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Sunny Days

Demystifying Solar Heating

by Andy Wilson

The sun is the source of most of our renewable energy supplies. Without the sun, there would be no weather or climate, no rivers, lakes or wind. We unconsciously use solar energy every single day in a myriad of ways, from the food we eat to the colours we enjoy in the world around us.

Essentially, the sun is an enormous fusion reactor which radiates energy out into space. This radiated energy is spread over a wide spectrum of wavelengths, ranging from ultraviolet to infrared with the visible part of the spectrum (which gives us colour) in the middle.

It is the infrared radiation which has the ability to warm surfaces it comes in contact with. The darker and less reflective the surface, the more heat energy can be absorbed. On a global level, the amount of solar radiation being reflected back into space is changing as a result of melting sea ice in Arctic areas. The exposed sea is much darker and less reflective than the ice which previously covered it, resulting in more solar radiation being absorbed. As is now known, this has serious implications for the stability of the earth's climate.

On a much smaller scale, solar radiation can be captured by solar panels to provide useful heat for domestic or municipal use. At these northern latitudes, solar heating systems are predominantly used for heating water, rather than for space heating.

This is because 77-81 percent of all solar radiation reaching Ireland arrives between the beginning of April and the end of September, when space heating requirements are very low. Domestic hot water heating requirements on the other hand, may actually be higher in the summer months because people tend to take more showers when the weather is warm.

A Year of Extremes

Because the sun is much lower in the sky in winter, the difference in solar radiation reaching Ireland on an average day in December and an average day in May, June or July is roughly a factor of ten. These average figures, however, do not tell the full story:

An analysis of twelve months solar data from the Met Eireann station at Dublin airport revealed that almost 100 times more solar radiation reached Dublin on the best day of the year (7.99 kWh/m^2) than on the worst (0. 08 kWh/m^2).

editors note: kWh/m^2 =kilowatt-hours of energy per square meter of horizontal surface

Of the 97 days when the total solar daily solar radiation at Dublin airport was under 1kWh/m^2, only 1 occurred between the beginning of April and the end of August while 82 occurred between the beginning of November and the end of February and included every single day in December. (see fig 1)

Domestic Hot Water

Estimates of domestic hot water requirements vary widely but a ballpark figure for a family of four is 3500kWh of heat energy per annum or about 10kWh per day.

Winter *space heating* requirements on the other hand may be as high as 200kWh in a single day. The family which uses 2000 litres of oil over a winter (not unheard of) will easily reach this figure on a cold windy day around Christmas time.

In Ireland it currently costs €5-8000 to have a domestic solar heating system installed. This seems extraordinarily bad value for money. At current oil prices and typically boiler efficiencies, it will cost under €400 per annum to provide domestic hot water for a family of four. Of this, the solar fraction (the proportion of total hot water provided by the solar heating system) may be as little as 15-20%.

In such cases, the value of the solar hot water may be no more than €60 per annum. A detailed assessment of solar water heating by Seamus Hoyne on behalf of the Tipperary Institute estimated the payback on a solar thermal system as 40 years! (see www.ilsu.ie/documents/SemRE/SHSolar.pdf)

Winter Contribution Tiny

Although it is often claimed that a good solar heating system will provide up to 20 percent of wintertime domestic hot water requirements, this is not the case.

The extremely low levels of solar radiation from mid November to early February will mean almost total dependency on conventional methods of heating water.

Even on those lovely but rare sunny winters days when there is potentially good solar energy to be harvested, no hot water can be drawn off a solar collector until it is heated to a higher tempature than the hot water cylinder to which the collector is connected.

In general, it can be assumed that on 90-110 days per annum, the output from the average solar heating system will be close to zero.

For a household which has a daily hot water requirement of 10kWh, a 6m2 solar collector with an overall system efficiency of 40% (well above average) will fully meet their needs only on days on which the total solar radiation exceeds 3kWh/m². [1]

An analysis of figures taken over a twelve month period by Met Eireann at Dublin airport showed that solar radiation exceeded this level on a total of 124 days, but that only one of these days occurred between Sept 21st and March 21st. On the best days in May, June and July however, solar radiation exceeded 7kWh/m².

