CHAPTER 2

Solar Radiation and Positioning of Collectors

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2. SOLAR RADIATION AND POSITIONING OF COLLECTORS

What this chapter is about

This chapter will provide the installer with a basic knowledge and understanding of:

- the best orientation and inclination for solar collectors to maximise annual performance
- the effect of variations in orientation and inclination from the best case
- how to ensure the collector faces the equator (i.e. north)
- the effects of shading and how to compensate for reduced performance.

For more detailed understanding of solar radiation and tools for the accurate assessment of shading, consult Annex 1.3.

2.1 Best flat plate collector orientation and inclination

In order to produce the maximum quantity of hot water, solar collectors need to face the sun directly. This means that the sun must strike the surface of flat plate collectors at right angles and not be subjected to any shade. The greater the angle of the sun to the glass the greater the amount of the sun's radiation that is reflected off the glass. This radiation never gets into the collector to heat the water.

Nearly all collectors are fixed and do not track the sun. So how should they be mounted for maximum performance?

Rule of Thumb 2.1 – Best collector orientation and inclination

The collectors should face the equator – in Australia and New Zealand this means facing **true north**. **Magnetic north** as read by a compass is near enough in Australia but true north should be used in New Zealand. (See Annex 1.3 for the difference between true and magnetic north and how to adjust for this difference.)

Flat plate collectors should be tilted up from the horizontal the same number of degrees as the **angle of latitude**. This means halfway between summer and winter (ie, equinox – when day and night are equal length) at midday, when the sun is absolutely at right angles to the collectors.

The collectors should not be shaded at any stage during the day in any season of the year.

This is the ideal way of setting up the collectors. It is also easiest and therefore cheapest if they can be mounted on a roof.

Variations from the ideal orientation

It is easy to say that this is how the collectors should be ideally mounted, but there are all sorts of reasons why this cannot be done. We will now look at each of these three factors (north facing, angle of upward tilt, and shading) and see how varying each factor influences the performance of the collectors.

Equatorial (north) facing

Some roofs *do* face north (in the southern hemisphere) and they *do* have enough space for solar hot water collectors. However, many roofs do not have enough space or they do not face due north.

Research has shown that if a solar collector in Melbourne is inclined at a roof pitch of 23º and oriented 45º off true north towards the east or towards the west, the performance of the solar collectors is reduced by up to 6% in winter (less in summer). Orientations 5º or 10º off north mean that the reduction in performance is negligible. However, for orientations of 45º or greater away from north, the reduction (in winter in particular) is greater for steeper roof pitches and increases as you move further from the equator. Optimum orientation and inclination becomes more important the further you are from the equator.

If collectors must face towards the east or the west, a much greater reduction – over 20% – occurs in winter. The performance is usually a little better if the collectors are west facing, as the day is warmer in the afternoon than in the morning and so heat losses to the surrounding air are lower. In this case, avoid roof pitches above 23º.

Rule of Thumb 2.2 – Orientations less than 45º east or west of true north

Orientations of up to 45º east or west of true north have little effect on system performance provided the collector inclination is no more than 23º.

Rule of Thumb 2.3 – Orientations greater than 45º east or west of True North

Collector performance will be significantly reduced in winter. If these orientations cannot be avoided, then increase the collector area by one collector to compensate.

Performance variation for non-ideal collector inclination and direction

Victoria

For Victoria's 5-star requirements, a solar water heater needs to provide 60% of annual hot water use from solar energy. When the collector inclination (tilt) and azimuth (degrees from true north) are not ideal, a higher performance system needs to be chosen to achieve this. This is from the Plumbing Industry Commission Victoria Technical Solution 6 (Solar Hot Water Performance Requirements).

