SOLAR WATER HEATING

Introduction

Hot water is required for many purposes and the sun can be used effectively, efficiently and economically to provide this heat. The warming effect of solar radiation is obvious and it is well known that a container of cold water, left exposed to the sun will be raised in temperature. Solar water heating systems are designed to make convenient use of this phenomenon.

Solar water heaters generally employ a solar collector and a storage tank. The collector is by far the most widespread solar energy conversion device and there are several million in use around the world, of which designs vary from very simple to complex. The extent to which construction and manufacture is easily achievable varies around the world but there are some encouraging examples of innovations and government schemes which have greatly increased the application of solar water heating, not only in affluent areas but also in poorer, less developed and often rural areas.

The availability of solar energy

Please refer to the technical brief "Solar Thermal Energy" for details on the availability and varaiation of solar energy around the world. *Insert link here....?*

The technology

Passive vs. Active

Solar thermal systems in their simplest form consist of a solar collector and a storage tank. These systems are termed *passive*, whilst those that contain circulating pumps are known as *active systems.* (*Solar Water Heater Industry in China, 2010*)

Passive systems rely on the natural buoyancy or thermosyphon effect created when the temperature of the water in the collector rises, causing the water itself to rise as it becomes less dense with increased temperature, thus inducing circulation in the circuit.

Advantages	*Disadvantages*
• No electricity required for operation • Minimal running costs • Maintenance costs reduced as no mechanical parts	• Reduced flexibility as collector has to be located beneath the solar store • Less reliable as inconsistent rate of circulation

Table 1: Advantages and Disadvantages of Passive Solar Water Heating Systems

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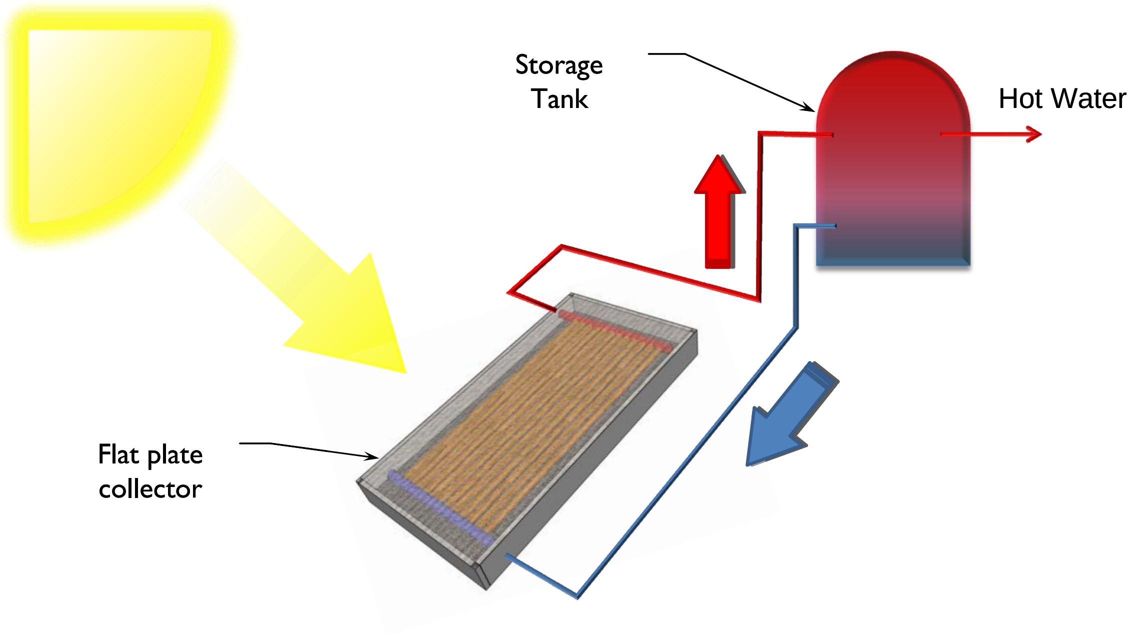

Figure 1: Passive and Direct Solar Thermal System (Illustration by Author, with reference to CIBSE Solar Heating Design and Installation Guide, 2007)

Active systems contain circulation pumps to induce movement of the water or heat transfer medium around the circuit.