Storage Capacity

The size of the cylinder used to store the hot water is also a major factor in determining the efficiency of a solar heating system. Many cylinders hold only about twenty four hours supply of hot water, so a number of sunny days in a row might count for very little if they are followed by two really poor days of wet and cloudy weather.

To best utilise Ireland's very variable solar resource, where the daily solar radiation on two consecutive days may vary by a factor of seven (as occurred 25-26 June 2006), a minimum of two days storage capacity is essential.

The performance of a solar heating system can be badly compromised by poor lagging of the hot water cylinder and pipes. Unlike an oil fired boiler, solar collectors can not be 'turned up' in order to compensate for lazy or careless installation practices. Whereas a 25kW boiler will eventually overcome circulation heat losses, the solar collector may simply be rendered redundant.

Resource Management

A consideration only rarely discussed in the solar energy sector is the management of the resource. To give an example, a very large percentage of new houses are fitted with electric showers which heat their own water using an internal heating element. Many dishwashers and washing machines also heat their own water, though some can accept external sources of warm water and will then boost the water to the desired operating temperature using an internal heating element.

In many cases, half to two thirds of a modern households domestic hot water needs will be accounted for by appliances which are unable to utilise solar heated water. At best about 60 percent of the remaining hot water requirements will be met by a solar heating system, and most of this contribution will occur during in the summer months.

This suggests that less than one third of the typical household's total hot water requirement can be met by a solar heating system, and in some cases the figure could be as little as one sixth. Doubling the size of the collector makes very little difference (see fig 2).

These figures are considerably at odds with the '60 percent of all domestic hot water requirements' mantra repeated endlessly by the solar heating industry and even by SEI, the Government body responsible for implementing the grants for renewable energy.

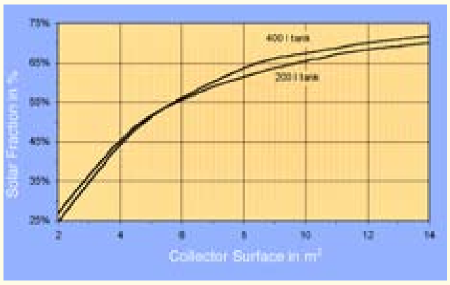

fig 2 At collector areas greater than 6m², the solar fraction increases only marginally.
Volker Quaschning: Renewable Energy

The way in which the solar resource is used on a day to day basis will also be a significant factor in the efficiency of the system. For example, it is better to use the hot water as soon as possible after it is heated, for every hour it sits in the cylinder it will be gradually cooling.

Where there are non-electric showers fed directly by the hot water cylinder, it is better to take showers in the evening rather than first thing in the morning. This is particularly the case during March or October when solar output can still be significant but may be compromised by the use of conventional energy sources to heat the thermal store. Unfortunately, very little attempt has been made by either the State or

