SOLAR COLLECTORS

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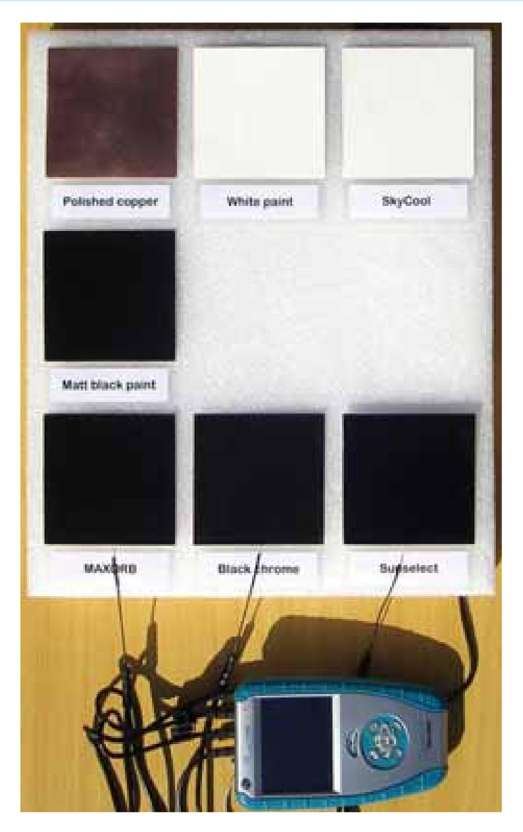
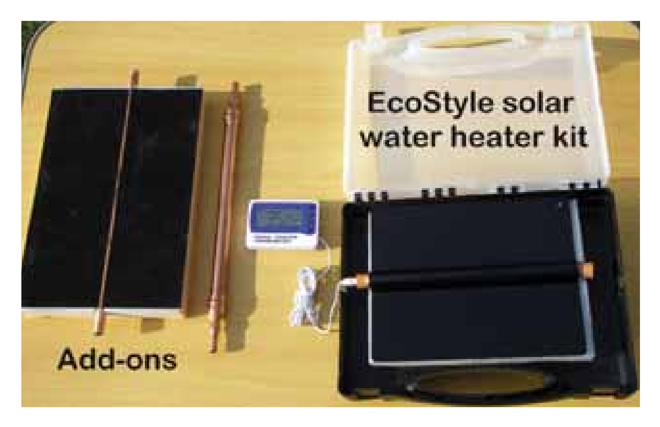
Having covered the basics of solar energy (D&T Practice 02.2012), we're now ready to investigate the construction and operation of flat plate and evacuated tube solar collectors.

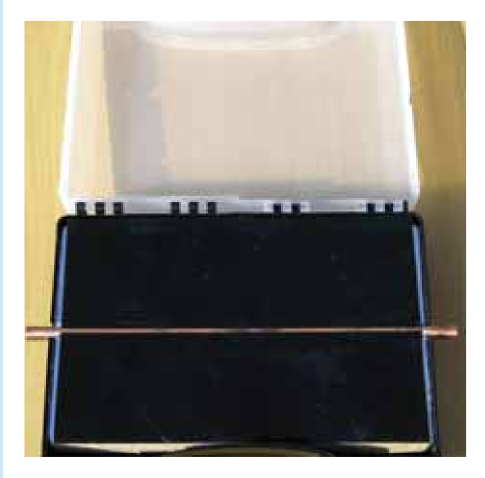


The effectiveness of various coatings and films at capturing solar radiation can be compared by measuring their temperatures under a clear sky, using a surface temperature probe. Apply each coating or film to a small (e.g.100mmx100mm) piece of sheet copper or steel. Lay the samples on some insulating material (e.g. foam plastic) and expose them under a clear sky. The potential of the coatings and films for solar heating or sky cooling applications becomes apparent from their relative temperatures.

Typical day and night sample temperatures are shown in the table below.

	Sunny day	Clear night
Air temperature	26.4°C	15.6°C
Sky temperature	-4.8°C	-9.5°C
Matt black paint	44.6°C	12.5°C
MAXORB	53.1°C	14.0°C
Black chrome	53.8°C	13.9°C
Sunselect	48.0°C	14.0°C
Polished copper	37.7°C	14.8°C
White paint	28.5°C	12.2°C
SkyCool	28.4°C	12.1°C





Solar water heating collectors

The purpose of a solar collector is to absorb most of the solar energy, convert it to heat, and transfer as much of that heat as possible to the water flowing through it. To do this efficiently, its loss of heat to its surroundings – via conduction, convection and radiation – must be minimised. This requires that its external surfaces be 'thermally decoupled' from the solar absorber surface.

