earns in a given climate zone.

As discussed in the first chapter, you can find a unit's STCs for a given climate zone in the Clean Energy Regulator's register: bit.ly/2s1oDz2. To use the tables, first find the climate zone for your postcode in the postcodes table, and then check the STCs for this zone.

The number of STCs that a system earns corresponds directly to the estimated amount of energy saved relative to a reference conventional system. When systems are tested and certified the number of STCs corresponds to the modelled number of megawatt-hours (MWh) of electrical energy saved over ten years for a given climate zone.

For example, a system might be reported as receiving 30 STCs in Zone 5, meaning that over ten years this system would use 30 MWh less energy than a comparable reference system in that climate zone. To convert the number of STCs into estimated average kilowatt-hours (kWh) saved per day, multiply by 0.274. See 'Which system suits my climate' on page 82).

A prevailing myth is that heat-pump hot water services are not suitable in cold climates.

Boosting

Heat pumps are designed to run whenever the tank temperature falls below a preset level (e.g. 60 °C). Some heat pumps struggle in air temperatures approaching freezing, and so may use a resistive electric element as a

booster in these conditions. If you live in an area that sees regular near-freezing temperatures, look for a system that will operate under such conditions without the need for a resistive booster.

You may also have your heat pump on a timer so that it can make use of higher daytime ambient temperatures and daytime PV generated solar, for instance. However, extra hot water may be needed at other times, so most timers have the ability to be overridden for just such requirements.

Cold weather operation

A prevailing myth is that heat

Heat pumps heat water very efficiently in most climates, saving up to 78% over a standard resistive element heater. You can save another few per cent with the addition of a ValveCosy on the pressure and temperature relief (PTR) valve.

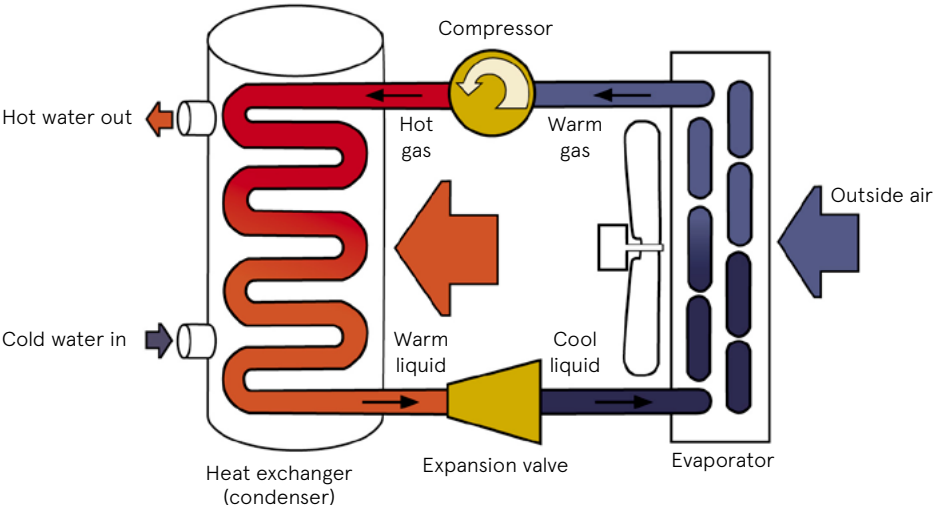

Figure 2.
A simplified diagram of how a heat pump water heater gathers heat from the outside air, concentrating it inside the water tank to heat the water. The warm liquid refrigerant flows through an expansion valve and into the evaporator, where it turns to gas, absorbing heat from the outside air as it does so. The compressor compresses the warm gas, increasing its temperature, and the heat is given off to the water in the tank and the gas condenses back to a liquid, where it starts the cycle over again.

pump hot water systems are not suitable in cold climates. It is generally true that the efficiency of heat pump systems is more sensitive to ambient temperature than conventional hot water systems, however the cold weather performance of many recent models can be good. The rating and regulation of these systems led to the introduction of a new climate zone (Zone 5) covering cold climates in 2011, and many have been tested in this zone.

Heat pump mechanisms are prone to icing within a certain band of temperatures and humidities just above freezing. Icing causes a layer of ice to accumulate on the external evaporator fins, which reduces performance. Icing conditions are a factor when systems are tested and certified, so the rated STC performance takes icing into account. It would

pay to check the reputation of a system if buying for a cold climate.

Optimal usage times

As with solar thermal hot water, the most efficient operation of a heat pump hot water system will usually be achieved if most of the household's hot water use is in the morning. This allows the system to take advantage of the generally higher ambient temperatures in the afternoon for the bulk of the day's water heating. However, the benefit gained from morning water use is less than for solar, as overnight heating is reasonably efficient with a heat pump.

Rate of recovery

This refers to how quickly the heat pump can reheat the water in its tank to a particular temperature. If you are big water users or have guests staying regularly, you should buy a unit that has a relatively fast rate of recovery.

Heat pumps with a supplementary resistive electric boost element will recover faster after unusually high demand for hot water or very low ambient temperatures. Larger tanks have greater standing heat loss, so, in some situations it might be more efficient to choose a smaller tank and opt for occasional boosting with a supplementary element, even though the heating element will be less efficient.

Minimising costs and emissions

Use the heat pump efficiently and source low-emission, 'clean' electricity to reduce the system's climate impact. Clean electricity can be a combination of rooftop PV generation and buying renewable power from your electricity retailer. GreenPower is certified clean electricity that can be purchased at a small premium (most retailers offer this), or buy from a retailer who predominantly sells electricity from hydro schemes. Established hydro power is not covered under the GreenPower scheme. You can also offset using schemes such as the Community Climate Chest, an ATA-run initiative that gives households and businesses access to cheaper, tax-deductible GreenPower and carbon offsets online, while directing a share of the proceeds to local environmental groups. Visit www.climatechest.org.au for more information.

The electricity tariff options in your area will have a large bearing on a heat pump system's running cost. Installation on a timed circuit (i.e. a circuit that is only powered at off-peak times) is not recommended because of the inability to recover heat at other times, leading to the risk of running out of hot water. If your electricity tariff operates on multiple tiers depending on the time of day, then consider a system that can be programmed with preferred times of day. Homes with solar PV and low feed-in tariffs could heat preferentially during the day (when operation is most efficient) and thus make use of free, locally generated power.

Noise

Being refrigerative systems with compressors and fans, heat pumps make some noise, although some are noisier than others. Avoid fitting them close to bedrooms unless they're on a timer and only run during the day.

Reported noise levels are typically in the range of 38 dB (noise inside a library) to 50 dB (background level of a quiet suburb). Noise is perhaps slightly more of a consideration for a heat pump hot water system than for an air conditioner because use is year-round and heating operation can engage at any time of the night or day.

Some systems have a controller that can be programmed to heat at certain times of the day.

Some systems have a controller that can be programmed to heat at certain times of the day. This ability to restrict time of operation may be useful if noise is a concern.

Seaside location

Resilience to salt corrosion will be a consideration for heat pumps located near the sea, just as it would be for air conditioners and other appliances. Data on this is not readily available. Check with the vendor and ask for case studies.

Dust and dirt

Anecdotally, some heat pump

systems are thought to be sensitive to high levels of airborne dust and dirt. This would not be a factor for most people, but might be a consideration in places such as mine sites, farms and remote locations. Ask the vendor for appropriate case studies to check suitability.

Refrigerant

The global warming potential (GWP) of refrigerants used in heat pump systems is often very high, which becomes a problem if they leak or are dumped illegally. This is an issue broadly for the refrigeration industry; the simplicity and size of domestic heat pumps means it is much less of a problem for them.

Most of the current generation of common refrigerants are hydrofluorocarbons (HFCs) which have very high GWPs. Many systems still use refrigerants such as R134a (1,1,1,2-Tetrafluoroethane) which has a GWP of 1430. Increasingly systems are becoming available that use low-GWP refrigerants such as hydrocarbons (e.g. propane, known as R290, with a GWP of 3.3) or carbon dioxide (known as R744), with a GWP of 1 (the Sanden heat pumps use carbon dioxide).

For a list of refrigerants and their properties see en.wikipedia.org/wiki/List_of_refrigerants

A hot water battery

Heat pumps are an efficient way to use renewable energy to meet your hot water needs. If you use your own rooftop solar photovoltaic (PV) system to power your heat pump around midday (instead of using mains electricity) it becomes a "hot water battery". Store your PV-generated energy in the form of hot water for later use when the sun isn't shining. This is one way to 'time-shift' and increase 'self-consumption' of your PV electricity without having to buy an electric car or chemical/electrical battery. See PV diversion in the following chapter.

Installation

The installation of a heat pump hot water system requires less labour than a solar thermal hot water installation, and the location of the equipment is much less sensitive to local factors such as shading and roof access.

Heat pumps need sufficient ambient air flow, which limits their installation in confined spaces such as a cupboard. However a split system could be located in a confined space, depending on the system design. Unlike gas systems there is no flue gas to be vented, so indoor installation such as in a garage is viable given sufficient room volume. Siting the unit against an external wall is more common. Minimum clearance from walls must also be observed.
An electrician is required to install the electric circuit for the hot water service. If the heat pump is replacing an existing conventional system then the plumbing and electrics should be no more difficult than for replacing a new conventional system.

Compared with solar, the location of equipment is less sensitive to local factors such as shading and roof access.

All water pipes should be insulated to reduce heat loss and to minimise or eliminate frost damage. Insulation of the tank's PTR (pressure/temperature relief) valve should also be considered.

Maintenance

Periodic anode replacement may apply to some tanks, as discussed in the Tanks chapter. Normal periodic testing of the PTR valve also applies.

Otherwise heat pumps should be maintained as required, dealing with issues if they arise. Owners should develop an awareness

You could add insulation to a split system heat pump by building the tank into a small insulated shed. This might not be possible with a close-coupled system.

of the normal pattern of operating behaviour, in particular the duration of heating cycles, which can be heard. If the heating cycles start taking much longer than normal for the season, bearing in mind the level of water usage, this might indicate that performance is degraded and maintenance may be needed.

Warranty and standards

Check that the product has a generous warranty of at least eight and preferably 10 years, and that prompt service is available in your area. This is perhaps more of an issue than with traditional hot water systems as the units are less common and their maintenance is slightly more specialised.

Heat pump tips

An integrated unit is simpler to install and more compact.

A split-system unit can give more flexibility in locating the two components.

Check the reputation of a system for operation in your climate.

A new climate zone (Zone 5) covering cold climates was introduced in 2011, and many have been tested in this zone.

Use hot water in the morning, when possible, to get the most efficient use of your solar or heat pump hot water system.

The electricity tariff options in your area will have a large bearing on the running cost of a heat pump hot water system.