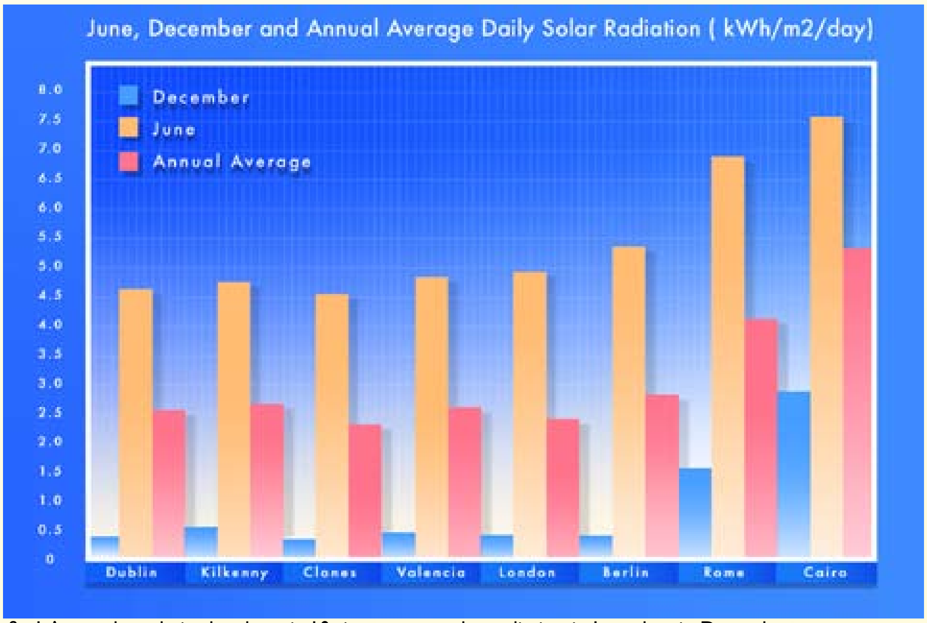

fig 1 At northern latitudes there is 10 times more solar radiation in June than in December

the solar energy industry to educate the consumer in solar energy management.

Instead, the unspoken assumption is that scalding hot water must always be available on demand, with nary a thought about where the non-solar fraction of domestic requirements will come from.

Space Heating Myths

It is stated on the SEI website that a solar thermal system providing space and water heating can "cover 30 to 40 percent of the annual [total] heating requirement of a house in Northern Europe". Elsewhere on the site, however, there is government data indicating that the average house in Ireland requires 20,000 kWh of heat energy per annum for space heating. Unfortunately, there is something of a contradiction in the two pieces of information.

Assuming four fifths of the annual space heating demand occurs between the beginning of October and the end of March, and that a solar collector is able to capture 40 percent of incoming solar radiation in the winter months (very optimistic), 40m² of solar panels and a thermal store in excess of 20,000 litres in size would be required in order to meet '30-40 percent' of heating requirements from solar. This would seem a trifle ambitious for the average household.
The bottom line is that solar collectors are very good for heating water from April through to September, and can make some useful contribution in the two months either side. For the simple reason that the time of year when their output is lowest coincides with the period when domestic space heating requirements are highest, they make extremely poor space heaters.

Evacuated Tube or Flat Plate

It is often taken as a given that evacuated tube collectors are more efficient than flat plate collectors. This however may not be the case. Tests carried out on 160+ different solar panels by the internationally acclaimed research organisation Solartechnik Prufung Forschung (SPF) found that the *gross efficiency* of flat plate collectors was considerably higher than evacuated tube collectors.

The gross efficiency is a measure of the percentage of the total solar radiation falling on the solar collector which the collector is able to capture. The average gross efficiency of the 120 flat plate collectors tested by SPF was about 70 percent, whereas the 42 evacuated tube collectors examined only averaged 50 percent.[2]