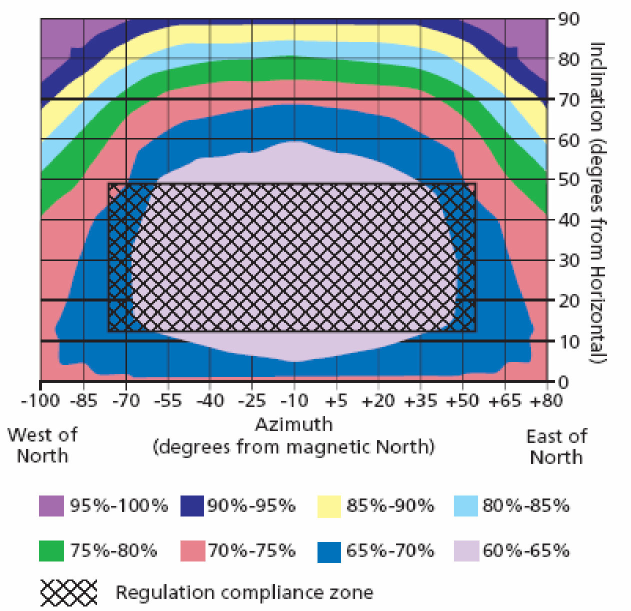


Figure 2.1.1 Required solar hot water performance by inclination and azimuth

New Zealand

Direction	(degrees)	0°	20°	40°	60°	80°	90°
		inclination angle					
West	270	0.85	0.85	0.80	0.72	0.60	0.53
	300	0.85	0.92	0.92	0.86	0.73	0.65
	330	0.85	0.98	0.99	0.93	0.80	0.71
North	0	0.85	0.97	$\boxed{1.00}$	0.94	0.80	0.70
	30	0.85	0.94	0.95	0.88	0.74	0.65
	60	0.85	0.88	0.86	0.77	0.65	0.57
East	90	0.85	0.80	0.73	0.64	0.52	0.46

Good orientation   Moderate orientation   Poor orientation

FACTORS FOR INCLINATION AND SOLAR ORIENTATION

The relative performance of flat plate collectors in different orientations is illustrated. It is clear that collectors should face within about 45° of north, and be fitted at an inclination angle between 20° and 50°.

If for some reason it were necessary to place collectors facing due west at 60° inclination, then to avoid loss in performance, the collectors would have to be 1/0.72 (or 1.4) as large, i.e. increased by 40 % in the collector area.

Where collectors other than flat-plate type (cylindrical shape for instance) are used similar optimum requirements for orientation will apply, i.e. the axis of the cylinder should be inclinded at 20° to 50°. The performance loss by using poorer orientations has not been as fully explored as for the flat-plate case.

Source: From G12AS2 (refer to www.solartraining.org.au for full details)

Mounting frames to help face collectors north

In many cases, it is not possible to find a suitable section of roof that faces the equator and so the use of a special mounting frame is required.

Figure 2.1.2 below shows the options. The use of a mounting frame adds to the cost of the installation. Cyclone areas require more robust mountings.

