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SERIES 13 | MODULE 08 | SOLAR THERMAL ENERGY

Making use of solar thermal energy

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Solar thermal energy is a valuable resource that for many is not as well understood as it might be. An earlier module in this series [Series 10, Module 4, September 2012 issue][1] covered domestic installations thoroughly and this module extends that, with references back as appropriate, to commercial and industrial systems.

The owner of a building with space available for solar energy collection faces a choice whether to use solar thermal energy, to generate electricity through PV (photovoltaic cells), or indeed hybrid solutions (PV-T). While it is not the purpose of this module to deal with photovoltaic systems, it is important to consider this choice early in any investigation.

We therefore review the competing technologies, and then focus upon solar thermal systems. There are many computer tools that will assist in the design and cost-benefit analysis of solar thermal systems, but it is useful to understand the basis of how these tools work. This, and how solar thermal can be integrated into consumer systems, forms the subject of the following.

Solar thermal systems heat a fluid (usually water or an antifreeze solution) in panels designed to capture solar radiation.

As their name implies, photovoltaic (PV) systems are designed to capture solar radiation and convert it to electricity. They are introduced in an earlier article in this series [Series 9 Module 8, February 2012 issue][2].

Aside from their appearance the property of PV panels that most dramatically differs from solar thermal is the efficiency with which they capture solar energy. Solar thermal systems achieve efficiencies in the range 60-80 per cent (as discussed below), whereas the more efficient PV panels currently available achieve a little over 22 per cent[3], at a cost, with the more economic choices typically several percentage points less.

This is not the whole story of course, because electricity has a greater value than thermal energy, which will tend to offset the lower efficiency. A cost/benefit analysis for the two technologies located in the available space, is required to make the most rational choice.

Hybrid or PVT panels at first sight offer the best of both worlds, offering both electrical and heat output. Their advocates correctly point out that PV panels tend to get hot during operation, yet operate better at lower temperatures: most panels have their performance quoted at 20 or 25°C. Therefore manufacturers offer PV panels that are cooled by either water or ducted air.

For water-based models there is a conflict: if the objective is to maximise the output of the PV elements the water must be at the cooler end of the desirable range in order to provide the cooling. Conversely if maximising heat and temperature output is the objective, the PV elements will have to operate in the higher temperature range and hence suffer in efficiency. Manufacturers deal with this by offering PV-T panels that are biased to prioritise electrical or thermal output, and claim combined outputs that are higher than panels designed separately for either output.

Air cooled models operate a temperature determined by ambient temperature and hence closer to the ideal conditions for PV panels, and ducting the air to building air intakes offers 'free' preheating of the air for distribution. This does of course introduce an extra cost for the ducting, but where air intakes and panels can be located with short ducting runs this may be attractive.

The reader will observe that PV and PV-T panels get hottest when heating is least required: in warmer weather. This is also true of solar thermal panels and is often considered as representing a fatal flaw for all solar heat-producing systems. However, even in temperate climates like the UK, the output of solar thermal panels can provide an attractive payback in domestic and commercial situations.

Solar radiation falling on the earth's surface is usually expressed as either irradiance or insolation. While the two terms are sometimes used interchangeably:

- irradiance is analogous to power: the instantaneous radiation at any one time measured in SI unit usually as W/m².
- insolation is analogous to energy and is the cumulative irradiance over a time. In SI units it is measured in kWh/m²/yr (or some other time period)

Both of these figures are useful, for predicting peak and time-based outputs respectively.

The most common stating point is referred to as the Global Horizontal Irradiance (GHI): the radiation falling on a square meter of the earth's surface. This is calculated from the diffuse radiation (Direct Horizontal Irradiance – DHI) and

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Table 1 – Global Horizontal Irradiance for UK locations