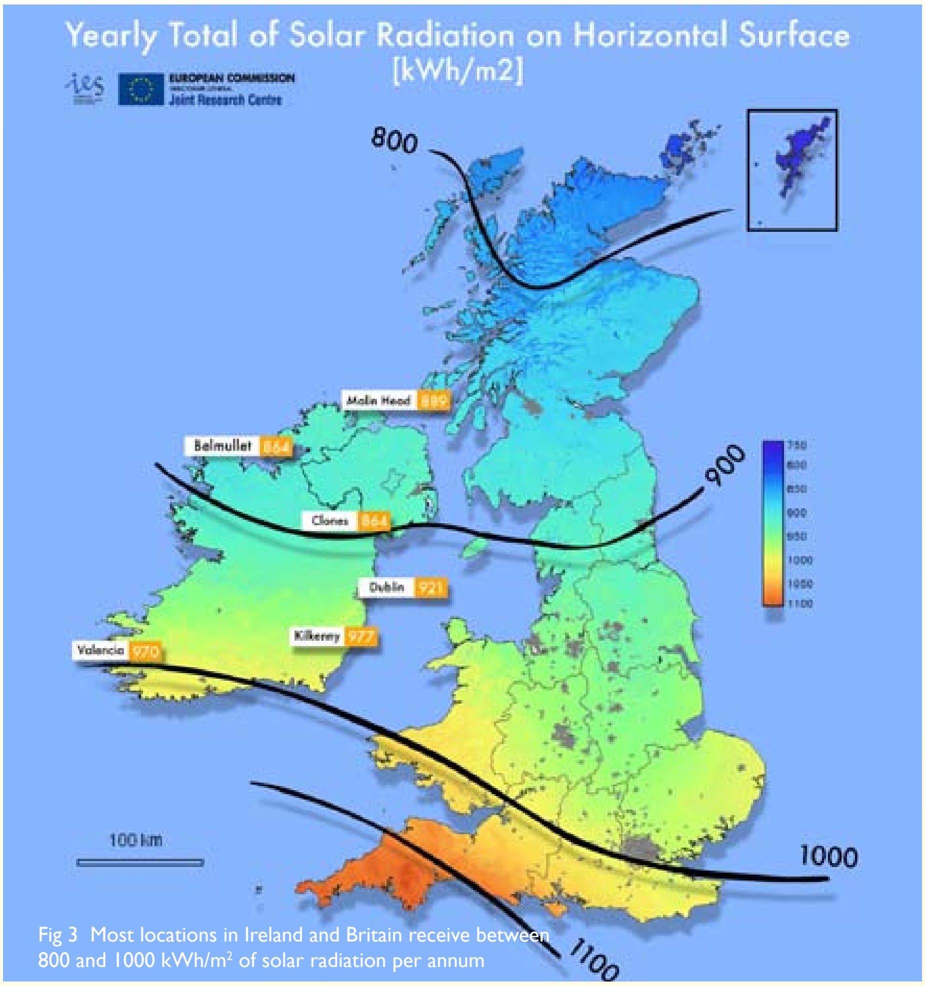

Fig 3 Most locations in Ireland and Britain receive between 800 and 1000 kWh/m² of solar radiation per annum

Massaging the Data

The manufacturers of evacuated tubes are able to claim their products are more efficient than flat plates by the simple expedient of comparing only the area of the aperture (the bit the sun shines through) of the two types of collector. On average, the aperture of an evacuated tube captures solar radiation more efficiently than the flat plate. There is however considerable variation between different models.

Much more significant however is the relationship between the aperture area and the gross dimensions of the panel. While the aperture of a flat plate collector may exceed nine tenths of the total area of the collector, the proportion is is lttle more than half with evacuated tube collectors. Any solar radiation falling on the space between the evacuated tubes is effectively lost.

The SPF results also gave some clear indications as to the source countries of the best and worst performing panels. Of the flat plate collectors tested, models manufactured in Austria and Germany were among the most efficient. The best performing evacuated tube collectors were manufactured in Switzerland and Northern Ireland.[3]
At the other end of the scale, six of the ten worst performing evacuated tube collectors were manufactured in China. The tests showed that the best performing collectors were more than twice as efficient as the worst ones.

Working Efficiency

It should be noted that the *working efficiency* of a solar collector when used for domestic water heating is only about three quarters of the gross efficiency. This is because the efficiency of the collector varies according to the manner in which the solar-heated water is used. Efficiency tends to fall as the temperature of the thermal store increases. In domestic situations, the relatively high temperature of the thermal store means that solar panels will operate at reduced levels of efficiency.

When calculating likely output from a solar heating system, it is also necessary to factor in heat losses from the thermal store and circulation system. Thus a 40 perecent working efficiency may translate into a 30 percent *overall system efficiency*. Of the 900 kWh of solar radiation falling on each square meter of solar collector per annum, only about 270kWh will be utilised.

Are Swiss Results Valid?