Installation requires less labour than a solar thermal hot water system. The location of the equipment is much less sensitive to shading and roof access.

Check that the product has at least an eight and preferably 10 year warranty, and that prompt service is available in your area.

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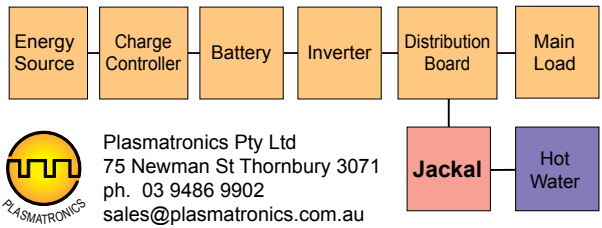

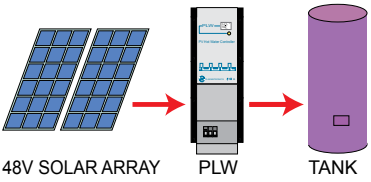

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PV diversion & direct PV

Households can now divert excess solar electricity to their hot water system, or run an electric hot water system from solar panels.

With the reduction in feed-in tariffs across Australia, the best way to get value for money with grid-interactive solar PV installations is to use as much energy as possible as it is being generated, rather than exporting it to the grid. One way to do this is to install a heat pump water heater, or even a resistive element water heater if you have a lot of grid-connected PV panels, and use the excess power generated to run your hot water system.

How does PV diversion work?

Electric diversion systems use excess energy from an existing grid-connected PV array to heat water in an electric storage water heater. The controller monitors the energy flows out of the house from the grid, and when energy starts flowing out to the grid, the diverter turns on and feeds that into the water heater. For example, if your PV system is exporting 500 watts of excess generation to the grid, the diverter will start feeding that 500 watts to the water heater instead.

Diverters are generally fully variable in their outputs; they don't just turn a load on and off at full power. They match the power fed to the water tank element with the excess generation in close to real time, measuring potential export and adjusting the power fed to the element accordingly.

Some diverters, such as the AWS SunMate, have adjustable thresholds which enable them to divert only when the excess generation reaches a desired level. This is useful when the load is a heat pump water heater rather than a resistive element. The threshold can be set to be equal to the average running power of the heat pump, so that the heat pump runs from excess solar generation whenever possible. Boosting times will need to be included (usually programmed into the diverter), for days of low generation when the threshold is never reached.

Installing a diverter usually means a clip-on sensor must be attached to the main lead into the home's switchboard. This sensor talks to the diverter either via a wireless link, a hard-wired cable or even via powerline communications, where data is sent over the mains cables in the home (such as with ethernet over power, or EoP networks, which are common in homes now). Generally, an electrician is required to install a diverter.

The advantage of using a diverter is that, rather than getting paid just a few cents per kilowatt-hour by the energy company for your excess generation, you get to use it on-site, offsetting energy from the grid that would cost you a great deal more.

Many grid-interactive inverters will have some form of diversion capability in the near future.

Diversion is now becoming a feature of some grid-interactive inverters, although inverter capabilities in this regard are generally more limited—often being a simple on/off output once a set export threshold is reached, with no ability to vary the output into the load. However, as PV diversion becomes more popular as a means of using excess generated energy on-site, we expect to see many, if not most grid-interactive inverters with some form of diversion capability in the near future.

The average cost of a diverter is around $900 or so, depending

Diversion systems, such as the Catch Power Green, send excess solar generation to a hot water system, rather than into the grid, and can greatly reduce water heating costs. Here you can see the main diverter unit (the big green box) and the current flow sensor (bottom right) and its associated transmitter with boosting control.

on features, although units range up to around $1700. Prices will come down as they become more popular, but for now you need to weigh the extra cost of the diverter against using a simple timer to run your heater during the day, although a timer gives far less flexibility.

How does direct PV work?

While the cost of photovoltaic (electric) solar panels has dropped dramatically in the past few years, the cost of solar water heaters, except for the direct Asian imported models, has not. The disparity between the two technologies is considerable—so big in fact that you can generally buy enough solar PV panels to electrically heat the hot water you need each day for a lower cost than the average solar water heater.

Because of this strange price

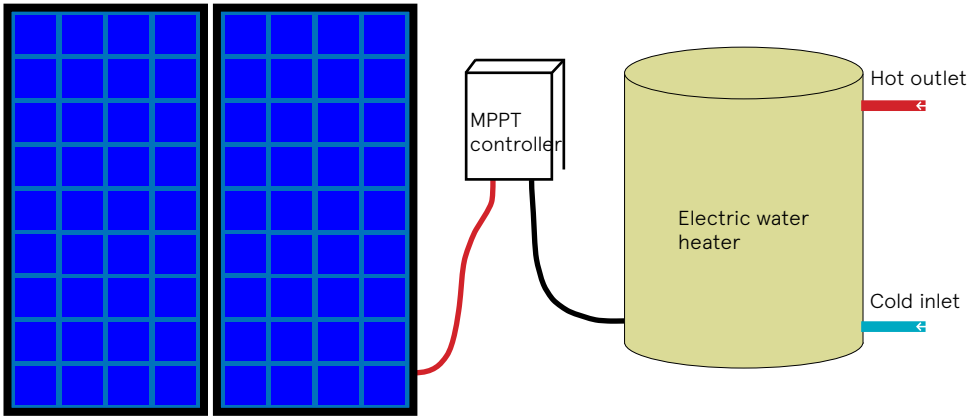

Figure 3.
Direct PV systems use photovoltaic (electricity producing) solar panels to power the element in an electric water storage heater directly, or via a maximum power point tracking controller.

difference, there's a small market for PV-based direct solar water heating. In such systems, PV panels are connected directly to an electric storage water heater via a maximum power point tracking controller/inverter, which ensures you get the most energy possible from the solar panels. The PV panels may be connected to the bottom element in a two-element tank or the single element in a standard single-element tank.

However, at present, very few solar installers/electricians will have wired such a system, so you will need to use the installer recommended by the system supplier.

When using direct PV systems with a mains pressure tank it is important that the controller is also either an inverter or produces chopped (regularly interrupted) DC so that the element is fed power that allows any arcs to extinguish—the wiring rules require that the over-temperature thermal cutout (OTTC) is wired in series with the element. Direct PV systems that produce continuous (non-interrupted) DC output must not

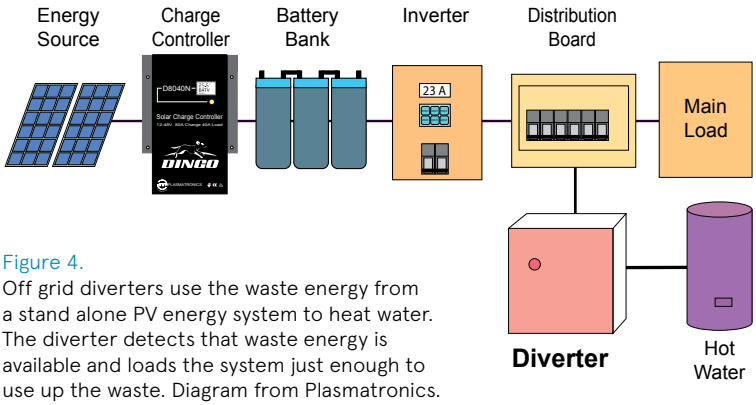

Figure 4.
Off grid diverters use the waste energy from a stand alone PV energy system to heat water. The diverter detects that waste energy is available and loads the system just enough to use up the waste. Diagram from Plasmatronics.

be connected to a mains pressure tank, only open-vented tanks, as these don't require an OTTC. Any direct PV systems that produce chopped DC, where the DC current is regularly electronically interrupted to allow arcs to extinguish can be used with an existing AC rated OTTC if the system conforms to IEC 62109. An example of such a unit is the Plasmatronics PLW. Similarly, using pure un-chopped DC in standard AC thermostats will cause excessive arcing which may burn the contacts.

While some direct PV systems are sold as a controller and you supply your own solar array, others (such as the Easy Warm Hot PV system) are sold as a complete package of solar array and inverter to simplify installation and ensure the system complies with the safety standards.

The advantages of such a system are many. PV panels are low cost and readily available. They can be installed by the DIYer, saving money, and getting the collected energy to the water heater requires a simple cable instead of expensive plumbing.

Direct PV systems can cost as little as $300 for a simple DIY style controller, through to several thousand dollars for a complete package.

PV diversion/direct PV considerations

Boosting

Boosting will be required on days with inadequate input from the solar PV, just as it would with a solar thermal hot water system. The boosting methods are generally the same, and might be overnight heating from mains grid power (via the settings on the diverter or a separate boosting timer) or using an instantaneous water heater for on-demand boosting.

It is important to consider how much boosting you are willing to pay for over winter. Water heating requires more energy input in the cooler months due to higher tank losses (heat loss rate is proportional to the temperature difference between the tank and the ambient air) and hot water demands are usually higher. Plus this is the time of year when solar input is lowest. Consider whether it is worth increasing the size of your solar system, especially if you are already upgrading or adding a direct PV array, to cover some of this extra energy requirement. Your energy bills should have the export component listed, so compare this figure to what your expected water heating usage will be (this might be listed separately on your bill if you have an off-peak tariff for water heating) to get an idea of just how much you are likely to gain from a diversion setup over winter.

Also consider appropriate boosting times, especially if you use most of your hot water at night. If you have a day of low solar input, but the next day is forecast to be sunny, and will therefore provide all the energy needed to reheat the hot water tank, you don't want the booster running overnight and preventing the PV from heating the water the next day.

One solution is to have the PV heating the bottom element of the tank, while the boosting only heats the middle or top element, leaving plenty for the PV to do the next day, while still supplying adequate hot water.

Everyone's hot water usage patterns are different, as is the output from PV systems, depending on time of year, local climate and personal preferences,

so you may need to work out a boosting regime that works best for you. Just make sure the boosting element is on a timer so that you can experiment to find the right balance without needing an electrician.

Warranty and standards

PV diverter warranties vary, but you should look for at least five years, much as you would with a PV inverter. If installing a new storage tank at the same time, again look for a long warranty, but don't sacrifice better thermal performance for the sake of an extra year on the warranty. For direct PV systems, you will be dealing with the PV panel warranties—most panels come with a performance warranty of at least 25 years.

For more information see the *PV Panel Buyers Guide* in *ReNew 134*.

Direct PV/diversion tips

Install a heat pump water heater, or even a resistive element water heater if you have a lot of grid-connected PV panels, and use the excess power generated to run your hot water system.

A diverter allows you to use your excess generation on-site, offsetting energy from the grid that would cost a great deal more.

Direct PV systems can cost as little as $300 for a simple DIY style controller, through to several thousand dollars for a complete package.

