Abstract:

Conventional energy sources through-out the world are soon going to be exhausted. Millennium Development Goal (MDG) by United Nation (UN) vision and aim now reflects upon numerous attempt and experiment conduction on different methods to harness energy from renewable sources which are more sustainable. This thesis work is a contribution to that purpose.

The technique that has been experimented on uses a closed insulated conduit with glazed through transparent glass medium. Basic theory of solar radiation and heat convection in water (working fluid) has been combined with heat conduction process by using copper tubes and aluminum absorber plate. Insulated materials, thermal reservoir are used for better result output.

By this experimental conduction, we have achieved a temperature difference of 33*C which is of 56.79% efficiency range. The obtained data and experimental findings are validated with the literature theoretical assumptions and experimental demonstration. Both show a cost effective and simple form of heat energy extraction for space heating/power generation use which has been thoroughly discussed with comparison. The result parameters also reflect upon considerable prospect of uses and recommend valid ways to increase efficiency improvising more acceptable energy conversion form.

This is the most cost effective and less complicated method of solar thermal energy harnessing which is also eco-friendly. Under-developed and developing countries can take this work as an illustration for renewable energy utilization for sustainable energy prospect.

Acknowledgement:

First of all, we are grateful to the almighty for giving us the courage and enthusiasm to conduct this thesis work. We would like to express our profound gratitude to **Col. Md. Habibur Rahman** for his whole-hearted support and assistance throughout this assessment period. We would also like to mention **Cdr Enayet Kabir** for helping us to build this thesis structure. The support and encouragement of our instructors have helped us to overcome the obstacles and present a full-fledged experimental data based work. The authors also acknowledge MIST authority's supervision specially **Brig. Gen Md. Lutfor Rahman** for aiding us with financial and moral support throughout this whole year to complete this assessment.

Student Declaration:

This is to certify that this thesis entitled "**Flat Plate Solar Collectors for water pre-heating using Concentrated Solar Power (CSP)**" is a record of work carried out by the author under the supervision of **Col. Md. Habibur Rahman**, Department Head of Industrial and Production Engineering (IPE), Military Institute of Science and Technology (MIST). It has not been the subject of any previous application for a degree and that all sources of information have been acknowledged.

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This is to certify that **Lt. Imran Sarkar, Student ID: 201318004; Md Al Amin Shekh, Student ID: 201318007; Leonard Sunny Peris, Student ID: 201318010** have completed their undergraduate thesis report on **“Water Preheating by Concentrating Solar Power (CSP)”** under my supervision. To the best of my knowledge, the report is their original work and was not submitted elsewhere for other purpose.

I wish their ever success in life.

APPROVED BY

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Nomenclature

A_c = Collector area in m^2

h_{p-c}= Convection heat transfer coefficient in between plate and glass cover in $(W/m^2)K$

$h_{r, p-c}$= Radiation heat transfer coefficient between plate and glass cover in $(W/m^2)K$

h_w= Wind heat transfer coefficient in $(W/m^2)K$

I_n= Solar insolation normal to the surface in W/m^2

I_{bn}= Solar beam radiation in W/m^2

K=Conduction heat transfer coefficient of insulator (W/m^2) K

L=Thickness of insulator in m

m= Mass of fluid flow in Kg

n= Number of day counted from 1st January

S_C= Solar constant= 1373 W/m^2.

s= Specific heat of fluid in J/ (kg·K)

T_P= Plate temperature in K

T_A=Ambient temperature in K

T_C= Glass cover temperature in K

T_S= Sky temperature in K

R_1= Total thermal resistance in between glass and atmosphere in K/W

R_2= Total thermal resistance in between glass and absorber plate in K/W

R_3= Total thermal resistance in between absorber plate and insulator in K/W

R_4= Total thermal resistance in between insulator and atmosphere in K/W

U_L = Over all heat transfer coefficient (W/m^2) K

$\mathbf{V}$ = Wind speed in m/s

$\mathbf{Q_U}$= Useful solar energy in J

$\mathbf{Q_{surface}}$ = Energy received by the surface in J

$\mathbf{Q_{fluid}}$= Energy gain by the working fluid in J

GREEK:

$\in_{P}$= Plate emissivity in J/m^2

$\in_{C}$=Glass Cover emissivity in J/m^2

$\boldsymbol{\theta}$= Angle of incidence in degrees

$\boldsymbol{\varphi}$= Latitude angle in degrees

$\boldsymbol{\delta}$= Angle of declination in degrees

$\boldsymbol{\omega}$= Hour angle in degrees

$\boldsymbol{\beta}$ = Tilt angle in degrees

$\boldsymbol{\theta_1}$= Water inlet temperature in K

$\boldsymbol{\theta_2}$= Water outlet temperature in K

$\Delta\boldsymbol{\theta}$= Rise in water temperature in K

$\boldsymbol{\eta_{collector}}$= Efficiency of the collector

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Chapter 1

Introduction

1.1 Flat Plate Solar Water Collectors

To find alternative of conventional energy sources, in recent year’s energy harness from viable renewable source is being encouraged and considered as of vital importance. Of all the renewable sources, solar power is considered to be the most efficient, cost effective, environmental friendly source of power. Harnessing solar power can be achieved in two ways: Photovoltaic (PV) and Solar Thermal. Solar thermal is the simplest and direct applicatory form of harnessing solar energy. One of the methods to utilize solar power is to use flat plate solar water collectors.