Advantages	*Disadvantages*
• Greater flexibility in design and location of system offered by integration of circulation pumps • Greater efficiency induced through consistent circulation of water/heat transfer liquid • Running costs of electricity used to operate pumps could be reduced through installation of renewable electricity power source, e.g. solar photovoltaics	• Higher maintenance costs as mechanical parts are present in the system • Running costs higher as electricity required for pump operation • Reliable source of electricity required for operation

Table 2: Advantages and Disadvantages of Active Solar Water Heating Systems

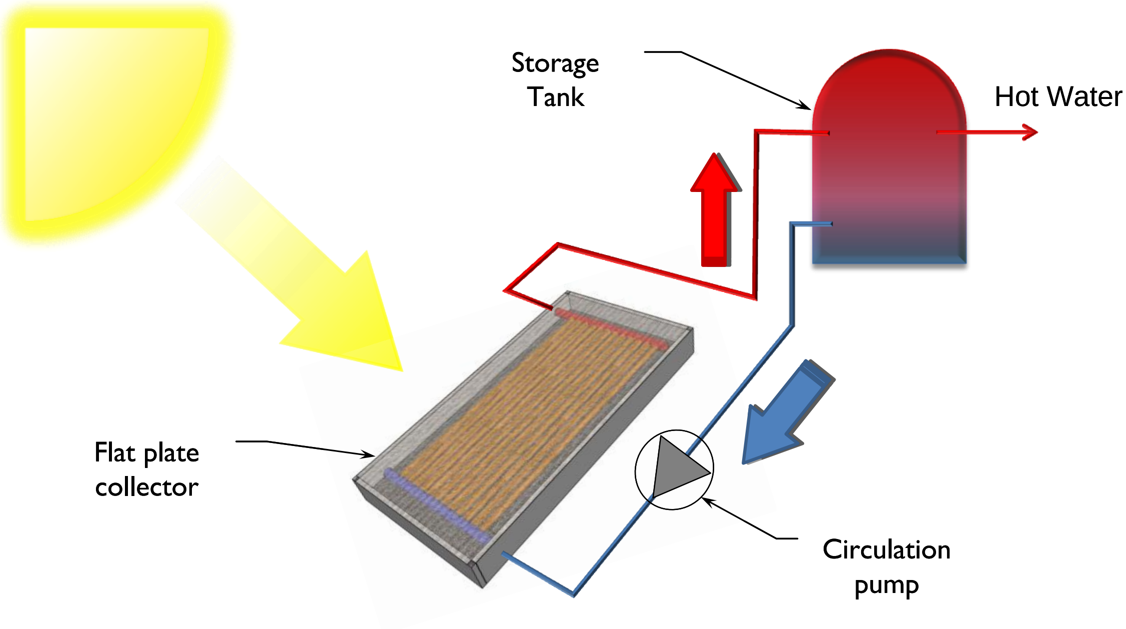

Figure 2: Active and Direct Solar Thermal System (Illustration by Author, with reference made to CIBSE Solar Heating Design and Installation Guide, 2007)

Direct vs. Indirect

Solar water heating systems can function as either *direct* or *indirect.* In a *direct* system, the heat transfer medium is water which is heated up and used directly from the collector/storage tank. In an *indirect* system, the heat transfer medium is not necessarily water and does not come into contact with the water that is used after being heated up through some form of heat exchange system.

The following are disadvantages inherent in *direct* systems.

Scalding	If the water has not been moving through the collector for a while and therefore becomes stagnant, upon using it again, the water may be at a dangerously high temperature by the time it leaves the point of use, i.e. a tap or shower.
Fluid freezing	This could damage the equipment or block safety vents.
Deposits	If circulation is reduced, the system becomes blocked or there is a build-up of bacteria, there is a greater risk of the accumulation of silt, lime-scale and other debris.
Loss of water quality	If there is a build-up of debris, the quality of the domestic hot water is likely to decrease. Another reason for this would be the water coming into contact with certain fittings and materials when the water in the system is stagnant and temperatures and pressures are high
Backflow/thermo-siphoning	There is a risk that hot water could flow backwards round the circuit into the cold water cistern.
Stratification disturbance	A reduction in collector efficiency occurs if the return temperature at the base of the solar storage vessel is increased due to the circulation pumps in the system.