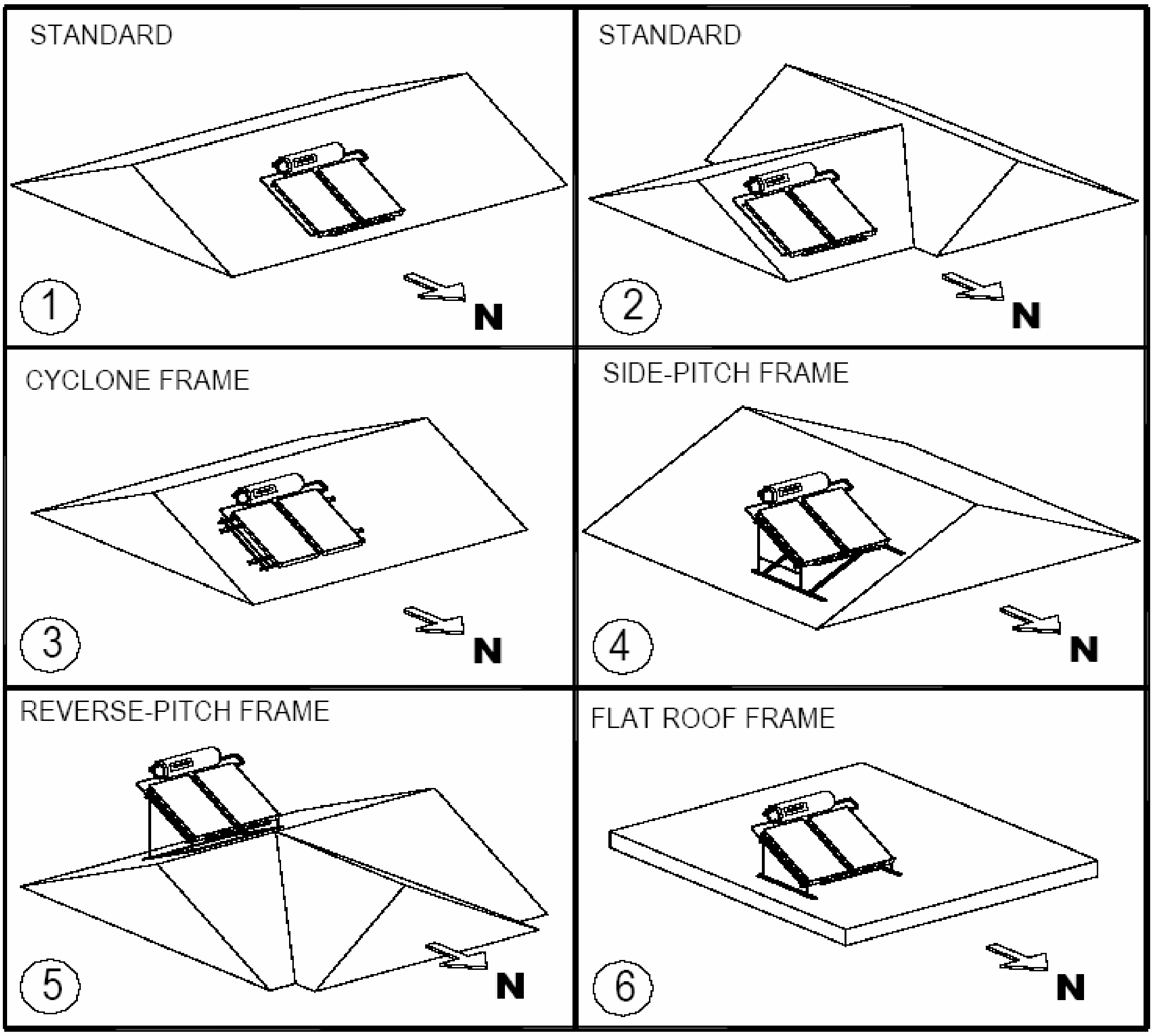


Diagram: Courtesy Rinnai

Figure 2.1.2 – Use of roof mounting frames to optimise collector orientation and tilt

The most usual installation is shown as 'with pitch' and the south facing roof requires an installation that goes 'against pitch'. If there is no section of north-facing roof it is possible to mount the system 'side pitch'.

Finding north

Solar hot water system collectors should face the equator. In the southern hemisphere (Australia and New Zealand) the collectors should face true north. We generally measure north with a compass, which gives us magnetic north. In most parts of Australia, the difference between true north and magnetic north is less than 12º, so facing the solar system to magnetic north has little effect on the system performance. However, in New Zealand the difference is much greater and true north should be found. Why is this important? Because the sun moves across the sky in relation to the position of true north, not the magnetic north. Hence facing true north gives better collector performance as the collector faces the strongest sunlight for longer. Annex 1.3 shows a map of Australasia for magnetic deviation from true north. It also shows how to find true north from magnetic north.

How does an installer find north?