A typical flat-plate collector is a metal box with a glass or plastic cover (called glazing) on top and a dark-colored absorber plate on the bottom. The sides and bottom of the collector are usually insulated to minimize heat loss. Sunlight passes through the glazing and strikes the absorber plate which heats up and converts solar energy into heat energy. The heat is transferred to liquid passing through pipes attached to the absorber plate. Absorber plates are commonly painted with ‘selective coatings’ which absorb and retain heat better than ordinary black paint. Absorber plates are usually made of metal typically copper or aluminum because the metal is a good heat conductor. Copper is more expensive but is a better conductor and less prone to corrosion than aluminum. In locations with average available solar energy, flat plate collectors are sized approximately one-half to one-square foot per gallon of one-day's hot water use.

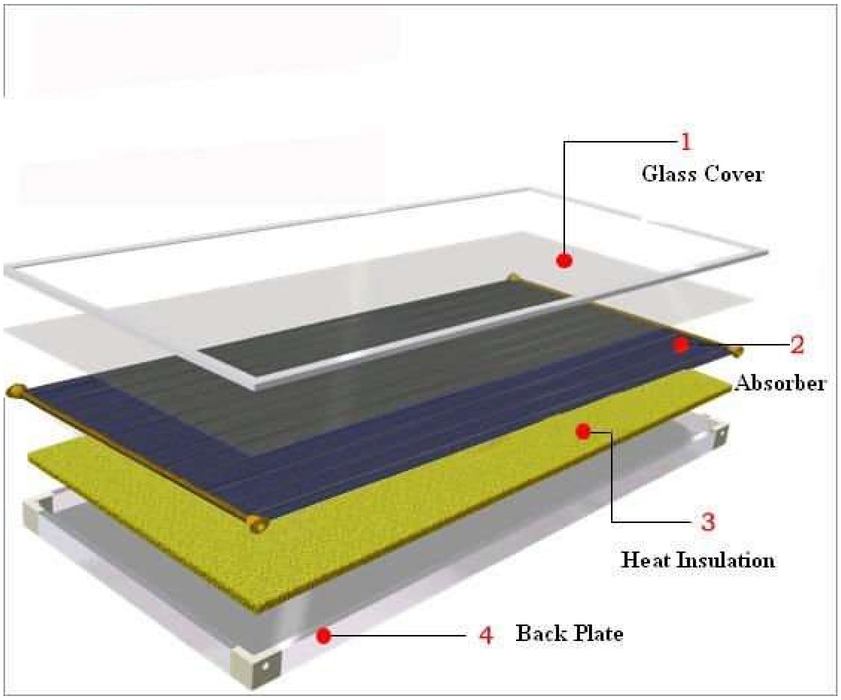


Figure 1.1: Typical Flat Plate Water Collector

The research in this thesis is concerned with improvements of the efficiency of the flat plate solar collector using cost effective heat transfer techniques. The experimental work involves tests conducted on a closed insulated wooden box frame that is covered with a transparent glazed glass medium. Solar incident light radiates through the glazed glass and photon beam heats up the absorber plate (Aluminum). Heat energy then is conducted through the copper tubes which heats up the working fluid (Water). Working fluid is then circulated using simple convection thermodynamics principle to the tube medium to the water reservoir tank. Inlet and outlet temperatures are calculated using Mercury Thermometers (Manual Process) or by thermal sensors (For ATMEGA-16: LM35). Thus, water is preheated using concentrate solar incident power.

Due to the nature of solar energy, two components are required in order to have a functional solar energy generator. These two components are a collector and a storage unit. The collector collects the radiation that falls on it and converts it to other forms of energy (electricity, heat). Whilst the storage unit is required because of the non-constant nature of solar energy, as during cloudy days the amount of energy produced by the collector will be quite small. The storage unit can hold the energy produced during the periods of maximum radiation and release it when it is needed or the productivity drops. Methods of collecting and storing solar energy vary depending on the use of the solar generator. In general, there are three types of collectors (flat -plate collectors, focusing collectors, and passive collectors) and many forms of storage units.

1.2 Background of Solar Energy

For many years, numerous experiments have been conducted on utilizing solar thermal energy through different methods. All of the previous trials have contributed to develop the investigation method of achieving higher efficiency and better result outcome. Some of the grounds breaking historical standpoints are mentioned as-

- In 1953 AT&T laboratory scientists developed the first silicon solar cell capable of generating an electric current. In 1956, solar photovoltaic (PV) cells were very expensive and electricity from solar cells cost about $300 per watt.