Heat loss through the back and edges of a solar collector occurs mainly via conduction and can be minimised by incorporating a layer of insulating material behind the absorber and around its edges. The temperature of a matt black absorber in a single-glazed solar collector under no load, on a hot clear day, may reach 150°C. The temperature of a spectrally selective absorber in the same circumstances can be as high as 200°C. These temperatures may be reached during installation, or at any time when the collector is not operating under load. The absorber and all materials in contact with it should therefore be capable of tolerating these high temperatures without degradation. This entails that most plastics and foam plastic insulating materials must be separated from the absorber by a protective insulator such as mineral wool.

With the exception of collectors for low temperature applications, such as swimming pool heating, most designs include a transparent cover to minimise heat loss via forced convection (wind). Low-iron ('water white') glass is an ideal cover material, as it is about 90% transparent to solar radiation and almost completely opaque to longwave radiation. 4mm thick float glass is a cheaper option but is only about 84% transparent to solar radiation. The spacing between the absorber and the transparent cover should be in the range 20-60mm.

Conductive and convective heat losses via the gap between the absorber and cover could be almost eliminated if all the air were removed from the gap, but it is very difficult to maintain a vacuum inside a flat plate solar collector. This problem is avoided by (in effect) dividing the absorber into narrow strips and enclosing each inside a doubled-walled evacuated glass tube. By thermally isolating each absorber strip from the outer surface of its glass 'envelope', evacuated tube solar collectors can operate at high thermal efficiency, even on cold winter days.

Solar water heater kit

The only solar water heater kit widely available for school use is that produced by EcoStyle Ltd. The kit comprises a black-painted clip-on aluminium solar collector fin, copper heating tube, temperature probe in a rubber stopper, digital thermometer, rubber end stopper, foam plastic insulation block, and plastic case with a transparent lid.

I've expanded this simple kit to enable the assembly and operation of a miniature solar water heating system. My kit is based on 8mm (outside diameter) connectors and 6mm (inside diameter) polythene tubing. To enable the collector to be readily connected into a complete system, I've soldered two short pieces of 8mm diameter copper tubing to a 225mm long piece of 15mm diameter copper pipe via two 15mmx8mm reduced couplers (see 'add-ons' in the photograph of the EcoStyle kit). I've enlarged the existing grooves in the sides of the plastic case to enable the 8mm copper connectors to protrude through them.

A copper 'steam generator' (see Hot Links) is almost ideal as a miniature hot water tank. I've hand-sewn an insulating jacket for it, from calico and synthetic fleece.

A suitable miniature water pump proved difficult to source. The M400S-180 micro centrifugal pump from TCS Micro Ltd. has an input voltage range of 3-12V DC and a power consumption of 6W so can be powered from a relatively small photovoltaic battery charger. It also has a wide operating temperature range.

Though not essential, I've included an in line flow indicator (see Hot Links) in my kit, to show the water flow rate and direction. I obtained a 31cm long Vaillant evacuated solar tube for my kit from my local solar energy system installer. Such small evacuated solar tubes are produced for marketing and demonstration purposes, but don't seem to be available for purchase. Individual fully functioning 60cm long evacuated solar tubes are available for purchase from Navitron Ltd. (contact john@navitron.org.uk)

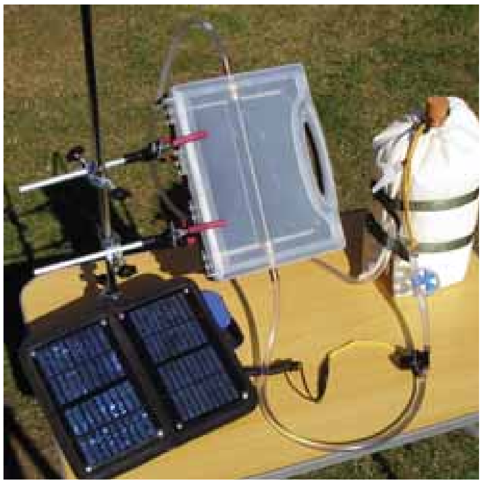
Solex Energy (see Hot Links) sells a variety of copper absorber panels (for their Solex Roof systems) at very reasonable prices. The panels can be obtained with either a black chrome or Sunselect spectrally selective absorber film and have a 10mm diameter integral copper pipe and polyurethane foam insulation backing. I've trimmed one to fit snugly inside the plastic case of the EcoStyle solar water heater kit.