As well as minimising and/or avoiding the occurrence of the above, another advantage to installing an *indirect* system is the capability to introduce certain performance enhancers to the heat transfer medium without compromising the health of those using the domestic hot water generated. These enhancements may be in the form of antifreeze or corrosion inhibitors, which reduce the risk of damage to the equipment during colder months and the frequency of part replacement and maintenance.

These systems are often designed with a storage tank and/or alternative, complementary heat source. With the latter, a system of pre-heating the liquid is employed to ensure the water reaches a temperature safe for domestic use, particularly with regard to the risk of legionella (*See Section "Health and Safety – Things to be aware of" for further details*). Pre-heating the liquid is achieved either by an instantaneous water heater or the collector itself.

(CIBSE Solar Heating Design and Installation Guide, 2007)

Connecting to an existing domestic hot water system

Connecting a solar hot water heating system to a conventional hot water storage vessel raises its own problems, such as a reduced dedicated solar storage capacity or a loss of the ability to operate the legionella control method of incorporating back-up heating appliances into the system design. (S*ee Section "Health and Safety – Things to be aware of" for more information on Legionella).*

Selecting and sizing a solar thermal installation

Solar collectors

Although the configuration of the system, i.e. whether it would be classified as *direct or indirect*, has an effect on the efficiency of a system, the collector itself generally has a greater influence.

The two main types of solar collector are *flat plate* and *evacuated tube.*

Flat plate *These tend to be cheaper but less efficient.*

In their simplest form, these collectors are a rectangular frame with a row of pipes connected at the top and bottom. Cold water enters the system of pipework at the bottom and travels up and down and across, whilst sandwiched between an absorber and a plate of glass/plastic to then leave the system at the top of the frame on the opposite side to the inlet.

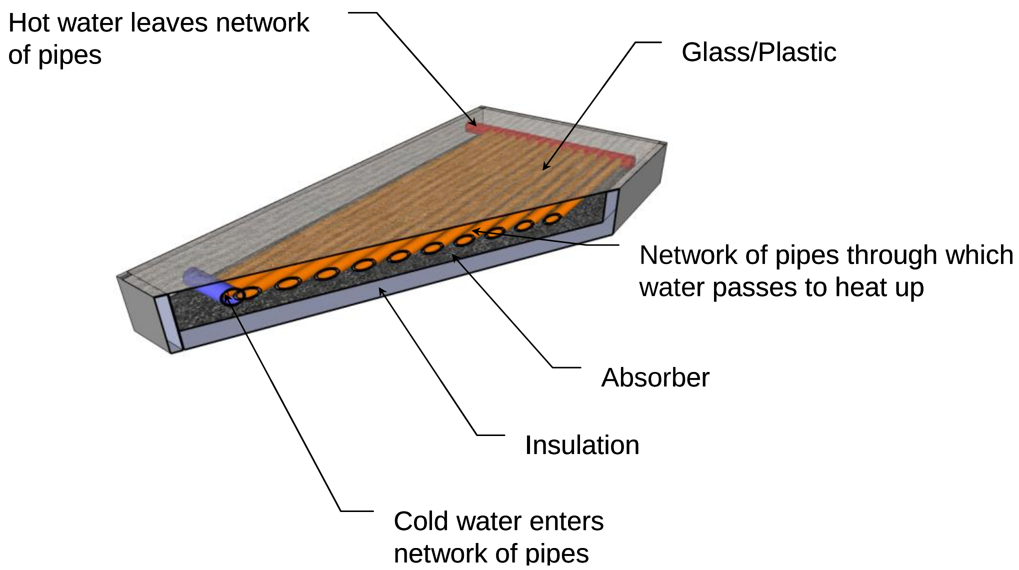

Figure 3: Section through a flat plate solar collector (Illustration by Author with reference made to CIBSE Solar Heating Design and Installation Guide, 2007 & Capturing Solar Energy, 2009)

Evacuated Tube These tend to be more efficient but more expensive

A series of pipes are connected at the top by a manifold. The tubes consist of a vacuum with a pipe running through the middle containing the working fluid. The water moves up and down and along through the series of pipes to exit the system at a significantly higher temperature.