Consider whether it is worth increasing the size of your solar system to cover some of the extra energy requirement for water heating and to cover winter boosting, especially if you are already upgrading or adding a direct PV array,

Solar Thermal Hot Water

Let the sun heat your water with a solar thermal system, often referred to as solar hot water. Find out how they work and how to choose the right system for your needs.

A solar thermal hot water system uses heat directly from the sun and consists of a hot water storage tank connected via pipework to solar collector panels. These collector panels are placed on a (preferably) north-facing roof, although a west-facing roof will also work well in many cases.

The tank can be situated immediately above the panels on the roof (a close-coupled system), above and a small distance away from the panels within the roof cavity, or at ground level (a split system). For split systems, a pump and controller are required to circulate water through the panels.

The collectors are usually mounted at an angle of no less than 15° from the horizontal (the minimum angle for close-coupled systems to ensure correct thermosiphon operation), although often a lot steeper to optimise the system performance for winter.

As the sun shines on a collector panel, the water in the pipes inside the collector becomes hot. This heated water is circulated up the collector and out through a pipe to the storage tank. Cooler

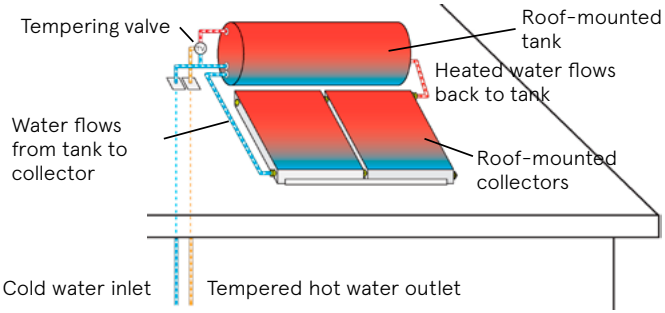

Figure 5.
A close coupled mains pressure system showing water flows between tank and collectors.

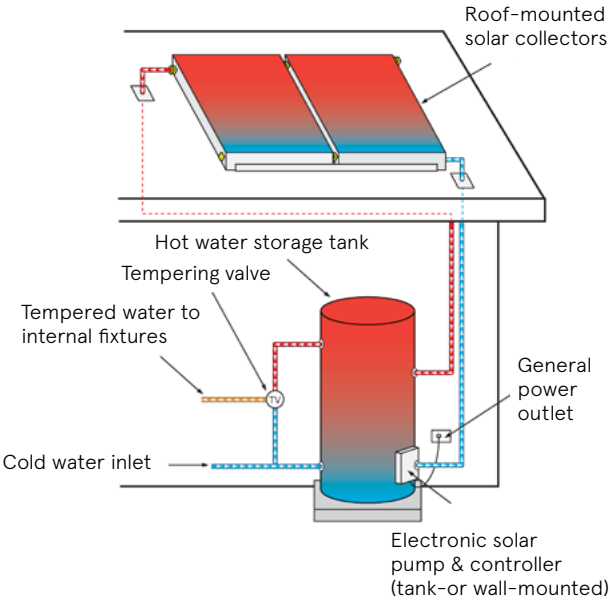

Figure 6.
In a typical split system solar water heater, a small pump circulates water from the bottom of the tank into the solar collector where it is heated and returned to the top of the tank.

water from the bottom of the tank is then returned to the bottom of the collector, replacing the warmer water.

Some systems don't heat the water directly but instead heat a fluid similar to antifreeze used in vehicle cooling systems. This fluid flows in a closed loop and transfers the collected heat to the water in the tank via a heat exchanger.

Evacuated tube collectors either heat the water directly or use copper tubes called heat pipes to transfer the heat to the tank or a manifold at the top of the collector.

Solar thermal hot water features and considerations

Although the basic design is simple, there are a number of system types and factors to consider when choosing a solar thermal hot water system.

To split or not?

Close-coupled systems: For close-coupled (non split) systems, the circulation of the water through the panels and tank occurs naturally as the heated water rises, by the process of thermosiphon. With no pump required, these systems are simpler than split systems, with less maintenance required. However, the storage tank does need to be above the collector panels, and the roof must be able to support the full weight of the tank.

Close-coupled systems have the advantage that all components are close together, reducing heat loss from pipe runs. However, with the tank on the roof, maintenance can be more difficult.

Split systems: Split systems use a pump to circulate water from a ground-mounted tank through the roof-mounted panels. A temperature differential controller gathers information from temperature sensors at the top of the panels and at the bottom of the tank, and tells the pump to operate when there is heat to be gained from the collector.

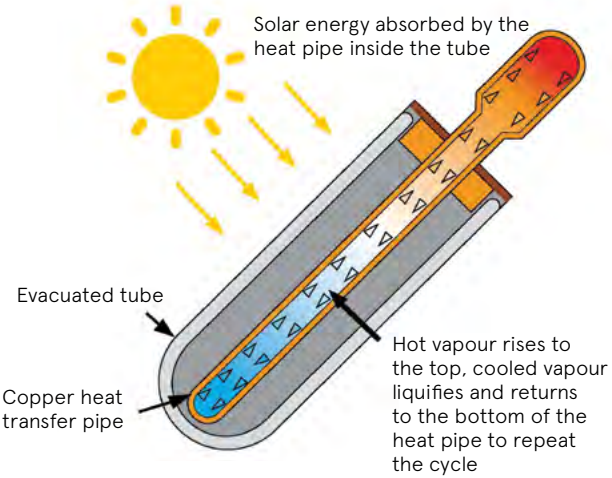

Figure 7.
Some evacuated-tube collectors heat the water directly whereas others use heat pipes (seen here) to transfer the heat to the tank.

The advantages of a split system include much less weight on the roof and easier tank maintenance. However, a split system has added complexity due to the pump and controller, as well as longer pipe runs between the collectors and tank which can lead to heat loss.

Collector types

There are two common types of solar thermal collector panels: flat-plate and evacuated-tube.

Which type of collector you use depends on personal preference and your climate. Evacuated tubes tend to work better in the cooler months in colder climates, but in warmer climates, either type of collector will perform well.

Flatplate collectors: A flat-plate collector consists of a metal collector plate to which a network of pipes is bonded. The metal plate absorbs incoming solar heat and transfers it to the pipes and the water inside them. The plate is usually copper or aluminium and is coated with special treatments to increase absorption of the solar heat energy. The pipes and plate sit inside a metal box with

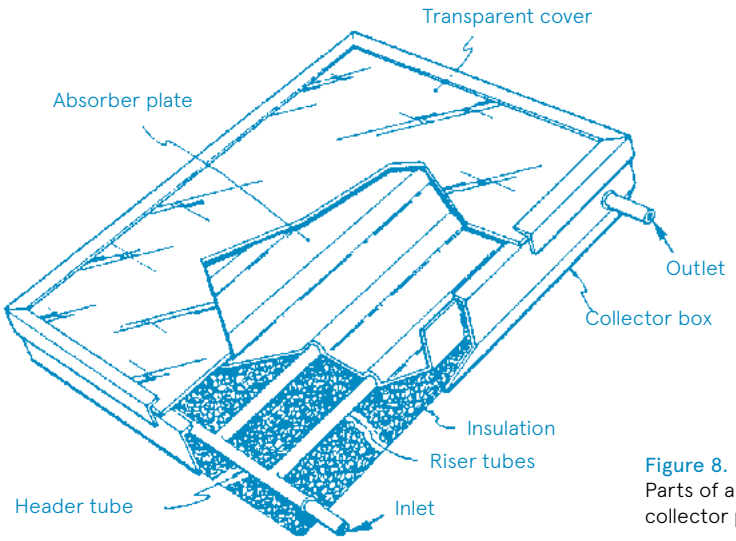

Figure 8.
Parts of a flat-plate collector panel

insulation behind it and a glass cover (usually low-iron glass for maximum heat transmission). The pipes are connected at the top and bottom to header pipes which provide the connection points to the external pipework.

Evacuated-tube collectors:
An evacuated-tube collector consists of an array of borosilicate glass tubes in a support frame with a header tube connected across the top for split systems. In close-coupled systems the tubes normally mount directly into the tank. Inside each glass tube is a second tube, and the space between the two tubes is a partial vacuum (evacuated of gas). The inner tube also has a heat-absorbing coating and so heats up rapidly. As solar radiation passes through the outer glass tube and heats the inner tube, it is trapped by the lack of gas, preventing convective and conductive heat losses.

The heat from the tubes is commonly transferred to the water via a copper heat pipe inside each tube. Inside the heat pipe is a non-toxic liquid, which,

The heat from the tubes is transferred to the water via a copper heat pipe. Image Nic Granleese.

when heated, turns to vapour which rises to the top of the heat pipe and transfers its heat to the water passing through the heat-transfer manifold (or directly to the tank).

Some systems instead have the water flowing through U-shaped copper tubes inside each evacuated-tube and heat this water directly.

If selecting an evacuated tube collector, check to see how easily tubes can be replaced if broken. Many collectors can have tubes removed without having to drain the collector or affecting operation of the rest of the system.

Boosting

The sun may not provide enough energy to meet a household's hot water needs at all times of year. This is rarely a problem in the tropics, but in more temperate

climates a boosting system is required for periods of insufficient sunshine. Virtually all solar thermal hot water systems on the market incorporate some form of boosting, although in some cases they may not be used.

and the only two suppliers of them dropped their models some time ago, so you would need to add a bolt-on heat pump system to a regular split system solar water heater. The added cost may mean this is not economically viable.

Electric boosting is likely to be the greener option, especially if it is 100% GreenPower or locally generated renewables.

Electric elements are the most common boosting option. They fit in well with cheaper night-rate tariffs and are cheaper than gas boosters. If you opt for electric boosting and plan to buy accredited GreenPower, make sure that your night-rate electricity is also GreenPower.

It is even possible to have a solar thermal hot water system that uses a heat pump for boosting, giving you the lowest energy use water heating system. However, such a system would be expensive

Gas boosting is now mostly in the form of instantaneous booster units that are connected to the outlet of the storage tank. If water from the tank is below the required temperature, the gas booster fires up, heating the water to the desired temperature. The advantage of this system is that there are lower standing heat losses compared to a system where the entire tank is heated to full temperature.

Instantaneous heating may, however, require a higher

capacity gas line as it burns a lot of gas to heat water quickly. Solar compatibility requires the booster to be able to operate with a low temperature differential between the hot water coming in from the solar system and the final hot water temperature desired at the taps. Some gas instantaneous heaters are designed specifically for solar boosting, and solar water heaters come as a package with an instantaneous heater as the booster.

