DESIGNING AND MAKING A SOLAR PANEL

Contents

Student Briefing Sheet 1 - Design Problem

Energy from the Sun

In this country our climate makes it fairly hard to use the sun as a useful source of energy. Photovoltaic cells can produce electricity from sunlight, but the electricity is expensive and is usually only worth considering for an application where there is no mains electricity available. This is because of the high initial cost and the relatively poor climate in this country. Developments in photovoltaic cell technology should make them cheaper in the future. However solar hot water panels can produce useful amounts of hot water cost- effectively, particularly if thought is put into sourcing the materials and the system is self built.

Design Brief

To design and make a solar collector to meet an identified need for hot water within the school or for a related application. The system might be fixed or portable depending on the needs of the application identified.

You should take responsibility for the development of the project and organise your time so that the project is completed on time

Getting Started

Getting started is one of the problems with designing anything. Looking at solutions to problems devised by others is always a good place to start. Obtaining product information from manufacturers will be a useful source of ideas. Visits to see systems operating will be very helpful if they are possible to arrange.

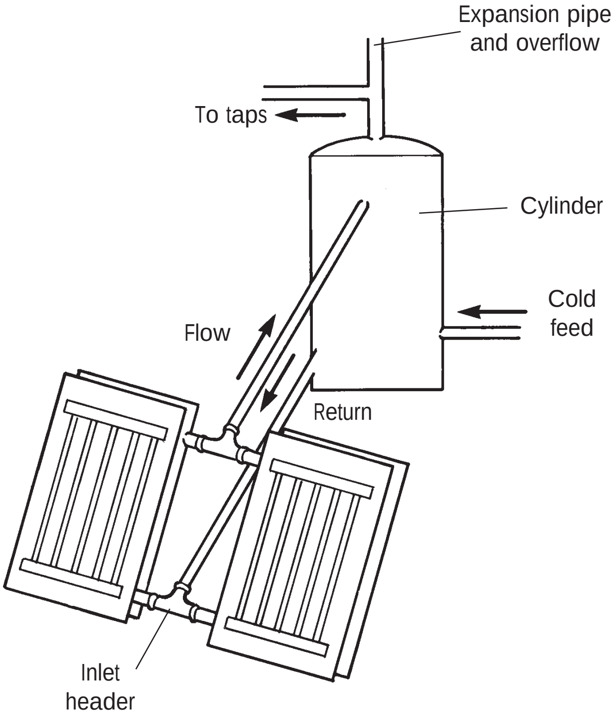
However a lot can be worked out from an understanding of heat transfer, conduction, convection, and radiation. The collector itself can be designed primarily with these principles in mind.

You will need to draw up an outline specification for each part of the system. It is important to develop an understanding of how the solar hot water system operates.

Elements of the Solar Hot Water System

- *Collector panel*
- *Collector casing*
- *Collector mounting*
- *Hot water storage tank (if required)*
- *Pipework*
- *Control system for hot water flow and for tracking sun (if required)*
- *Hot water draw off points*

The following diagram illustrates a basic solar hot water system.



Water flow around the system is produced solely by the natural circulation of water as it heats up, expands and is replaced by higher density colder water . This is called thermo-siphoning. This is the simplest system to construct but for it to be effective a number of criteria have to be satisfied, see Information Sheet 9.

The collector itself is likely to be either some form of flat plate collector or a parabolic reflector. The decision will be guided by the type of application chosen and the materials that are available.

BUDGET AVAILABLE

This has to be discussed with your teacher. Every school's situation is different. However, you will see that there are possibilities within this project for using and adapting 'scrap' or found materials and items. You will find that it requires more skill to select useful items from what you can find, than to order them new.

TASKS

- Research the background of solar water heaters and their application.
- Identify the budget you have available.
- Develop an outline specification for the proposed solar panel.
- When carrying out this project you need to plan your time carefully. How long will you allow for: research, design, making and evaluating?

STUDENT BRIEFING SHEET 2 - IDENTIFYING A NEED FOR HOT WATER AND SITING THE SYSTEM

IDENTIFYING A NEED

Your design must be matched to a real need you have identified for hot water within the school or college. You will need to consider a range of issues when identifying a particular application such as;

- **volume and temperature of water required, and therefore the energy requirement.**

  You need to be realistic with the scale of need you intend to meet. It is useful to calculate approximately the amount of energy required to meet this need to give an idea of what you will be expecting from your solar collector. Is it feasible to consider meeting this need?

- **the nature and timing of water demand.**

  You need to identify what the water will be used for and when, to help gauge the required storage capacity of the proposed system and the degree to which the proposed application matches the variations in solar radiation.

- **budget limitations.**

  Obviously your budget limit will constrain the size of the proposed system and will therefore limit the number of appropriate applications available to you.

- **practical constraints such as any siting restrictions and the relationship with the existing hot water system.**

  You might need to re-examine your chosen application after you have considered in more detail the siting of the device as these two things are closely linked.

SITING YOUR SOLAR COLLECTOR

Your choice of site will be dependent on a range of factors;

- **the level of solar radiation over a period of time.**

  Obviously the higher the levels of solar radiation the better. You can measure this over time using a solarimeter as outlined in unit 1, or you can judge the best site from observation of shading, wind speed and direction etc. Excessive wind speeds can reduce the collector efficiency.

- **where the hot water will be used.**

  The three elements of your system, the collector, the storage tank (if there is to be one) and the point of use, should be as close together as possible to reduce heat losses from the pipework. This has obvious implications for the siting of the solar collector. In addition it is necessary to consider the feasibility of the pipe runs. Putting pipework across the playground is an obvious non-starter.

- **safety and security.**

  You will need to consider the safety of the collector, keeping it free from vandalism and accidental damage.

- **ease of access.**

  It is important to consider the ease of access for maintenance purposes. In addition you might wish to consider the educational and informative value of what you have done. Do you positively want other students to be able to see the device and understand why it has been installed and how it works? Additionally, would you like in some way to be able to display how well it is achieving its aims when it is in use?

- **environmental impact.**

  In this context this refers mainly to visual impact, although the collector's impact on land use might be an issue depending on the siting choice.

Clearly it might be necessary to make a compromise between the above factors as it is rarely possible to find an ideal all round site but it is necessary to consider which are the most important factors.

TASKS

- Quantify as clearly as possible the quantity of water required and the percentage to be met from the solar hot water system.
- Consider the overall type and size of collector that might be appropriate to your application.
- On a plan of the site mark out the relationship between potential sites and points of use for the hot water.
- Balance the issues outlined above to identify an appropriate application and a suitable site.
- Begin sourcing elements of the system, collector panel, storage tank etc.

Risk Assessment
Care needs to be taken in scrapyards as customers are frequently expected to work in unsafe places. Visits should always be accompanied by a member of staff.

STUDENT BRIEFING SHEET 3 - DESIGNING THE SOLAR COLLECTOR

Having made a first assessment of the type of collector that you will be designing you will also need to consider the following issues in more detail;

- **what size the collector panel should be**
  It will be very difficult to design the collector such that you will be able to provide all the hot water you need. Therefore the size of the collector(s) you design will be dependent on;

  - the efficiency of the collector,
  - the quantity of hot water required,
  - the required temperature of the water,
  - the percentage of the energy demand for the chosen application you intend to meet with the solar collector.

  The size will also depend on what materials you can obtain, budget limitations and practical siting constraints.

- **the collector design**
  The collector design should maximise the heat transfer between the surface exposed to the sun's radiation, and the water circulating around the system. The efficiency of the heat transfer will depend on the materials used, the volume of water held by the collector, the surface area of the collector and the rate of heat loss from the collector. During operation the collector efficiency will also depend on its orientation to the sun, the amount of solar radiation, the water temperature and the surrounding air temperature.

- **the type of collector box required and its mounting**
  The boxing of the collector panel if required, needs to be designed to be weatherproof, and to minimise heat loss and maximise solar gain where appropriate. The mounting needs to be constructed such that the collector can be moved into the most effective position relative to the sun. Should it be fixed or moveable?

- **what materials are available to you now or as a result of some time spent researching sources**
  What materials you have available will heavily influence your collector design. With a limited budget you will need to prioritise your expenditure. Which is the key element of your collector design in terms of increasing the collector efficiency?

TASKS

- Produce a detailed design specification for the collector panel, box and mounting.
- Produce working drawings for the collector, its casing and its mounting.
- Identify sources for materials and components taking into account any budget limitations.

Risk Assessment
Care needs to be taken in scrapyards as customers are frequently expected to work in unsafe places. Visits should always be accompanied by a member of staff.

STUDENT BRIEFING SHEET 4 - DESIGNING THE SOLAR HOT WATER SYSTEM

You will need to consider;

- **whether the hot water will be used as it is heated or will it need to be stored**
  Most applications will require some form of hot water storage, but obviously if you can just use the water as it is heated then it makes the system design very easy, but not very flexible.

- **the amount and distribution of water you need to produce**
  The amount of water you need to produce will affect the size of storage tank required as well as the collector design. It is also important at this stage to identify the number of draw off points required.

- **whether the system needs to be incorporated into the existing hot water system or will it stand alone**
  If the system is isolated from the existing hot water system it will only produce useful quantities of hot water during the summer months. If however the system is used to pre-heat water before the use of a conventional fuel source, then even the small amounts of solar energy during the winter months might be made use of.

  When considering this issue it will also be necessary to compare the distribution of the draw off points required with that of the existing pipework, as well as considering the practical difficulties involved with incorporating a solar collector into the existing hot water system.

- **whether the system requires a pump for circulating the water**
  A pump will allow the flow of water around the system to be closely controlled, and will be required if the system is to fit into a space that will not allow the necessary arrangement of tank and collector to generate thermo-siphoning.

  If a pump is to be used you will have to establish how it will be controlled. You will also need to consider how to prevent the collector acting as a radiator at times when there is no sun.

- **how to protect exposed elements of the system from the cold**
  It will be necessary to protect the collector and any external pipework from the cold to prevent freezing. There are several ways that this might be done depending on the type of solar collector design you are producing.

TASKS

- Produce a detailed design specification for the solar hot water system.
- Map out the pipe runs in some detail to identify any problem areas that might arise.
- Produce working drawings of the solar system identifying the main components and their connections.
- Identify sources for materials and components taking into account any budget limitations.

STUDENT BRIEFING SHEET 5 (OPTIONAL) - DESIGNING A SOLAR PUMP CONTROLLER

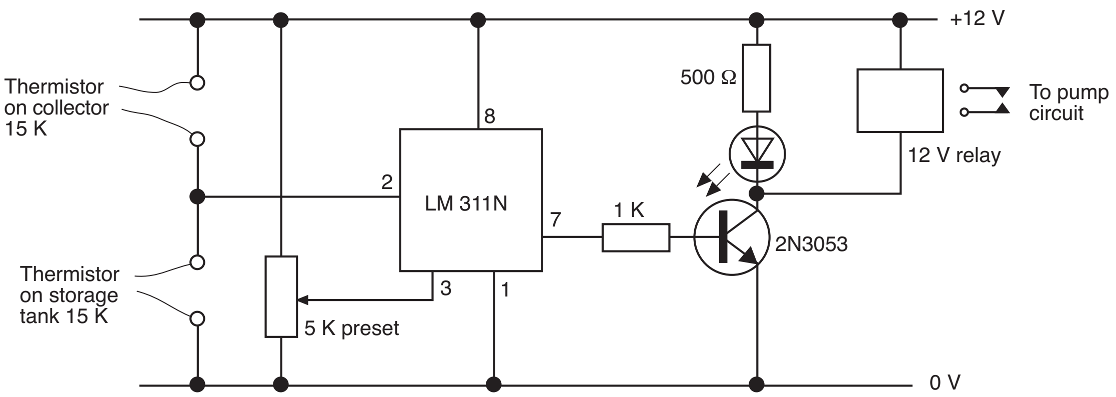
If you need a pump in your solar system you will need to be able to control its operation to maximise the heat transfer from the collector to the storage tank. To do this the pump needs to operate when the temperature of the water in the collector is higher than the water in the storage tank.

You will need to consider:

- The specification of the pump and how to supply power to it.
  Low voltage in-line pumps are available from marine equipment suppliers at a reasonable price. But it will be necessary to check whether they are larger enough to pump the volumes of water required within the solar system.

- How to supply power to the controller.
  The controller requires a *smoothed* 12V DC power supply to operate the relay.

- The design of the solar controller.
  The schematic diagram below shows the basic system which can either be designed to your own choice of components, or built straight from the detailed construction plan within Information Sheet 12.



- How to calibrate the controller.
  The controller can be calibrated by setting the potentiometer so that the LED comes on when the thermistors are at the required temperature difference.

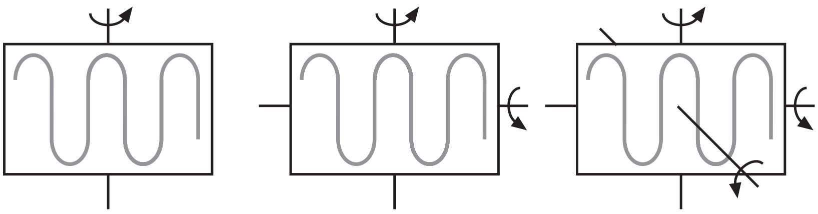
- The size of the temperature difference.
  The temperature difference needs to be set high enough to offset the heat losses from the pipe runs as well as the power loss from the pump. This ensures a net energy input into the storage tank. So the insulation levels and the length of pipe runs are important in this assessment. However a temperature difference of around 4 or 5 degrees C is common.

STUDENT BRIEFING SHEET 6 (OPTIONAL) - TRACKING THE SUN

The collector needs to obtain as much energy from the sun as possible. The sun moves across the sky during the day. It is will also be at different heights in the sky depending on the season. This variation will affect the efficiency of the collector. One option then is to develop mechanisms that will enable the collector to track the sun as it moves in the sky.

There are a number of things to consider if this is to be attempted;

- Under what conditions do you need the collector to move?



1 axis 2 axes 3 axes

- How many axes do you wish the collector to move in?
- What can you sense to operate the movement and what sensor can you use?
- What output device could you use?
- What voltage supply are you going to use? What will govern this decision?
- How will the output device switch on when movement is required?
- How will you ensure enough current to operate the output device?
- Do you need to return the collector to a starting position at some point?

A number of specific issues relating to the mechanisms involved need to be considered.

- Does your output device provide enough force or torque to move the collector? How can you increase it?
- Do you need to slow down or speed up the motion from your output device?
- Does your output device move in the same plane and direction as your collector needs to move?

TASKS

- Consider whether it is advantageous to the system you are developing for it to track the sun.
- If so you will need to develop the design specification for the electronics and the mechanisms required.
- Produce working drawings of the required control systems.
- Source the materials and components required by the designs.

Risk Assessment
Electrical systems for control will need to run at a low voltage avoiding any chance of shock or overheating and fire from short circuits.

STUDENT BRIEFING SHEET 7 - MANUFACTURE AND INSTALLATION OF THE SOLAR COLLECTOR AND SYSTEM

Risk Assessment
Working at heights is hazardous and should be carefully supervised
Solar panels can produce very hot water, care needs to be taken to avoid burns.
Care should be taken when handling and storing glass
Soldering and welding should be carried out in a safe manner.

Having produced detailed design drawings of the solar collector and associated system, you will need to:

- **produce a production plan**
  You should draw up a schedule for production in order to identify when there might be hold ups, for example due to ordering of materials or as a result of any production processes. It will then be possible to minimise the impact of these delays.

- **order materials**
  You will already have identified the balance between new and found materials. Hopefully sources for the main components of the collector and solar system have already been identified.

- **produce any aids for manufacture, jigs and formers**

- **prepare materials and manufacture solar collector**

- **install solar system**

- **produce an instruction guide for use and maintenance of system**
  This is an essential stage in the development of the finished product. You need to pass on to future users of the system the key points that they need to know about its operation and maintenance.

- **site trial and evaluate system**
  This is the crunch; does the finished system meet the original specification? How much water does the system heat and to what temperature?

  - on a cloudy day in June
  - on a clear day in June
  - on a clear day in December
  - as an annual average

  Does it satisfy the need originally identified in the school? Does it provide the amount needed, when it is needed?

  What type of fuel does the system displace? What financial saving does this represent (a) now and (b) over the next ten years? How much carbon emission will the system prevent?