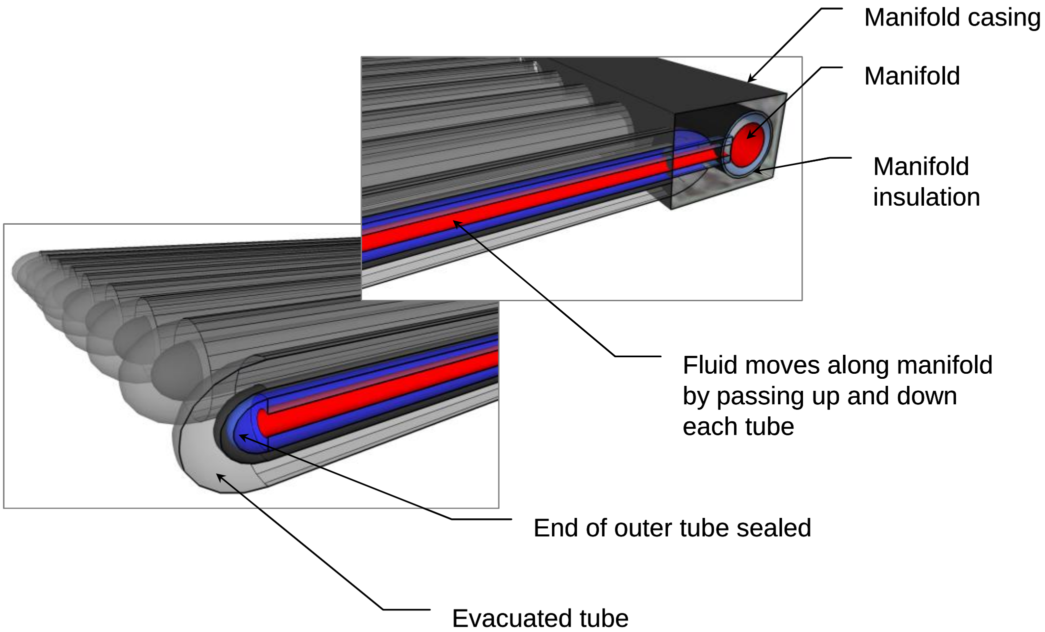

Figure 4: Sections through an evacuated tube solar collector (Illustration by Author with reference made to CIBSE Solar Heating Design and Installation Guide, 2007 & Capturing Solar Energy, 2009)

An important feature of both of the above is the medium through which the solar radiation is absorbed, i.e. the 'absorber'. It is well known that dark surfaces with a matt finish absorb radiation more effectively than light and polished, therefore the absorbers incorporated into the design of these collectors are often painted/coated in a dark, matt finish.
(Capturing Solar Energy, 2009)

There are four main types of *flat plate collectors*:

Type	Output Temperature (°C)	Uses	Sector	Mounting
Glazed & liquid-based	30-80	Heating, domestic hot water, swimming pool heating (indoor)	Domestic, commercial buildings, leisure centres	New build and retrofit as flexible mounting possibilities.
Glazed & air-based	20-50	Heating of ventilation air. Can sometimes provide domestic hot water heating.	Domestic	Roof-mounted
Unglazed & liquid based	<30	Outdoor swimming pool, car wash and fish farm water heating	Commercial	Flexible
Unglazed & air-based	20-30	Heating of ventilation air, crop drying	Commercial	Wall-cladding

Table 3: Types of Flat Plate Collector (Capturing Solar Energy, 2009)

Although liquid-based collectors are more prone to freezing and/or overheating, they are generally more efficient than their air-based counterparts.