While gas has previously been thought of as a fairly good option environmentally, that view has changed as the full life-cycle analysis and resulting greenhouse emissions of gas have become more fully understood. In many cases, electric boosting is likely to be the greener option, especially if it is 100% GreenPower or locally generated renewables—something gas simply cannot be.

Frost protection

The system should be fitted with a freeze protection system if frosts are a possibility in your area. Water expands as it turns into ice and if there is no ability to absorb this expansion or prevent it happening, then the result will be ruptured pipes in the collectors. Repairing collectors can be difficult and replacement is expensive. All manufacturers offer frost protection on at least some models.

Close-coupled systems: There are several frost protection methods for close-coupled systems. Many systems use a heat exchange fluid which flows through the panels and into a heat exchanger in or around the main storage tank. The fluid in this outer circuit contains propylene glycol, an antifreeze additive, and does not freeze under any conditions likely to be experienced by the collectors. However, the fluid level in this circuit must be checked regularly and replaced after an interval as recommended by the manufacturer. This fluid is more slippery than water and has been

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known to leak out through the panel connectors. Owners should look out for this and replace the seals and fluid before irreparable damage is done to the collector panel.

Split system: In a split system using flat-plate collectors, the controller will usually have a freeze-protection mode. It will turn the pump on when the sensor at the top of the collector shows a temperature of 5 °C to pump warm water from the tank through the collector, preventing freezing. The pump will only run until the top of the collector is warmed by the water, so only a small amount of heat is lost with each pump cycle.

Evacuated tubes: Evacuated tubes often use heat pipes to transfer the heat from the tube to the tank or collection manifold. As this type of evacuated tube does not contain circulating water, there is none to freeze. In frost-prone and colder areas, a heat pipe evacuated-tube system should be considered.

A PTR (pressure/temperature relief) valve. All pressurised water heaters must be fitted with one for safety.

Dump valves: Another method is dump valves. These are only used in flat-plate close-coupled systems that use water in the panels instead of a heat exchange fluid. The valve works by opening as the water temperature approaches freezing, allowing warmer water from the tank to enter the panels, which also causes the valve to reclose. This method is not common nowadays but may still be found on lower cost or direct-import systems.

Temperature control

Solar water heaters are effectively connected to an uncontrolled heat source (the sun) and so the temperature in the tank may become much higher than in a regular non-solar water heater. In hot weather, with minimal hot water use, tanks may actually reach boiling point. There are several mechanisms employed to prevent this from happening.

PTR valves: A PTR (pressure/temperature relief) valve is required on all mains pressure tanks, solar or not. The PTR valve will open when the tank temperature or pressure exceeds the rating of the valve, dumping hot water until enough cold water has entered the tank to reduce the temperature and/or pressure to a safe level.

Heat dumps: Some systems have a heat dump or radiator that dissipates excess heat to the air when tank temperature exceeds a set level. These can vary in reliability.

Circulation control: For systems that use evacuated tubes with internal heat pipes, the temperature control is often simply to have the pump controller stop circulating water between the collectors and the tank when the tank temperature reaches a threshold, which might typically be 85 to 90 degrees Celsius.

Increase collector slope at installation time: Due to the

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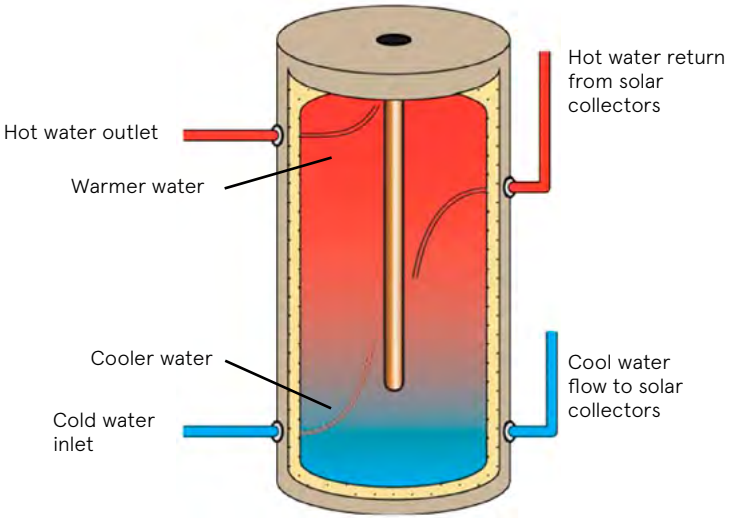

Figure 9.
A vertical hot water storage tank showing temperature stratification.

change in the sun's angle above the horizon throughout the year, increasing the collector mounting angle will reduce heat input in summer but increase it in winter, thus reducing summer overheating and slightly improving winter performance.

Tempering valve: Under the plumbing code AS3500.4, it is a requirement that all water heaters connected to an uncontrolled heat source, such as solar collectors and wood stoves, have a 'tempering' valve fitted. This valve drops the temperature of the tap water to a maximum of 50°C by mixing cold water with the hot water. PV diversion and direct PV systems use the water heater's original thermostat (or temperature monitoring in the controller) and so operate like a regular controlled heat source system.

Stratification

Stratification refers to the layering of different water temperatures inside the tank, a natural effect arising from convection. Strong stratification occurs in a vertically mounted tank; there is hot water at the top of the tank, graduating to cold water at the bottom as

cold water feeds in to replace hot water drawn off at the top. This is the ideal situation and means that almost the entire contents of the tank can be used before the water becomes too cool to be usable as hot water.

Horizontal tanks tend to have less well defined stratification and so may offer a smaller usable volume of hot water; this should be considered when sizing the tank.

Installation

Installation methods will vary depending on the type of system chosen, the house roof angle and structure and the location and orientation of the home. There are several issues to consider.

When considering plumbing the pipe runs should be kept as short as possible by locating the system central to all usage points; this will minimise heat loss from pipes. However, this is an ideal situation and is not always possible.

Panel siting & collector angle

To get the most out of a solar thermal hot water system the collectors should be suitably sited on the roof. The collectors should be tilted towards the sun for optimal performance, which in Australia means mounting them on a north-facing roof. The main requirement is that there are no long periods of shading.

The usual tilt angle is the same as the roof angle to simplify mounting. With close-coupled systems, the angle of the collectors must be 15 degrees or more to guarantee that the thermosiphon circulating the heated water into the tank will work.

It is also important to consider the optimal angle of the collectors to maximise solar gain, particularly for systems outside the tropics. Tilt frames can be used to increase the tilt angle, but you will need to assess whether the additional cost is worth it. Most manufacturers sell a mounting frame as an optional extra.

Outside the tropics collector tilt angle should be set to optimise solar gain for winter, where possible, as this is when sunlight hours are reduced and demand

Even a non-ideal roof can take a solar thermal collector with the right frame.

for hot water can be greater. Doing this reduces seasonal variation in performance and maximises the number of days in the year with sufficient solar gain to require minimal boosting. As a rule of thumb, winter optimisation involves setting the collector slope to the site's latitude plus around 23 degrees. This also lessens overheating issues in summer, and reduces winter-time grid energy demand. In the future it's likely that peak demand will be in winter.

The other important consideration for panel location with split systems is to keep the pipe run between the collectors and the tank as short as possible. Long pipe runs mean greater thermal losses, even from insulated pipes. Of course, the tank should also be located as close to the points of hot water use as possible. If these are all on the south side of the building, you will either have to settle for long pipe runs from tank to collector, or use a tilt frame on the south roof.

Non-north-facing options

A system will still perform well if a west-facing roof is the only option, provided there are no shading issues. Such a system may perform up to 20 per cent less efficiently than a north-facing system, but should still produce good quantities of hot water.

Special frames are also available that allow a collector to face north, even if mounted on an east, west or even shallow south-facing roof. These will add to the cost of installation and may not gain approval with some local councils.

Roof strength

Roof strength is another important consideration for the installation of close-coupled systems. Every litre of water weighs one kilogram, which means that a 300 litre tank will weigh as much as 420 kilograms when the weight of the materials is taken into account. Needless to say, the roof must be inspected and its carrying capacity assessed.

The system should span as many rafters as possible, and these may need to be braced from inside.

Long pipe runs mean greater thermal losses, even from insulated pipes.

Trussed roofs provide particular problems as they are designed to be supported from the extremities only. When designing a new house with trusses, the inclusion of extra trusses in the area chosen for the solar thermal hot water system or the use of stronger trusses must be considered.

Gravity-feed tanks may be located within the roof space, but they must be supported. They are usually located over load-bearing walls, with passageways being popular supports. They must not be mounted on the bottom chord of trusses.

Roof strength is not a concern with split systems as only the

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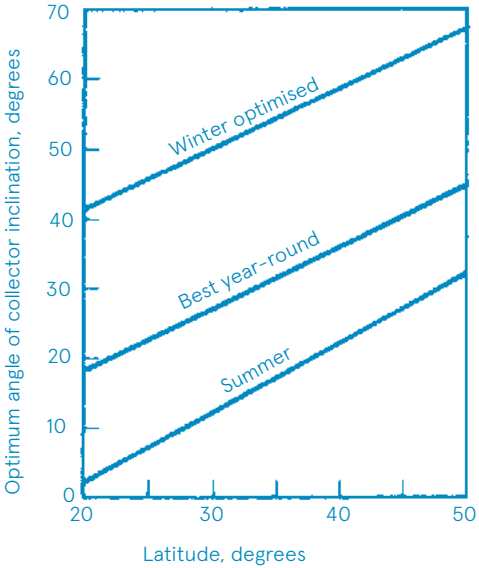

Figure 10.
The best collector angle varies with latitude.

collector panels are mounted on the roof and their weight and area represent very light loadings.

In cyclone-prone areas, all roof-mounted components must be on cyclone-rated mountings.

Plumbing considerations

A heat trap or one-way valve can be used to prevent unwanted night-time convective flow of hot water from the tank to the collector.

Heat trap: A heat trap is a simple inline, U-bend section of pipe at least 150mm long that impedes natural convective action.

One-way valve: Different one-way valves are available for different applications. A spring-loaded valve can be used for mains pressure cold water tank inlets, but a valve with far less operating pressure is required for the connection between the tank and collector. A simple flap valve, which has a

Split systems have the heavy tank on the ground and only the relatively light collectors on the roof. Most installations will require both a plumber and an electrician to complete.

pivoting flap that mounts against a seat inside the valve, is the easiest solution. These require almost no pressure to operate and will not interfere with the thermosiphon operation during the day time, while blocking reverse flow at night.

Ring mains: Some plumbers may recommend you install a ring main. This is a loop of pipe that circles all the hot water outlets of a house. Hot water is pumped through it continously and back to the tank, ensuring that hot water is available at each outlet on demand. While this reduces water wastage from waiting for hot water to arrive, the constant heat loss in the pipes adds to the standing losses of the system, resulting in increased boosting and energy use. The pump also adds to energy use and will eventually require maintenance. Further, depending on the plumbing configuration, the heat loss from the ring main pipes

may add to the heating load of the home, which will make it harder to keep cool in summer.