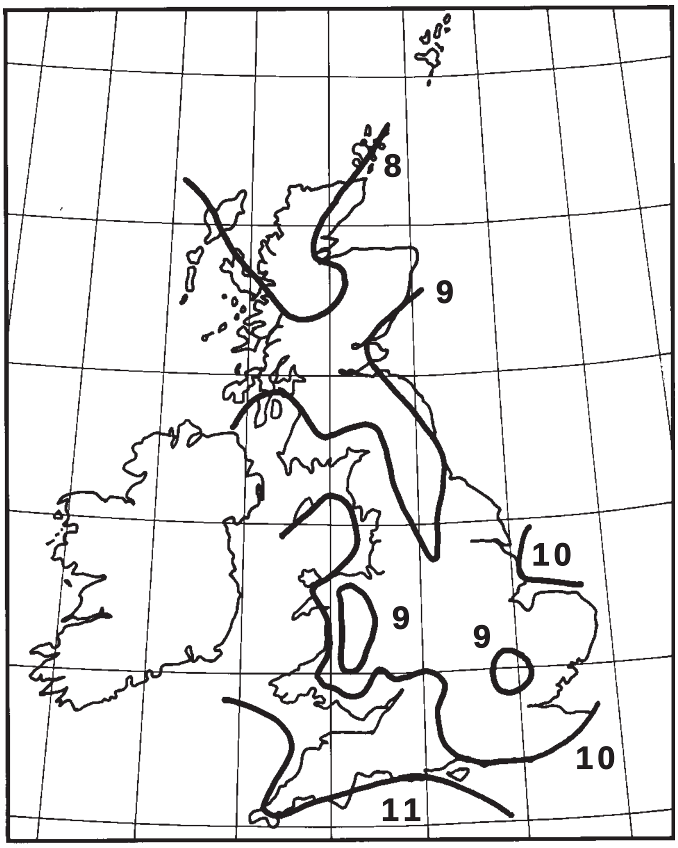
  Can you identify ways in which the performance of the system could be improved? How would you do it differently if you did it again?

INFORMATION SHEET 1 - BACKGROUND INFORMATION

Back up to Briefing Sheet 1

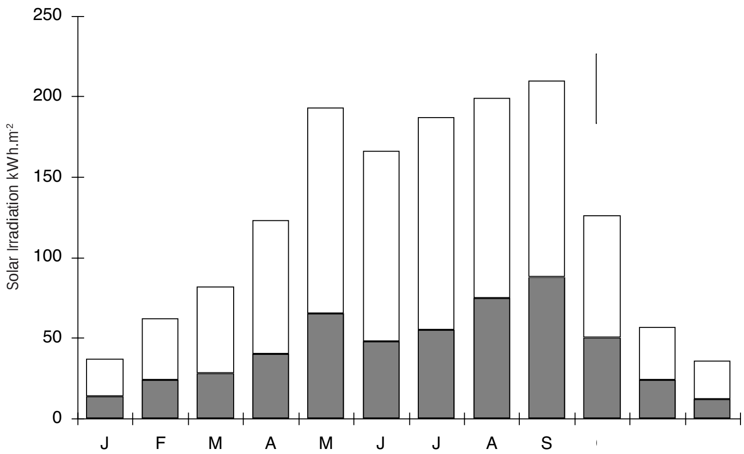
Solar intensity is far easier to estimate than windspeed because it is fixed by far fewer, and more certain variables. The level of solar radiation that reaches the earth is governed by the position of the sun in the sky, a known quantity, and the level of cloud cover and atmospheric dust and pollution. Therefore the solar radiation received over one clear day in any month of the year can be quite accurately estimated . On average the number of hours of sunshine is also fairly well established. This then is very different from wind energy which can vary much more widely and unpredictably as a result of quite complex atmospheric interactions.

The intensity of solar radiation above the earth's atmosphere is about 1,365 W/m^2. However this figure is reduced as a result of reflection and absorption by water vapour and gases in the atmosphere. The map below shows the variation in annual average daily totals of solar radiation across the country. Solar radiation levels can vary between 1000 W/m^2 on a clear summer day to less than 200 W/m^2 on a cloudy summer day, and much lower still in midwinter.



Daily totals of solar radiation averaged over the year (MJm^{-2})
[3.6MJ = 1 kWh]

The total or 'global' solar radiation levels have an element of direct solar radiation and an element of 'diffuse' solar radiation. The diffuse radiation is caused by scattering by the atmosphere and is at a peak on overcast days. The graph shows the balance between diffuse and direct solar radiation over a whole year. The figures are based on south facing surface tilted at 45 degrees to the horizontal.



The amount of solar energy that is then converted into useful heat in the form of hot water coming out of the tap, is dependent on the conversion efficiency of the solar hot water system itself. Efficiencies range from between 25% for a DIY system to 60% for an advanced commercial system.

The applications for solar collectors vary depending on the design. The most common application for solar collectors in this country is for domestic hot water systems, some specialised systems provide water to central heating systems but usually the temperature required is too high. Another useful application is to heat swimming pools where the temperature level required is only a few degrees above air temperature.

In other countries, usually but not always the hotter ones, larger scale developments have been put in place where great numbers of solar collectors are arranged to provide large quantities of hot water for whole communities. Solar systems can also be used to cool buildings.

The other most important option for utilising solar energy is the use of photovoltaic cells that convert solar radiation into electricity. They are already commercially viable in this country for remote applications where there is no grid electricity. The manufacturing costs of these cells is constantly falling and the manufacturers and industry experts believe they will be able to compete with conventional fuel sources within the next two decades. They require complex manufacturing processes and are currently out of the budget of most schools for meeting any real electricity need that the school might have. There are many small but useful kits that are available, at reasonable prices, that enable effective study of the potential for photovoltaic cells.

Solar hot water systems however can be constructed within the resources that schools have available and can effectively meet small scale needs for hot water that the school might have.

GLOSSARY

PLATE EFFICIENCY - efficiency of transfer of heat from the absorber surface to the fluid passing through the collector. A well designed absorber should have one of about 90%.

ABSORPTANCE - capacity to absorb solar radiation.

AMBIENT TEMPERATURE - surrounding air temperature.

ANGLE OF INCIDENCE - angle between a light ray and a normal to the surface on which the ray is incident.

COEFFICIENT - number expressing amount of some change or effect under certain conditions of temperature, pressure etc.

DIRECT SYSTEM - the water coming out of the hot taps has actually passed through the collectors.

EMITTANCE - ability to emit infra-red radiation.

EMISSIVITY - power of a surface to radiate heat or light.

FLAT PLATE COLLECTOR - variety of different collectors that have combinations of flat, grooved and corrugated shapes as the absorbing surface and various ways of transferring the absorbed solar radiation from the surface of the collector to the heated fluid - no concentration of the solar radiation.

HEAT LOSS COEFFICIENT - rate of heat loss at a given collector temperature - affected by the cover, the insulation at the back and sides of the collector and the emittance of the absorber surface - U(W/m^2.°C).

INCIDENT SOLAR RADIATION - the solar radiation falling on the collector at any point in time.

INDIRECT SYSTEM - the fluid passing through the collector is not the same as that which will come out of the hot tap.

OPTICAL EFFICIENCY - maximum efficiency with which the solar radiation can be collected = product of the transmission of the cover, the absorptance of the absorber coating.

SYSTEM EFFICIENCY - the efficiency of the whole system, includes heat losses from the pipework and the storage tank.

PANEL LOOP - water in the whole solar system.

PARABOLA - a particular curve where parallel rays of light approaching it from the front are focused onto one point.

SELECTIVE SURFACE - one which absorbs sunlight efficiently but re-radiates heat as infra-red radiation far less than a normal black body would do.

SPECIFIC HEAT - energy needed to raise the temperature of 1kg of a substance by 1°C. (J/kg.°C)

STAGNATION TEMPERATURE - temperature the collector might reach on a sunny day when no fluid is flowing in it.

THERMAL CAPACITY - quantity of heat required to raise the temperature of a body by 1°C.

THERMAL MASS - an object's capacity for storing heat (objects with high thermal mass warm up slowly but store a lot of heat in the process).

THERMAL RADIATION - infra-red radiation.

THERMO SIPHON - the process of water circulation that is powered by density changes within the panel loop as a result of water temperature changes in the collector panel.

TILT ANGLE - the angle between the collector surface and the horizontal (the ground).

TRANSMITTANCE - ability to transmit (allow through) heat or light.

Information Sheet 2 - Siting the Solar Collector

Back up to Briefing Sheet 2

Assessing the Demand for Hot Water
It is important to get an overview of hot water use in the school before deciding what element of that demand might be able to be met through a solar hot water system.

Possibilities
- sinks - hand washing (most frequent in toilets and workshops?)
- kitchens
- showers
- swimming pool
- food technology facilities - washing up?

To get an idea of the energy requirement for these uses it is necessary to estimate both how much water is used and what temperature the water is heated to. Note that it is not the temperature the water comes out of the taps that is important in this context, but the temperature that the water is heated up to when it is stored.

For all the uses with a water outlet (tap or shower head) you could time how long people keep it flowing, note how far they have turned on the tap, work out the average for each activity and then used a stopwatch, bucket and calibrated container to calculate how much water is normally used. You will have to decide how big a sample you need in order to ensure that you have an accurate enough average figure.

Alternatively you could use average figures for hot water use.

Then you need to know how many times this is done in a day and also when. For example almost all the hand washing might be between morning break and the end of lunchtime.
As well as the time of day used you also need to consider seasonal variations.

You will need to separate out the use according to location if you are going to be able to assess whether you will be able to meet a particular need in one part of the site.

You will also need to assess what temperature the water needs to be for each particular use.

Then fill out a table something like this (add or remove categories if you find that this will not provide you with the information you need) -

Type of use	Location	Litres used	Storage Temp	Time used	Season used

How can you display the information you have collected in a way that makes it easy to draw some conclusions about the most appropriate hot water need to meet?

Calculating the Energy Required
It is possible to calculate the amount of energy required to heat the amount of water required to a set temperature using the following formula;

Energy Required = M × C × (T1 - T2)

Where: M = Mass of water to be heated (kg)
C = Specific Heat Capacity of water = 4200 J/kg.°C
T1 = Temperature required of hot water (°C)
T2 = Temperature water supplied at (°C)

Assuming that the mains water is at 14°C and the hot water is required at 55°C and 100 litres of water are required daily:

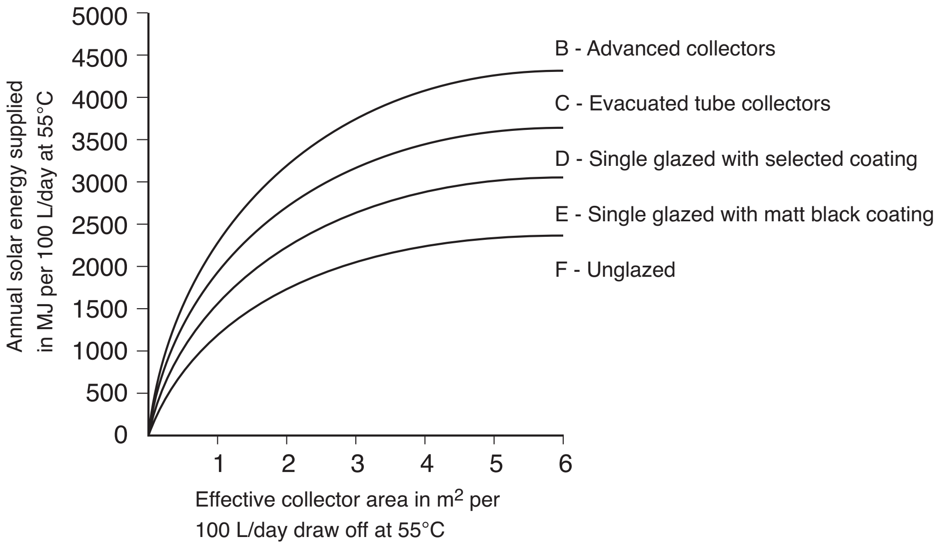
Daily Energy Requirement = M × C × (T1 -T2)
= 100 × 4200 × (55 - 14)
= 17220000 J
= 17.22 MJ

Annual Energy Requirement = 17.22 × 365
= 6285.3 MJ

1 MJ = 0.278 kWh
3.6 MJ = 1.0 kWh

The average daily global irradiation on a horizontal surface is approximately 10 MJ / m^2. However, not all this energy may be harnessed towards heating water due to the efficiency of the collector and the hot water system.

Matching Energy Requirement with Collector Performance
The following graph outlines the performance of different types of solar collector. It shows the amount of energy that might be expected to be produced from the collector. Using the graph it should be possible to draw some basic conclusions about how much of the hot water demand you might be able to meet.



It is important to remember that one option to consider might be to meet a only a percentage of the hot water needed for any application.

Matching Supply with Demand
It is necessary to consider when the hot water will be required and the degree to which this matches the variation in solar intensity on a seasonal and possibly daily basis.

Seasonally it is worth drawing up a comparison of supply and demand on a graph showing monthly figures for energy required, calculated as above, and monthly figures of solar energy supplied to the solar system, calculated from the table below and the graph above. You should assume 2 or 3 m^2 of collector type D (mid way through class).

Approximate percentage of the annual solar energy supplied in each month

January	2	July	13
February	5	August	13
March	6	September	12
April	10	October	8
May	12	November	4
June	13	December	2

Note: these values apply to systems located in the London area, with south facing collectors tilted at 30°

On a daily basis, a system with a storage tank, particularly if it is well insulated, will even out any of the daily variations in solar radiation. However if the system does not have a storage tank, i.e. the hot water is being used as it is produced, then obviously there will not be a lot of hot water first thing in the morning.

Assessing Levels of Solar Radiation
If you have a solarimeter, either manufactured from Unit 1 or borrowed for the project, it will be possible to measure the amount of solar energy falling on a certain spot.

It will probably not be practical to take readings with the solarimeter all over the site, so you need to consider on what basis you will decide where to take detailed readings.

If you do not have access to a solarimeter then estimates of solar radiation levels can be made using data from the meteorological office. However it will still be necessary to refine the data with reference to the actual site.

You only need to stop for a moment to realise that you already know quite a lot about the effect of solar energy on your school site. You will be well aware of which rooms become intolerably hot in June and which never get any sunlight, and you will probably know which areas in the playground get sunlight even in January.

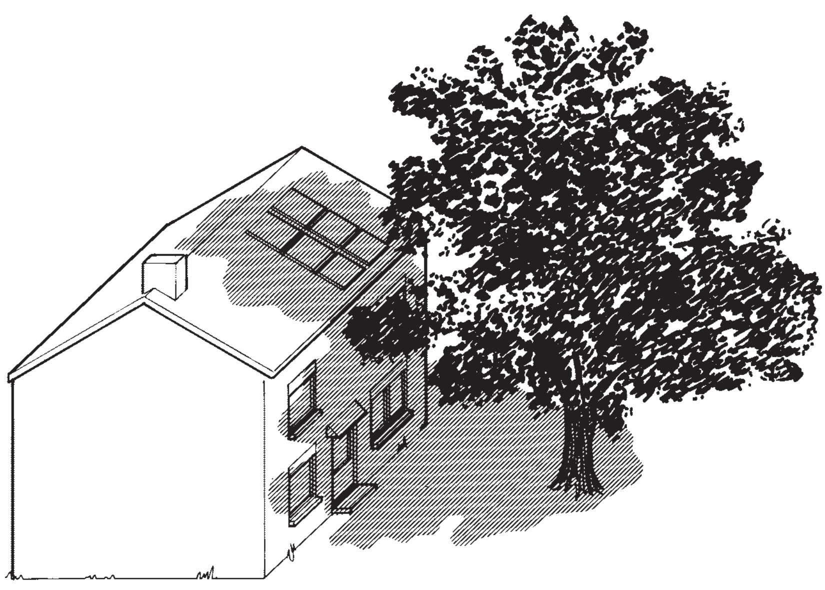
Beware of the effect of shading, it could be that trees, buildings and other obstacles might cast a shadow over the site. Might there be obstructions at 8am which you will not observe between 9am and 4pm? Does this matter? Is there any way that you can predict accurately where the sunlight will fall at any time of day?

Do you need to design any devices to enable you to track and record the path of the sun through the sky at different times ?

The collector will have to be positioned such that it can absorb as much radiation as possible within its design limitations. Clearly the sun does not remain stationary and therefore it is necessary to consider the best orientation and inclination for the collector. As the sun does not remain at the same height in the sky all year this will also need some consideration.

It might of course be possible to move the collector in order to maximise the solar radiation falling on it.

Wind will also have a cooling effect on a collector hence it is necessary to choose a sheltered site. Try comparing wind speeds at different sites.