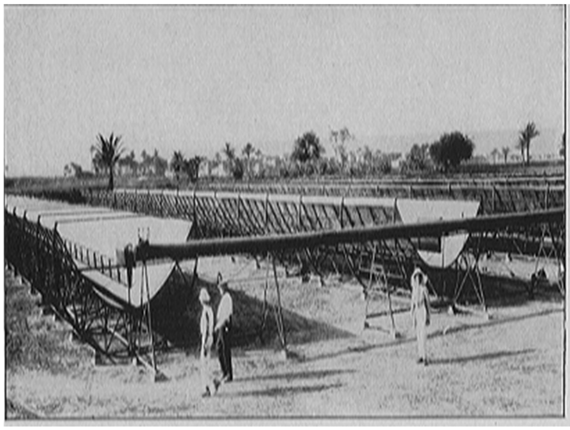


Figure: 1.2a First Parabolic Trough in Russia

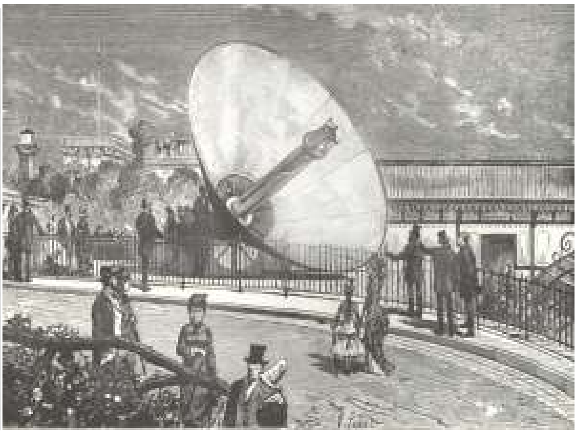


Figure: 1.2b First Solar Dish in Britain

- In 1866, Auguste Mouchout used a parabolic through to produce steam for first solar steam engine.

- In 1886, the first patent for a solar collector was obtained by the Italian Alessandro Battaglia in Genoa, Italy
- In 1913, Frank Shuman finished a 55HP parabolic solar thermal energy station in Maadi, Egypt for irrigation
- Albert Einstein was awarded the 1921 Nobel Prize in physics for his research on the photoelectric effect; a phenomenon central to the generation of electricity through solar cells
- In 1929, the first solar power system using a mirror dish was built by American Scientist Dr.R.H. Goddard.
- In 1968, the first concentrated-solar plant, which entered inti operation in Sant'llario, near Geona, Italy
- In 1981, The 10MW Solar One power tower was developed in Southern California
- In 1984, the parabolic-trough technology of the Solar Energy Generating Systems (SEGS) begun its combined capacity is 345MW.
- In 2014, The world's largest solar thermal plant (392MW) achieves commercial operation in Ivanpha, California, USA

1.3 The Outline of This Thesis

Solar thermal energy can be utilized via many processes which are differed from one another by the criterions of cost, efficiency, installation parameters. Various type of solar thermal power plants with their background and principle uses have been thoroughly described in this paper. The main work of this paper is emphasized on the working procedures of Flat Plate Solar Collector.

Advantages of Flat Plate Solar Collector over other solar thermal plants and their comparison were thoroughly delineated. Also, different improvement parameters and design modifications which will enhance the collector efficiency have been elaborately discussed. Other additional important methods as Thermal Energy Storage System integration process are also thoroughly analyzed.

Solar irradiance amount and incident radiation are derived using solar engineering thermal process equations. Different calculation parameters as absorber plate conduction, principal working fluid (Water) convection formulations are described with proper theoretical base.

Experiment conduction process is based on observational values of individual day's temperature difference calculation thus energy gain via solar thermal energy. All the acquired values are represented in table form with associated graphical representation. Model calculation is shown using thermal energy gain and efficiency equation for derived inputs and outputs.

Solar thermal prospects with current aspects are described with referenced data. Integration with other power sources to enhance the field of use have been elaborately discussed. At the very end summarization of this thesis work with recommendations are given for future research aid in-view of improving performance and efficiency.

Chapter-2

Literature Review

2.1 Utilization Fields of Solar Water Heating

The utility fields that solar water heating can serve can be classified in broad out-view. Application of pre-heated water can meet up demand in both domestic and industrial scale. The main use of this technology is in residential buildings where the demand for hot water has a large impact on energy bills. This generally means a situation with a large family, or a situation in which the hot water demand is excessive due to frequent laundry washing.

Commercial applications include Laundromats, car washes, military laundry facilities and eating establishments. The technology can also be used for space heating if the building is located off-grid or if utility power is subject to frequent outages. Solar water heating systems are most likely to be cost effective for facilities with water heating systems that are expensive to operate, or with operations such as laundries or kitchens that require large quantities of hot water.

In domestic view, solar water heating is popular in China, Iceland, and Norway for space heating of houses; In Iceland cooking and road embroilment in winter is done by heated water. Especially in Europe and North American countries where the climate is cold in nature, solar heated water is a popular and economically efficient way for utilizing in daily household necessities.

Unglazed liquid collectors are commonly used to heat water for swimming pools. Because these collectors need not withstand high temperatures, they can use less expensive materials such as plastic or rubber. They also do not require freeze-proofing because swimming pools are generally used only in warm weather or can be drained easily during cold weather.

While solar collectors are most cost-effective in sunny, temperate areas, they can be cost effective virtually anywhere in the country so should be considered. For a developing or under-developed country cost efficiency and installment parameters which are effective must be given the utmost importance.

Many developed countries have solar plats of different model and structure to harness renewable energy. Among them USA, Russia, China, Japan, Australia, Iceland, Greece and Denmark are worthy names that have invested in this sector and have set up the aim to meet the Millennium Development Goal (MDG) to achieve 50% of total energy demand of world by renewable source.