Some ring mains are set up to be on-demand, in that they only operate when water is requested. These reduce the ring main standing losses but add complexity and cost to the installation as an on-demand pumping system is required, with a demand control switch or button at each outlet.

Overall, it is hard to justify the use of a ring main. A better solution for those taps sited a long way from the hot water tank is a point-of-use instantaneous water heater. Another simple alternative is a diversion valve. These work by diverting the initial flow of cold water to another source, rather than wasting it. Once the water has reached the correct temperature, the valve stops diverting and hot water becomes available at the tap. A common diversion point is to an existing rainwater tank. Diversion valves are also much cheaper and simpler to install than a ring main.

Insulation

All water pipes should be insulated to reduce heat loss and to minimise or eliminate frost damage. Australian Standard 3500.4 defines minimum levels of pipe insulation for hot water systems. Be aware that this is an area where installers might cut corners. Some types of exposed pipe insulation can also degrade rapidly when exposed to sunlight. It is a good idea to ask the vendor to be explicit about the level of insulation to be used and whether it is UV-rated. See Table 1 below.

It is also a good idea to insulate the system's PTR valve using something like a ValveCosy available from the ATA shop. They can be purchased from www.valvecosy.com.au and shop.ata.org.au

Maintenance

The amount and type of maintenance required for a solar water heater depends on the type of collector and tank used in the system.

Sacrificial anode: Systems with enamel-lined steel tanks have a sacrificial anode, which is a rod of metal such as magnesium

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or aluminium that is designed to corrode away instead of the steel tank, should the enamel be compromised. These anodes are rarely checked and replaced when needed as many homeowners are not aware that they exist. The lack of maintenance of anodes is the primary cause of failure of this type of tank.

The anode should be checked every three to five years, and replaced if it is significantly eroded.

See the *Tanks* chapter for more on sacrificial anodes.

Circulation pump: There are a number of other areas in a split system that must be maintained. The one that gives the most problems is the circulation pump. Being a mechanical device, these wear out and usually need replacing every three to five years. Because this (technically) requires a plumber, replacement can run to $500 or more, depending on the pump and plumber.

Controller and sensors: Split systems also include a pump controller and temperature sensors. Occasional failures of these are not uncommon. Often

Location	Insulation R value	Thickness of closed-cell foam
Brisbane, Darwin, Sydney coastal, Adelaide, Perth	0.3	13mm
Melbourne, Albury, Hobart, Canberra, Sydney inland	0.6	25mm
Alpine areas	1.0	38mm

Table 1.
Minimum pipe insulation for external hot water piping (source: AS/NZS3500.4 S8.1)

the pump controller will cause the pump to operate continuously, causing hot water to be pumped through the collectors after sundown, resulting in unnecessary heat loss, excessive boosting and high running costs. If your solar thermal hot water system suddenly requires a lot more boosting each day, check the pump and see if it is operating at inappropriate times.

Valves: The PTR valve on the tank should be tested regularly and replaced if dripping continuously.

In mains pressure systems there is often a non-return or anti-backflow valve on the cold water inlet. These can sometimes make strange noises, requiring adjustment or replacement.

The tempering valve can also give problems, and will sometimes allow flow from the hot water side to the cold water side. If you find that the cold water flowing from any tap is warmer than expected, this is a good place to start.

In gravity-feed systems there is normally a pressure-breaking valve, much like the float valve in a toilet cistern. Rarely, these can become stuck, and this will be apparent if the water heater tank is overflowing from the air vent, or if you suddenly have no hot water.

Solar collectors: While solar collectors are fairly maintenance free, they may need occasional cleaning in dust-prone areas. In systems that use glycol in a heat exchanger, glycol levels should be checked every year and any signs of leakage rectified quickly.

Warranties and standards

The warranties offered on solar thermal hot water systems vary from one manufacturer to another and should be carefully scrutinised when buying a system. Generally, the tanks and collector panels are warranted for five to ten years while the associated valve work will carry a 12-month warranty only. Read the warranty conditions carefully, especially those concerning labour. Some

warranties are conditional on installation by appropriately qualified personnel, regular servicing and water quality.

All Australian systems are built to a set of standards outlined by Standards Australia. These cover design, construction and performance. Installation standards are covered in the National Plumbing and Drainage Code AS 3500.4. Manufacturers are now part of a quality control system for all water heaters under AS 3498, also known as the Watermark. After successfully undergoing an assessment process, manufacturers are entitled to attach the Watermark to their products and promotional material.

Solar thermal hot water tips

All components are close together in a close-coupled system, reducing heat loss from pipe runs. However, maintenance can be more difficult with the tank on the roof.

A split system can have added complexity due to the pump and controller, as well as longer pipe runs between the collectors and tank which can lead to heat loss.

Evacuated tubes tend to work better in the cooler months in colder climates, but in warmer climates, either type of collector will perform well.

Check to see how easily evacuated tubes can be replaced if broken.

The pipe runs should be kept as short as possible by locating the system central to all usage points.

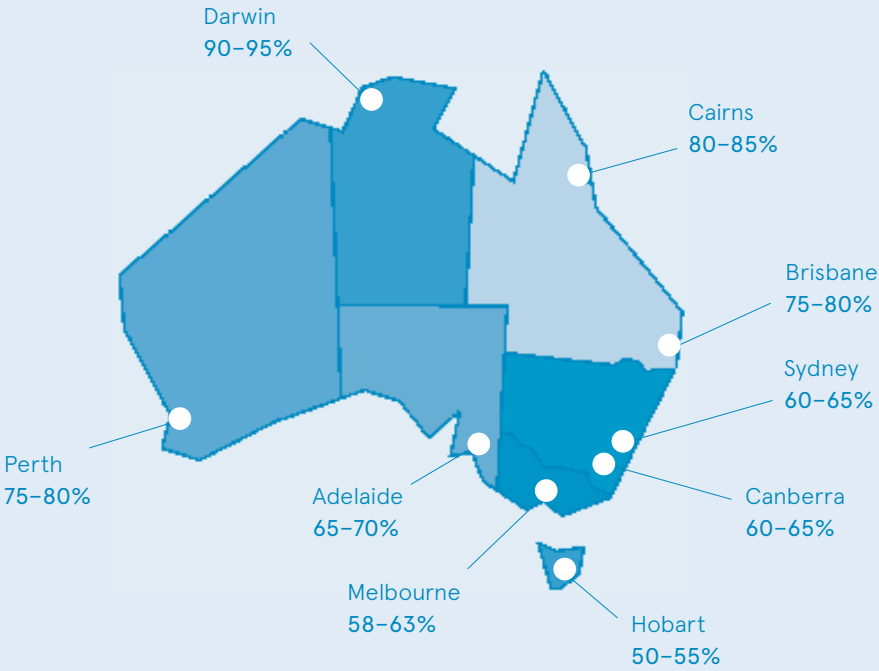

Figure 11.
The percentage of an average household's hot water needs typically available from solar around Australia.

A4 footprint

No tank
- Less water than a soft drink can
- Small footprint

Molecular heat technology

Latest technology
No heat elements
- No scale
- No burn out
- No thermal inertia

99%+ energy to heat efficiency

Full Digital control
- Only uses the energy that is needed

No risk of scalding

Temperature control
- Needs no additional control devices
- Safe for all the family and applications

Can be installed at point-of-use

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Delivering unequalled energy efficiency and temperature control

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Sizing your system

To work out your system size consider the number of people in your household, your future household and the impact of size on the system's efficiency.

Determining the required size of a water heater is the most important aspect of system selection. Sizing is a trade-off between cost and performance, and a key element of performance is the level of risk of running out of hot water.

The system should be sized for the dwelling, not necessarily its occupants. People sell houses and move on but the hot water system stays. It is generally accepted that each person will use around 50 litres of hot water per day. In a storage system it is good to have 1.5 days capacity. A three-bedroom house can comfortably accommodate four people and so it should have a 300-litre tank, even though it may currently be occupied by a

retired couple.

Another consideration in choosing the best tank size is to determine whether the dishwasher and washing machine need plumbed hot water. Increasingly the design of these appliances is tending towards in-device water heating, so household hot water storage requirements may be reduced.

Solar Thermal

Solar thermal systems are configured as a tank and collectors. The number of collectors or evacuated tubes for a given tank size may vary, depending on climate zone and expected water usage patterns. An undersized system will be a disappointment to the user and will require excessive boosting, increasing running costs and possibly environmental impact. An excessively oversized system will overheat in summer which may damage the system and cause significant dumping of water to relieve the built up pressure.

For the highest proportion of the total energy required to run the system to be provided by solar, choose a winter-optimised collector which is large relative to the tank.

Electric element tanks have both a rated and actual capacity. The rated capacity is the quantity of water above the element: a system sold with a 300-litre tank may have a rated capacity of only 250 litres above the element. However, it will have 300-litre capacity under solar, as this method heats the whole tank. If your system is likely to need considerable boosting during certain times of the year, then you should size for the rated capacity.

The collectors should also be sized based on usage. On average, one square metre of panel (or evacuated tube collector) is required per person, and panels are generally approximately two square metres each in size. This means a 180-litre system will have one collector panel and is suitable

For evacuated-tube systems the number of tubes used varies with system size, but the tubes are normally in a fixed size array of a set number of tubes, such as 15, 18, 20 or even 30 tubes. So a 180-litre system may have 15 tubes, with 300-litre systems having 30, and larger systems having more.

for one or two people, a 300-litre system will have two panels and is suitable for three to four people and a 440-litre system will have three panels and is suitable for five to six people, or for a home with more than four bedrooms.

Heat pumps

The smallest tank size will nearly always give the lowest energy use for heat pumps, but at the risk of running out of hot water. Often sizing is based on very conservative assumptions, leading to large tanks which might only be required very rarely, if at all.

Since heat pump systems can heat efficiently at any time of day, you may be able to select a smaller tank than required for a solar thermal hot water system; each manufacturer has their own recommendations, so refer to those for guidance.

PV diversion/Direct PV

Solar PV diversion systems are usually used with an existing

electric resistive or heat pump system, so it may not be possible to change the tank volume. If you are replacing an existing system because it has reached the end of its useful life, or you are 'ditching' gas for cleaner electric water heating, then you have the opportunity to size the tank appropriately. Sizing in these cases is similar to sizing a solar thermal hot water system.

When using PV-generated electricity to heat water directly, it's important to ensure that your solar array has enough capacity to provide the majority of hot water needs. For example, if you only have a small 1.5 kW solar array, and export, say, 3 kWh a day on average, then unless you are using a heat pump for your hot water or your hot water needs are very small, you will need to do a lot of boosting at night.