It has been argued that because the SPF tests were carried out in Switzerland, the results are not valid for countries like Ireland and Britain. Certainly there are differences in the climates. Switzerland receives roughly one third more solar radiation than Ireland annually and two to three times as much during December and January. During the summer however the difference between the two countries is small. Switzerland suffers much colder winter temperatures which one would have expected to disadvantage flat plate collectors as they tend to lose heat faster. However, this disadvantage may be cancelled out by the lower wind speeds in Switzerland.

In Ireland there are more days with very poor levels of solar radiation, and on these particular days the evacuated tubes may out-perform the flat plates.

As analysis of the Dublin airport figures revealed however that the combined solar radiation on the 100 *worst* days of the year contributes only a little over 6 percent of the total annual solar radiation, astonishing as this might seem. So even if the evacuated tubes were to perform twice as well on these days, the net gain would be very small.

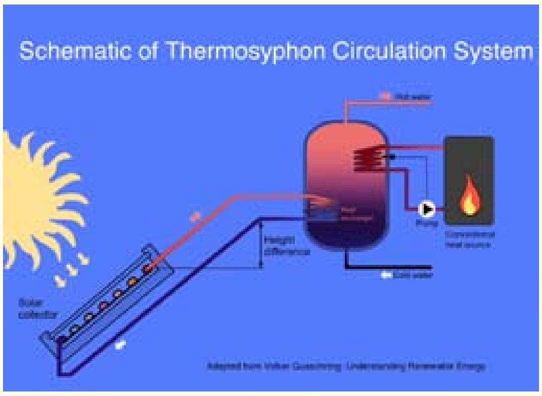

Fig 4 Where the hot water cylinder is higher than the solar collector a pump may not be neccessary. The water circulates by thermosyphon.

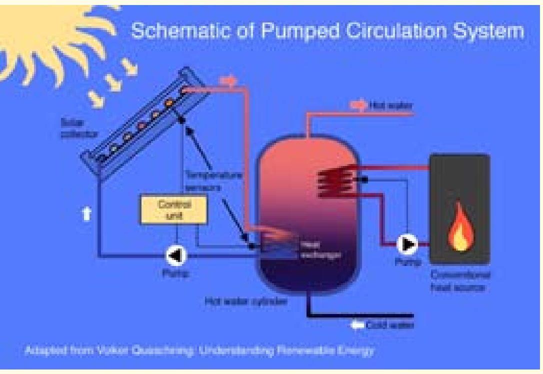

Fig 5 Where the hot water cylinder is lower or at the same height as the collector, a pump is necessary for circulation.

UK Tests

In different tests, this time carried out by the UK Department Trade and Industry on 8 models of solar panels, the evacuated tube collectors used performed better than the flat plates but the small sample suggests these results should be viewed with some caution.

The two evacuated tube collectors tested are among the best of their type on the market and were certainly not representative of the whole sector. The flat plate collectors included five models glazed with synthetic materials such as twin wall polycarbonate, which have much lower optical efficiency than glass.

One of the models tested was the Solar Twin, which uses a tiny solar photovoltaic panel to operate the circulation pump. The pump comes on whenever solar radiation levels are sufficient to deliver the required electrical output from the photovoltaic panel. While this conveniently removes the need for sophisticated controls, it also means that sometimes the water is being circulated when the collector temperature is lower than the temperature of the thermal store. As a result the overall efficiency of the Solar Twin is low.[4]

While clearly there is a need for considerably more research into the performance of solar collectors, claims that evacuated tubes collectors are more efficient than flat plates should certainly be treated with suspicion and need to be properly qualified.

Flat Plates are the Future

The flat plate collectors have a number of other advantages over evacuated tubes. They require only half the embodied energy of evacuated tubes to manufacture, even excluding the energy used in transport to import evacuated tubes from places like China. The production process associated with flat plates is less complicated, which lends itself to localised small scale production. Flat plates are normally cheaper than evacuated tubes.