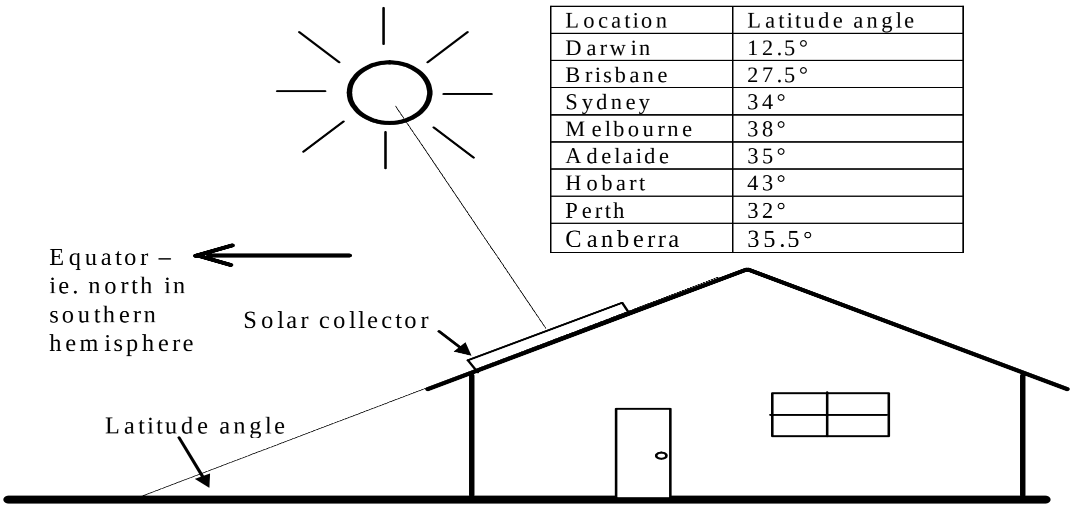
- Use a map – most maps have north at the top of the map, so if you are in a suburban area use the street directory to determine where north is relative to the street and house where the solar water heater is to be installed. If it is not a street directory but some other map, find the north indicator arrow on the map.
- Position of the sun – note where the sun is at midday, or if you are not on site in the middle of the day estimate where the sun will be at midday. Don't forget if it is Daylight Saving/Summer Time, so you base your calculations on true midday.
- Use a compass – the compass will give you magnetic north and not true north. In most parts of Australia either is OK as the difference is no more than about 12º. But there are places, particularly in New Zealand, where it is definitely not OK and magnetic north may differ from true north by 25º or more. You will need to check using a topographic map for the deviation between true north and magnetic north. This deviation varies according to the year. If you are being really accurate (and you do not need such accuracy for the installation of a solar hot water system) you will need to know when the map was produced. (See Annex 1.3 for more details.)
- Use a GPS (Global Positioning System) – the GPS can provide true north because it is using satellites and not the earth's magnetic field.

Notice that none of these methods relies on asking the house owner. While many owners do know where north is for their house, there are many who do not know and their advice cannot be relied upon.

As has already been discussed, it is not essential that the collectors face exactly north and in most installations the task is simply to determine which section of the roof is the most suitable.

Angle of collector inclination (or tilt)

If the collectors are tilted at the angle of latitude as shown in the following table, the sun will be at right angles to the collectors halfway between the longest and the shortest day. In summer the sun will be higher in the sky and strike the collectors at an angle and in winter the sun will be lower in the sky and strike the collectors at an angle.



Location	Latitude angle
Darwin	12.5°
Brisbane	27.5°
Sydney	34°
Melbourne	38°
Adelaide	35°
Hobart	43°
Perth	32°
Canberra	35.5°

Figure 2.1.3 – Optimum Collector Inclination = Latitude Angle

In southern Australia, because the sun has considerably less ability to heat in the winter than the summer, one way to improve winter performance is to tilt the collectors up more than the angle of latitude (by 10º). For example, in Hobart (latitude 43ºS), they would require an inclination of 53º to the horizontal.

The summer performance is largely unaffected as there is usually more sun, the days are warmer and less hot water is needed. Example 3.1 below shows the benefit in winter in Melbourne of increasing the inclination angle from 23º to 45º.