Place	Latitude	Longitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aberdeen	57.17	-1.92	0.456	1.092	2.222	3.114	4.642	4.664	4.294	3.717	2.353	1.322	0.492	0.292
Aberdeen - Dyce Arpt	57.2	-2.22	0.472	1.108	2.444	3.708	4.875	4.564	4.442	3.553	2.450	1.439	0.672	0.372
Aberporth	52.13	-4.57	0.739	1.422	2.561	4.133	5.125	5.553	4.997	4.197	3.072	1.717	0.839	0.581
Aviemore	57.2	-3.83	0.419	1.053	2.103	3.333	4.475	4.578	4.192	3.486	2.431	1.294	0.572	0.317
Belfast - Aldergrove Arpt	54.67	-6.22	0.528	1.194	2.136	3.614	4.850	4.875	4.456	3.664	2.647	1.464	0.711	0.433
Boulmer	55.42	-1.6	0.619	1.214	2.475	3.842	5.164	5.097	4.708	3.781	2.786	1.625	0.794	0.464
Bracknell	51.38	-0.78	0.683	1.367	2.408	3.619	4.683	5.044	5.044	4.378	2.861	1.861	0.911	0.558
Camborne	50.22	-5.32	0.819	1.517	2.575	4.181	5.106	5.619	5.011	4.486	3.356	1.922	1.019	0.689
Dunstaffnage	56.57	-5.43	0.383	0.933	1.944	3.394	4.411	4.456	3.892	3.258	2.297	1.192	0.494	0.306
Edinburgh	56.45	-3.07	0.469	1.119	2.144	3.431	4.717	4.889	4.614	3.789	2.589	1.400	0.664	0.342
Eskdalemuir	55.32	-3.2	0.433	1.017	1.889	3.161	4.219	4.214	4.117	3.389	2.453	1.317	0.608	0.375
Hemsby	52.68	1.68	0.672	1.431	2.386	3.900	5.058	5.239	5.214	4.539	2.872	1.778	0.894	0.506
Jersey Arpt	49.22	-2.2	0.878	1.558	2.744	4.142	5.364	5.967	5.756	4.939	3.544	2.089	1.083	0.661
Lerwick	60.13	-1.18	0.258	0.781	1.744	3.078	4.569	4.539	3.992	3.353	2.097	1.042	0.369	0.161
London Weather Centre	51.52	0.12	0.678	1.306	2.317	3.517	4.597	5.011	4.878	4.308	2.911	1.800	0.872	0.542
Odiham	51.23	-0.95	0.786	1.408	2.669	4.272	4.783	5.728	5.194	3.967	3.128	1.831	0.981	0.625
Waddington	53.17	-0.52	0.689	1.272	2.494	3.961	4.756	5.381	5.111	3.972	2.975	1.717	0.922	0.594
Wattisham	52.12	0.97	0.736	1.425	2.639	4.544	4.964	5.533	5.094	4.072	2.983	1.742	0.894	0.639

the direct radiation of the sun (Direct Normal Irradiance - DNI) by the equation:

GHI = DHI + DNI x cosϕz,

where ϕz is the angle of the sun from the vertical at the time.

Fortunately, it is not necessary to measure these variables unless the project requires great precision, because all of this data is available from a number of ready sources. The most easily accessible is the free OpenSolarDB[4]. Others are available for a subscription fee[5].

The data from OpenSolar DB for some UK locations is reproduced in Table 1 - Horizontal Irradiance for UK locations. The units in the body of the table are the average insolation in kWh/m^2/day. Negative longitude is west of the Greenwich Meridian and a negative longitude would be in the Southern hemisphere.

Leaving out Jersey and the Shetlands (Lerwick), these data give an average of 973 kWh/m²/yr +/- approximately 15 per cent. This gives rise to a rule of thumb that global insolation for the UK is about 1,000kWh/m².

However this data relates to a horizontal plane and it is common to set solar panels at an angle to the horizontal so as to face the sun better. This is less important in tropical and near-tropical regions where the benefit from the angle is offset by the shading that one inclined panel causes on the next. In temperate climates inclining the panel does offer benefits.

It is difficult to calculate the radiation on an inclined plane manually from Insolation data, especially where, as in Table 1, the data does not separate the DHI and DNI: only the direct component is affected by the angle. Software is available to calculate this, Retscreen is one, and is free: other tools are available.

The UK SAP calculation Appendix H also provides a version of this calculation, and continues through the next steps in this procedure to estimate a final yield. SAP is intended for use in Domestic situations, but in this instance provides useable results for larger installations. Most of the commercial building HVAC modelling and design packages also include a module that performs similar calculations.