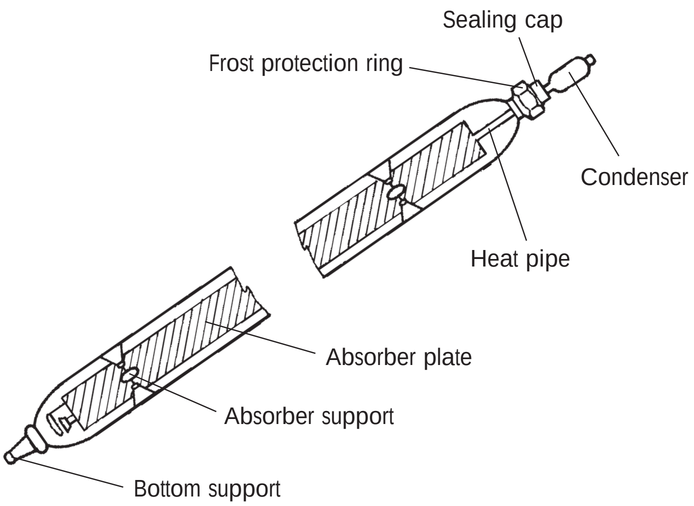


INFORMATION SHEET 3 - TYPES OF SOLAR COLLECTOR

Back up to Briefing Sheet 2 & 3

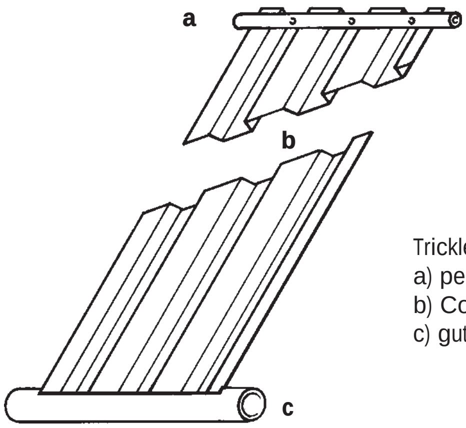
There are a range of different types of collector, some of which are far too expensive to consider but are worth being aware of.

Evacuated tubes
The evacuated tube consists of an inner tube containing a refrigerant that boils at a low temperature. In-between the inner tube and outer glass casing there is a vacuum to reduce heat loss. The fins attached to the inner tube also have a selective coating on them that greatly reduces the re-radiation of heat. The refrigerant absorbs the sun's energy, rises up the tube and is condensed by water circulating around the system. As the refrigerant is condensed it passes its latent heat to the water which is then circulated to the storage tank.



Evacuated tube systems are commercially available, however they are very expensive. They prove useful in situations where high temperatures are required, e.g. solar cooling appliances and industrial applications. They are also of use where they need to operate under difficult conditions e.g. space heating where the main demand is in the winter.

Trickle Collectors
This is the simplest and cheapest type of solar collector. It has a perforated water feed pipe running along the top of some form of corrugated sheet. The water is allowed to trickle down the gulleys to be collected by the gutter pipe at the bottom. The water will be warmed by the sun's radiation directly and by transfer of heat from the collector itself.



Trickle absorber:
a) perforated feed pipe
b) Corrugated sheet
c) gutter pipe

Of the commonly available corrugated materials, aluminium is the best choice because of its thermal conductivity, which is four times greater than that of mild steel.

The surface contact area can be increased by adding a detergent to the water, which will break the surface tension of the water and allow it to run over a larger area of the gully.

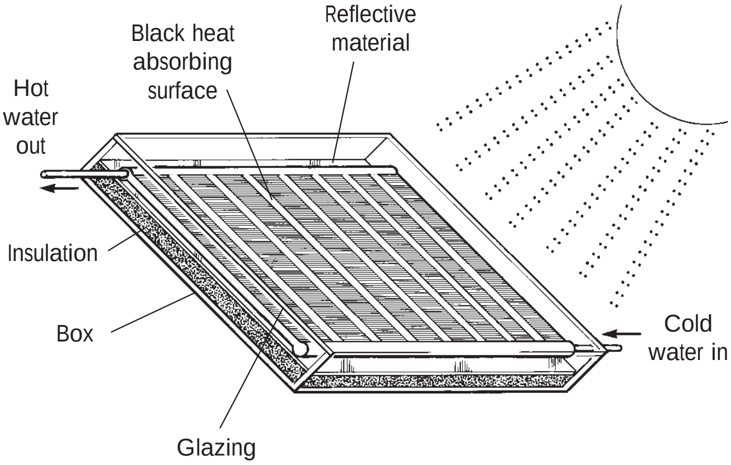
The collector will have to be well treated to withstand the corrosive effect of air and water combined. Dry temperatures of up to 200°C can be reached causing expansion followed by rapid contraction as water circulates. A stoved-on finish would be a good choice.

Although a trickle absorber is the cheapest it does have several disadvantages. It is less efficient as water can evaporate as it runs down the gulleys. This increases the heat loss and can obscure the glazing cover when it condenses thereby reducing the amount of solar radiation that can enter the collector. The collector will require extra maintenance as dirt and dust will get into the system so access to the collector pipes must be possible for cleaning. It is also much more difficult to control the pump, if there is one, because of the wide fluctuations in the collectors wet and dry temperature.

Flat Plate Collectors

Water is spread between two sheets of material, the upper of which forms the solar absorbing surface. Water is in contact with the whole or a large proportion of the absorbing surface, therefore heat only has to pass through the collector plate in order to heat up the water.

An important consideration when using this type of collector is the volume of water within it. If the absorber has a large amount of water in it, it will take a long time to heat up as it will have a high thermal capacity. Ideally it should have a water capacity of less than 2.5 litres/sq. metre, however a compromise may be necessary if cost is a major consideration.

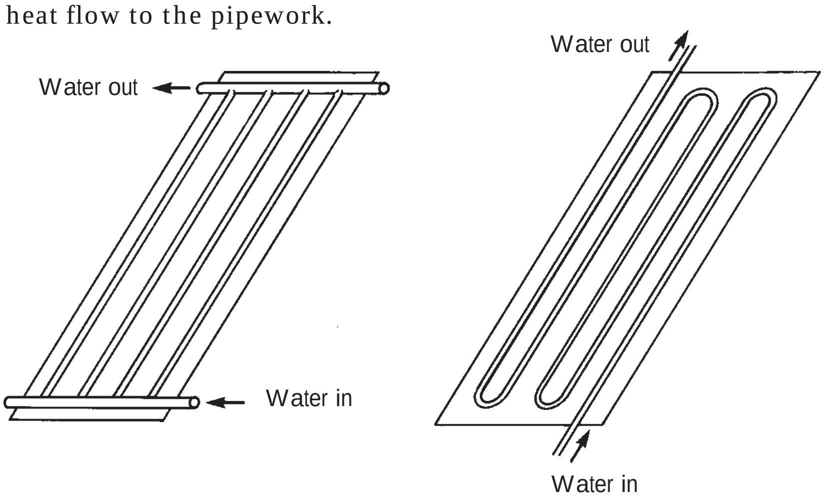


The thermal conductivity of the materials is not so important when the water is in contact with the whole absorber surface as long as the material is not too thick. Modern central heating radiators, often used as collectors, behave partly as sandwich collectors and partly as tube and sheet collectors.

Many flat plate collectors are now commercially available, the best also possess a selective coating to reduce re-radiation as the collector heats up. They also attempt to reduce the ratio of water volume to surface area to maximise heat transfer.

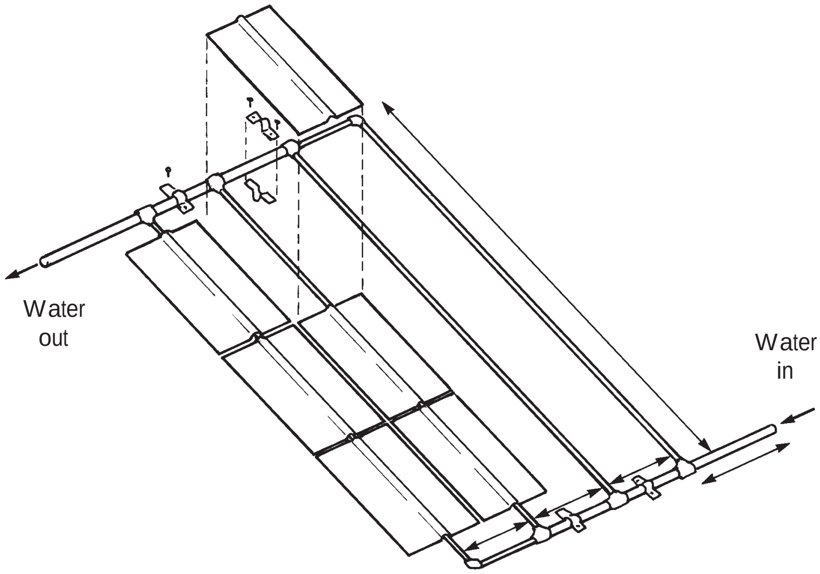
Tube and Sheet Collectors

The materials used within tube and sheet collectors are of greater importance as they rely heavily on the ability of the sheet to transfer heat to the water in the piping. The spacing between the piping, and the bond between pipe and sheet are also of crucial importance. With materials that are poorer conductors of heat, like steel, it will be necessary to have the piping spaced closer together and to have thicker sheet to reduce the resistance to heat flow to the pipework.



The parallel configuration is far better for systems that rely on natural thermo-siphoning to encourage water circulation, as there are no downward flow elements that would cause problems in this sort of system.

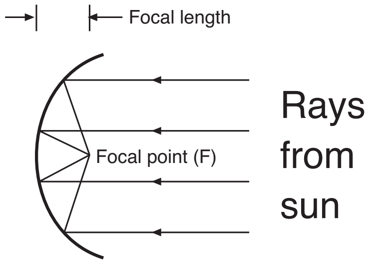
The clip fin collector is a type of tube and sheet collector. It is made from an aluminium plate attached to copper piping. Heat is absorbed by the plates and transferred to water passing through the pipes. Piping is arranged in a simple grid. Cold water enters the grid at the bottom, passes through the grid, where it is heated, and hot water leaves the panel at the top, diagonally opposite the point at which it enters.



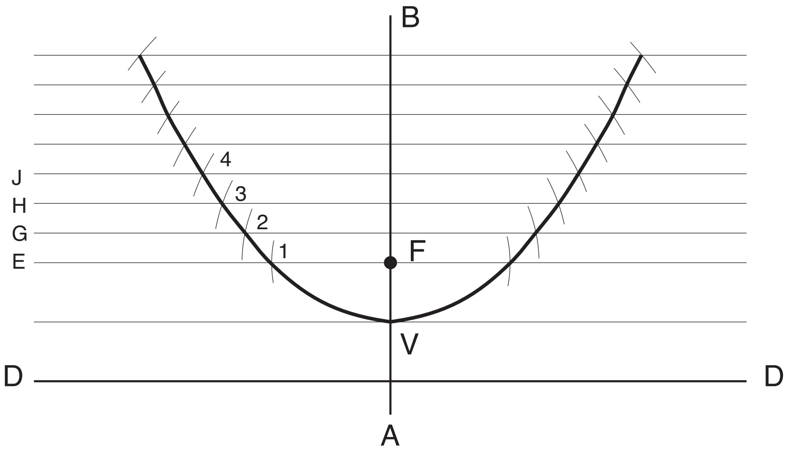
Heat losses may be reduced by the addition of glazing and insulation. Clearly the main advantage of tube and sheet collectors over the majority of sandwich collectors is that there will be a greater surface area exposed to the solar radiation, in proportion to the volume of water passing through it.

Parabolic reflectors

A parabolic mirror will focus light being aimed directly at it onto a point, shown as F on the diagram below. The focal length can be altered by changing the size and shape of the parabola.



Constructing a Parabola Graphically



Focus, F, is 20 mm from directrix DD.

Draw axis AB through F perpendicular to DD.

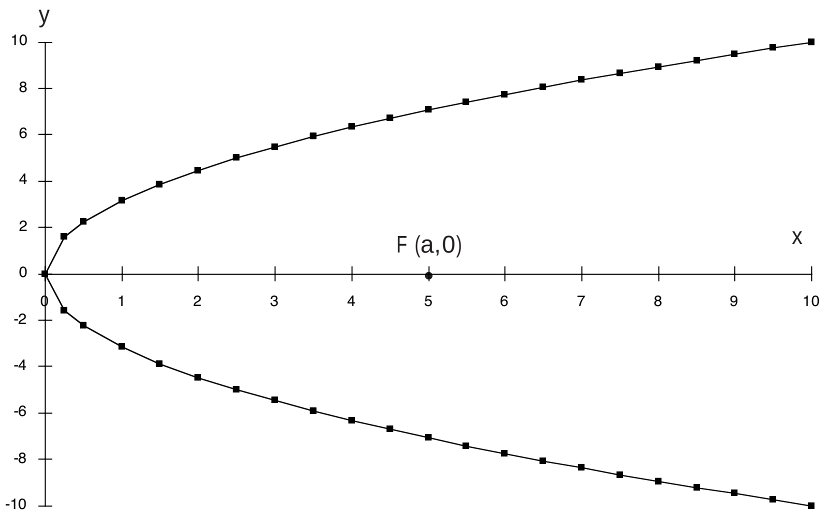
Bisect FA to give V, the vertex.

Construct lines E, G, H, J and so on at equal intervals from V parallel to DD.

With centre F in each case and radii equal to the perpendicular distances of E, G, H, J, etc. from DD, strike arcs to cross the lines in 1, 2, 3, 4, etc.

Draw a curve through 1, 2, 3, 4, etc. to give the required parabola.

Constructing a Parabola Mathematically



Considering the above graph, if the parabola has a focal point at (a,0) the parabola may be plotted using the equation:

$$y^2 = 2ax$$

Try constructing different shaped parabolas altering the focal length to see the affect it has on the shape.

Points to Consider in Designing a Parabolic Reflector

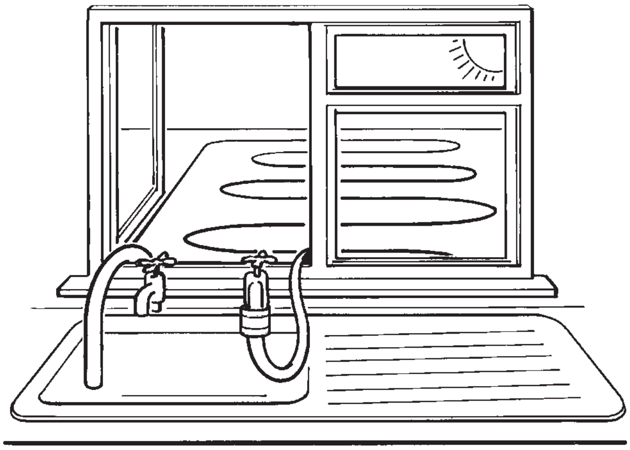
- What advantages or disadvantages are there in having a long focal length rather than a short one?
- What properties does the material used for the reflector need?
- Is heat going to cause a problem?
- How are you going to make your reflector?
- How are you going to move and hold your reflector?

It is worth noting that parabolic reflectors will concentrate direct radiation only. Therefore careful consideration needs to be given to the efficiency of such a device in our climate with a large amount of diffuse radiation. Are there any advantages that might offset this?

INFORMATION SHEET 4 - DESIGNING THE SOLAR COLLECTOR

Back up to Briefing Sheet 3 & 6

The collector is the device which heats the water. It has to collect the solar energy and transfer it into hot water. Basic systems have sets of pipes which start with cold water in them and heat up in the sun.



Hosepipe solar water heater

This is clearly not difficult. It would be difficult to prevent water-filled pipes from heating up in the sun. But how do you ensure that this process is as efficient as possible?

Consider how the following factors will affect the solar collector's efficiency:

- *surface area of the collector*
- *volume of water in collector*
- *water flow rate through the collector*
- *material of which the collector is made*
- *heat transfer between collector surfaces and circulating water*
- *surface treatment of the collector*

There are a range of collector configurations that will vary in efficiency depending on the factors outlined above. Consider the configurations outlined below bearing in mind your needs and the availability of materials.

Parallel tubes bonded to upper surface of absorber plate.

Corrugated sheets riveted together to enable passage of heat transfer fluid between them.

Tubes bonded to lower surface of absorber plate.

Formed metal sheets spot welded to produce sandwich configuration.

Tubes bonded to formed absorber plate to give increased contact area for good thermal conduction.

Trickle collector with fluid passing directly over absorber plate.

Integral tube and plate.

Corrugated sheet spot welded flat sheet.