In northern Australia, where ambient temperatures tend to be higher year-round, this additional tilt is not necessary. In Darwin, for example, it is better not to add this extra tilt as the tank may shade the collector. This is because for all of summer, the sun is in the southern part of the sky.

If the collectors can be mounted flat against the roof this is usually the cheapest and neatest way to mount them. A common pitch on roofs is 22.5º, and most roofs in Australia would be set below the optimal angle. Again the question arises, how much does this matter?

Variations from the ideal collector inclination

The same argument applies as for orientation; i.e. a few degrees extra tilt above or below the optimum angle of latitude tilt makes virtually no annual difference. So in most situations, attaching the collectors directly to a north-facing roof, even if the roof pitch angle is not ideal, is the cheapest and simplest option.

If the roof pitch is not optimal, it is generally cheaper and neater to install an extra collector than to use a frame to achieve the optimum performance.

Photo: Andrew Blair

Figure 2.1.4 – Frame-mounted solar hot water system

This solar hot water system in Victoria has been tilted back a little so that it is at the optimal angle. The tilting would reduce the shading by the storage tank for part of the day but would probably make very little difference to the performance of the collectors compared with them being installed flat against the roof. Shading by the tank could be avoided by extending the connecting pipes between the collectors and the storage tank, separating the tank and collectors by perhaps 300mm to 500mm. The frame is unattractive and would have added significantly to the expense and complexity of the installation.

Example 3.1 – Improving the collector performance in winter

In Melbourne, for a collector facing north and a 200 litre per day hot water demand, increasing the tilt angle from 23º to 45º increases:

- the annual solar fraction from 72% to 74%
- the June/July solar fractions from about 39% to 46%.

Summer performance is largely unaffected.

Flat roofs

On flat or nearly flat roofs a mounting frame will be required. The **minimum angle** for mounting flat plate solar collectors is 10º, so that adequate thermosiphon flow occurs, carrying the heated water from the collectors to the storage tank. A 10º pitch also means that rain will wash dust off the glass of the collectors.

Rule of Thumb 2.4 – Minimum collector inclination or tilt angle is 10º

This helps to ensure:

- thermosiphoning force is adequate to circulate water through the collector to the tank
- self-cleaning of the collectors by rain.

The maximum recommended angle is 50º. Any greater angle means that with close-coupled systems, shading by the storage tank is likely at some times of the year. Another consideration if exceeding 50º is how the whole system is to be attached to the roof. The normal method of just letting the system *sit* on the roof is not satisfactory, and better security is required. This applies particularly in cyclone areas.

Rule of Thumb 2.5 – Maximum recommended tilt angle for close coupled, thermosiphon systems equals latitude angle plus 10º (for orientations facing north)

This helps to prevent shading of the collectors by the storage tanks with close-coupled thermosiphon systems. Note:

tanks may require extra support as roof pitches increase above 40º

tanks above collectors will shade the tank more so in winter if the orientation is too far from true north; e.g. east or west.

For orientations greater than 45º east or west of north, limit tilt angles to 23º.

2.2 Shading

Any shading is best avoided. At a minimum, it is generally recommended to avoid shading between 9am and 3pm since most of the solar energy to heat the water is received during this period. Partial shading of parts of the collector in the afternoon will have little effect.

Rule of Thumb 2.6 – Avoid all shade between 9am and 3pm

In general, the collectors should be located in the sunniest area, and the hot water storage tank should be located closest to the place where most hot water is used. This is usually near the bathroom as about 66% of hot water use is for showers and baths, or alternatively, near areas of most frequent use like the kitchen. However, some times this ideal location for the hot water system is in conflict with the sunny location of the collectors. In these cases, creative solutions are required. Figure 2.2.1 shows a situation where the collectors and storage tank are separated for this reason and for aesthetic reasons. Insulated piping is required between the collectors and the storage tank. Some partial shading of the collectors occurs in the late afternoon.

These solar collectors have late-afternoon shading from a chimney and the upper connecting pipe. Neither is of great consequence as, from 4pm onwards, there is no further heat input to north-facing collectors.