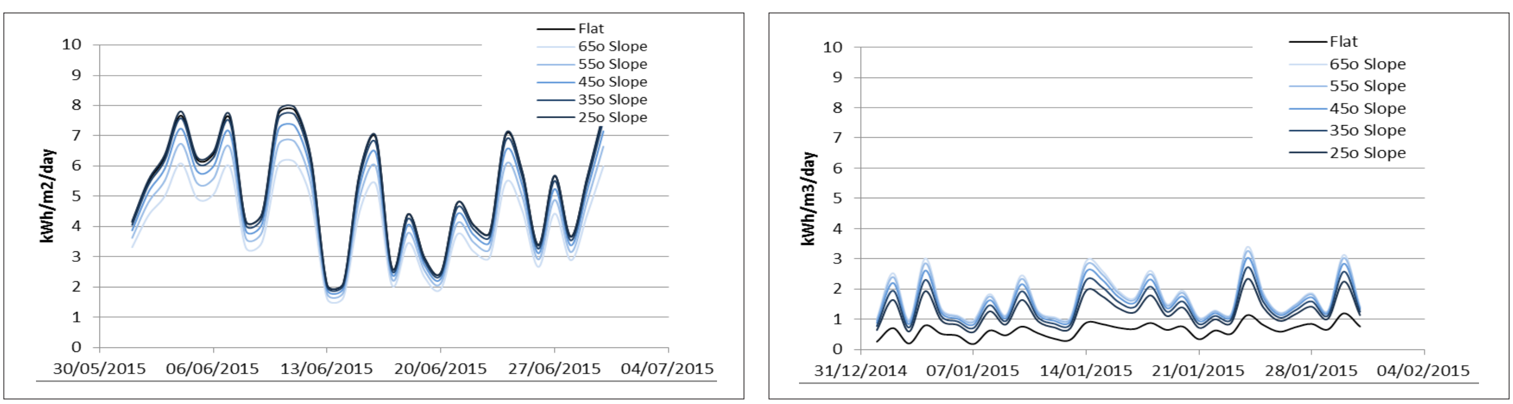
Figure 1 shows the benefit of sloping the panel at different angles, with results taken from Retscreen. Data is for January and June 2015 for Waddington in Lincolnshire, UK, which is close to the mid-latitude for the UK.

The data assumes that the slope of the panel is facing solar south (the position of the sun at midday – this is often not the same as Compass South.

In the January data the best result is for a panel inclined at 65°, and in June a flat or 25° panel gives the best result. Overall the highest annual total figures are for a 45° slope, which is often taken as the rule-of-thumb angle for UK installations.

From the table, the reduction in total insolation either side of 45° is not substantially less, and a greater or lesser slope can be used to optimise output for the time when the hot water will be most valuable. This always bears consideration.

Figure 1 – Variation of incident radiation for sloped surfaces, January and June 2015



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The receiving area of thermal panels is less than the plan area the panel occupies. Manufacturers try to minimise the 'wasted' space in their panels, but space is still required for frames, connections, and on larger installations, access. Therefore the available area for collecting heat is less than the floor (or roof) area available.

For domestic installations, 2 to 6m² will be sufficient depending on occupancy. For installations wishing to maximise the use of an available area, for example on the roof of a commercial building, it is best to prepare a layout drawing using the actual dimensions of the panels. Panel dimensions are quoted by the manufacturers

The space required for framing of the panels varies from manufacturer to manufacturer, and with the type of panel selected. The dimensions and some other properties required for calculation are listed below. A comprehensive data set of manufacturers is provided within Retscreenvi and also from other sources[6].

The properties of the panel required for a fair estimate of the likely output are:

- aperture area (in m² per panel);
- conversion (or collection) efficiency, η0; a percentage in the range 75 to 85 per cent (Note that this assumes zero heat losses from the panel);
- heat loss coefficient a1: the first order heat loss coefficient used in the equation below below (units: Watts/(m².K));
- heat loss coefficient a2: the second order heat loss coefficient used in Equation 2 below (units: Watts/(m².K)). This is required for most calculations, but not for UK SAP 2009.
- longitudinal Angle Modifier K1 (a decimal fraction);
- transversal Angle Modifier K2 (a decimal fraction).

The full efficiency, η, of a panel installation can be calculated from the following equation:

$\eta = \eta 0 - a1.\{(Tm - Ta)/Gr\} - a2.\{(Tm - Ta)/GT\}2$[7]

where η0, a1 and a2 are as defined above, Tm is the mean temperature of fluid in the panel, Ta is the ambient temperature and GT is the average insolation to the panel. This correction can be applied hour-by hour when the data is available, or to reasonable approximation, using annual daytime averages.