There are two main types of *evacuated tube collectors*:

Type	Output Temperature (°C)	Uses	Sector	Mounting
Direct-flow	50-95	Domestic hot water and swimming pool heating (indoor), cooling	Domestic, Commercial	Horizontal and vertical mounting possible
Heat pipe	50-95	Domestic hot water and swimming pool heating (indoor), cooling	Domestic, Commercial	Mount at an angle >25° to horizontal

Table 4: Types of Evacuated Tube Collector (Capturing Solar Energy, 2009)

Although evacuated tube collectors are able to operate at lower radiation levels and provide higher output temperatures than flat plate collectors, they are more expensive and therefore less widely applied.

The size of the installation is dependent on location and capacity required as the collector area is proportional to its efficiency. Certain rules of thumb defined by the Chartered Institute of Building Services Engineers (CIBSE) can be used as a guideline when sizing a system. From the below it is evident that less area is required for the evacuated tube collectors as they are more efficient. However, this should be considered alongside their higher cost when selections are being made.

Required collector area:

- Flat plate: 1.0-1.5m^2 of absorber per person
- Evacuated tube: 0.7-1.0m^2 of absorber per person

Dedicated solar storage volume:

- Flat plate: 30-45litres per m^2 of collector absorber
- Evacuated tube: 40-60litres per m^2 of collector absorber per person

NB: The above are figures quoted for the UK and should be used in conjunction with solar irradiance values for the region being considered.

(Capturing solar energy, 2009)

In the UK and other countries with a similar climate, the optimum solar water heating systems are those which have been designed to supply 100% of the hot water demand experienced during the summer. Due to the reduction in solar radiation available and increased hot water demand likely during the winter months, it is usually assumed that systems are not best designed to cover 100% of the winter load.

The following table has been extracted from the CIBSE Knowledge Series publication 'Capturing Solar Energy', which provides a guide to the hot water demand experienced in different types of building.

	Hot water demand (litres / person / day)		
Type of Building	**Service**	**Catering**	**Total**
House	-	-	30-50
School/College			
- Average	3	6	6
- Large	7	18	13
Hotel/Hostel			
- Average	80	14	137
- Large	303	62	464
Office			
- Average	3	10	8
- Large	10	33	26

Table 5: Typical daily hot water demands (Capturing Solar Energy, 2009)

From this table, the hot water demand in a certain type of building can be approximated, i.e. the daily hot water demand for a 4 person household can be calculated as:

4 people x 30 litres/person/day = 120 litres/day

The CIBSE Knowledge Series publication 'Capturing Solar Energy', 2009 contains tables and explanations describing the steps involved in sizing the various components of a solar water heating system, i.e. the collector, storage requirements and heat exchanger. Guidelines are also listed approximating the hot water demands for different types of buildings.

Maintenance Tips

Although the complexity of a solar hot water heating installation can vary, encouraging maintenance at regular intervals is advisable as this will help to reduce the occurrence of significant failures over the life-cycle of the system. Below is a list of visual checks that could be carried out on an annual basis:

- Check the collector for any sediment accumulation and damage
- Check any joints and connections for leaks or damage
- Check the pressure levels of the working fluids
- If the system contains a pump, check for any damage and that both the pump and the associated valves are fully operational and for any damage
- Check that any controls and temperature sensors are producing plausible results
- Check any required safety notifications are still in tact

(Capturing Solar Energy, 2009)

A more extensive list has been produced by an organisation in Lebanon, following the installation of solar water heating systems in four hospitals. These installations are described further in the section “Success stories around the world”.

Costs

Due to the wide range of size, type and complexity of systems installed around the world, alongside the economic schemes that may exist under various Governments, it is difficult to accurately advise of the costs incurred when designing and installing a solar water heating system.