Figure: 2.1 Solar Water Heater by Zesca Company over a House in Iceland

2.2 Comparison of Solar Thermal with other Renewable Sources

Renewable energy sources can be classified according to their method of power harnessing process. A simple out view of that purpose can be presented as-

1. Solar Energy
2. Wind Energy
3. Ocean Energy
4. Hydropower
5. Biomass
6. Biodiesel (Bio-degraded Oil)

Of all the sources of renewable energy Solar Thermal is the most advantageous form of power generation in the categories of environmental aspect, cost efficiency, availability of energy extraction in geographical out view. Some of the standpoints are described to have a better understanding by comparing each source of energy with solar thermal:

2.2.1 Wind Energy

1. **Noise Disturbances:** Though wind energy is non-polluting, the turbines may create a lot of noise. This alone is the reason that wind farms are not built near residential areas. People who live near-by often complaint of huge noise that comes from wind turbines. The visual pollution is another reason why people do not find it attractive to install it in their backyard.

2. **Threat to Wildlife:** Wind turbines in particular can also be harmful to birds and other flying creatures. Studies conducted to determine the effect of wind turbines on birds and animals suggest that animals see wind turbines as a threat to their life. Also, wind turbines require them to be dig deep into the earth which could have negative effect on the underground habitats.

3. **Wind can never be predicted:** Yet another main disadvantage of wind energy is that winds can never be predicted. In areas where wind doesn't blow reliably or winds strength is too low to support wind turbine. Moreover, strong tornadoes or deadly hurricanes can prove harmful to the wind turbines.

4. **Suited to Particular Region:** Wind turbines are suited to the coastal regions which receive wind throughout the year to generate power. Therefore, countries that do not

have any coastal or hilly areas may not be able to take any advantage of wind power. The location of a wind power system is crucial, and one should determine the best possible location for wind turbine in order to capture as much wind as possible.

5. Inefficient: Sure, wind energy is clean, but it certainly isn't efficient. When converting the wind energy into usable electric energy, the machinery within the turbines are only able to extract about 59% of the wind's power. This seems to be one of the major issues with using wind energy, and this inefficiency appears to be remaining static at the moment, with little to no improvements in this area on the horizon.

6. Installation Costs: As you can imagine, installing a group of these huge turbines can cost a lot of money. Installing just one of them can be as pricey as $2 million or more, with more costs coming for maintenance. Another cost in installing a turbine is less a monetary issue as it is an environmental one. The production, transport, and installation of one these turbines have a sizable "carbon footprint", which is important to know, especially considering that the whole idea behind its construction is for clean power **[1]**

Solar Thermal

- Solar thermal plants are not noisy and not at all possess any criterion design that can be a threat to the wildlife.
- Solar radiation incidents on area of earth surface that covers the total of 82%. So, it covers more area.
- Solar Thermal can use direct form of energy usage as space heating, water desalinization etc. Efficient in power generation also in thermodynamic scale.
- Installation cost is less than of the wind turbine.

2.2.2 Ocean Energy

1. **Current high cost of investment:** Because wave energy is still in the developmental stage, it is very costly to build wave devices. As the technology improves and the

demand for renewable energy technologies increases, the costs of investment and construction of wave energy technology are expected to decrease.

2. **Maintenance and weather effects:** Equipment that is exposed to rugged oceanic conditions 24/7 can lead to damage to wave equipment and to corrosion from salty seawater, requiring maintenance. Oceanic storms such as hurricanes are particularly damaging to wave equipment.
3. **Marine life impacts:** Marine life may be harmed or displaced, or their habitats negatively impacted by the construction of wave energy devices.
4. **Reduced sea usage:** The physical presence of wave energy device "farms" could potentially reduce the size of shipping channels, as well as opportunities for recreation and fishing.
5. **Few implemented**: Thus far, only a few pilot wave energy projects have been constructed globally. Further research is necessary to determine the the lifespan of the equipment, the associated costs with running the devices, and the impacts of these machines on both human and marine life.
6. **Noise:** Constantly running wave energy devices can be much noisier than waves are naturally, and this could potentially be disruptive to both humans and sea life living near these devices.
7. **Slow technology improvements:** Wave energy has been developing since the 1700s, and yet it is still a nascent technology that needs to be more fully developed. This slow development is an impediment to investment in this type of renewable energy.
8. **Difficult to transmit wave energy:** It is currently very challenging to transport ocean wave-generated electricity long distances to where it will be consumed inland. [2]

Solar Thermal

- Comparatively less installment cost/hr energy production. And maintain ace of solar thermal after installation is not given that of much costly effort.
- Sea water is used for water treating and also desalinization process, no negative impact.

- Implementation process to derive output power varies over a wide range.
- Transmission of energy in easy and efficient.
- Technological improvement is considered as the fast as of comparing with all the other sources.

2.2.3 Hydropower

1. Emission of methane and carbon dioxide: The reservoir of water for hydroelectric power releases a large amount of carbon dioxide and methane. The area around the dam is filled with water. The plants and trees in them start rotting and decompose by other method without the use of oxygen. So, this type of decomposition dumps a great amount of methane and carbon dioxide which increase pollution.

2. Disturbance of habitat: The formation of large and huge dams destroys the living beings around them. Local life is disturbed as human can't live in such a flooded area and plants are destroyed. People living nearby have to relocate.

3. Divert natural waterway: Dams and rivers collect water for the production of electricity which alters the natural system of water flow thus depriving houses of the water they need.

4. Effects on agriculture: Making dams on rivers affect the amount, quality and temperature of water that flow in streams which has drastic effects on agriculture and drinking water.

5. Fish killing: The water while flowing through the dam collects nitrogen which can damage and also kills fish. They can also damage the reproduction of fishes thus eliminating the whole species of fishes.