It takes 1 calorie (4.184 joules) to heat 1 mL of water by 1 °C, so to heat, for example, 300 litres of water by 50 °C requires 300 x 50 x 1000 x 4.184 = 62,760,000 J or 62.76 MJ, which is equal to 17.4 kWh. This doesn't allow for heat losses from the tank, which can add at least another 2 kWh per day. However, it is rare that you will need to heat an entire tank from completely cold, so the actual energy required will usually be much less than the theoretical maximum, probably around half.

Often sizing is based on conservative assumptions, leading to large tanks which might be required very rarely, if at all.

However, knowing this figure means that you can calculate how much energy might be needed to provide your hot water needs, given the size of your hot water tank and the average tank temperature just before heating starts.

Sizing tips

A three-bedroom house should have a larger tank, even though it might currently be occupied by a retired couple.

On average, one square metre of panel (or evacuated-tube collector) is required per person, and panels are generally approximately two square metres each in size.

The number of solar thermal collectors or evacuated tubes for a given tank size may vary, depending on climate zone and expected water usage patterns.

When using PV-generated electricity to heat water, it's important to ensure that your solar array has enough capacity to provide the majority of hot water needs.

Heat pump systems can heat efficiently at any time of day, so you might be able to select a smaller tank than required for a solar hot water system.

Consider whether the dishwasher and washing machine need plumbed hot water.

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#Tanks

Tanks come in a number of different materials including copper, stainless steel and lined steel. System pressure and water quality will determine the most appropriate tank material to use.

Tank types

Mains pressure tanks

Most tanks used in heat pump and solar thermal hot water systems are mains pressure tanks, much like the tanks used in regular gas and electric water heaters. Mains pressure tanks enable the use of flick-mixer taps (single taps that mix hot and cold water) and give a strong flow in the shower. Mains pressure solar water heaters are suitable for use with water supplied from a reticulated town supply, a pressure pump or even a tank located high on a hill.

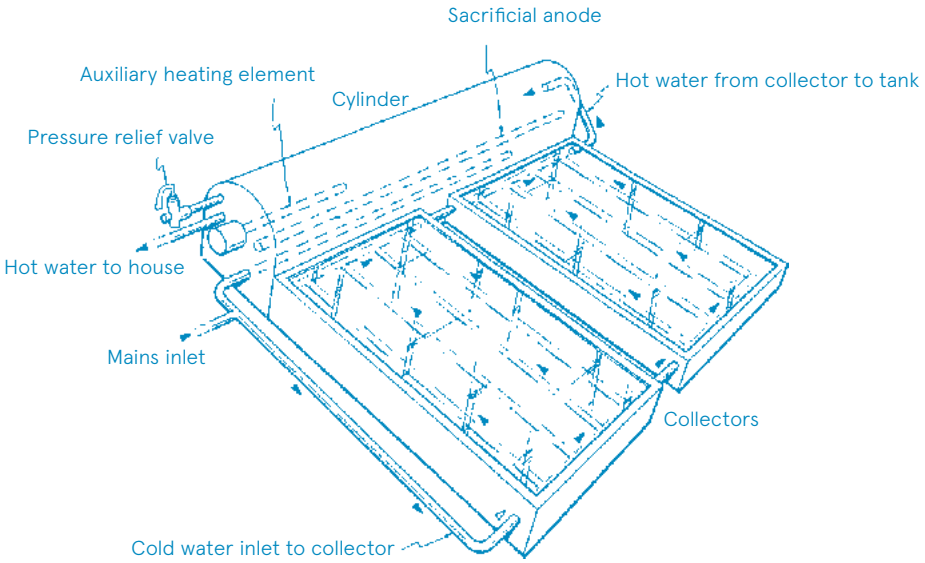

Figure 12.
An electric-boosted tank showing the positioning of the sacrificial anode.

Mains pressure system tanks must be strong enough to hold pressures of 1000 kPa and above so must be made of steel. Some companies use marine-grade 316 stainless steel while others use mild steel with a coating of vitreous enamel (glass).

Glass-lined tanks must have a sacrificial anode fitted (a metal rod inside the tank, usually magnesium or aluminium) which is designed to be eaten away by galvanic, or corrosive, action in preference to the tank material. The anode should be checked at regular intervals to assess wear and be replaced if required; with good quality water this replacement time may be every five to seven years. If the water quality is poor then the replacement time will be much shorter. Failure to replace the anode when required will

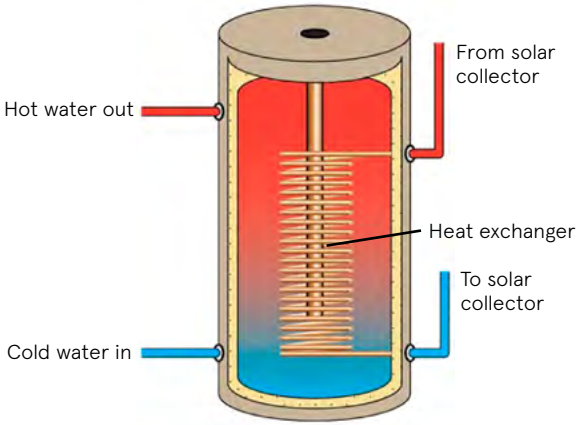

Figure 13.
A split system mains pressure tank with solar collector heat exchanger. Antifreeze runs in the heat exchanger circuit to the solar collectors so they are immune to frost damage.

generally result in premature failure of the tank and may void the warranty.

Gravity feed or constant pressure tanks

Some systems use constant pressure tanks, often called gravity feed, which might suit when the water comes from rainwater. These are usually copper tanks placed in the roof cavity space and are open-vented (open to the outside air via a small vent pipe). Because they contain no pressure they can be directly connected to the heat exchanger on a wood stove as there is no explosion risk if they boil. They are suitable for most water conditions and can give many years of service before failure, usually due to corrosion or failed seams.

Tank with heat exchanger

It's even possible to have the

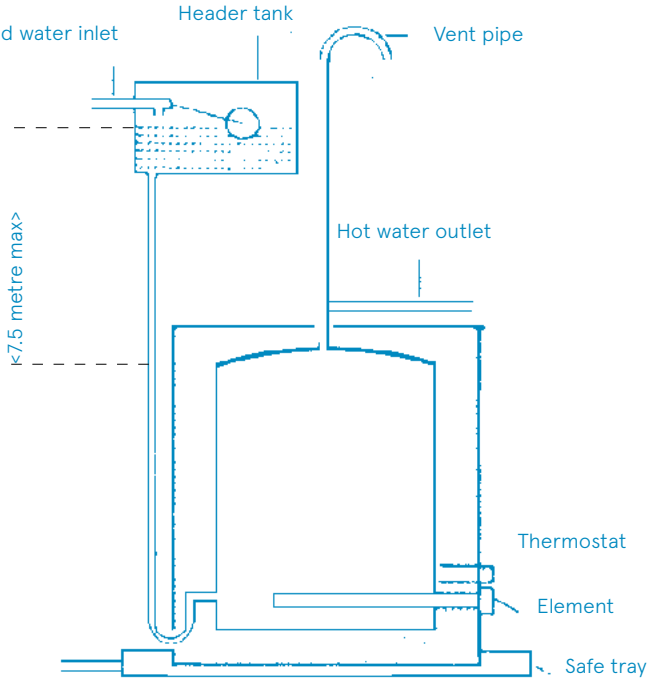

Figure 14.
A gravity-feed system has a header tank that reduces the mains water pressure down to gravity pressure. The tank is usually mounted in the roof space with the header tank above it either inside the roof space or outside on the roof or chimney to provide more gravity pressure.

advantages of both mains pressure and gravity feed systems by using a tank with a heat exchanger. The heat collection system is open vented, heating the water in the tank. Mains pressure water for use in the home flows through a coil of copper pipe inside the tank and is heated by the water in the tank. This allows the use of standard-sized pipes and fittings without the problems associated with mains pressure tanks, such as regular replacement of PTR (pressure/temperature relief) valves and the like.

Tank insulation

Tanks are usually insulated with polyurethane foam. The industry standard foam is CFC-free. Some manufacturers make their horizontal tanks for close-coupled systems so that the insulation on the top is thicker than on the

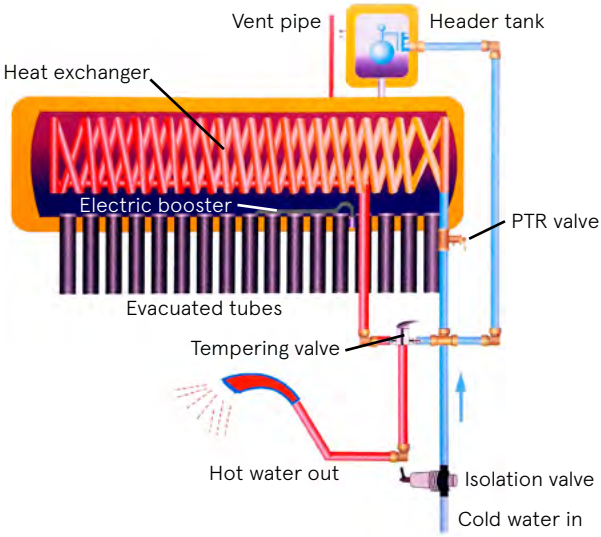

Figure 15.
A close-coupled gravity feed system with mains pressure heat exchanger. Such a system allows mains water pressure inside the home with the advantages of a gravity pressure tank system.

bottom, as the hottest water is at the top of the tank.

On ground-mounted electrically boosted or heat pump tanks it is possible to add extra insulation in the form of a tank blanket; however, the only product designed specifically for this task, the Eco Wrap Hot Water Cylinder Blanket from Autex, is no longer available. Alternatively, there are a number of bulk/foil laminate insulation products, such as Bradford Anticon and Fletcher Permastop, suitable for use on indoor-mounted tanks (see our *Insulation Buyers Guide* in *ReNew 127*). There is a real hole in the market here in Australia for a product like the Mayplas cylinder jacket from the UK (www.mayplas.co.uk). The other option is to locate the tank itself in an insulated 'cupboard'. You will need to ensure you can still access the safety valves.

Legionella

It should also be remembered that the entire volume of any storage water heater, regardless of energy source, must reach 60 °C for half an hour at least once a week to provide Legionella bacteria elimination.

Tank tips

Mains pressure system tanks must be strong enough to hold pressures of 1000 kPa and above so must be made of steel.

The anode should be checked at regular intervals.

The entire volume of any storage water heater, regardless of energy source, must reach 60 °C for half an hour at least once a week to ward against Legionella bacteria.

Other Efficient Water Heating

Replacing a hot water system can be expensive, but there are alternatives that might cost less.