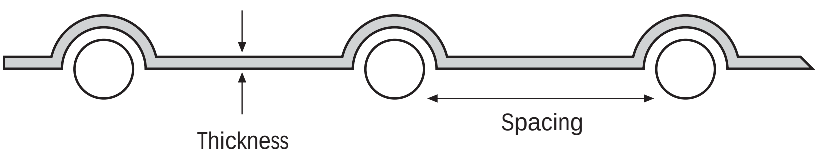
There are several key points that should be noted when considering the construction of the solar collector:

- the solar collector should ideally have a water capacity of less than 2.5 litres/m^2 of absorber surface.

- Flow rates of between 0.01 to 0.02 kg/s per square metre of collector area have been found to be satisfactory.

- If a pipe and plate system is being used then there are optimum thicknesses for the plate, and optimum distances between the pipes, to maximise heat transfer dependent on the material being used. Minor variation around these figures will not cause major problems.

Material	**Thickness (mm)**	**Spacing (mm)**
Copper	0.25	138
Aluminium	0.5	138
Steel	1.0	100



- Having a very good bond between pipes and plates is very important to maximise the rate of heat transfer between the two (i.e. a good thermal bond such as welding, brazing or high temperature solder). Soft solder should be fine unless you achieve a very high absorbency temperature, in which case the bond might fail. Maximising the surface area of pipe in contact with the plate is also important.

Materials
You should consider the following factors when considering the materials to be used for the collector.

- thermal properties - absorption and conduction,
- not easily damaged by heat,
- durable,
- will hold water,
- can be easily joined to itself or other materials with waterproof joints,
- compatible with the other components in the system and fluids used (corrosion)
- affordable price.

Copper has the best thermal properties but is also the most expensive of the commonly used materials. However the pipe and fittings are readily available and are frequently used with aluminium sheet.

There is a danger of corrosion when you mix metals in a system. Metals have different electro-chemical potentials and, as a result, when two different metals are immersed in water, there is an increased tendency for one of them to dissolve.

You may inadvertently be effectively creating a battery between the two metals. Dissolved oxygen in the water can increase this problem. With a direct system where mains water is used there will always be oxygen present.
In a sealed, indirect system there can be some corrosion in the early stages which reduces the oxygen content. This is particularly a problem where water flows from a copper pipe into aluminium or galvanised iron.

Manufacturers of aluminium absorber plates stress that they should only be used in indirect systems with anti-corrosive additives in the water and they should be electrically isolated from any other metallic elements and they should never be connected directly to copper pipes.

If aluminium absorber plates are used with copper tubing care must be taken to ensure that moisture will not be able to collect between the two (for example from condensation).

Surface Treatment
A surface of matt black paint is very good at absorbing sunlight (it will convert about 95% of the incident sunlight into heat) but it is also very good at re-emitting heat. As the temperature increases so does the rate of emission of heat.

In a single glazed collector the maximum temperature might reach 150°C so paints and primers have to be temperature resistant.

However, because the heat loss from the collector increases as the temperature of the water increases, its efficiency will be poor at high temperatures. Solar systems will therefore operate more efficiently when raising water temperature from 10 to 20°C than from 40 to 50°C. The hotter an object becomes, the greater the rate at which it loses heat. So, it is most efficient to make a collector operate at the lowest useful temperature and minimise the temperature difference between the inlet and outlet water flows.

One way of controlling the operating temperature is to speed up the rate of water flow through the collectors.

This effect can be minimised if the collector has some form of selective surface. A 'selective' surface will still absorb most of the energy, but will also retain it better. These surfaces may be applied by electro-plating or by dipping a metal absorber in appropriate chemicals to produce a thin semi-conducting film over the surface. The thin film will absorb short wave solar radiation, but not emit longer wave thermal radiation well. A good selective surface will have an absorbtance of solar radiation greater than 90% and a low emittance of thermal radiation of less than 20%. Good selective surfaces may reach temperatures of 200°C.

Selective surfaces include -

- *black chromium*
- *black nickel*
- *oxidised stainless steel*
- *black copper oxide*
- *electro-plated zinc*

There is an adhesive metal film coated with a selective surface which can be applied to an absorber. Thin, selectively coated nickel foil can be bonded onto the absorber.

The following table shows the effect of different numbers of covers and using a selective surface. It shows the overall loss of heat to the surroundings from the top cover, assuming a mean wind velocity of 5m/s and an ambient temperature of 10°C. Other losses from the back and sides are not included. The long-wave emissivity of 0.1 indicates the selective surface.

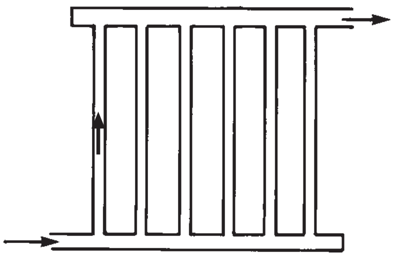
Overall loss of heat from top cover in W/sq.m

Plate temp.	**40°C**		**80°C**	
Surface Type	**Black**	**Selective**	**Black**	**Selective**
long-wave emissivity	0.95	0.1	0.95	0.1
1 cover	189	93	525	263
2 covers	78	57	280	168
3 covers	63	45	182	119

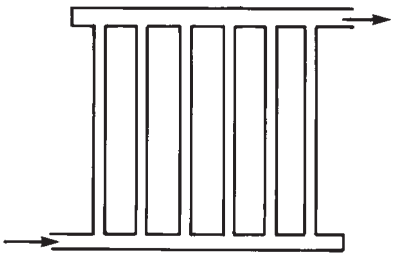
The reduction in energy loss due to the selective surface becomes increasingly significant as the collector plate gets hotter, so what a selective surface will add to efficiency depends on how often the collector reaches high temperatures.

Water Flow Through the Collector
If a pipe and sheet type collector is being constructed then it is important to consider the type of water circulation that will be required. If the circulation is occurring through thermo-siphoning then it is important that this flow is not hampered in any way.

If the system is pumped, then horizontal risers will not cause any problems. However it is important to try to avoid back circulation as shown below. This can be done either by varying the size of riser to artificially increase the resistance to flow in the right hand risers, or by having the outlet on the same side as the inlet.



Expected flow pattern in a grid of pipes



Actual flow pattern in a grid of pipes with pumped circulation

Reflectors
Lenses or reflectors can be used to achieve higher temperatures by focusing the solar energy. Only direct sunlight can be concentrated, so, if you design a system based on reflectors you may find that you can greatly increase the temperatures you can reach in direct sunlight, but you need to consider how your system will perform when there is only diffuse solar energy and also how it will be affected by wind chill, or simply cold air conditions. Also, what happens when the device is not directly facing the sun?

See information sheet 3 for more information on parabolic reflectors.

Information Sheet 5 - The Collector Box

Back up to Briefing Sheet 3 & 6

You should consider what the collector box needs to do;

- keep heat in,
- keep rain, snow etc. out,
- keep out creatures such as small mammals, large insects and birds.
- allow condensation to escape,
- contain the collector and associated pipework
- allow for expansion and contraction due to changes in temperature

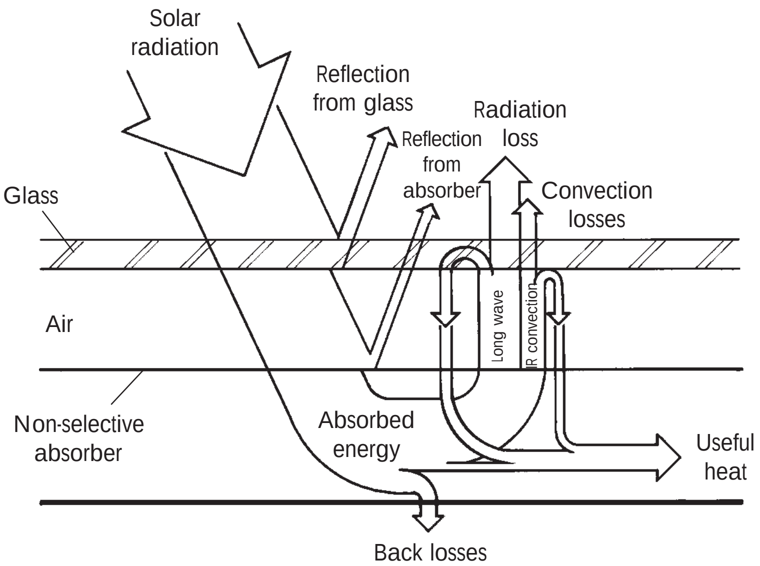
Materials
The container could be made of:

- painted timber (3 coats and repainted at least every 3 years)
- tanalised timber (and painted)
- rot resistant wood, such as cedar, European larch or oak (all air dried and not green). You can treat timber yourself and there are 'environmentally friendly' treatments available
- glass reinforced plastic,
- galvanised steel,
- aluminium.

You should consider ways of reducing deterioration of the materials over time and therefore the need for maintenance. For example as well as weatherproofing the construction materials and the joints, use corrosion resistant screws and avoid mixing metals, such as mild steel screws in aluminium boxes.

Efficiency and minimising heat loss
Once the water in the pipes has heated up you will need to ensure that this heat goes where you want it, and does not just escape out of the back of the panel or heat up the air around the pipework on its way to be used.

The hot collector can lose heat by conduction into whatever is touching it, by convection up into the air and by radiating it from its surface. Heat can therefore be retained by insulation and the glazing.



Energy balance of a flat plate collector

Glazing

The maximum spacing between the glazing and the absorber should be 40mm to prevent excessive heat loss through convection and excessive edge shading. The minimum spacing should be approximately 25mm to minimise heat loss due to conduction.

The glazing cover should allow in the maximum amount of solar radiation whilst also acting as a barrier to heat loss from the absorber. As the collector's absorber surface heats up, it radiates heat out in the infra-red range at a wavelength of 3 microns and more. These long wavelengths cannot pass through some glazing materials and are therefore absorbed by the glazing and some of the energy is re-emitted towards the absorber.

Glazing material needs to be chosen to let through visible daylight and ultraviolet but to reflect back any infra-red radiation from the surface of the absorber itself. So it needs to have high short-wave transmittances (below 3 microns) but low long-wave transmittances (over 3 microns). About 98% of incoming solar radiation is at less than 3 microns. Optical wavelengths are measured in Angstrom Units (Å). 1000 Å = 1 micron; 1Å = 10^{-10} m.

Ordinary glass (3mm window glass) is quite good for solar panels - it will transmit through about 90% of the solar radiation falling on it. Some of the other 10% is absorbed by the glass and is then re-radiated from both the internal and external surfaces.

4mm float glass has a transmittance for solar radiation of about 84%.

Water white glasses have a low iron content and are available with a higher solar transmittance, but may be expensive and difficult to get hold of.

Horticultural glass comes in standard sizes and is cheaper. Some transparent plastic materials have high short-wave transmittance characteristics but also have appreciable long-wave transmittances and will therefore allow heat to escape. With some plastics their transmittance deteriorates when they are exposed to the ultra violet light of the sun for periods of time. Filon - glass fibre in resin with a surface coating to protect it from degrading (should be 90% transmittance)

Tedlar - thin plastic sheet, a fluorocarbon in the same chemical family as teflon, does not degrade significantly, very durable, very difficult to tear, very light weight, about the same price as glass (should be 97% transmittance) (used for drum skins).

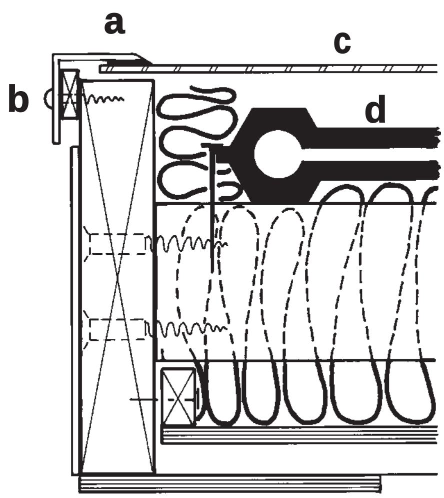
Teflon - usually very thin, very clear film capable of withstanding high temperatures, therefore good next to the absorber in multiple layer systems.

Acrylic sheet - has very good transmittance but would not stand up well to high temperatures. It is used in some commercial collectors, but has to be well supported, so as not to distort too much if it softens when hot.

There are transparent coatings which can be applied to the inner surface of a glass cover to increase the reflection of long-wave radiation. These include tin oxide and indium oxide.

The glazing also protects the collector from the chill effect of wind. Glazing will reflect away and absorb some of the solar radiation but, by reducing heat losses, it substantially increases the overall efficiency.

The fixings of glass to the box should be flexible in order to give the glass room to move. One option is outlined in the diagram below.



Cross-sectional view of solar collector.

a) glazing angle

b) glazing angle spacer strip (on bottom side only)

c) glass

d) absorber plate

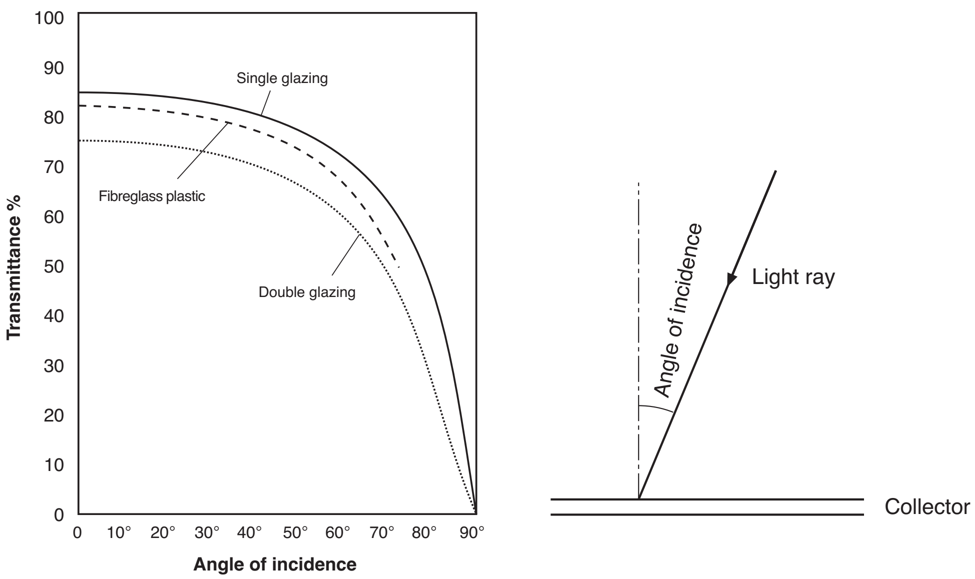
Double glazing

Double glazing would lower heat loss but it also reduces energy input to some extent because each layer absorbs and reflects away some radiation, and it is expensive. When the absorption of energy into each cover is taken into account, the transmittance losses for incidence angles up to 35 degrees, are typically about 10% for single glazing, 18% for double glazing and 25% for triple glazing. Losses can however be substantially less for very thin film covers.

Two layers of different glazing materials could be used to optimise the characteristics of both.

The inner layer of double glazing will reach much higher temperatures than the outer one and the consequences of this must be considered.

Low temperature systems, such as those heating water for swimming pools, often do not use glazing at all.
In direct radiation, transmittance properties vary with the angle of incidence. Transmittance does not drop very much up to an angle of about 50° but it then starts to drop quite sharply.



However because a large proportion of the energy absorbed is from diffuse radiation, and because diffuse radiation is best collected on a horizontal surface, the ideal tilt angle to maximise transmittance will be less than 50°. See Information Sheet 8.

Insulation

Consider the need for insulation both to reduce heat loss and to protect exposed parts of the system from freezing. Where then are the key areas that need insulating?

In the solar circuit, is there any advantage in insulating the pipes returning the cooled water to the panel?

What about the effect of high temperatures inside the container? Any insulating material needs to be resistant to -

- *high temperatures (not melt or give off gases),*
- *infestation by insects,*
- *moisture,*
- *fire.*

Warmcel insulation is made from fireproofed, shredded, recycled paper. It is the most environmentally sound insulating material, having much less energy expended in its manufacture and a cleaner production process than rockwool or fibreglass. It is non-toxic and a very good insulator (125mm depth of warmcel gives equivalent insulation to 150mm of fibreglass).

Low temperature plastic foam insulation materials, like polystyrene, should not be used immediately behind an absorber because of their reactions in the high temperatures that they may be exposed to. Some give off vapours which can condense on the back of the glazing and interfere with its transmittance.