6. Breaking of dams: Many dams which were built for industrial use or for mills are not now used and occupying a great space but they can't be broken or removed as it would cause serious flooding. This would not only affect the humans but also many buildings and property.

7. Deposition of silt: So, the research is going on decrease its disadvantages and to make it happen on a large scale. **[21]**

Solar Thermal

- No contribution for green house emission.
- Habitual cycle of the animal kingdom is not affected.
- No soot composition or slit formation.

2.2.4 Biomass

1. <u>Harmful to Environment</u>: Thirdly, using animal and human waste to power engines may save on carbon dioxide emissions, but it increases methane gases, which are also harmful to the Earth's— ozone layer. So really, we are no better off environmentally for using one or the other. And speaking of using waste products, there is the smell to consider. While it is not physically harmful, it is definitely unpleasant, and it can attract unwanted pests (rats, flies) and spread bacteria and infection.

2. <u>Consume More Fuel</u>: Finally, using trees and tree products to power machines is inefficient as well. Not only does it take a lot more fuel to do the same job as using conventional fuels, but it also creates environmental problems of its own. To amass enough lumber to power a nation full of vehicles or even a power plant, companies would have to clear considerable forest area. This results in major topological changes and destroys the homes of countless animals and plants.

3. <u>Require More Land</u>: Combustion of biomass products require some land where they can easily be burnt. Since, it produces gases like methane in atmosphere; therefore, it can be produced in those areas which are quite far from residential homes. **[3]**

Solar Thermal

- No negative effect on environment.
- Fuel consumption consideration is not accounted.
- Comparatively consumes less area and plant is fusible with other resource from.

2.2.5 Biodiesel

1. **<u>Variation in Quality of Biodiesel</u>:** Biodiesel is made from variety of biofuel crops. When the oil is extracted and converted to fuel using chemical process, the result can vary in ability to produce power. In short, not all biofuel crops are same as amount of vegetable oil may vary.
2. **<u>Not Suitable for use in Low Temperatures</u>:** Biodiesel gels in cold weather but the temperature that it will gel depends on the oil or fat that was used to make it. The best way to use biodiesel during the colder months is to blend it with winterized diesel fuel.

3. **Food Shortage:** Since biofuels are made from animal and vegetable fat, more demand for these products may raise prices for these products and create food crisis in some countries. For e.g.: the production of biodiesel from corn may raise its demand and it might become more expensive which may deprive poor people from having it.
4. **Water Shortage**: The use of water to produce more crops can put pressure on local water resources. The area where there is water scarcity, production of crops to be used in making of biofuels is not a wise idea.
5. **Monoculture**: Monoculture refers to the practice of producing same crop over and over again rather than producing different crops. While this results in fetching best price for the farmer but it has some serious environmental drawbacks. When the same crop is grown over large acres, the pest population may grow and it may go beyond control. Without crop rotation, the nutrients of soil are not put back which may result in soil erosion.
6. **Slight Increase in Nitrogen Oxide Emissions**: Biodiesel has about 10% higher Nitrogen Oxide (NOX) than other petroleum products. Nitrogen Oxide is one the gas that is used in the formation of smog and Ozone. Once it gets dissolved in atmospheric moisture, can cause acid rain. [4]

Solar Thermal

- Wide range of temperature usage.
- Water consumption rate is not as high as biodiesel (less about 37%)
- No negative agricultural effect.
- No release of green-house gases.

2.2.6 Difference of Solar Thermal and Solar PV Cells

The most importance is given on the consideration of using which method to harness solar energy. So, the comparison between the Photovoltaic Solar Cells and Solar Thermal is a very important topic to be discussed. Distinction between these two solar power utilization methods is discussed below-

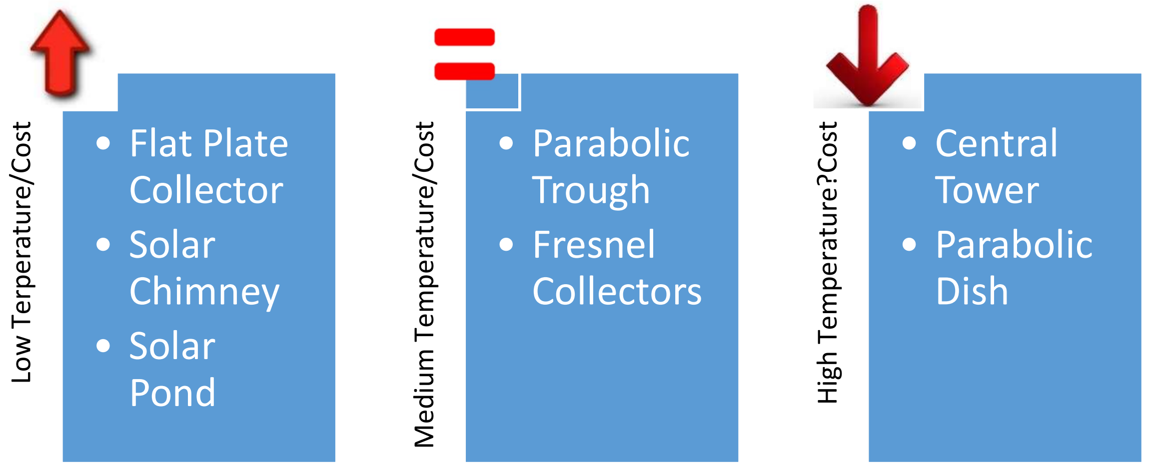
Topic of difference	**Photovoltaic Cells**	**Solar Thermal**
Space Consumption	Consumes comparatively more space	Solar thermal is more space efficient than Solar Photovoltaic Cells
Efficiency	Solar to electricity generation efficiency is comparatively higher but other power conversion lacks proper utilization	They can be up to 70% more efficient in collecting heat from sun rays than Solar PV
Technology Complexity	As it is an electrical conductive grid system, design complexity is greater than of the solar thermal	The technology itself is less complex than solar PV. No extra maintain ace or supervision is required rather than simple plant check
Expense in Production	Cost per watt for this technology is currently 18-43 cents per KWh	Solar thermal energy costs between 19-35 cents per KWh
Storage Capacity of energy	PV cells can store generated electrical power in batteries but not the harnessed solar power in any form	Solar thermal can store enough energy for 7.5 hours of generation in lieu of sunlight. Therefore, solar thermal can potentially generate power 24 hours a day
Installation parameters	Mobile can easily be dispatched to another location	Not as simple constructional advantage of mobility as in PV plats
Usage	PV cell usage as source of energy consumption reaches the rate of 800MW capacity	Solar thermal energy conversion rate is as half of the PV cell standing in 418MW production [5] [6]