Solar water heating systems

The pump and in line flow indicator should be connected to the outlet near the bottom of the hot water tank, so that cool water from the bottom of the tank passes through the pump to the lower connector on the solar collector (the connectors on the evacuated solar tube are both at the top, so can serve equally well as inlet and outlet). As long as the water in the storage tank isn't agitated too much, the warmest water rises to the top and the coolest to the bottom. Pumping the coolest water from the bottom of the tank to the solar collector ensures that the latter is kept as cool as possible, thereby minimising its heat loss to its surroundings. In flat plate solar collectors, the water should flow from the bottom to the top in order to carry air bubbles out of the collector. (Airlocks in solar heating systems are a notorious problem, so particular attention should be given to ensuring a steady rise in the fluid path through absorbers and collector arrays, to a point where air can be removed.) The water heated in the solar collector should flow to the inlet connector on the hot water tank.

The types of solar water heating systems that can be modelled using this kit are described as *direct* systems, in which water for use at a domestic tap is passed directly through the collectors. Such systems are prone to freezing in cold weather, and to corrosion if mixed metals are used in the fluid path. These problems can be avoided by passing the heat transfer fluid from the collectors through a copper coil 'heat exchanger' in the water tank and back to the collectors, so that anti-freeze and corrosion inhibitors can be added to the fluid without contaminating the water in the tank. Solar water heating systems with such a closed-loop fluid path are referred to as *indirect* systems. The heat exchanger coil reduces the overall thermal efficiency of the system, but it enables the use of anti-freeze and corrosion inhibitors that can greatly prolong the system's operational life.

Another type of solar water heating system that is difficult to model in miniature is a *thermosyphon* system. By raising the water tank so that its outlet is higher than the top of the solar collector, the buoyancy of the water heated in the collector causes it to rise up the fluid path into the water tank, displacing the cooler water at the bottom of the tank down the fluid path into the collector. As long as the water is being heated sufficiently in the collector, it will circulate around the fluid path without the need for an electric pump and controls. A one-way valve must be incorporated in the fluid path to prevent the water circulating backwards at night. The use of relatively wide diameter tubing is essential in such systems, to minimise the flow resistance in the fluid path, hence the difficulty in modelling such a system in miniature.



Though relatively crude, the kit described in this article can help elucidate the construction and operation of flat plate and evacuated tube solar collectors and their incorporation into a water heating system. Most of the collector parts are readily accessible for temperature measurements, e.g. in thermal performance investigations. When dismantled, the entire kit can be packed into a deep storage tray.

Acknowledgements

My thanks to Steve Emery for donating the EcoStyle solar water heater kit and to Gareth Jehu for providing the Vaillant evacuated solar tube sample.

Hot Links

ClearDome Solar Thermal: www.cleardomesolar.com/
EcoStyle kits: www.ecostyle.co.uk/renewable_energy_kits.html
Energy – Post 16: www.tep.org.uk/renewable_p16.html
Evacuated tube collectors: www.navitron.org.uk/product.php?proID=115
In line flow indicator: www.specialtech.co.uk
Instruments Direct: www.inds.co.uk/energy/index.htm
Miniature water pumps: www.micropumps.co.uk/TCSM400range.htm
Solar absorber samples: www.solexenergy.co.uk (see Shop: Clearance)
Solar-Active: http://new.solar-active.com/
Solar Spark: www.thesolarspark.co.uk
Solar Spark STEM: www.nationalstemcentre.org.uk/elibrary/collection/788/the-solar-spark
Steam generator: www.timstar.co.uk/Physics/Steam/Steam-Engines/STEAM-GENERATOR-/
US Energy Education lesson plans: www1.eere.energy.gov/education/lessonplans/
US Energy Kids – Solar: www.eia.gov/kids/energy.cfm?page=solar_home-basics

Further Reading

Duffie, J.A. and Beckman, W.A. Solar engineering of thermal processes (4th edition). Wiley. 2012 (ISBN 978-0470873663)
Energy – Post 16. Technology Enhancement Programme. (ISBN 1 898126 90 9)