INFORMATION SHEET 6 - CALCULATING COLLECTOR EFFICIENCY

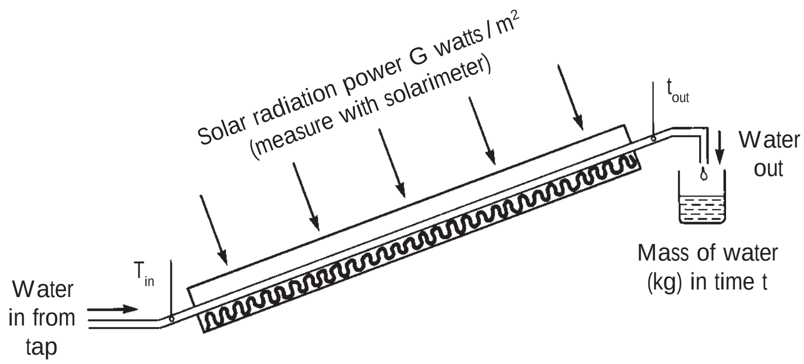
Back up to Briefing Sheet 3 & 6

There are two approaches to finding the efficiency of your collector:

1. Experimental measurement of the performance of the complete collector.

2. Calculation of the collector efficiency from data obtained on the constituent parts of your collector.

Experimental Measurement of Overall Collector Efficiency
The simplest method of measuring efficiency is to set up a constant flow experiment where measured heat energy is removed from the collector and compared with measured solar energy supplied to the collector.



$$\text{Efficiency} = \frac{\text{Useful power output from collector}}{\text{Total power input from sun}}$$

Now, total power input form the sun = GA Watt

G = Solar radiation power in W/m^2
A = Area of collector in m^2

Useful power output from collector = power gained by water through collector

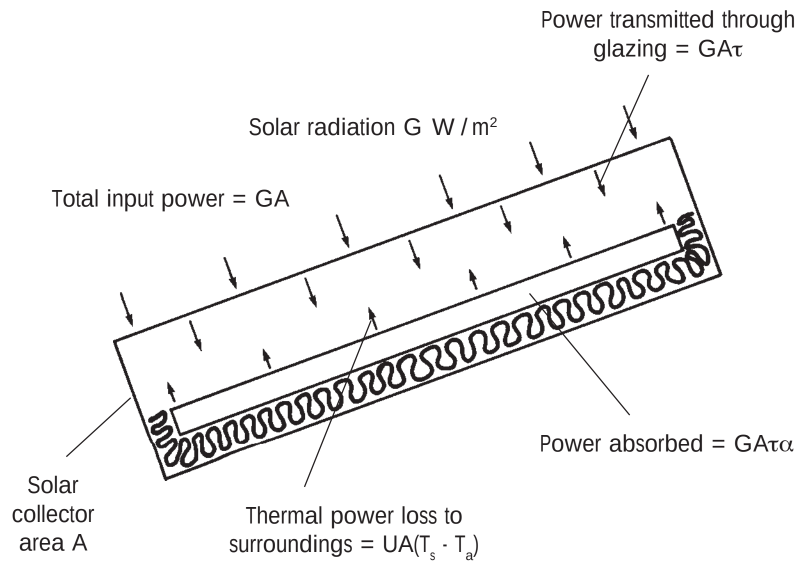
So, useful power output = $\frac{mc_w(T_{out} - T_{in})}{t}$

m = mass of water (kg) collected in time t
c_w = specific heat capacity of water (4200 J/kg°C)
T_{out} = outlet temperature
T_{in} = inlet temperature
t = time taken in seconds

Therefore, efficiency = $\frac{mc_w(T_{out} - T_{in})}{GAt}$

This approach can usefully measure the significance of various changes to your design.

Calculating Collector Efficiency from Constituent Data
By considering the action of the parts of a solar collector and their effect on the overall efficiency the design can be optimised.



The relevant equations are:

Efficiency = $\frac{\text{Useful power output}}{\text{Total power input}} = \frac{P_c}{GA}$

G = Solar radiation power in W/m² (measured by solarimeter or from standard data)
A = Area of collector in m²
P_c = Power output from collector in W

But,

Power output from collector	=	Power absorbed by the black surface	-	thermal power lost to the surroundings

or $P_c = GA\tau\alpha - UA(T_s - T_a)$

τ = transmission factor for the glazing
α = absorptivity of the black surface
U = heat loss factor for the absorber (commonly called 'the U value') in $W/m^2{}^\circ C$
T_s = mean temperature of absorber = (input temp + output temp)/2
T_a = ambient temperature

Putting this into our Efficiency equation gives:

$$\text{Efficiency} = \frac{P_c}{GA} = \frac{GA\tau\alpha - UA(T_s - T_a)}{GA}$$

or
$$\text{Efficiency} = \frac{G\tau\alpha - U(T_s - T_a)}{G}$$

Note that for a given collector, $\tau\alpha$ and U are fairly constant while $(T_s - T_a)$ and G both vary.

It is usual to present the 'efficiency curve' as a function of the variable

$$\frac{(T_s - T_a)}{G} \quad \text{or} \quad \frac{\Delta T}{G}$$

When designing a collector you will want to vary τ and α to see the effect of using different materials.

Some Typical Values Used in Efficiency Calculations

τ, the transmission of solar radiation by the cover is typically;

0.85 for single 4mm glass or acrylic sheet
0.72 for double 4mm glass or acrylic sheet
0.90 for tedlar thin film
0.95 for Teflon thin film

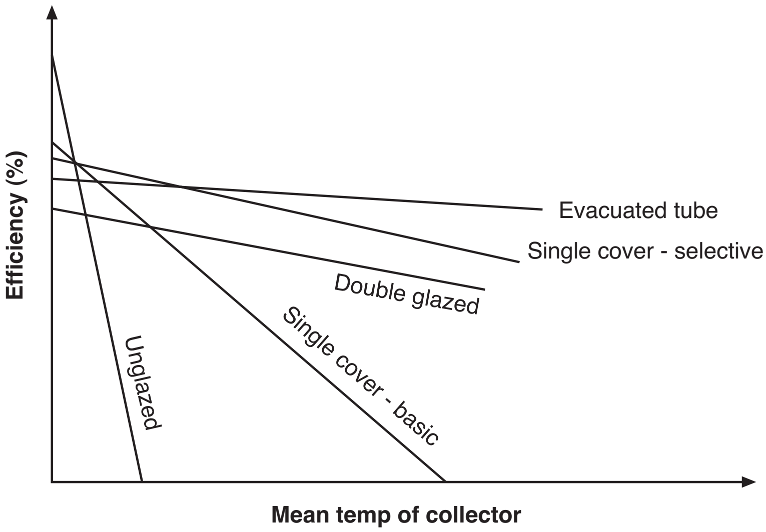
These figures can be reduced by 1 or 2% due to dirt and up to 8% due to dust in very dry areas.

α, the absorbtance of the collector surface is typically 0.93 for a good matt black paint.

With collectors having high levels of insulation behind the absorber panel, the heat loss factor, U, is determined mainly by the number of covers and the wind speed. It also increase a little at high absorber temperatures.

Typically: 1 cover, U=5.5; 2 covers, U=3.0.

The graph below illustrates how the efficiency of different types of collector vary with the temperature conditions.



The graph shows that increasing the number of glazing covers only becomes viable when you need higher temperatures from the solar collector. For example, heating swimming pools requires only a low temperature increase, therefore glazing the collector for this application would be counter productive.

An added factor needs to be considered to account for the additional losses between collector and tap.

Systems can vary between 25% to 60% efficient depending on their design and material use. Therefore a solar system will convert between 25-60% of the solar energy falling on the collector into heat energy coming out of the taps.

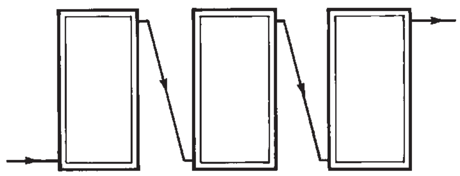
INFORMATION SHEET 7 - CONNECTING THE COLLECTORS

Back up to Briefing Sheet 3 & 6

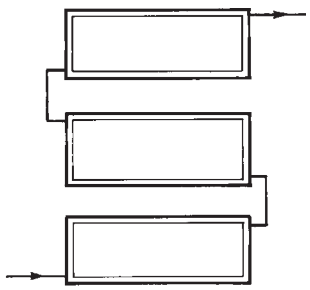
Unless the identified need for hot water is quite small, there will be a need for more than one collector. How the collectors are connected up could have a major impact on the even flow of water through the system and therefore it's overall performance.

Connecting Thermo-Siphoning Systems

System 'a' will cause problems as it forces the flow downwards. Within a thermo-siphoning system all pipework should allow an unrestricted flow upwards as in 'b'.

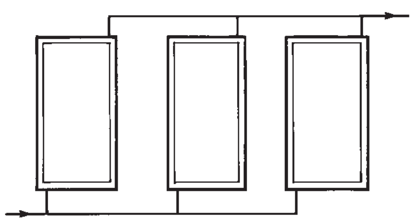


a

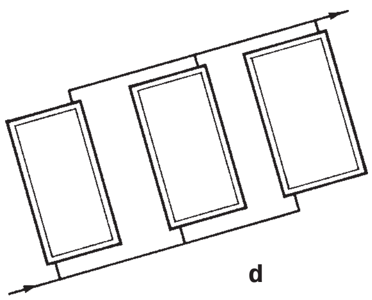


b

Both 'a' and 'b' are arranged in series, this will produce higher temperatures which will reduce the efficiency as a result of higher heat loss. System 'd', arranged in parallel, will usually be preferable unless the high temperatures are actually required. System 'd' is also slightly tilted to encourage more efficient upwards flow of water.



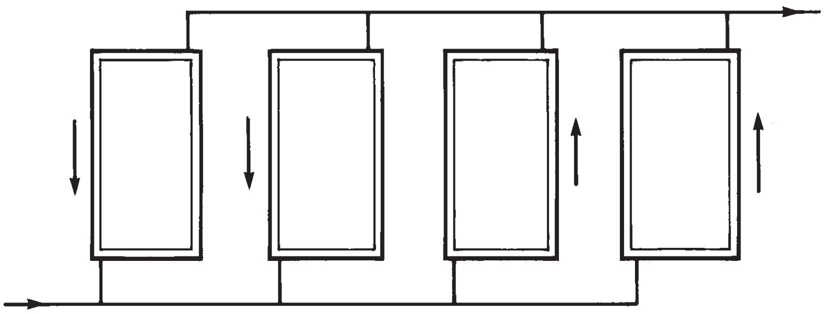
c



d

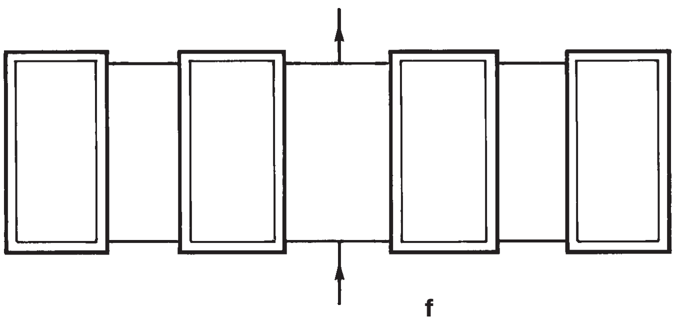
Connecting Pumped Systems
Again parallel connection of collectors is better unless high temperatures are specifically required.

However within a pumped system connected in parallel as in system 'e', the water flow could be uneven causing no flow areas and even reverse flow as illustrated. This could greatly reduce the efficiency of the system.



e

System 'f' then provides a well balanced circulation pattern with no flow disturbances.



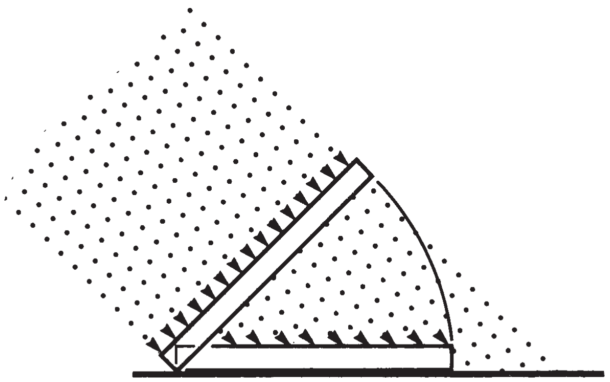
f

It is worth considering the use of compression fittings as opposed to soldered joints to allow the easy removal of a panel if necessary.

INFORMATION SHEET 8 - MOUNTING THE COLLECTORS

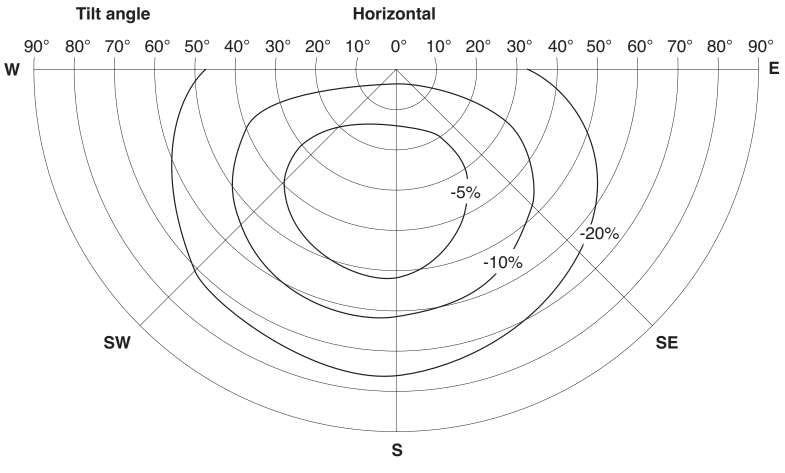
Back up to Briefing Sheet 3 & 6

Having identified the best spot for the collectors taking into account the factors outlined in information sheet 2, you will need to mount the collectors facing the right direction and at the right angle to maximise the amount of solar radiation that they receive. The tilt angle will increase the amount of absorption of solar radiation, see below. However, the optimum angle is a compromise between the need to collect direct radiation, which in winter requires a very steep angle, and the need particularly in this climate to collect diffuse radiation, which is at a maximum when the collectors are horizontal.



Direct radiation - tilt increases absorption

If they are being mounted on a sloping roof then the choices are limited, with a flat roof however there is a lot more freedom. The diagram below illustrates that the optimum settings for the collector range quite considerably. For example, with the collector facing due south, the angle from horizontal could range from 15 to 50 degrees and still produce a very similar amount of energy.



Variation of the solar energy supplied by the example system with a class E collector, with orientation and tilt of the collector

Mounting on the ground within the school grounds might make the collectors easier to maintain, and will make them more noticeable and higher profile. Although these might be important considerations, the possibility of accidental or non-accidental damage should be carefully considered before ground level mounting is decided upon.

Mounting the collectors requires only a triangle frame set at the required angle, though it is important to consider the weight of the collector full of water when deciding upon the strength of the frame. In addition the frame should be secured to the surface it is resting on in some appropriate way, particularly if the collectors are being fixed to the roof. It is worth noting where rain water collects on the surface and try to avoid these places.

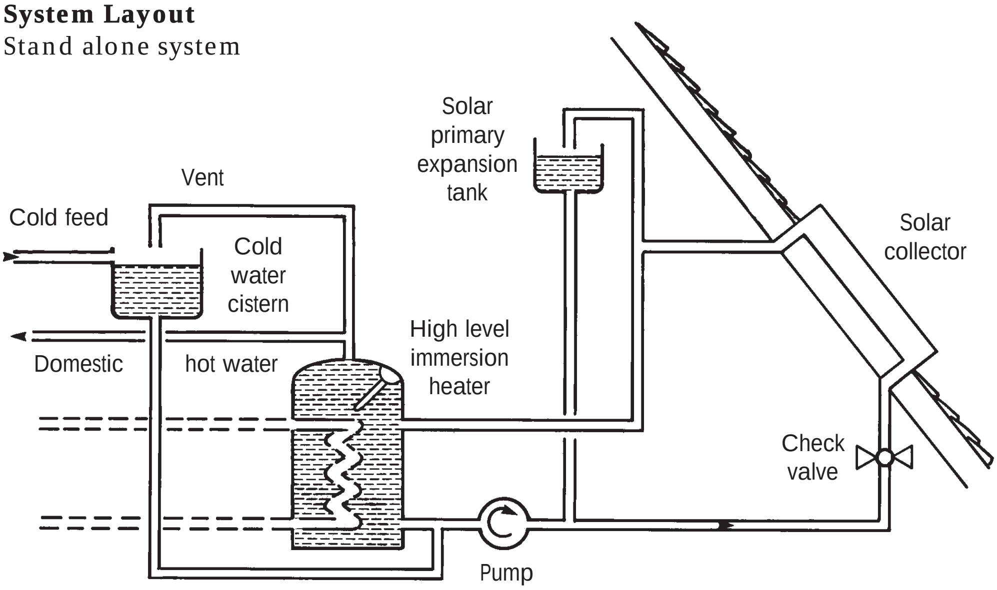
Would it be worth considering the need to allow the collector to be moved to track the sun either during the day or over the year to reflect the variation in height of the sun in the sky? It could be automatic or manual control.