2.3 Out view of Various Solar Power Collector

Solar thermal power generation systems collect and concentrate sunlight to produce the high temperature needed to generate steam/electricity. All solar thermal power systems have solar energy collectors with two main components: reflectors (mirrors) that capture and focus sunlight onto a receiver. In most types of systems, a heat-transfer fluid is heated and circulated in the receiver and used to produce steam. The steam is converted into mechanical energy in a turbine, which powers a generator to produce electricity. Solar power systems have tracking systems that keep sunlight focused onto the receiver throughout the day as the sun changes position in the sky.

Solar thermal power systems may also have a thermal energy storage system component that allows the solar collector system to heat an energy storage system during the day and the heat from the storage system is used to produce electricity in the evening or during cloudy weather. Solar thermal power plants may also be hybrid systems that use other fuels (usually natural gas) to supplement energy from the sun during periods of low solar radiation.

There are various type of solar power plants and use various approaches to harness solar radiation to collect solar heat and produce power. From different experimental conduction, their efficiency and use are being developed. Concentrating solar technologies can be classified in many parameters. By temperature increase range and cost of installation a simple view is given below as-



2.3.1 Flat plate collector

Flat Plate Solar Collectors harness the power of the sun to provide energy for hydraulic systems while reducing utility costs and pollution. They are coated with a selective material to enhance solar energy absorption. These collectors are placed on fiberglass insulation, encased in a weather resistant frame, and topped with glass for increased efficiency. Quality construction and smart design assurance can result in highest standards for reliability, heat output, and return on investment.

Installing a solar flat plate water heating system for your home can reduce your energy consumption by as much as 40% to 50%. It only takes 1 or 2 solar flat plates to heat over 80 gallons of hot water per day - all for free. Many people don't realize how much energy is used just to provide hot water in your home. In fact, 20% to 25% of the average family's energy consumption is just for heating water for things like laundry, cooking, cleaning, dishes, and showers. Installing a solar flat plate system would mean significantly reducing - or eliminating - these costs.

There are also many other financial incentives that may be available in your area. Many states, counties, and other localities offer cash rebates, or other incentives to help promote clean, free, solar hot water.

Figure 2.3.1: Flat Plate Solar Collector

2.3.2 Solar Chimney

Solar updraft technology is attracting interest in desert regions worldwide in Chile, the Southwest United States, Australia, China, and the Middle East. Fueled by hot air, rather than direct sunlight, solar chimneys present a compelling prospect for producing clean, renewable energy. They also offer significant advantages over conventional photovoltaic (PV) panels—but at the moment, they face even more significant financing hurdles.

A massively large, transparent canopy, or collector, is suspended 2 to 20 meters (6 to 65 feet) off the ground, and the air beneath it, warmed by the sun, becomes hotter than the air outside. In the middle of the collector is a tall, slender tower. As the buoyant, warm air is drawn up through the tower, it passes through turbines attached to the tower's base that feed off the rising air's kinetic energy, powering a generator.

Figure 2.3.2: Solar Updraft tower in Manzanares, Spain

2.3.3 Parabolic Trough

Parabolic trough power plants are the only type of SOLAR plant technology with existing commercial operating systems until 2008. In capacity terms, 354 MW of electrical power are installed in California, and a plenty of new plants are currently in the planning process in other locations.

The parabolic trough collector consists of large curved mirrors, which concentrate the sunlight by a factor of 80 or more to a focal line. Parallel collectors build up a 300–600-meter-long collector row and a multitude of parallel rows form the solar collector field. The one-axis tracked collectors follow the sun.

The collector field can also be formed from very long rows of parallel Fresnel collectors. In the focal line of these is a metal absorber tube, which is usually embedded in an evacuated glass tube that reduces heat losses. A special high-temperature, resistive selective coating additionally reduces radiation heat losses.