A typical domestic installation in the UK is 3-4m^2 costing between £3000 and £5000, whereas simple passive and direct systems developed in countries such as Brazil and India that are produced from recycled materials are vastly less expensive. This is a reflection of the relative wealth of the local beneficiaries. *(Capturing Solar Energy, 2009)*

For example, a local initiative introduced in the Cote d'Ivoire on the west coast of Africa, with the support of an organisation, has enabled the mobilisation of cooperatives to produce solar water heaters locally and therefore reduce costs incurred to around $200-$400. This is described in more detail in the s*ection “Success stories around the world”.*

Health & Safety – Things to be aware of

Legionella Pneumophilia

When a water temperature of between 20°C and 46°C is maintained for prolonged periods of time, the risk of bacterial growth in the water increases. As the heating of water by solar energy is not fully controlled, it is advisable to couple a solar hot water heating system with an alternative instantaneous hot water heater to ensure the water is heated to a minimum of 60°C, thus reducing the risk of the bacterium legionella pneumophilia growing and legionnaires' disease being contracted.

Should legionnaires' disease be contracted, the following symptoms may be experienced:

- High temperature
- Fever
- Cough
- Muscle pains
- Headache
- Diarrhoea
- Mental confusion
- Pneumonia

(www.hse.gov.uk)

Success stories around the world

A notable increase in the widespread application of solar water heating is evident around the world with systems varying in levels of complexity, from large commercial to small, very simple domestic applications. The *2010 Survey of Energy Resources by the World Energy Council* provides an overview of the progress made by 43 countries across the globe. This is a useful document for those wishing to know how successful, or unsuccessful, solar water heating has been in their country or continent. If a country has so far been unsuccessful, an explanation is often provided as to why and future plans to overcome this are noted. An encouraging point to note is that increased application of this technology has not been limited to developed countries.

Solar water heating systems have been installed around the world in varying levels of complexity, from large commercial to small, very simple domestic applications.

The following are some encouraging examples of progress evident in some developing countries over the last 10 years or so:

A School (India, 1997)

Whilst working in conjunction with a charity and an aid organisation, Marios Cleovoulou constructed a solar water heating system largely from local recycled materials to improve the physiotherapy work undertaken at a school for handicapped children. Although Cleovoulou admits that the system may not be the most efficient, it was made viable through his ability to keep the costs to a minimum. The most expensive component of the system was the 250litre tank which cost approximately US$36 (£22). Although this one component is more than most of the people in rural India can afford, the costs saved on fuel were a significant benefit.

The system itself was a direct, passive system operating as a thermosyphon with a flat plate collector. Several innovative solutions were engineered, further reducing the costs. The insulation of the hoses connecting the collector to the tank was particularly interesting as this was achieved through the linking together of plastic bottles, top to bottom, and feeding the hose through the centres of each one.

A certain degree of control was afforded through the incorporation of a tap on the cold water inlet, another on the hot water outlet and a stopcock on the cold water intake. This design allowed the system to operate in two ways, either as a pressurised system or an overflow system, incorporating a certain degree of flexibility into its use. The staff were also able to use the cold water inlet as a second source of water, although training was required to ensure the system was still able to operate effectively, i.e. the tank would be refilled.

Marios Cleovoulou's description of the development and installation of this system is informative and can be found on his website.

(Cleovoulou.com, 1997)

Affordable community collector (Brazil, 2002)

Jose Alano, a retired mechanic in Brazil has single-handedly had a large impact on the application of solar water heaters in Brazil through his development of a solar collector constructed using 100 recycled plastic bottles and 100 recycled milk cartons. The collector operates using the thermosyphon effect as part of a direct and passive system. Whilst providing a more attainable solution to solar water heating in Brazil and reducing fuel costs, this invention also has the added benefit of combating the waste removal problems experienced in Brazil.

This invention has won Alano the Superecologia prize and he now gives lectures and leads workshops in schools and community centres around Brazil. In Santa Catarina state, Alano's home state, his invention has improved the lives of over 7 000 people. The total number of collectors installed in another state rose to 6 000 in 2008.

The rise in the number of installations of this technology and its availability to the general population of Brazil has been enhanced through the publication of a "DIY Leaflet". This coupled with the workshops lead by Alano and others has meant people are able to construct their own systems.

(*How to make a solar water heater from plastic bottles, 2002)*

Community installation (Cote d'Ivoire, 2001)

This project addressed the problems inherent in the importing of solar water heaters such as higher costs and consequently reduced accessibility to the rural population of developing countries such as Africa. The production of solar water heaters locally was therefore investigated and with great success.