INFORMATION SHEET 9 - SYSTEM DESIGN

Back up to Briefing Sheet 4

There are a range of different system designs, the choice of which depends on the particular situation, and type of hot water need that you are dealing with.

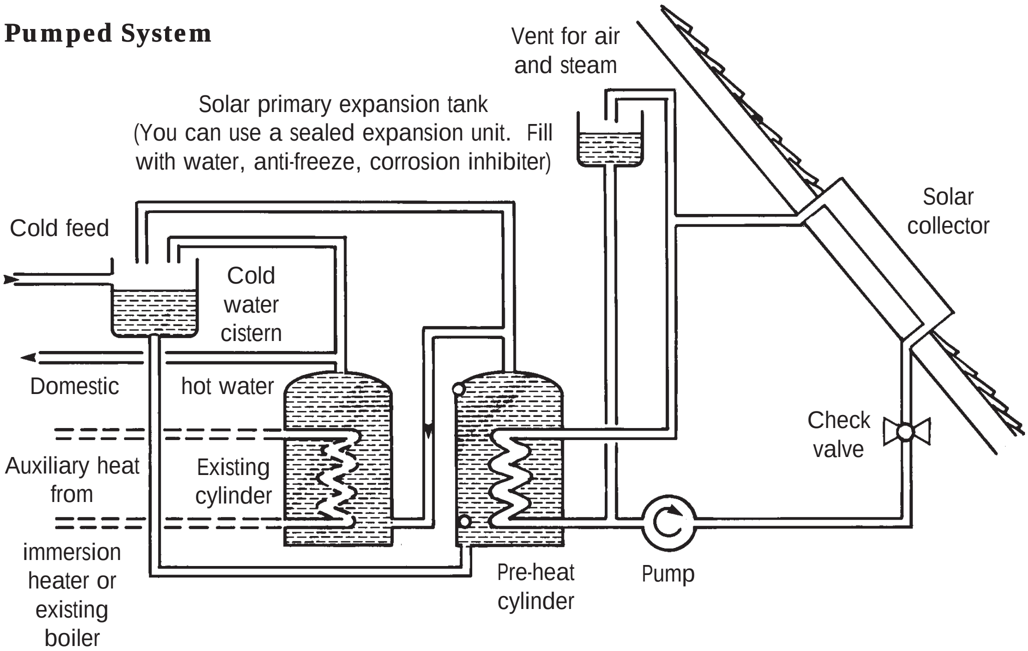
System Layout
Stand alone system



Pros
- Easier to set up if only supplying water to one or two draw off points.
- No need to worry about existing system.
- More efficient for smaller hot water demands *when there is enough sun*, due to lower standing heat losses from tanks and pipes.

Cons
- Produces less useful heat all year round. Some form of pre heat system will supply more useful heat to the whole system when hot water is required during periods with lower sunshine levels.
- Becomes complicated to install if water is required at a number of existing draw off points.
- Might need some form of back-up system

Pumped System



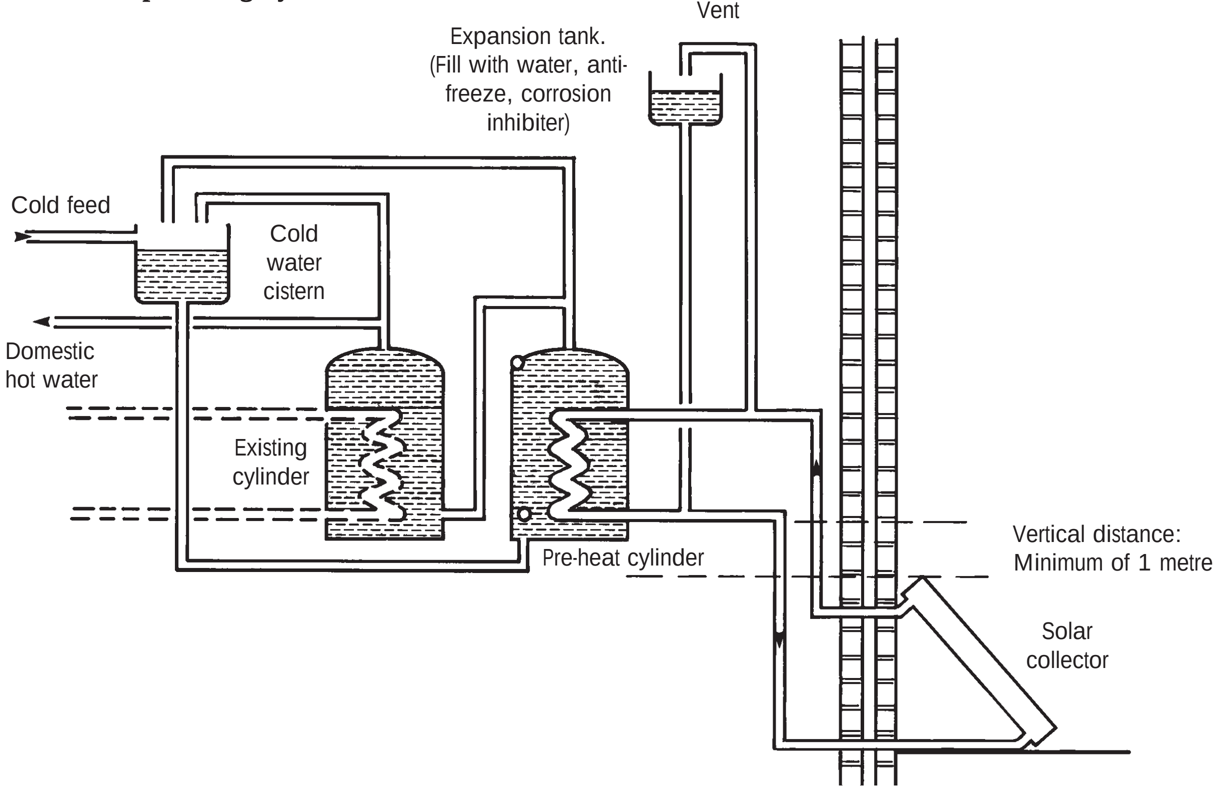
Pros

- Flexible system arrangement
- Slightly more efficient heat transfer between panel and tank

Cons

- More complicated system requires solar controller to operate pump
- More maintenance, higher running costs

Thermo-Siphoning System



Pros

- System is a lot simpler, no need for pumps, solar controllers etc, water flow is controlled automatically by changes in density of water due to varying water temperatures .
- System is a lot cheaper for the same reason.
- Requires less maintenance.
- No electricity required to run system.

Cons

- There are a number of system configuration restrictions that could cause problems during installation.
  - Pipework in solar circuit needs to be at least 22mm, preferably 28mm.
  - The pipe running from the top of the panel to the tank must run uphill all the way.
  - The pipe running back must run downhill all the way.
  - The tank should be at least 600mm, preferably 1m above the top of the panel. This might need to be increased if the horizontal distance is more than a few metres.
  - The pipe layout within the collector should consist of vertical risers as opposed to horizontal lengths (diagram 3).
  - It is not possible to have a self draining thermo-siphon system.

Elements of the System

Cold Water Feed Tank
The cold feed tank should be connected to the mains supply via a ball cock, similar to the valve found in W.C. cisterns. An overflow pipe is also required in case the ball valve should ever fail to turn off the cold water supply.

Expansion Tank
As water in the solar tank is heated it will expand and any dissolved air will come out of solution. It is therefore necessary to have an expansion tank to allow for pressure changes within the solar system, and a vent to allow the air to escape to help prevent blockages. There should be a vent pipe in the hot water supply side of the system, usually back into the cold water feed tank, as well as a vent pipe to a separate expansion tank as part of the solar collector circuit, see diagrams above.

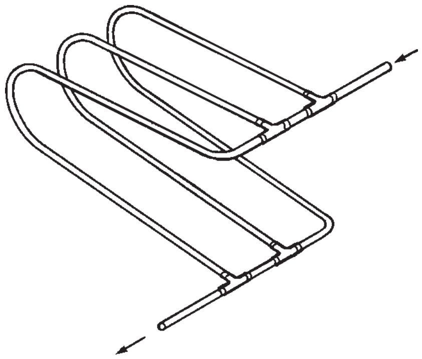
Pump
If a pump is being used then it will need to be capable of providing a flow rate of between 0.01 and 0.02 kg/s per square metre of collector area. A normal 30 W central heating pump should be sufficient except for very large systems. A variable head pump would be ideal if available, to be able to experiment with different flow rates. However to avoid 240V appliances it might be necessary to use a car water pump or similar.

The pump should be installed where it will remain full of water and on a vertical piece of pipe to avoid airlocks. All pipework should be flushed out before the installation of the pump to ensure that there are no loose particles that could clog up the pump when it starts working. The pump should be isolated by a gate valve on each side of it in the circuit to enable easy removal if necessary. A controller should switch the pump on when the temperature of the collector is about 4°C higher than that of the solar tank and switch it off again when the temperature difference falls to 1°C. If the temperature difference is less than 1°C then the pump will probably be using more energy than the collector is collecting.

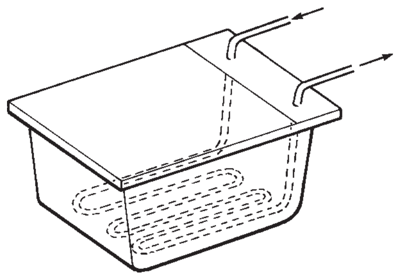
Storage Tank
The hot water storage tank should be sized with the daily demand for hot water in mind. Ideally the tank should be greater than 80% of the daily hot water demand, however in reality the choice may be limited by availability. Again the ideal tanks are the typical hot water cylinders with an integral heat exchanger coil.

If one of these tanks is not available, then it will be necessary to construct a heat exchanger to place in an open topped tank. The best material to use is copper piping because of its good heat conduction properties.

The heat exchanger size should ideally be in the region of 0.2-0.3 m^2/square metre of collector area. This equates to 4 metres of 15mm pipe or 3 metres of 22mm pipe. It is best to bend the pipe in slow bends, see diagram below, as sharp bends tend to increase the resistance to water flow. This is particularly important in thermo-siphoning systems where the flow is already quite slow. Remember the flow in these systems should be upwards, in pumped systems the direction of flow does not matter.



Heat Exchanger for a thermo-siphoning system



Heat exchanger in a pumped system

All pipework and hot water tanks should be well insulated to prevent heat loss.

It is also important to remember that each litre of water weighs 1kg, so a full tank, maybe 200 litres will be quite heavy. You will need to ensure that this is considered when the tank is installed and structural supports for the tank are provided.

INFORMATION SHEET 10 - PLUMBING TECHNIQUES - WATER PIPES, FITTINGS AND JOINTS

Back up to Briefing Sheets 3, 4 & 7

The following is an extract adapted from a 'DO IT ALL' DIY guide (produced here by kind permission). A range of such guides is available, and, of course, consumable materials and small equipment can easily be obtained from this source.

1. TYPES OF PIPE

COPPER PIPE

This is commonly used for domestic water and central heating systems. It is available in diameters 8, 10, 12, 15, 22, 28 and 32mm. The most common sizes being 15mm and 22mm. Old copper piping is in Imperial sizes:

a) 1/2" is the same as modern 15mm and all fittings should be interchangeable.

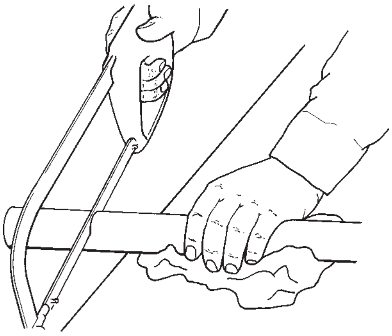
b) 3/4" is slightly smaller than modern 22mm so an adapter is needed.

Bendable corrugated copper pipe is also available. It is easy to bend by hand and is ideal for use in awkward areas.

PLASTIC PIPE

This is a available in diameters of 15mm and 22mm. It is easy to use and is flexible enough to be bent through 90° by hand. It can be used for domestic water and central heating but must not be used to connect directly to a boiler.

2. CUTTING AND PREPARING PIPE



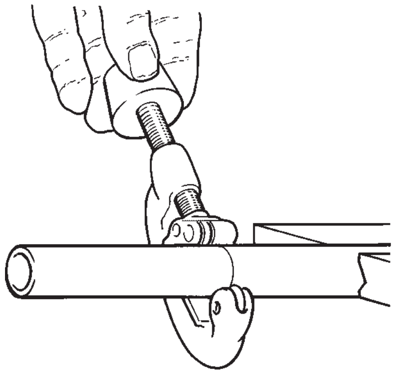
COPPER PIPE

This can be cut with a hack saw, but the saw will leave burrs both inside and outside the pipe. Use a flat file to smooth off the burrs on the outside and a reamer or round file for the inside.

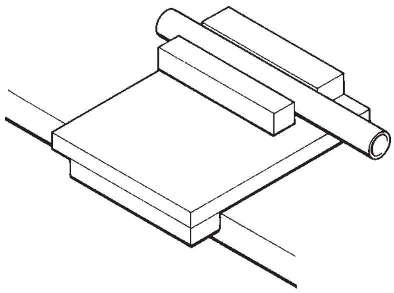
PLASTIC PIPE

This can be cut with a trimming knife or a hack saw. When jointing plastic pipe a metal insert must be placed inside the pipe to provide support so the fitting can grip the pipe better.

Pipe cutters are simple and fast to use and make a perfect square cut. The cutter leaves a lip on the inside of the pipe which should be removed with a reamer (part of the pipe cutting tool) or round file, to avoid the build up of scale.



Copper pipe can be easily crushed in a vice, so when cutting with a hack saw, use a bench hook to rest the pipe on.



INFORMATION SHEET 11 - DESIGNING WITH ELECTRONICS

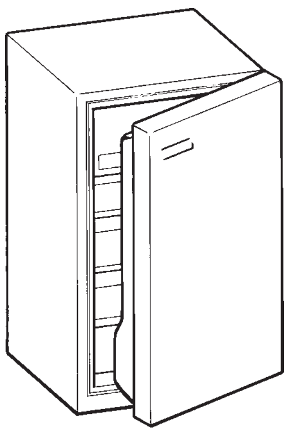
Back up to Briefing Sheets 4 & 6

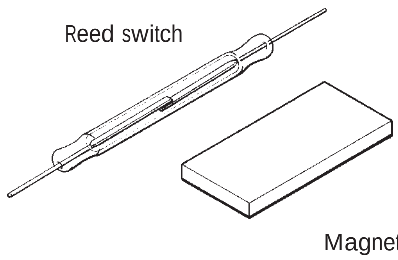
When solving a problem with electronics, it is best to break it into separate blocks. Each circuit will be made up of at least three blocks:

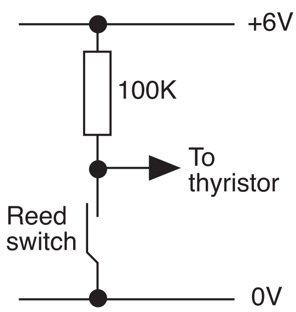
INPUT → PROCESS → OUTPUT

The Input senses and reacts to changes. Some typical input devices are:

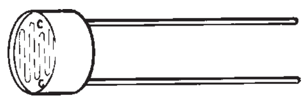
1. Switch
A switch may be used to sense pressure on it. E.g. it can sense if a door is open or closed or if someone is pressing it.



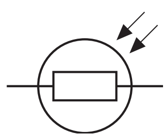




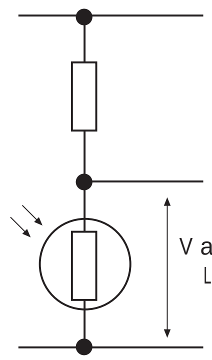
2. Light Dependent Resistor (LDR)
An LDR's resistance is dependent on the level of light falling upon it and hence the voltage drop across it may change.