The final correction reflects the sensitivity to the plane of the panel relative to the sun: the Incident Angle Modifier (IAM). Although the angle of the sun relative to the panel is taken into account in Insolation results like those shown in Table 2, different panel designs are able to absorb different proportions of the incident radiation as the sun's angle changes. This applies to both the seasonal movement higher or lower in the sky (Longitudinal) and the daily movement of the sun east to west (Transversal) and hence two factors are required. The properties of the panel K1 and K2 referenced above are an annual average that may be applied to annual figures multiplying the efficiency or output. Some manufacturers can also provide values of these factors for different sun angles in the two planes and these can be used for hour by hour calculations. Note that for evacuated tube panels (see below) K2 can be greater than 1.

Panel types

The types of panel available are widely discussed elsewhere, so this discussion is deliberately short.

Flat plate collectors are a literally a flat plate, usually metal (copper or aluminium) treated with a solar-absorbing coating, and with a similar metal tube carrying the collection fluid (usually water or antifreeze). They are usually well insulated at the back to prevent heat losses and may be glazed (double or single, glass or other materials) at the front for the same reason. Of course glazing in front of the panel reduces the efficiency of the assembly and this is a major cause of reduced collection efficiencies. Manufacturers trade-off this aspect of collection efficiency (η0) with the heat loss coefficients (a1 and a2).

Evacuated tube collectors are a series of double walled tubes. The outer tube is glass and the inner tube usually metal with a solar-absorbing coating. The first benefit is that the space between the two is a vacuum, keeping heat losses to a very low-level as in a vacuum flask. The second is that the circular section of the tube means that their surfaces are perpendicular to the sun's rays to for a larger proportion of the time, and this leads to higher values of constant K2 described above. Evacuated tube types are more expensive than flat plates type and, due to their glass construction, more fragile than flat plates.

Integration with hot water and heating systems

The integration of solar thermal panels into domestic systems is well described in earlier module in this series [Series 10, Module 4, September 2012 issue]i. It shows connection to a hot water storage tank: similar to the ones traditionally installed in UK homes, but either an additional tank or a single tank with a second coil. It shows the two ways of avoiding freezing (and of avoiding radiating useful heat out through the panels):

'Drainback': emptying the panel when there is no heat gain

Using antifreeze solution, so the panels can remain fully flooded.

If the aim of a larger installation in commercial or industrial premises is to heat domestic hot water for taps and showers, the principles are exactly the same. A storage tank is required, because the use of the hot water is most unlikely to coincide with consumption patterns.

In large installations, the legionella risk is proportionally greater, and the UK Health and Safety Executive provides guidance on controlling the risk[8]. Most users chose the option of heating water to 60°C before distribution. Solar thermal systems will not achieve this alone all of the time, so the simplest way to make use of the heat is to use a separate make-up water tank as a store of pre-heated water which then passes, to a standard domestic hot water system heater and circulation system.

Using the heat for space heating is possible but affects design decisions for the system as a whole. It is normal practice to circulate hot water for heating at 75 or 80°C, with a return temperature of 60 to 70°C. While solar thermal panels, especially the evacuated-tube type, can achieve these temperatures at times and provide some pre-heat, the contribution to the system is unlikely to be sufficient to provide an economic case for the installation.

As required space temperatures are generally around 20°C, it is possible to provide heating from hot water at flow temperatures as low as 50°C. This requires that all of the heat emitters (radiators, heating coils) are considerably larger than common practice. This of course adds costs to the heat distribution system. Under-floor heating systems can run at this and sometimes lower temperatures, so are worth considering. The solar installation would then work in the return line, in series and before the normal heat input (boiler, etc). It is a matter of judgement whether or not a storage tank is required for this application.

In the UK, the RHI provides a subsidy for using renewable heat, including solar thermal installations up to 200kWth. The procedures applicable to claiming under the incentive are available from Ofgem[9]. For domestic installations an Energy Performance Certificate[10] is required. Non-domestic installations under 45kWth require MCS Certification[11] which for Solar thermal energy effectively means that panels listed under the CEN Solar Keymark database[12] must be used.

From 1st January 2016 the RHI tariff rates payable for solar thermal output are 19.51p/kWh for domestic installations and 10.16p/kWh for non-domestic installations. These are reviewed periodically and may reduce in future, but the tariff rate is fixed at the time of application and will not reduce after that. The fixed payments will increase in line with the Retail Price Index.