These collectors have been located on the south side of the roof so that they are not visible from the street. A supporting frame was required. The galvanised down pipe protects the insulation round the 25mm copper tube to the in-ceiling storage tank.

Photo: Andrew Blair

Figure 2.2.1 – Partial shading of collectors from chimneys and interconnecting pipes

Shading from trees can be far more extreme as they can grow rapidly. Figure 2.2.2 shows some extreme cases of shading where the solar water heater is no longer being heated from solar energy. Instead, it has become an expensive electric storage hot water system. The pictures were taken in far north Queensland in July when most hot water is needed. The right picture shows total shading year-round. The left-hand photo shows how the nearest solar system is significantly shaded but the furthest one is in the sun. In this case, careful site assessment using a **sun path diagram** should have been used to avoid shading problems (see Annex 1.3 for how to use a sun path diagram).

Photos Trevor Berrill

Figure 2.2.2 – Extreme shading of solar hot water systems

Types of shading

What forms of shading should an installer be looking out for?

- Buildings – close to the roof where the solar collectors are to be installed. Experience is going to be the best guide as to whether they will be a problem. Winter is the usual problem time when the sun is low in the sky. There are devices and techniques available to determine exactly where the shadow of a building will fall. If in doubt use one.
- Future buildings – there may be no shade from existing buildings, but take into consideration what is likely to be built in the future and where. *Solar access* can be cut off by the erection of new buildings that shade their neighbours.
- Trees and shrubs – the problem with trees and shrubs is that they grow … taller! Often they may not be a problem at the time of installation, but may grow and shade the collectors some years after the installation. Often owners of the trees do not foresee this problem and are reluctant

to cut the trees down. The two north Queensland pictures above clearly show the problem associated with rapidly growing trees.

- Parts of the building – shading by parts of the building on which the collectors are to be installed can be a problem. Collectors on a roof close to an upstairs room may be shaded for part of the day. Some roof parts will cast a shadow on the area selected for the solar collectors. Chimneys, vent pipes and other structures may cause shadowing. A television antenna over the collectors may provide a perch for birds whose droppings on the collectors may not only cause localised shading but also corrosion of the metal components of the collectors.

When will shading occur?

The diagram shows how the sun moves across the sky during the day above you (the observer). Note that in winter the sun rises not in the east but north of east, and even in the middle of the day is much lower in the sky than in summer time.

Notice how in summer the sun rises to the south of east and sets to the south of west, but at noon it is much higher in the sky.

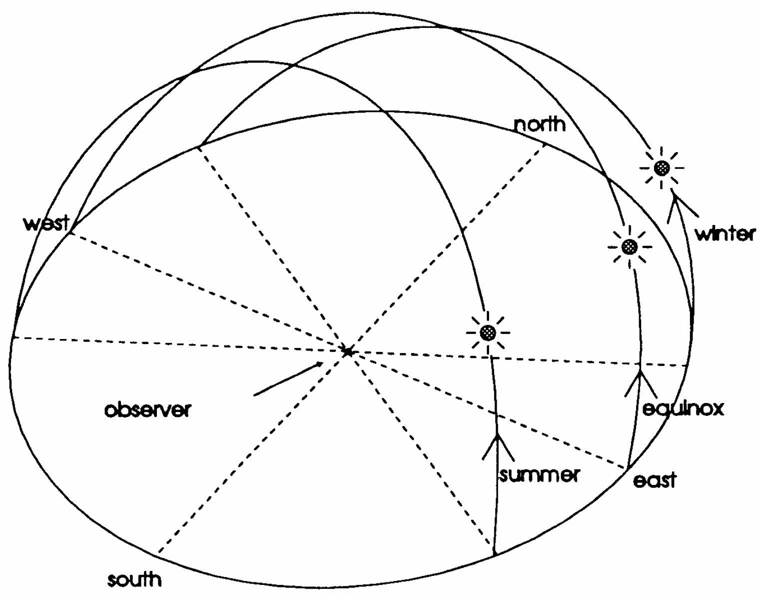


Figure 2.2.3 – Sun's path across the sky

This sun path helps to show why in summer, or in winter, flat plate solar collectors do not start producing hot water until 8am and cease at 4pm. It does not matter whether it is summer or winter (we are ignoring Daylight Saving time). They really perform best between about 10am and 2pm when the sun is close to right angles to the surface. After these times the sun's rays are at more of an angle and much of the radiation is reflected off the glass.

