Physics

Evaluating the Performance of Solar Thermal Collectors for Hot Water

Time – 45 minutes to 1 hour

This lesson is divided into two halves. The first half looks at a simple method to evaluate the ‘payback’ time for a solar hot water system. The second half evaluates the performance of two solar panels with different efficiencies and heat loss coefficients. You may choose to do only one half, or do one half in class and one half for homework.

TEACHER NOTES

Print out copies of the student sheets. Work through the sheets with the students if required.

Print one copy of the Teacher sheets. These include the answers.

Teacher Sheet 1 - Evaluating the ‘payback’ time for a solar hot water system

A family of four is considering buying a solar hot water system. The system uses energy from the sun to heat hot water. It consists of some solar panels to go on the roof of their house, pipes to feed heated water from the panels into the boiler and a control system. By using the sun’s energy to heat (or partially heat) their water, the family will use less electricity and as a result cut their carbon emissions.

The system costs £3,500. How long will it take for the system to pay for itself? In other words how long will it take for the savings made in electricity to reach £3,500?

The family wants the system to pay back in 10 years – how much should they be prepared to pay for it?

Use the following data:

- The system is expected to supply 60% of their hot water requirements.
- The average person uses 50 litres of hot water a day.
- Water enters the boiler from the mains at 10°C and needs to be heated to 60°C to avoid harmful legionella bacteria from developing in the system.
- The specific heat capacity of water is 4.187 KJ/kgK.
- The average cost of electricity is 11p per kilowatt-hour (kWh).
- 1 litre of water weighs 1 kg.

How much hot water does the family use in a year?

Each person uses 50 litres a day, so 200 litres a day for a family of four.

So 73,000 litres per year.

How much energy in kWh is required to heat the water?

- The water needs to be heated from the average mains temperature of 10°C to 60°C. So a total increase in temperature of 50°C.
- Noting that 1 litre of water weighs 1 kg and using the specific heat capacity given, the total energy in KJ required to heat the water is
- 73,000 x 4.187 x 50 = 15,282,550 KJ
- Convert this to kWh.

  1 kWh is the energy supplied by a source of 1000W for one hour, so 3,600,000 J = 3,600 KJ.

  So the total energy required in kWh is 15,282,550 / 3,600 = 4,245 kWh.

How much of this energy is expected to be supplied by the solar system?

The solar system is expected to supply 60% of this, so 2,457 kWh.

How long will the system take to payback (ignore interest – “the time value of money”)?

The system is supplying 2,457 kWh per year.

At 11p per kWh, this is worth £280 per year.

On this basis, a system costing £3,500 will take 12.5 years to pay back.

If the family wants it to pay back in 10 years, they should try and bargain down to get it for £2,800. (In fact the government provides a grant of £400 so they only need to get a further saving of £400 from the supplier).

Teacher sheet 2 - evaluating the performance of two solar panels with different efficiencies and heat loss coefficients.

Collector performance parameters

The power output Q (measured in Watts) of a solar collector of area A (m^2) is described by the following equation:

- $Q = A*(n0*G - a1*dT - a2*dT^2)$ [W]

where:

- G is the Solar irradiance hitting the collector [W/m^2];
- dT is the temperature difference between the collector surface and the ambient air temperature [K] (Kelvin);
- n0 is the optical efficiency of the collector – the percentage of solar irradiance that gets absorbed by the collector;
- a1 is the 1st order heat loss coefficient ($W / m^2 K$);
- a2 is the 2nd order heat loss coefficient ($W / m^2 K^2$).

There are essentially two types of solar collector:

Flatplate collectors which consist of a flat black absorber plate with a glass cover.

Watt Solar (a Polish company) produce a collector with these performance parameters:

n0 0.837

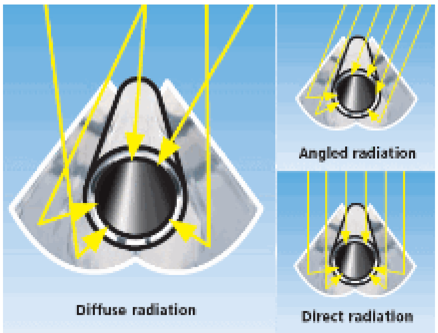
a1 4.06 $W / m^2 K$

a2 0.0172 $W / m^2 K^2$

Evacuated tube collectors. These consist of glass tubes with absorbers in the middle. The tubes contain a vacuum to minimise heat loss.

Sometimes the tubes have mirrors behind them to enhance performance (by concentrating sunlight onto the absorber).

These are called CPC tubes (CPC stands for Compound Parabolic Collector since the mirrors are made up of two parabolas).



Watt Solar produce a CPC collector with these parameters:

n0 0.552

a1 0.86 W / m^2 K

a2 0.003 W / m^2 K^2

Note that the heat loss coefficients are much lower than for the flat plate collector.

On a hot sunny day, the peak level or solar radiation (G in the above question) falling on the earth is 1.0 kW / m2, or 1000 W / m2.

Taking G as 1000 W / m2, and the area of each collector A as 1m2, plot a curve of Q (the power output) against dT (the temperature difference between the plate and the air). You should vary dT between 0 and 100°C, and calculate points on your curves for every 20°C. Plot the curve for each of the above collectors.

The data should be as follows:

n0	0.837	0.552
a1	4.06	0.86
a2	0.0172	0.003
	Flatplate	**CPC**
dT	**Q**	**Q**
0	837	552
20	749	534
40	647	513
60	531	490
80	402	464

100	259	436

In this case the flatplate performs best until the collector has heated up to 70°C above the ambient air temperature, at which point the CPC collector starts to perform better.

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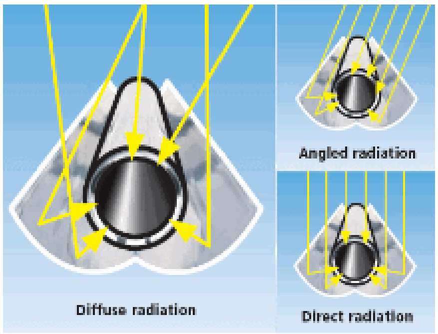

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