Improve your current system

The simplest option may be to improve the efficiency of an existing system. Improvements can include:

- if not already done, install low-flow shower heads to reduce hot water requirements
- add a Valve Cosy to the PTR valve (www.valvecosy.com.au)
- improve any insufficient pipe insulation
- add an 'Eco Wrap' or equivalent to electric systems (www.bit.ly/AutexEW)
- adjust the tank's temperature control to reduce tank temperature if it's set too high, noting that the static set point should not be less

The Siddons Bolt-on heat pump water heater can be added to an existing tank.

than 60 degrees for biosafety reasons. If there's a tempering valve fitted then it might not be feasible to measure the tank water temperature. Adjusting the set point might require an electrician.

Retrofit your existing system

It is possible to retrofit an existing electric storage hot water system to use solar thermal heating, provided it is in good condition (five years old or less). For a split mains pressure system, a fitting can be installed on the cold water inlet.

Add-on heat pumps can be connected to an existing gas or electric water heating tank.

It is not really advisable to connect solar to gas storage hot water systems because they are designed for the gas to reheat the water as soon as some is used, so the sun can't really contribute any heat.

There are add-on heat pump systems that can be connected to an existing gas or electric water heating tank. The original heating source (gas or electric element) is disconnected and the heat pump system takes over all heating, greatly reducing the heating energy requirements. Almost any hot water storage tank can be retrofitted using these systems. The Siddons Solarstream Bolt-on heat pump is an example of such a system.

It should be noted that, for any system that receives STCs, STCs and other rebates are invalidated by retrofits. If looking purely from a cost perspective it's usually advantageous to install a complete new system as the rebate more than covers the cost of a new tank.

Of course, for PV diversion and direct PV systems, you need an existing electric storage water heater (or heat pump unit) in good condition, preferably a tank with both top and bottom elements, with the solar powering the bottom element and boosting powering the middle/top element.

Solar as a pre-heater

Another method of adding some solar input to an existing system is to use a solar water heater as a pre-heater to a larger storage tank system. For example, a small solar water heater of around 180 litres could be added as a pre-heater to a 250 or 300 litre electric system; the output of the solar water heater goes to the cold water inlet of the existing water heater, which will only operate if the incoming water is not of sufficient temperature.

One advantage of such a setup is that you can install a smaller and therefore cheaper solar water heater than you would require if you were to replace the existing heater completely. This means that you can add solar even if you have budgetary constraints. Further, most solar water heaters overproduce during summer, and an undersized system will avoid this issue. While it won't produce a lot of solar heated water during winter, most systems don't anyway as there is generally far less energy available during this period.

Another advantage of using a solar heater as a pre-heater is that you can add solar heating to an existing gas system without having to make changes to how the gas system operates. As the incoming water to the gas system is already hot, at least during summer, the gas burner will operate minimally.

The main disadvantage of using a solar water heater as a pre-heater is that you effectively double the standing heat losses of the system as you have two water tanks instead of one.

However, you can even use a solar water heater as a pre-heater to a gas instantaneous water heater, with a few provisions—the instantaneous heater must monitor incoming water temperature to prevent it running when the water is already hot (many instantaneous water heaters do this); the instantaneous water heater must be designed to handle a range of incoming water temperatures; and there must be a tempering valve between the solar unit and the instantaneous heater, as most units have an upper limit for the incoming water temperature—often around 60 degrees Celsius. There are a number of instantaneous water heaters on the market that are designed to act as boosters to solar water heaters.

What about electric instantaneous?

As its name suggests, an instantaneous system heats the water as it passes through the heater. Like gas instantaneous heaters, there is no storage in the water heater, just a heat

exchanger, which is essentially a small chamber with an element inside it.

Instantaneous electric water heaters are suitable where they replace an instantaneous gas unit, or when there is minimal solar access and a heat pump can't be fitted or would result in long pipe runs to the water outlets. The unit can use a lot of power to heat a useful volume of water by several tens of degrees so might be unsuitable in many homes. Instantaneous electric water heaters range in size from in-tap or point-of-use units of 2kW or so (which really only allow for low water flows if you want a good level of water temperature increase) through to large 3-phase wall-mounted units that can supply a whole house.

Power draw on the larger units can be more than 20 kW continuously so the home needs a suitable electrical connection to the grid such as 3-phase power (rare in domestic situations) or a high current single-phase connection.

The Stiebel Eltron 3-phase DHE AU series instantaneous water heaters can supply a whole house with hot water. They can also accept preheated water up to 55 °C, making them suitable for solar boosting.

Point-of-use instantaneous heaters can solve long pipe run issues.

Smaller point-of-use units need a regular electrical power circuit. Either way, new electrical wiring will most likely need to be installed to the new heater.

Instantaneous electric water heater performance depends on the incoming water temperature, as they are rated to heat water by a set number of degrees for a given water flow rate, so the colder the incoming water, the lower the outlet temperature (although this isn't a linear relationship for lower flow rates, so check datasheets). If you live in a cold climate where water temperatures are low, you must take into account the inlet water temperature. Of course, this also applies to storage type water heaters, but they have the advantage of being able to heat water over a long period of time rather than having to heat it on demand, so boosting can provide the extra heat required at cold times of the year.

Efficiency tips

Add a Valve Cosy to the PTR valve and improve your pipe insulation.

Reduce the tank thermostat temperature if it is set too high.

Look at the incoming water temperature for instantaneous systems

Making a choice

After looking at the various types of water heating systems you might wonder which one is right for you. Solar, heat pump, PV diversion—which one suits your situation?

A hot water system is a big investment and one that won't be replaced too frequently, so a household should consider a number of factors when making a choice. The main considerations are the environmental benefits of a system, how a water heater works with their existing power supply, the upfront cost and the cost to run, along with other factors such as reliability, climate and complexity of installation and of the system.

What about the economics for a home with existing PV?

With lower feed-in tariffs in place there is greater value in using your solar electricity on site rather than exporting it to the grid. The biggest

The biggest opportunity lies in shifting a large energy user, such as water heating, to solar generation hours via a heat pump or a traditional resistive hot water system.

opportunity lies in shifting a large energy user, such as water heating, to solar generation hours via a heat pump or a traditional resistive hot water system.

A solar household choosing a resistive electric hot water system would set it to run during the day and use the solar electricity to cover it for a good part of the year. The hot water system alone will need at least 2 kW of solar to minimise use of grid electricity, depending on your hot water use and location, of course—it will need more in cooler locations, particularly if wanting to minimise grid import in winter months.

It's hard to go past a heat pump for energy use though. Heat pumps are up to four times more efficient than resistive electric systems, but cost three to four times as much. The ATA compared the cost of purchasing, installing and running a traditional electric resistive hot water system versus a heat pump hot water system for a Sydney home with existing solar and about to lose the premium feed-in tariff. Irrespective of solar system size, the analysis suggested that, given maximum possible use of the solar to run the hot water system, most households would be better off or at least no worse off over 10 years with a heat pump compared to an electric resistive system.

How can I decide between a heat pump and solar thermal hot water?

Each type of system has

advantages and disadvantages. Solar thermal systems require either a strong or reinforced roof for close-coupled systems, or require regular pump maintenance for split systems.

Integrated (one-piece) heat pumps, being fully ground-mounted and not having water pumps, require neither of these. Split system heat pumps usually have water pumps for circulation between the compressor unit and the tank, but have the advantage that the tank can be inside while the compressor is outside—reducing heat losses from the tank in colder climates and making for flexible installation and ease of adding extra insulation.

Being refrigerant-based systems, heat pumps can require regassing from time to time, although if the system is properly sealed this should not occur any more than every 8 to 10 years. After all, how often do you have to regas your fridge or air conditioner?

Heat pumps can be run on a timer, either to make use of low off-peak tariff prices or to run more efficiently during the day due to higher ambient temperatures or to use excess solar PV—they are more flexible than solar thermal water heaters in this respect.

However, heat pumps must always use electricity, even during summer, whereas solar thermal systems may be completely solar-powered during the warmer months—and in warmer climates, this can be most of the year. In cooler climates, they can still provide good savings, particularly if usage is well managed to suit the solar heating cycle.

In situations where shading is a big problem for solar thermal systems and drastic tree surgery is not an option (or shading is caused by the neighbour's house), a heat pump may be the best option.

When would I consider direct PV?

Direct PV is a bit like an off-grid system dedicated to heating water, so only works for specific situations. If you're already on solar then it's probably more efficient to use that power to run a heat pump or resistive electric system than set up a new

stand-alone system dedicated to water heating. However, if you're grid-connected and can't add solar panels because you'll lose your feed-in tariff, then you might consider a direct PV option. And off-grid households with limitations on how they can expand their solar electricity system might consider direct PV.

You might consider a direct PV or a PV diversion system if you have an existing electric storage water heater running from peak rate power (there may be no off-peak rates available) or where installing a solar thermal system would result in long pipe runs or cause other problems. The PV array doesn't need to be close to the water heater storage tank, as the connection between the PV array and the tank is an electrical one, not hydraulic, so energy losses are minimal.

Which system suits my climate?

Certain types of hot water system are more suitable in some climate zones than others. For example, evacuated-tube solar thermal systems usually work better than flat-plate systems in colder areas that see heavy frosts and/or snow. In tropical and subtropical areas, both types of system work well, although in warmer regions evacuated tubes can over-produce and the system must be set up to cater for this.

Direct PV and PV diversion system performance relies on the available output from the PV array, which relies directly on solar insolation. For diversion systems, this depends on what other loads are using electricity in the home during daylight hours, so it doesn't just come down to climate. Looking at your energy bills and seeing how much you export each day or quarter, will give you a good idea of the ability of the PV array to provide hot water. Whether this amount will be enough to provide the majority of your hot water needs (you should be looking at producing more than 50% from solar, on average), will depend on your hot water usage.

There is something of a myth regarding heat pumps and their lack of suitability in colder climates. There are a number of heat pumps available,

especially those that use CO_2 as a refrigerant, that are suitable for use in climates with even sub-zero temperatures. So regardless of where you live, heat pumps are almost always a viable option—but check the efficiency curve, which is usually part of the brochure or datasheet (if not, contact the manufacturer or supplier) of the proposed system for suitability in your climate.

One way to compare the climate applicability of systems is to check the number of STCs that apply to the system in your climate zone (for systems where STCs apply, such as solar thermal and heat pump systems). You can find the register of STCs by climate zone at www.bit.ly/HW_STCs. The higher the STCs for your zone, the better.

Note that there are different zones for solar thermal and heat pumps (cold-climate zone 5 applies only to heat pumps), so you will need to separately determine your climate zone for solar thermal hot water and heat pumps.