How to roughly assess if shading may occur

Shading is most likely to occur in winter when the sun is lower in the sky. An installer needs to know how far above the horizon the sun will be on the shortest day, at noon. This day (21 June) is when the sun is lowest in the sky all day.

Table 2.1 shows the midday, 9am and 3pm angle of the sun above the horizon (called the **altitude angle**) for the shortest day for various locations in Australia and New Zealand. It also shows the sun's altitude angle for the middle of spring/autumn.

Rule of Thumb 2.7 – Shading check at midday, for shortest day of year

Use an inclinometer to check for shading on the shortest day of the year (worst case) using the sun's angle above the horizon at noon using the angles in Table 2.1.

The sun's angle above the horizon at 9am and 3pm is roughly half the midday angle.

Table 2.1 – Sun's angle above the horizon at 9am, noon and 3pm for various latitudes and cities for winter, spring and autumn

Latitude (º)	**City**	**Season**	**Angle of sun (º)**		
			Altitude at 9am	*Altitude at noon*	*Altitude at 3pm*
12.5	Darwin	Winter	33	54	33
		Spring/Autumn	44	78	44
20.0	Townsville	Winter	28	47	28
		Spring/Autumn	42	70	42
27.5	Brisbane	Winter	23	39	23
		Spring/Autumn	39	63	39
32.5	Perth	Winter	20	34	20
		Spring/Autumn	37	58	37
35.0	Adelaide	Winter	18	32	18
	Canberra	Spring/Autumn	35	55	35
37.5	Melbourne	Winter	16	29	16
	Auckland	Spring/Autumn	34	53	34
42.5	Hobart	Winter	12	24	12
	Christchurch Wellington	Spring/Autumn	31	48	31
47.5	Dunedin	Winter	8	19	8
	Invercargill	Spring/Autumn	29	43	29

Source: Phillips

Using a compass and inclinometer, the installer should find where north is and then measure the altitude angle of any potential shading objects to the north, northeast and northwest of the collector's position. Measurements should be taken from the lowest point of the collectors to the nearest objects to the north.

The installer must now decide whether there will be shading of the collectors between 9am and 3pm. More accurate assessment is required in some cases. This requires the use of sun path diagrams, compass, inclinometer or sun path finder instruments. These methods and instruments are described in the Appendix.

What can be done about shading?

- Ignore it – if the shading is in the early morning or late afternoon it can probably be ignored. If it is only going to be partial shading and then only in the middle of winter, it can possibly be ignored. If the collectors are shaded right in the middle of the day and right across the collectors then it cannot be ignored. The shade will significantly reduce the output of the collectors.
- Remove the source of shading – it may be as simple as pruning back a tree or even removing it. It's not so easy if it is a neighbour's building.
- Relocate the collectors – install the collectors higher up the roof or on another part of the roof that is not going to be shaded. It is possible that if the collectors are a long way from the point of use, a close-coupled system should be replaced by a pump-circulated system with the hot water store near the main point of use (kitchen) and the collectors a long way away. Well-insulated pipes are required.
- Add additional collectors – to compensate for the effect of shading.
- Use an alternative form of solar water heating – such as air-sourced heat pumps or some other form of water heating. The bottom line is that a solar hot water system is an expensive piece of equipment. If it is to give a good return on its capital investment it needs to be performing for as much of the year as possible. If it is not going to do that then its installation is inappropriate.