In the Californian systems, thermos-oil flows through the absorber tube. This tube heats up the oil to nearly 400°C, and a heat exchanger transfers the heat of the thermal oil to a water steam cycle (also called Rankine cycle). A feed water pump then puts the water under pressure. Finally, an economizer, vaporizer and super-heater together produce superheated steam. This steam expands in a two-stage turbine; between the high-pressure and low-pressure parts of this turbine is a re-heater, which heats the steam again. The turbine itself drives an ELECTRICAL that converts the mechanical energy into electrical energy; the condenser behind the turbine condenses the steam back to water, which closes the cycle at the feed water pump. It is also possible to produce superheated steam directly using solar collectors. This makes the thermos-oil unnecessary, and also reduces costs because the relatively expensive thermos-oil and the heat exchangers are no longer needed. However, direct solar steam generation is still in the prototype stage.

Figure 2.3.3: Parabolic Trough Solar Collector

2.3.4 Compact Linear Fresnel Reflector

Solar Euromed’s Linear Fresnel solar CSP technology produces energy as heat through the use of long and narrow segments of mirror that pivot to reflect the sunlight onto a fixed absorber tube located at the common focal line of the reflectors called Linear Fresnel Reflectors. This energy can be used either directly in the form of heat, either in the form of electricity after conversion.

Solar thermal energy is collected and concentrated with mirror reflectors equipped with tracking devices to maximize the amount of solar energy collected over the day. The reflected sunrays are focused on a receiver tube located on the focal axis of the reflectors. Inside the tube, a heat transfer fluid circulates - water in this case - which is heated, evaporated and superheated by the concentrated solar energy

CLFR uses the principles of curved-mirror trough systems, but with long parallel rows of lower-cost flat mirrors. These modular reflectors focus the sun's energy onto elevated receivers, which consist of a system of tubes through which water flows. The concentrated sunlight boils the water, generating high-pressure steam for direct use in power generation and industrial steam applications.

Advantages of Fresnel Reflector:

- Fresnel system requires flat or less-shaped mirrors than the other CSP systems; flat mirrors are cheaper and can bent on site.
- Fresnel plants facilitate direct steam generation, i.e. use of water within the receiver instead of a heat transfer fluid which is toxic and flaming, thus eliminating the need for costly heat transfer fluids and heat exchangers. This technology is consequently cheaper to implement and allows for a strong construction modularity.
- Operations and maintenance are easy; hence, the associated costs are moderate.
- Fresnel technology has CSP’s best land-to-electricity ratio due to a compact design and the usability of space below support structure.

Figure: 2.3.4: Compact Linear Fresnel Reflector

2.3.5 Central Solar Tower

A Solar Power Tower also known as a Central Receiver, is the big daddy of all concentrating solar collectors. Solar towers use hundreds if not thousands of small suns tracking mirrored solar dish collectors, called heliostats similar to the ones in the previous parabolic and dish collector tutorials that are used to reflect the sunlight directly onto a centrally located heat absorbing receiver.

The *solar power tower* name comes from the fact that the *concentrated solar power* or CSP is focused not at the focal point of each heliostat dish but at the top of a very tall vertical tower. The sunlight from many mirror like dish reflectors spread over a large area is focused to one central point achieving an extremely high temperature which is used to produce high pressure steam which is then used to generate electricity.

A power tower has a circular array of large two-axis tracking reflective dishes or flat multiple mirror heliostats on the ground that accurately follow the sun's path across the sky during the day. These reflective dishes capture and concentrate the sunlight onto a central receiver mounted at the top of the high “solar power tower”. These “heliostats” are basically large mirrors equipped with computer controlled sun tracking mechanisms that keep the mirrors aligned so the reflected rays of the sun are always aimed at the blackened heat absorbing receiver creating a focal point. For multiple mirror heliostats, the position and orientation of the individual mirrors on top of the supporting structure is different for every heliostat within the same heliostat field to take account of its relative position and angle towards the tower. Solar Power Towers have many advantages over other forms of concentrating solar collectors for use in a solar electricity generating system or SEGS. They are a non-polluting, zero emissions (except for the scattered sunlight).

Figure: 2.3.5: Central Power Tower

2.3.6 Parabolic Dish/Solar Dish

Mirrors are distributed over a parabolic dish surface to concentrate sunlight on a receiver fixed at the focal point. In contrast to other CSP technologies that employ steam to create electricity via a turbine, a dish-engine system uses a working fluid such as hydrogen that is heated up to

1,200° F in the receiver to drive an engine such as the Stirling engine. Each dish rotates along two axes to track the sun.