The tendency in most European countries is towards flat plates. According to the European Solar Thermal Industry, of the 1,500,000 m^2 of solar collectors installed in 2005, over 91 percent were flat plates.

In Austria, many flat plate collectors are available in kit form, and there is a thriving industry based on low cost DIY solar. At the end of 2005, Austria had over 100 times more installed solar panels per head of population than Ireland. Less than 1 percent of solar collectors installed in Austria in 2005 were evacuated tubes, compared with an estimated 30-40 percent in Ireland and Britain.

The European leader in solar thermal is now Denmark, with over 7,000,000 m^2 of installed solar capacity. Ireland's installed solar capacity is around 20,000 m^2, while Britain's capacity is about 240,000m^2. As Denmark shows, installed capacity has little to do with climate or annual solar radiation levels, but is more a reflection of national priorities.

Price may also be a factor. In Ireland, domestic solar thermal installations are overpriced by 2-300 percent. By far the most economical way to install solar collectors is to forget the government grants which are available, buy the collector and hot water cylinder separately and do the plumbing work yourself (with help from friends or a local plumber if necessary).

Conclusions

Solar energy is an amazing resource, and the equipment to harness it for heating purposes, once installed, requires little maintenance and has a long life. Unfortunately, Ireland, like Britain, has got off to a very bad start in developing the sector. For a role model, we should look to Austria, where almost every town of any size has classes in DIY solar installation and where the component parts can be purchased locally.

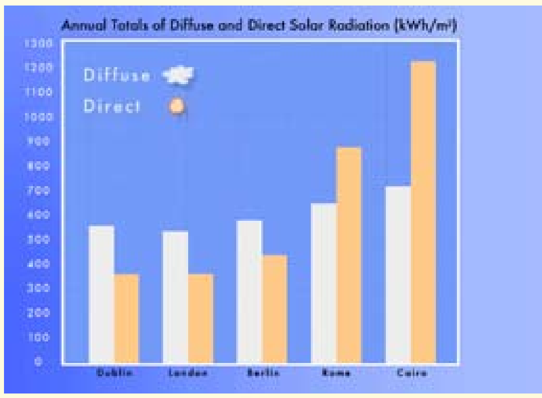

Fig 6 In northern Europe, less than half of solar radiation comes from direct sunshine

The installation of any solar equipment should always be preceded by a careful evaluation of energy demand, with the aim of streamlining energy usage and maximising the energy efficiency.
For renewable energy to be used to best advantage, education is probably the single most important tool. Solar thermal technology is not rocket science. It could be taught in schools and at evening classes aimed at adults. The long term objective should be an indigenous, localised solar thermal industry producing low cost easy to install solar collectors for mass deployment in a manner similar to Austria. There is some way to go.

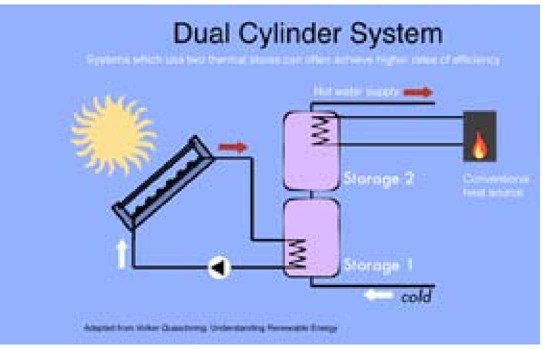

Fig 7 Using two cylinders in series. Volker Quaschning

Notes

1 Assumes overall system efficiency of 41.7%, which is generous

2 The SPF website: www.solarenergy.ch is well worth a visit. Click on the English language version, go to 'test reports' then 'collectors'. There is a downloadable pdf for each collector tested. On page two of the pdf the gross efficiency of the collector is given. A figure of 0.408 for example, means the gross efficiency of the collector is 40.8%. The outputs in kWh/m2/yr are given for aperture taken in isolation, so a further calculation is needed to determine the output per square meter of panel.