Key points

- From the view of an observer on the Earth's surface, the sun travels across our sky from east to west. In summer, the sun rises to the south of east and sets to the south of west. In winter, it is the reverse, rising and setting to the north of east and west. This pattern exists for all latitudes. The difference is that at locations further from the equator (higher latitudes), the sun's path and time in the sky is much shorter in winter and longer in summer than for locations closer to the equator (lower latitudes). As the sun travels lower in the sky and for a shorter time in winter, then less solar energy is available over the day. The reverse applies in summer.
- The collector's orientation to the equator and its inclination from the horizontal affect the performance of the system. The general rule of thumb is to face the collector to the equator (true north) and tilt it at an angle approximately equal to the latitude angle for optimum year-round performance.
- Most systems, however, are not optimally located but are simply put on an existing northerly roof pitch to make installation easier and to reduce cost. This generally will reduce the system performance only a little when averaged over the year, but may reduce winter performance substantially.
- The minimum recommended inclination angle is 10º. This ensures proper thermosiphoning system operation and self-cleaning.
- The maximum recommended inclination angle is 50º. This avoids excessive shading of the collectors by the tank. Steep angles incur higher installation costs.
- The higher the inclination angle, the more important it is to face the collector to the equator.

Shading of collectors, particularly between 9am and 3pm, can significantly reduce the system performance and should be avoided by careful siting. To do this approximately, measure the altitude of the tops of potential shading objects from the lowest point on the collector using an inclinometer. Compare this angle with the midday, 9am and 3pm altitude angles of the sun using Table 2.1.

To do this accurately, you need:

- a compass and inclinometer
- a sun path diagram for your location (or nearest latitude)
- a chart of magnetic deviation from true north.

Or:

- a solar pathfinder instrument.

Refer to Annex 1.3 for more details on measuring sun path and shading.

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Section 2 questions

1. There are three critical ideas that need to be understood in order to obtain the maximum performance from flat plate solar collectors. Put another way, what needs to be understood when mounting solar collectors for a solar hot water system to give optimum performance? What are the three mounting conditions that must be understood?

2. In the previous question we were discussing optimal or 'best performance' conditions. In most installations these optimal conditions are not able to be provided. Why not?

3. Having discovered that very few roofs match the ideal orientation or slope, we ask the question of what happens if we do not match the ideal? The simple answer is, there can be significant variation from the ideal and it will not matter all that much. But what are the limits and when does the variation become significant? The way this is answered is using what would be a very common scenario.

   Orientation – How far off north would be the maximum that a roof could be for a square or rectangular house?

   Tilt (Inclination) – What is the most common roof angle?

   Given these two parameters, what effect will they have on the optimal performance? Put another way, how reduced will be the solar gain by getting away from the optimum?

4. What is the minimum and maximum tilt (inclination) that is acceptable for the mounting of collectors?

5. Clearly it is best if the collectors can be mounted in the optimum way, but significant variation is possible with very little adverse impact on the collector performance. There will be installations, however, when a special mounting frame will be required. List the situations where a mounting frame may have to be used.

6. It is desirable that there be no shading on solar collectors; however, there are times of the day when shading becomes unimportant. What are these times and why is the shading unimportant?

7. Why is shading more likely to be a problem in winter than in summer?

8. What is the date of the shortest day of the year – the day when the shadows will be their longest?

9. Arriving at a house (in Australia or New Zealand) where a solar water heater installation is planned, one of the first things that needs to be determined is the location of north. What are the methods that could be used to determine north? Is it true north or magnetic north that we require?

10. The angle of tilt of the collectors is usually determined by the slope of the roof. In order to check the slope of the roof an inclinometer or level and protractor can be used.

    a. If a roof where solar hot water collectors are to be mounted does not face north, but perhaps east or west, what effect does the roof slope have on the installation? Realise that this is not as straightforward a question as it seems. The latitude of the installation has an effect.

b. Suppose the roof is set at a low pitch, say 15º, and is located in Tasmania (latitude 40º), how might you compensate for the fact that in winter solar hot water production would be very poor?