Light dependent resistor

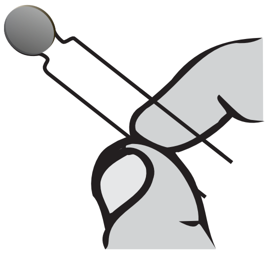


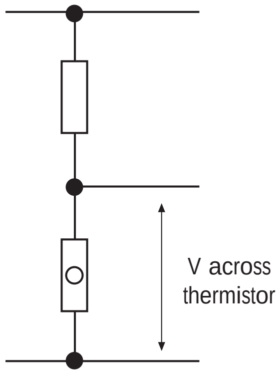
Symbol



3. Thermistor

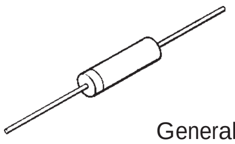
A thermistor acts as a resistor whose resistance changes depending upon its ambient temperature. Therefore the voltage drop across the thermistor will change with temperature.



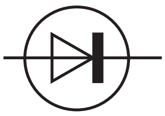


4. Diode

The voltage drop across a diode will change slightly as its ambient temperature changes. This change in voltage may be increased by using several diodes in series.



General purpose diode



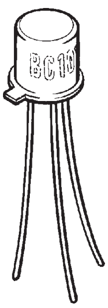
Symbol

The Process reacts to changes of the input and controls the output. It may be necessary to perform operations on the input changes as these changes may not be sufficient to directly control the output.

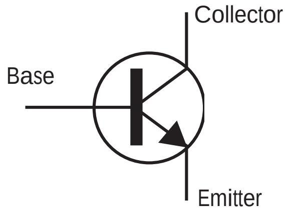
The following devices may be used to amplify input changes:

1. Transistor

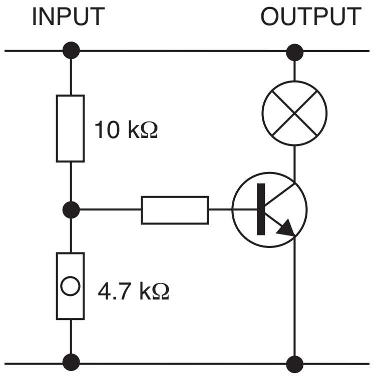
A transistor may be used as a switch and/or an amplifier.



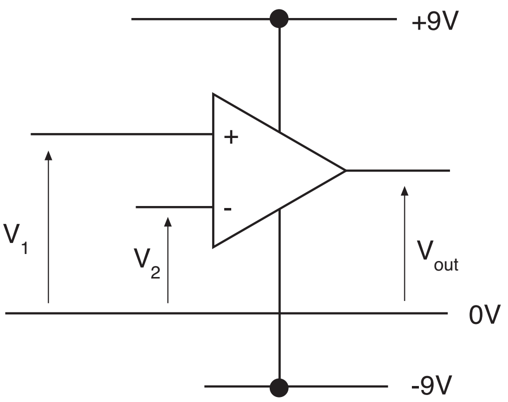
Transistor



In the circuit below, the transistor needs to be on for the bulb to be on. There must be more than about 0.7 volts across the base and emitter connections of the transistor for it to be on.
If one of the input resistors is replaced with an LDR or a thermistor, the circuit could be used to switch a light on (or off) when certain light or heat conditions are met.



2. Operational Amplifier (OP AMP)
The operational amplifier may be used to amplify the difference between two voltages. It has a gain of about 10000.



Output Voltage (V_{out}) = Gain × (V_1 - V_2)

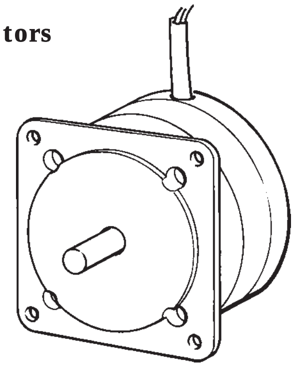
However the output voltage may not be outside the range of the supply voltage (i.e. +9V to -9V). In fact in practice it would be about 8V to -8V as there is a voltage drop across the Op Amp to take into account.

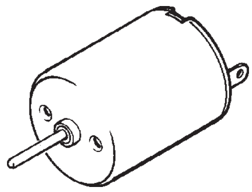
As the gain of the Op Amp is very large, the output voltage will be either +8V when V_1 is greater than V_2 or -8V when V_2 is greater than V_1.

The output is switched on and off by the process part of the circuit. It can perform similar functions to what the sensors are detecting , e.g. heat, light, movement.

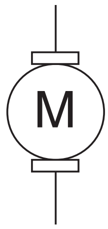
Typical output devices include:

1. Motors





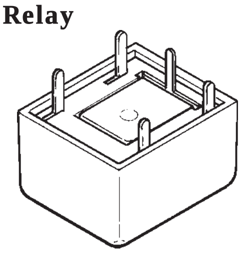
Electric motors



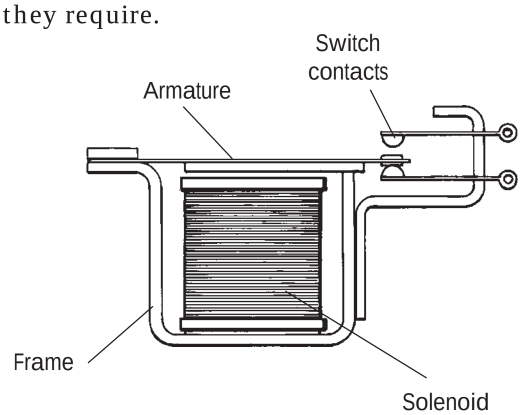
Circuit symbol for motor

Motors provide a rotary motion and , in general, the greater their torque, the more current they require.

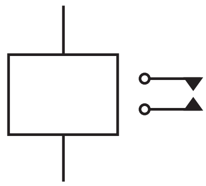
2. Relay



Enclosed relay with PCB mounting pins



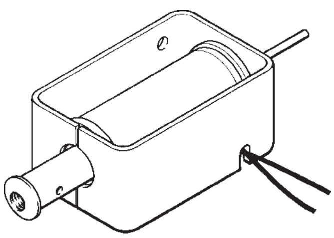
Open frame relay



Symbol for relay

A relay is used to separate two circuits electrically. A coil in the relay is energised by a voltage being put across it. This in turn creates a magnetic field in order to operate the switch in the secondary part of the relay.

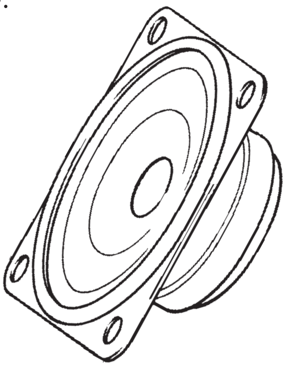
3. Solenoid

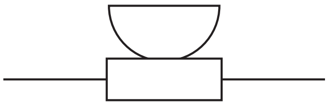


A solenoid also relies on a magnetic field being created when a voltage is applied across the coil. However, this field is used to operate a bolt which is quickly drawn into the field. A spring may be used to return it to its "off" position.

4. Speaker

A speaker can produce a sound output. However it is necessary to 'switch' it on and off very quickly in order to produce an audible noise.

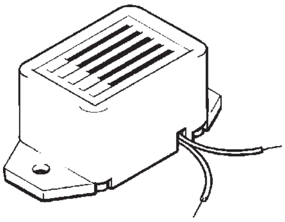




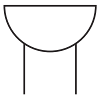
Symbol

5. Buzzer

A buzzer can be used to produce a sound and it only requires a D.C. voltage across it to operate.



Buzzer



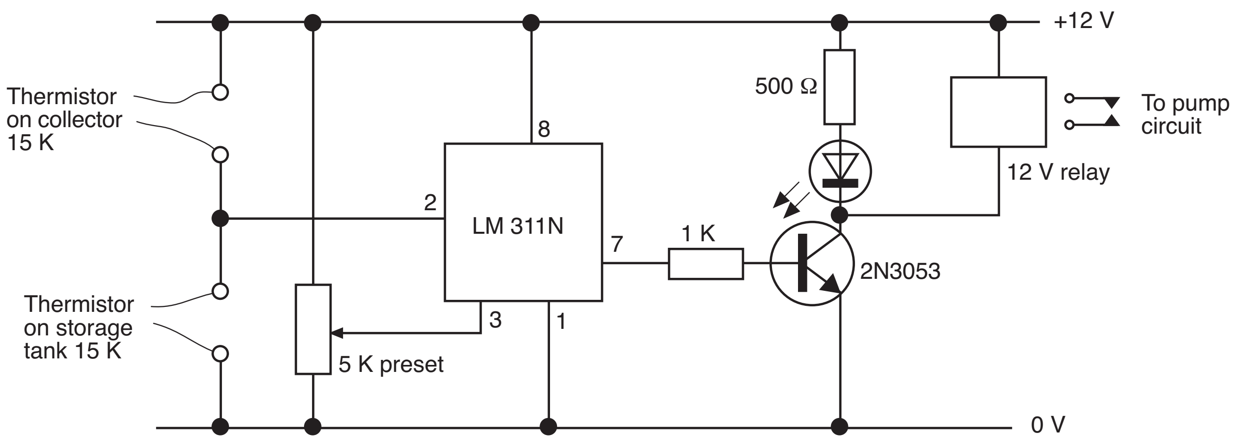
Symbol

INFORMATION SHEET 12 - DESIGN OPTION - THE SOLAR PUMP CONTROLLER

Back up to Briefing Sheet 5

Construction Plan
Stripboard is probably the most convenient system, with the following components.

Voltage comparator	*LM311N plus 8 pin socket*
Transistor	*2N 3053*
Potentiometer	*Cermet Pre-set 5K*
Relay	*12 V miniature Relay: PCB Mounting*
2 bead thermistors	*15K*
LED	*To show relay operation*
Metal film resistors	*500 Ω and 1000 Ω*



The best way to fix the bead thermistor to the collector and storage tank is with silicone sealant to prevent condensation shorting the contacts.

The 5K Cermet preset should be adjusted to set the required temperature difference between the two thermistors to operate the relay and then the pump. The thermistors should be put in different substances, possibly water, with known temperatures to enable the accurate calibration of the controller.

INFORMATION SHEET 13 - WEATHER PROTECTION

Back up to Briefing Sheet 3, 4 & 7

The exposed collector and pipework will be vulnerable to the extremes of the weather, particularly high winds and freezing weather.

Apart from the extremes, the collector should be built to prevent water penetration, using mastic on all joints and at the inlet and outlet holes, and the surfaces treated to reduce the need for maintenance. Aluminium or fibreglass casings will last years. Timber casing, even if it is well treated, will need the re-application of some form of protective coating after a few years. Silicone sealant will last a lot longer than conventional putty for sealing the glazing covers to the frame.

High winds
From a structural point of view the forces placed on the collector by high winds should be considered when mounting the collector. All fixings should be strong and secure, however it would be best to avoid windy sites if at all possible.

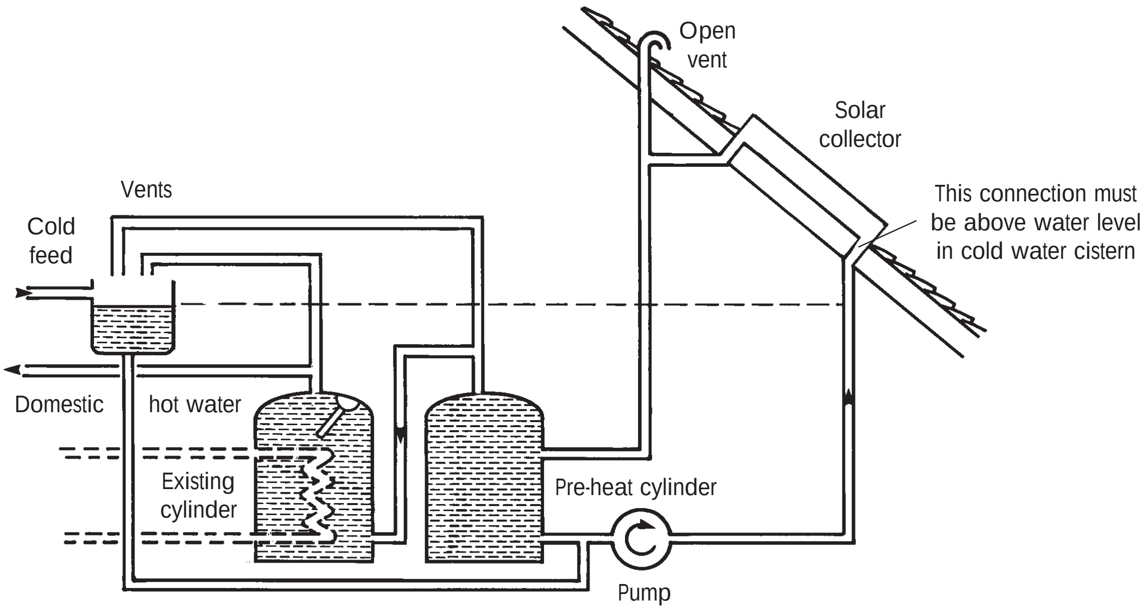
Freezing weather
All external pipework should be insulated to reduce the risk of freezing. Anti-freeze can be used as an additive to the water in the solar circuit as long as the water that is heated by the solar panels is separated from the water that comes out of the taps by a heat exchanger (an indirect system). Car anti freeze is not recommended because of its toxicity. However if the system is arranged such that the water level in the cold feed tank is higher than the water level in the solar expansion tank, this ensures that the pressure in the solar circuit is lower, so if there is a leak between the two parts of the system, the water flow will be to the solar circuit rather than the other way round.

There should be approximately 20-25% antifreeze within the solar circuit to effectively prevent freezing. This will probably need replacing after approximately 5 years.

An insulated cover placed over the collector at night is a simple option but it does require a good memory to remember at the crucial time.

The other option is a self draining system that drains the water out of the collector during the winter. A manual system relies on memory; the diagram below illustrates the system layout for an automatically draining system.

Because the collector and all exposed pipework are above the level of the cold water cistern, when the pump is not working the water falls to the level of the cold water cistern thereby protecting the exposed parts of the system.



An open vent is required as shown in the diagram and the cold water tank must be large enough to take all the displaced water. The layout of the pipework should encourage easy draining and filling without developing air pockets, blockages or pools of water.

There could also be a problem in hard water areas with scale formation. It will not be possible to add an inhibitor to the solar circuit because the water heated is the water that comes out of the taps. Excessive scale formation in the collector could reduce the efficiency of the collector over time, requiring de-scaling every few years.

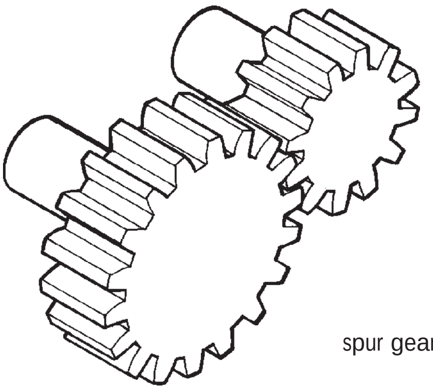
INFORMATION SHEET 14 (OPTIONAL) - TRACKING MECHANISMS

Back up to Briefing Sheet 6

It may be necessary to speed up, slow down, increase or decreases a force or torque, or convert one type of motion to the other, when considering the design to move your collector.

The following mechanisms may be worth considering.