3 Thermomax Ltd, Bangor

4 See www.dti.gov.uk/files/file16826.pdf.

Forthcoming Tests

The Sustainability Institute intends to carry out tests on a number of commercial solar collectors over a 12 month period.. We are asking suppliers/ manufactures to donate collectors for testing. At present, we still need to raise a further €3500.00 for test equipment, hot water cylinders, and other installation accessories. If you would like to support our work, please take out a subscription to the magazine and/or make an individual or corporate donation to The Sustainability Institute. Any help, no matter how small, will be greatly appreciated.

The Institute also runs workshops on DIY Solar Thermal. Further details are elsewhere in this magazine and on our website. A DIY solar collector made from recycled domestic radiators erected on a site near Westport has circulated water at over 90ºC!!

Solar Heating Glossary

Collector
The collector is the part which captures the solar radiation. There are two main types:

The **flat plate collector**, which can be thought of as a large radiator in a glass (occasionally polycarbonate or acrylic) fronted box.

The **evacuated tube collector**, which is more like a series of long transparent thermos flasks each with a water pipe running up the middle.

Both come in a range of sizes, but 2-3m² is fairly typical. Where larger installations are needed, collectors are connected together in series or parallel.

Thermal Store
This is just another name for the hot water cylinder. In spite of the solar industry preference for expensive stainless steel cylinders, there are many good reasons for using the more traditional and much cheaper copper cylinder. Usually the cylinder will require two internal coils, one for the solar circuit (the lower coil) and one for a conventional heat source such as a stove or boiler.

Circulation System
The circulation system is the bit which connects collector with thermal store. Usually it is a closed loop with integral expansion cylinder, pressure release valve or vent pipe to relieve excess pressure should it occur. The longer the circuit, the greater the heat losses on route.

Controls
The simplest solar heating circuits require no pump. Instead circulation is effected through thermosyphon. For this to work, the collector must be below the thermal store, and there should be a constant upward gradient between the two. The beauty of this type of circulation system is that nothing can go wrong. See Fig 4

In most installations, the collector will end up higher than the store, so a pump must be used for circulation. Ideally the pump should only be running when the collector temperature is higher than the store temperature, or there is the risk of re-circulating warm water from the store back into the collector. See Fig 5

One solution is to use a controller which has two sensors to monitor collector and store temperatures. When the collector is warmer than the store by a predetermined number of degrees (usually 5-8º) the pump is activated. When the difference between the two drops, the pump turns off again.

The Solar Twin System, is to use a small solar PV panel to run the pump. The underlying princple is that if there is sufficient solar radiation to activate the pump, there is a need for the pump to be going. It sort of works.

User
The success of the system does require some intelligence on the part of the user. A solar panel is not an immersion heater. It will not heat water on demand, but only when there is an adequate level of solar radiation. Watch the system and see how it works. A useful educational aid is a small dial thermometer which can be clipped to the domestic hot water supply pipe where it leaves the cylinder. This will indicate the water temperature at the top of the cylinder (some solar pump controllers have digital temperature displays).

Rules of Thumb for Domestic Water Heating

The area of collector required is 1-2m² per permanent inhabitant of the building. The low end of the scale is more applicable for larger households as there will be some economies of scale and greater degree of efficiency within the system.

The volume of thermal store should be 60-120 litres per m² of collector. The store should be much taller than it is wide, in order to facilitate stratification. A height to width ratio of 2.5-3:1 is recommended. Stratification allows the hottest water to rise and form a layer at the top of the cylinder, where it can easily be drawn off.

The collector should be orientated somewhere between SE and SW and be in an open unshaded position. The angle of inclination is not critical but 20-40 degrees from the horizontal will give best results. Only 40 percent of the solar radiation reaching us is from direct sunlight, the rest is defuse and comes from a much wider part of the sky.

On average, around 65-70% of the total daily incoming solar radiation occurs during a 6 hour period straddling the middle of the day.