Reliability and simplicity

No one wants a sudden cold shower and a failed hot water system is usually an urgent problem. So which types are most reliable?

A relatively simple choice is a close-coupled solar thermal heater with flat-plate collectors. However, being exposed to harsh conditions on the roof, the valves and pipes must be robust and the system must cope with boiling and freezing. The booster heater (e.g. an electric element) introduces complexity, but also useful redundancy. If the solar heating fails, you can still get hot water from the booster. Automatic boosting is nice, but has a downside. If the solar heating fails, you might not realise until you get your next electricity bill! Adding further complexity, in some weather conditions the water might get hot enough for a shower, but not hot enough to suppress Legionella bacteria. So the booster must be operated in a way to eliminate this. Other types of solar thermal hot water introduce extra levels of complexity. If the water tank is at ground level, the pump and its controller become another potential failure point.

Electric resistive water heaters have no moving parts and electric cables are less affected by weather conditions than plumbing. But you're reliant on the electricity grid (unless you have an off-grid or hybrid solar system). A heat pump is a relatively high-tech machine, like a fridge or an air conditioner. But its operation is simple otherwise—there's no boosting required and no plumbing on the roof.

Many hot water failures are due to installation errors. Solar thermal systems are perhaps most prone to this, so it's important to use a trusted installer. On the other hand, heat pumps are dependent on quality control in manufacture, so a trusted brand and model is crucial.

Consumer reports on reliability vary widely for each of these options. Ultimately the decision may depend on consumer preference and availability of products and trusted installers in your local area. It's best to do your homework early, before a cold shower forces a snap decision!

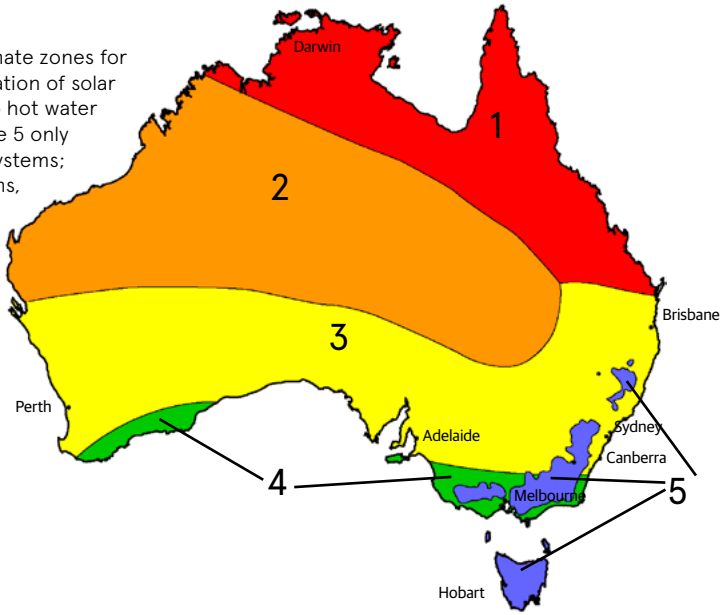

Figure 17. Indicative climate zones for the testing and certification of solar thermal and heat pump hot water systems. Note that Zone 5 only applies to heat pump systems; for solar thermal systems, Zone 5 corresponds to Zones 3 or 4. Melbourne is in Zone 4 for both solar thermal and heat pump systems; Tasmania is in Zone 4 for solar thermal systems, but Zone 5 for heat pumps.

Questions for hot water system suppliers

It's best to sound out an installer to check their reliability before handing over your hard-earned cash. Have they successfully installed this particular hot water system before? What happens if they go out of business? Here are some key questions to get you started.

General questions regarding all systems

- What's your experience with heat pumps/solar thermal/PV diversion systems etc?
- Are you licensed to install this kind of system?
- What happens if the system needs to be fixed under warranty, and your business is no longer operating?
- How long have the equipment manufacturers been in the industry, and do they have a local office?
- What's the warranty on the tank? And on the other components of the hot water system?

Installation of a heat pump hot water system. Image: Whywait Plumbing Services www.whywait.com.au

- Does the quote include all system components as well as installation?
- Does the quote include all labour, transportation and inspection charges?
- What maintenance is required on the system?

- Are replacement parts readily available?
- How long can I expect my system to last?
- How long will it take to install the system?
- Do you handle the rebate application process?
- How many STCs does my system qualify for?
- What material is the tank?
- Will the installation be designed to reduce weathering of the storage tank?
- What level of insulation and lagging do you offer on the system? Do you install measures to prevent heat coming out of the pressure relief valve?
- What is the maximum output water temperature and is a tempering valve included? (Note tempering valves are compulsory.)
- Will the system meet the household's needs regarding number of occupants and bathrooms?
- Can I retrofit my current system?
- If you're looking at an electric hot water system, ask if they can set up a timer so that it runs in the middle of the night, or in the middle of the day if you have solar PV.

Questions for heat pump installers

It's important to differentiate between high quality heat pumps and those that are less efficient. The best heat pumps will have a coefficient of performance of 3.5 to 4 or higher, while some of the lesser quality heat pumps may be down at 2 to 2.5. Some tradespeople will also tell you that heat pumps don't work in cold weather. A more accurate statement is that some brands don't work in the cold, while others actually work quite well.

One way to compare heat pumps is by the number of STCs they receive for your climate zone, available at www.bit.ly/HW_STCs, with more STCs meaning they operate more efficiently in that climate zone. "They're too noisy" is also another comment about heat pumps, whereas only some brands

are actually noisy. Look for a heat pump with a noise rating less than 50dBa.

Here are some questions to help pick a quality heat pump.

- What's the heat pump's coefficient of performance?
- What is the heat pump's coldest operating conditions, or operating temperature range?
- What is the heat pump's noise rating? Does the compressor have a block out timer/timing function?
- Does the heat pump have a resistive element? (If so, it could mean that the actual heat pump doesn't work as well as others. You'd also need to be wary of what impact the resistive element could have on household electricity use.)
- What is the tank warranty, compressor warranty and installation/workmanship warranty?
- What's the process to enact a tank or compressor warranty after the installation warranty has expired?
- Are there any additional costs such as safety switch costs, set up for block out timing (to match solar PV generation times), or extra cost for an elevated work platform?

Questions for solar thermal installers

Solar thermal systems can take a number of days to install due to the plumbing and roofwork involved. Quiz your installer about the full installation process.

- How well does the system perform in overcast conditions?
- Will my roof need to be strengthened for a close-coupled system?
- What is the tank, collector, booster and installation warranty?
- Will my system need a tilt frame?
- Does the system come with freeze protection?
- How long will it take to install the complete system?

Glossary of Terms

Ambient temperature: the temperature of the surrounding air.

Boosting: provides additional heat to solar water heaters during cloudy periods. Can be gas, electricity or solid fuel.

Compressor: that part of a heat pump system that forces the refrigerant around the system. The compressor uses most of the energy consumed by a heat pump unit.

COP, coefficient of performance: the ratio of energy consumed to energy moved in a heat pump system. For instance, a system that used 1kWh to move 3.5kWh of energy from the air to a water storage tank would have a coefficient of performance of 3.5 or 350 per cent.

Freeze protection: a method to prevent damage to a solar thermal hot water system from water freezing inside the pipes and collectors.

Glycol: an organic chemical, usually propylene glycol, used as a heat-transfer fluid in some solar thermal hot water systems.

Gravity-feed systems: systems that rely on gravity as the only source of water pressure.

Header tank: a small tank used to refill the main storage tank in a gravity-feed system.

Inlet temperature: the temperature of the cold water entering the solar water heater.

Insolation: The amount of solar energy that falls on a certain area of the earth's surface. Usually specified in watts per square metre.

Off-peak or night-rate tariffs: low-priced electricity tariffs available only during certain hours of the night, usually used for water heating.

Pressure/temperature relief (PTR) valve: a safety valve used to protect hot water tanks in case of excessive temperatures or pressures, such as if the water were to boil.

Sacrificial anode: A rod of metal, usually magnesium or aluminium, that protects the tank material by allowing itself to be attacked first by water with 'aggressive' chemical makeup.

Solar fraction: the percentage of water heating performed by the solar input to a solar thermal hot water system.

Solid fuel: fuels that are burned, such as wood and coal.

Stratification: the settling of hot water into layers depending on temperature, with the hottest at the top. It is an essential aspect of hot water system design.

Tempering valve: a valve that mixes cold water with the hot water from the water heater to prevent excessively hot water being delivered to the house's taps, thus eliminating the possibility of accidental scalding.

Thermosiphon: the mechanism whereby water rises up a solar collector panel and into a storage tank by natural convection as it is heated, being replaced by cooler water from the bottom as it does so.

Thermostat: a device that switches off a heating source when the water reaches a preset temperature.

Trusses: extra supports fitted to the roof structure of a house to provide support for the weight of the solar water heater.

Uncontrolled heat source: any heat source, such as the sun or a wood heater, which cannot be easily regulated.

Resources

Contacts and resources

ATA (Alternative Technology Association)

Level 1, 39 Little Collins St
Melbourne VIC 3000
ph: (03) 9639 1500
fax: (03) 9639 5814
email: ata@ata.org.au
www.ata.org.au

Clean Energy Council (CEC)

Consumer guide (includes installation checklist)
www.cleanenergycouncil.org.au/technologies/solar-water-heating

Your Energy Savings

Information on saving energy and how efficient hot water systems work
yourenergysavings.gov.au/energy/hot-water

Clean Energy Regulator

Table of STCs by climate zone for tested solar and heat pump hot water systems
bit.ly/2s1oDz2

Your Home

yourhome.gov.au/energy/hot-water-service

Publications

ReNew magazine

ReNew 139 includes an efficient hot water buyers guide.
ReNew 125 includes an article on solar hot water system basics.
www.renew.org.au

Sanctuary magazine

Sanctuary 15, ***Sanctuary 20*** and ***Sanctuary 26*** include articles on efficient hot water.
www.sanctuarymagazine.org.au

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Alternative Technology Association

The Alternative Technology Association (ATA), is a not-for-profit organisation that has been promoting the use of renewable energy, water conservation and sustainable building since 1980. The ATA has thousands of members across Australia who are actively walking the talk in their own homes.

ATA also publishes two magazines *ReNew: technology for a sustainable future* and *Sanctuary: modern green homes,* available from newsstands across Australia.

Become a member of the ATA and you gain access to a large support network of knowledgeable people and receive a range of privileges to help you achieve your sustainability dreams.

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- Invitations to local branch activities. An opportunity to network and exchange information with like-minded individuals.
- Quarterly issues of *ReNew* and/or *Sanctuary* magazines; packed with practical information on the latest and greatest in sustainable technologies.
- Updates on the ATA's local, national and international projects

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www.ata.org.au or call
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