Two types of solar water heaters were developed during this project and were tailored to suit the surrounding environment.

Auto-storage Model	*Solar Collector Model*
• Simple to construct • Suitable for rural areas • Dark and insulated tank containing 200litres of water placed in a semi-parabolic reflector which directs the solar energy	• Complicated to construct • Suitable for urban applications • Direct system operating using the thermosyphon effect • Collector is a black water cistern covered by a pane of glass • Recycled and local materials used to reduce costs

Table 6: Solar water heater models developed

These developments were achieved by affording 30 previously unemployed young people the opportunity to work as a cooperative formed by the Opportunities Industrialization Center (OIC). Mini-cooperatives were then setup and the 30 original people in the scheme were helped to start their own businesses. This scheme was therefore not only improving the lives of local people through access to hot water and the inherent sanitary benefits, but was also advantageous to the local economy and self-sufficiency of the area. Cost savings achieved through the reduction in firewood required was also a notable benefit.

The affordability and adaptations for implementation are key to the success of this project as community facilities such as health clinics, schools and community centres can greatly benefit from these systems. By the end of the first phase of the project, solar water heaters had been installed in 10 public facilities.

The cost of the equipment and installation were noted to be between $280 and $430 per unit when produced locally. When this is compared to the significantly higher costs associated with the import of these heaters ($1000 - $2000), it is not difficult to appreciate how this scheme made the heaters more accessible to the local population of this area of West Africa.

The article notes that at the time of its publication, a second phase of the project was underway investigating the installation of the heaters into new homes, with the cost of the unit being integral to the cost of the house.

A similar project was initiated by the same organisation in Egypt in the year 2000 which also experienced the benefits to health and employment afforded by a scheme of this type.

(Community Action to Address Climate Change, 2003)

Hospitals (Lebanon, 2007) (Pakistan, 2011)

In Lebanon, Government funds coupled with grants from Spain afforded the chance to install solar water heating systems in four hospitals, each with a capacity of 4000litres. This was part of the Country Energy Efficiency and Renewable Energy Demonstration Project for the Recovery of Lebanon (CEDRO). One article describing these installations focuses on the lessons learned from the experience. It contains a link to a presentation that describes the system installed in one of the hospitals, the problems encountered and a suggested preventative maintenance checklist.

(*Lebanon: Checklist for Solar Installations in Hospitals, 2007)*

In Pakistan, Jo Wilson describes the triumphs and failures experienced during the design and construction of a thermosyphon solar water heating system that would serve a hospital laundry. The drive behind installing the system was to reduce the gas bills incurred as a result of the two gas geysers (boilers) currently used. The processes undertaken throughout construction are described alongside the lessons learned.

The installation was found to consistently heat water to 40-50°C throughout the day with the existing gas geysers being used when required to increase the water temperature to the thermostatically controlled levels defined by the users.

Whilst the author notes that the installation was successful, the section describing the lessons learned is particularly informative as it provides reasons for the problems incurred and how they were overcome.

Another interesting point to note from the project in Pakistan is that the author highlights the matter that the cost of the system was not far different from the cost of a ready-made installation; the reason that a self-build system was chosen being that those who built it would then have the skills and knowledge to maintain it themselves. This in itself is an important point to consider when introducing a new technology to a less widely educated area.
(Thermosyphon solar water heater system for a hospital laundry, 2011)

Alternative Applications of Solar Energy

Several alternative applications to manipulate and harness solar energy have been developed and implemented in developing countries. Further information on these developments is described in the technical brief "Solar Thermal Energy". *Insert link.....*

Links and Publications

1. Solar Heating Design and Installation Guide, The Association of Plumbing and Heating Contractors, the Chartered Institute of Building Services Engineers, the Council for Registered Gas Installers, the Heating and Hot Water Industry Council, the Heating and Ventilating Contractor's Association, the Institute of Domestic Heating and Environmental Engineers, the Institute of Plumbing and Heating Engineering, the Oil Firing Technical Association, the Scottish and Northern Ireland Plumbing Employers Federation, the Underfloor Heating Manufacturers Association, 2007

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