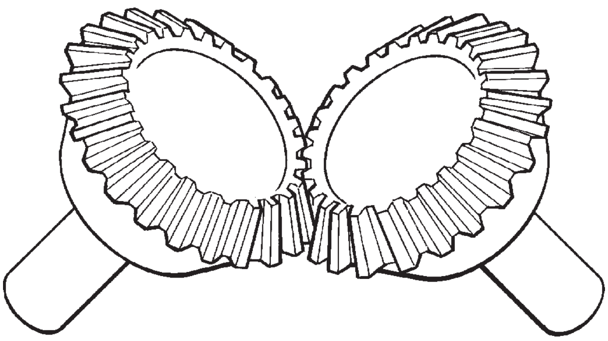
1. Spur Gears - used to increase and decrease rotary speeds and to decrease and increase the torque respectively.



spur gears

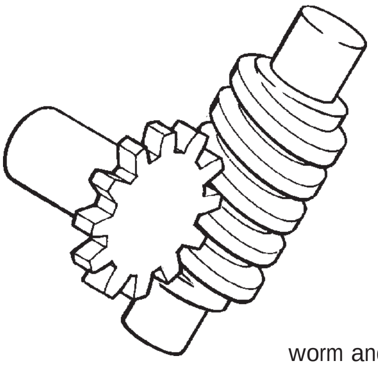
$$\text{Speed of driven gear} = \text{Speed of driving gear} \times \frac{\text{no. of teeth on driver}}{\text{no. of teeth on driven}}$$

2. Bevel Gears - are used to transmit a rotary motion through 90°



bevel gears

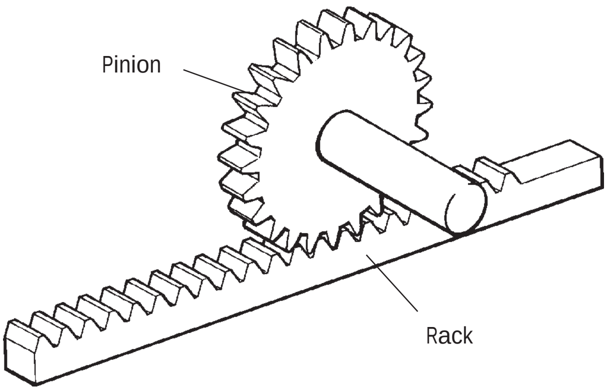
3. Worm and Wheel - As the worm only has one tooth per turn of the helix, this mechanism slows down a rotary motion by a large ratio.



worm and wheel

$$\text{Speed of wheel} = \text{speed of worm} \times \frac{1}{\text{teeth on wheel}}$$

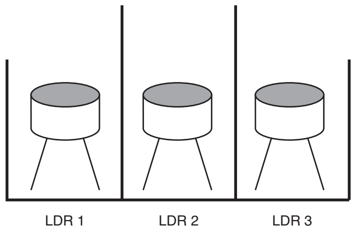
4. Rack and Pinion - is used to convert a rotary motion to a linear motion or vice versa.



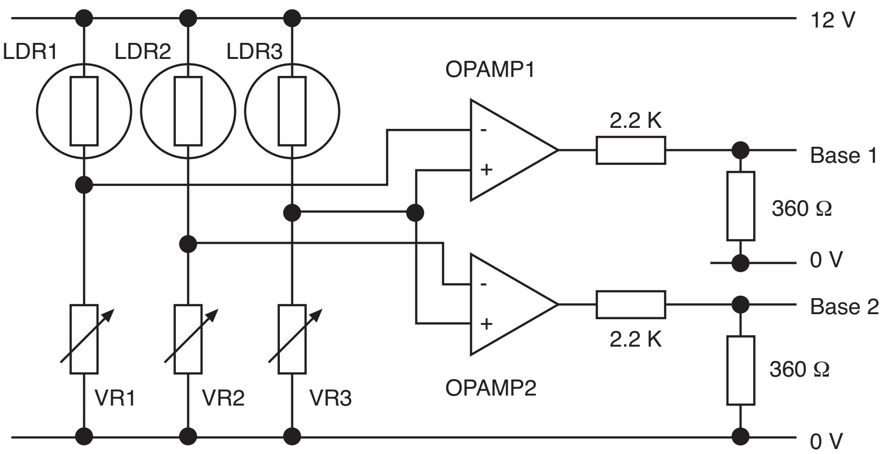
INFORMATION SHEET 15 (OPTIONAL) - DESIGN OPTION - TRACKING THE SUN

Back up to Briefing Sheet 6 & 7

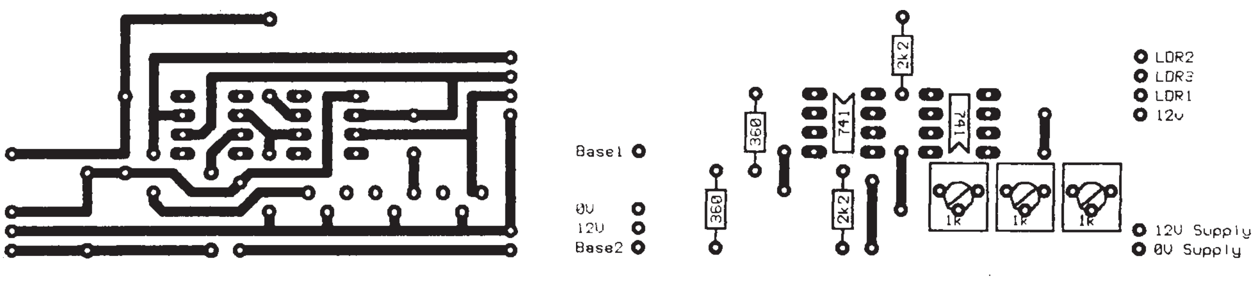
Parabolic mirror movement circuit



The three LDR's are set up as above. LDR 3 provides the reference voltage to both op amps. As the sun moves, the level of light on the LDRs alters and will cause a positive voltage from one of the op amps. This in turn causes the motor to move in one direction or the other. See the motor control circuit for connection to this circuit.



Parabolic mirror movement PCB



Motor Control Circuit
The circuit is based on two transistor pairs. Each pair is driven by a third transistor. When Q5, see diagram below, is turned on, it turns on transistor pair Q1 and Q3. This means current flows from the power rail through Q1, through the motor from left to right, and then through Q3 to the ground rail. Likewise Q6 drives transistors Q2 and Q4 which allows current to flow through the motor from right to left, therefore reversing the direction of rotation.

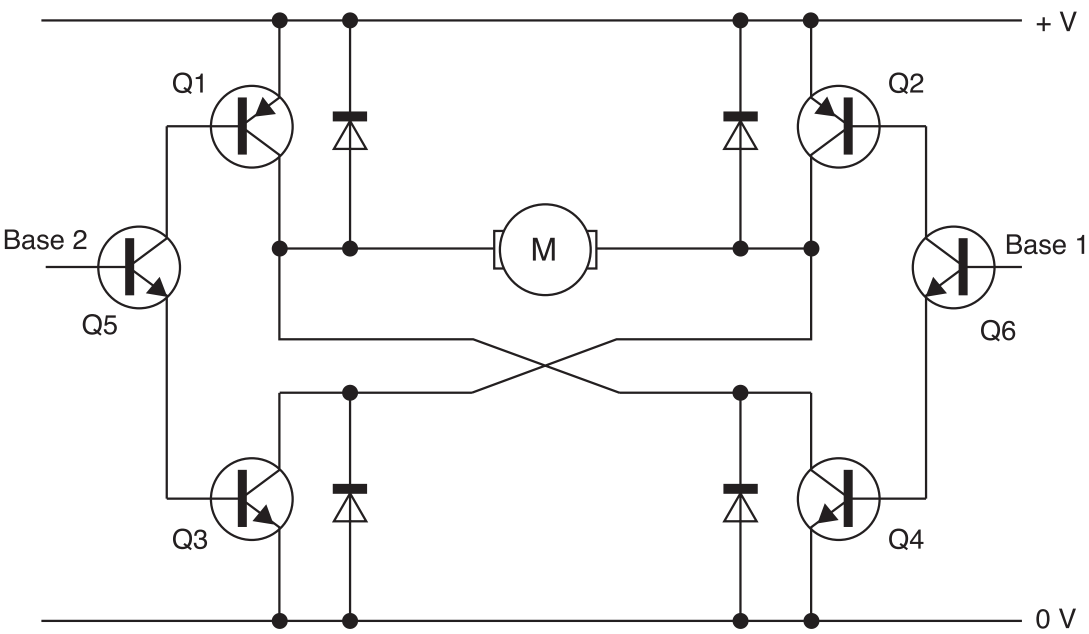
Care must be taken that Q5 and Q6 are not on simultaneously as this results in a short circuit between Q1 and Q2, which shorts out the power rails and will damage the transistors.

In normal use Q1 - Q4 will become quite hot and so should be connected to a suitable heat sink. They are placed in a row on the PCB to allow connection to the same heat sink, although they must be electrically isolated from each other by use of mica heat sink pads.

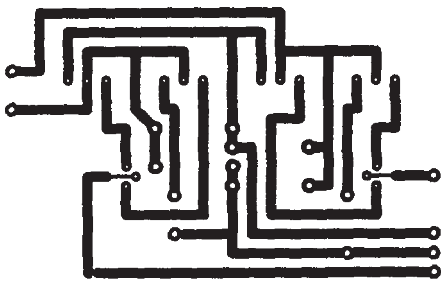
The diodes are used to protect the transistors from back EMF which may be caused by the dc motor.

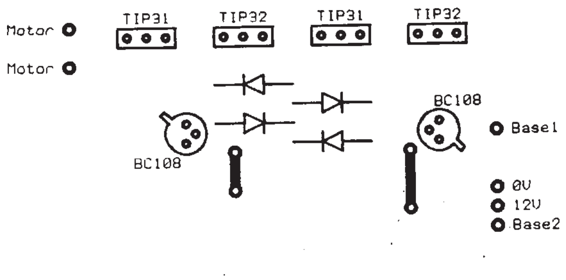
The circuit could be uprated to control a higher power motor by changing the stated transistors to transistors with a higher current rating.

The weight of the collector is a very important factor when considering if tracking the sun automatically is worthwhile.



Motor control PCB





Information Sheet 16 - Useful Addresses

**INTERNATIONAL SOLAR ENERGY SOCIETY,
UK SECTION (UK ISES)**
C/o Solar Energy Laboratory, (Dr. Leslie Jesch), Department of Mechanical Engineering, University of Birmingham, Edgbaston, Birmingham, B15 2TT.
Tel. 0121 414 3344 Fax. 0121 4143958
Aims to promote the use of all forms of solar energy; communicates ideas and developments in all aspects of solar energy through conferences, meetings, journals & other publications. Membership open to both professionals and interested lay-people.

SOLAR TRADE ASSOCIATION
Brackenhurst, Greenham Common South, Newbury, Berkshire. RG15 8HFI.
Tel. 01635 46561
Aims to maintain standards within the solar industry, and to promote the use of solar power in general. Member companies are obliged to adhere to codes of conduct covering advertising, selling, installation, servicing and repair. Up-to-date list of members is available from the above address.

CENTRE FOR ALTERNATIVE TECHNOLOGY
Machynlleth, Powys, SY20 9AZ,
Tel. 01654 702400. Fax. 01654 702400,
Educational charity with over 20 years experience as a working demonstration of renewable energy technologies (solar, wind, water, energy conservation), organic growing and other aspects of sustainable living. Wide range of information sheets and books on solar power. Weekend courses on solar collectors and other topics. Consultancy and information departments. School visits. Open to visitors.

RENEWABLE ENERGY ENQUIRIES BUREAU
Energy Technology Support Unit, B156 Harwell Laboratory Oxfordshire, OXll ORA. Tel. 01235 432450.
Co-ordinates development of renewable energy in the UK, an behalf of the Department of Energy. Range of free publications eg. on solar research program in general ('Using energy from the sun'), project profiles of research in progress, summaries of research completed. Free journal 'RE View'.

Manufacturers and Suppliers of DIY Kits

APPROPRIATE ENERGY SYSTEMS LTD
The Park, Findhorn Bay, Forres, Moray, Scotland IV36 OTZ.
Tel. 01309 690132 Fax. 01309 690933.
Manufacturer of lightweight high performance flat plate collectors. Supplies hot water kits and panels.

DULAS ENGlNEERING LTD
The OId School, Eglwys Fach, Machynlleth, Powys SY20 8SX.
Tel. 01654 781332 Fax. 01654 781390.
Complete or part kits supplied.

ENERGY ENGlNEERING
Herons Reach, Cound Moor, Shrewsbury, Shrops. SY5 6BB.
Tel. 01694 731648 Fax. 01694 731696.
Complete or part kits. Also solar collectors and systems for swimming pools.

GREENSLADE SOLAR, (A DIVISION OF BRITISH FUELS LTD)
146 Fisherton Street, Salisbury, Wiltshire SP2 7QR.
Tel. 01722 427000 Fax. 01722 339498.
Solar heating, installers of flat plate and evacuated tube systems; swimming pool heating; supplies DIY kits.

R.S.U.
1-3 Cwmffrwd Trading Estate, Cwmffrwd, Camarthen, Dyfed SA32 822.
Tel. 01267 222606 Fax. 01267 221758.
Manufacturer of Daystar domestic hot water systems. System design, installation, advice for DIY.

SENSIBLE ENERGY SYSTEMS
16a Belham Road, Kings Langley, Herts. WD4 8BY.
Tel. 01923 260970 (No fax).

SOLAR ENERGY SERVICES
86 Firle Road, Eastbourne, East Sussex, BN22 8EJ.
Tel. 01323 646979.
Solar heating,'Thermomax' evacuated tube installers; swimming pool heating; also supplies DIY kits.

SOLAR STORE
349 Canterbury Road, Densole, Folkestone, Kent CT18 7BE.
Tel. 01303 892491 (No fax.)
Installers of flat plate systems; supplies DIY kits.

TIMBER TREATMENT AND PAINTS

AURO ORGANIC PAINT SUPPLIES LTD
Unit I, Goldstones Farm, Ashdon, Saffron Waldon CBlO 2LZ.
Tel: 01799 584888 (No fax.)
Manufactures and supplies low toxic wood preservatives such as Cuprinol and organic paints.

BIOFA NATURAL PAINTS
5 School Road, Kidlington, Oxford, Oxfordshire OX5 2HB
Tel. 01867 55008 Fax. 0186755008.
Supplier of environmentally friendly paints and wood treatments. Full ingredients list.

ENVIRONMENTAL PAINTS LTD
Unit 71, Dunscar Industrial Estate, Blackburn Road, Egerton, Bolton BL7 9PQ.
Tel. 01204 596854 Fax. 01204 309107.
Manufacturers of environmentally friendly paint.

NUTSHELL SUPPLIES
Newtake Staverton, Devon TQ9 6PE.
Tel. 01803 867770 Fax. 01803 866650.
Manufactures and supplies environmentally friendly paints and wood treatments

ABSORBENT SURFACES

INCO SELECTIVE SURFACES LTD
Wiggen Works, Holmer Rd, Hereford HR4 9SL.
Tel. 01432 382200 Fax. 01432 264030.
Manufacturers of Maxorb & Maxlam, materials designed to absorb but not re-radiate solar energy, from which you can make other types of collectors.

PULMAN PANS LTD
Eastfield Industrial Estate, Penicuik, Edinburgh, Scotland, EH26 8HA. Tel. 01968 678386
'Clip Fin' solar collector plate which can be clipped over standard 15mm copper piping. Also available from the Centre for Alternative Technology
Price: £4.15 per fin or 12 (enough for one 1m^2 panel) for £46.75 not including p+p.

INSULATION

Warmcel, made from fireproofed recycled newsprint - highly effective, non-toxic, non-irritant. This is available in an 8kg bag - enough for four panels - for £13.00, including p+p, from Centre for Alternative Technology

Glazing for Collectors

APPROPRIATE ENERGY SYSTEMS LTD
See section on DIY.

FORMERTON SHEETS SALES LTD
Unit 39, City Industrial Park, Southern Rd, Southampton SOI OHG. Tel. 01703 332761 Fax. 01703 225748.
Manufacturers of selective absorption glazing materials, that let in the right light frequencies and keep in infra red.

FILON PRODUCTS LTD
Aldridge Rd, Streetly, Sutton Coldfield B74 220.
Tel. 0121 353 0814 Fax.0121 352 0886.
Manufacturer of glass fibre sheet glazing, will advise on local distributors.

Solar Anti-Freeze and System Cleaners

FERNOX MANUFACTURING CO. LTD.
Britannica Works, Clavering, Essex CBll 4QZ
Tel. 01799 55081 1 Fax. 01799 550853.
Suppliers of Alphi non-toxic anti-corrosion and antifreeze, and Superfloc low toxic system cleanser.

Pump Suppliers

APPROPRIATE ENERGY SYSTEMS LTD
See DIY section .

PUMPING SERVICES (GB) LTD
Whitehouse Street, Hunslet, Leeds LS1O IAD.
Tel. 01532 446111 Fax. 01532 465649.

RA-SOLAR
Frogs Hall Farm, Lavenham, Sudbury, Suffolk C070 9QH
Tel. 01787 247359 Fax. 01787 248458.

Solar Controllers

DULAS ENGINEERING LTD
(See Kit Suppliers)
Supplies a complete kit of parts to build the solar controller - as well as the ready-made article.

ELECTROMAIL
P.O. Box 33, Corby, Northants. NN17 9EL.
Tel. 01536 204555 Fax. 01536 405555. Individual components available by mail order.

MAPLIN ELECTRONICS
P.O. Box 3, Rayleigh, Essex SS6 8LR.
Tel. 01702 554155 Fax. 01702 553935.
Supplies individual components by mail order.