Table 2 - Incident radiation on an inclined plane

Slope	Flat	65 degrees	55 degrees	45 degrees	35 degrees	25 degrees
Year	Total insolation kWh/m2 in year					
Average	982	1134	1181	1201	1195	1164
2011	1043	1219	1267	1287	1278	1243
2012	979	1167	1210	1225	1214	1177
2013	963	1096	1143	1165	1161	1133
2014	944	1083	1128	1148	1143	1114
2015	981	1108	1157	1180	1177	1150

References

1. Also available at https://www.energyinst.org/training/energy-management-courses/cpd-articles

2. Ditto.

3. At date of writing: January 2016.

4. http://www.opensolardb.org/db/extractcopypaste

5. A listing can be found at http://www.photovoltaic-software.com/solar-radiation-database.php

6. At http://www.spf.ch/Collectors.111.0.html?&L=6 see also ref xiii below, where panel datasheets are available.

7. Widely used equation, e.g. Solar Panel Efficiency in SAP 2009 – Products with High Second Order Coefficients, Stuart Elmes MA. http://www.viridiansolar.co.uk/Briefings/Solar_Panel_Efficiency_in%20SAP_2009_Second_Order_Coefficients.pdf

8. UK Health and Safety executive: "Legionnaires' disease: The control of Legionella bacteria in water systems (L8)". ISBN 9780717666157

9. Non-domestic RHI: https://www.ofgem.gov.uk/publications-and-updates/non-domestic-rhi-main-guidance, Domestic RHI: https://www.ofgem.gov.uk/environmental-programmes/domestic-renewable-heat-incentive-domestic-rhi/about-domestic-rhi

10. https://www.ofgem.gov.uk/key-term-explained/energy-performance-certificate-epc

11. http://www.microgenerationcertification.org/mcs-standards/equivalent-schemes

12. http://www.solarkeymark.dk/

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CPD ENTRY FORM

SOLAR THERMAL ENERGY

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

QUESTIONS

1. What is the meaning of the acronym PV-T?

☐ Polyvalent thermodynamic.
☐ Photovoltaic tiles.
☐ Photovoltaic thermal
☐ Photo vivicated thermal

2. What is the most important difference between photovoltaic and solar thermal panels (aside from the output of electricity or heat)?

☐ Appearance
☐ Operating temperature.
☐ Desirable angle of inclination.
☐ Efficiency

3. What is the meaning of the term GHI, Global Horizontal Irradiance?

☐ The direct heat of the sun falling on one square meter of the Earth's surface.
☐ The direct heat of the sun falling on a panel arranged at 45o to the horizontal.
☐ The total radiation falling on a square meter of the Earth's surface.
☐ Solar radiation diffused by the earth's surface collectable on one square meter.

4. What is a rule of thumb for the average GHI in the UK?

☐ 1000kW/m2/yr
☐ 973W/m2
☐ 1000W/m2
☐ 973kW/m2/yr

5. If the best angle for a solar panel is 45°, given a free hand why would you change this?

☐ To get the panels closer together.
☐ To help the water flow up the panel by density difference.
☐ To get more output in winter or summer.
☐ To make it look nicer.

6. Can you expect to collect all of the sun's radiation arriving on the panel?

☐ No. I need to apply the collection efficiency.
☐ Yes.
☐ No. I need to apply the collection efficiency and other efficiency factors.
☐ Yes, but the hot water will lose some heat so I need to allow for that.

7. What temperature of hot water can you expect?

☐ Variable up to 80°C.
☐ Variable up to 60°C.
☐ It depends on the panel.
☐ It depends on the panel and the inlet temperature

8. "I can keep water in the panels all year, because the sun will stop it freezing." True or false?

☐ True.
☐ False: I will need to automatically drain the system to avoid freezing.
☐ False: I can automatically drain the system to avoid freezing or use antifreeze solution.
☐ False because I will end up pumping hot water through the panels and cooling it down.

9. What is the RHI?

☐ An incentive from the European commission to encourage the use of solar energy.
☐ A UK government incentive to use renewable energy, and solar thermal power is included.
☐ A UK government incentive to use renewable energy, but solar thermal power is excluded.
☐ Royal Horticultural Institute.

10. "I can't use solar thermal energy for space heating." True or false, and why?

☐ True, I will never get an adequate temperature.
☐ True: I need heat in winter and solar thermal doesn't work then.
☐ False, but I need to design the heating system to operate with lower temperature hot water than normal.
☐ True, but not worth the effort, stick to domestic hot water.

Please complete your details below in block capitals

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Business ....

Business Address ....

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