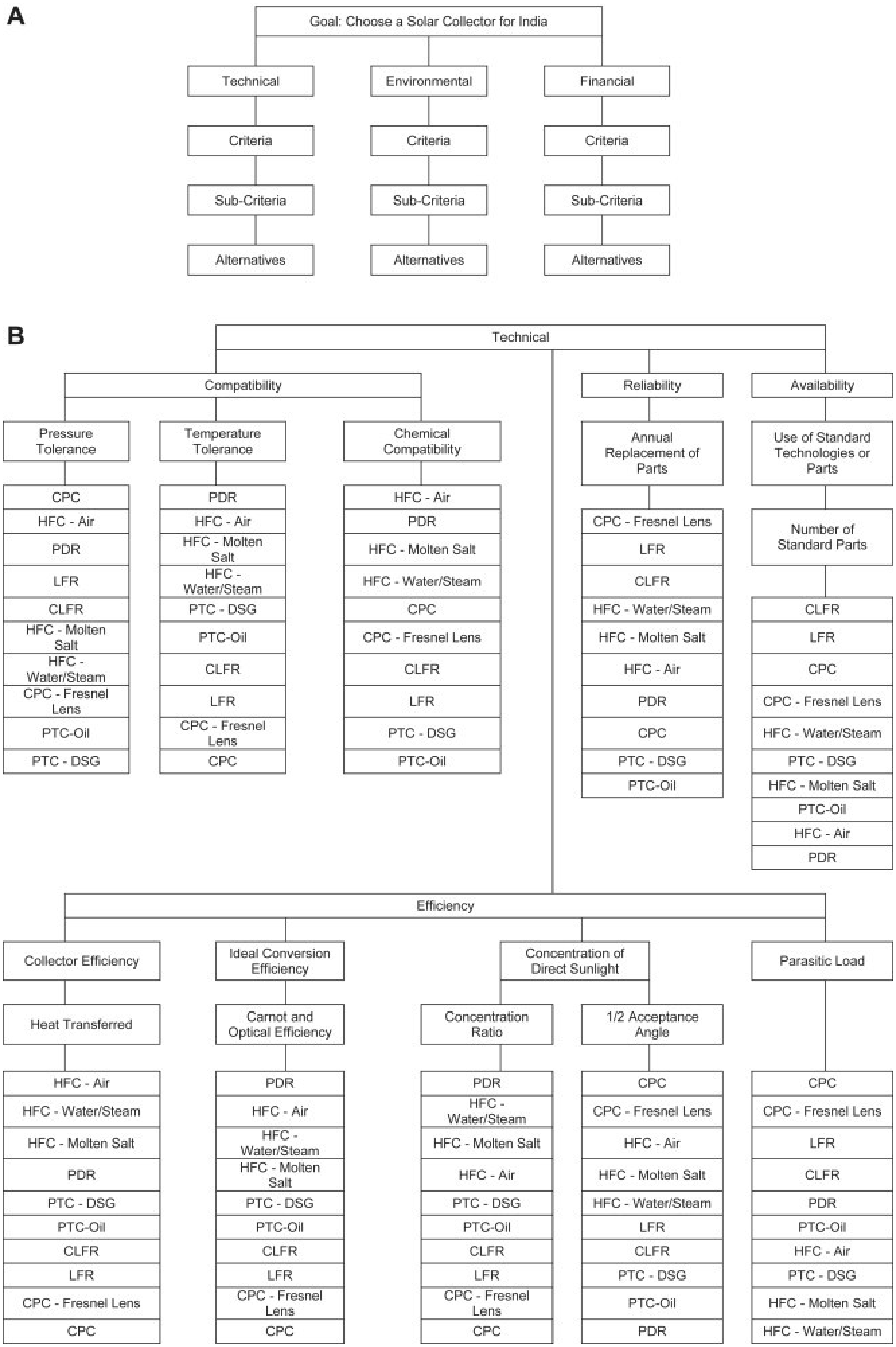
Parabolic Dish systems use satellite-like mirror dishes to focus the light onto a single central receiver in front of the mirror. They so far have the highest heat-electricity conversion efficiencies among all CSP designs (up to 30 %). The size of the concentrator is determined by its engine. A dish/Stirling system's concentrator with a nominal maximum direct normal solar insolation of 1000 W/m2 and a 25-kW capacity has a diameter of approximately 10 meters. It could also run on a single Brayton cycle, where air, helium or other gas is compressed, heated and expanded into a turbine. Parabolic dish could be applied individually in remote locations, or grouped together for small-grid (village power, 10 KW) or end-of-line utility (100 MW) applications. The electricity has to be used immediately or transmitted to the gird as the system has no storage device. Intermittent cloud cover can cause weakening of highly concentrated receiver source flux. Sensible energy storage in single-phase materials was proposed to allow a cylindrical absorber element not only absorb the energy but also store it in its mass, thus reducing the amplitude of cloud cover transients. Although this design only allows short period energy storage, potential longer time storage technology would make parabolic dish more appealing.

The Stirling Engine used in the above parabolic dish: it produces grid-quality electricity using the heat gathered by the receiver directly. It is a 4 cylinder, each with a 95cc displacement engine (4-95 engines) that evolved from the Philips engines of the 1960's.

Figure: 2.3.6: Dish-Stirling Prototype Systems in Spain

2.4 Advantage of Flat Plate Solar Thermal over other Collectors

As it has been discussed, there are many methods via which solar thermal energy can be utilized. Among them Flat Plate Solar Thermal collector is advantageous in many perspectives. A decision hierarchy tree for selection of a suitable solar collector is represented


A
Goal: Choose a Solar Collector for India
Technical
Environmental
Financial
Criteria
Criteria
Criteria
Sub-Criteria
Sub-Criteria
Sub-Criteria
Alternatives
Alternatives
Alternatives
B
Technical
Compatibility
Reliability
Availability
Pressure Tolerance
Temperature Tolerance
Chemical Compatibility
Annual Replacement of Parts
Use of Standard Technologies or Parts
Number of Standard Parts
CPC
HFC - Air
PDR
LFR
CLFR
HFC - Molten Salt
HFC - Water/Steam
CPC - Fresnel Lens
PTC-Oil
PTC - DSG
PDR
HFC - Air
HFC - Molten Salt
HFC - Water/Steam
PTC - DSG
PTC-Oil
CLFR
LFR
CPC - Fresnel Lens
CPC
HFC - Air
PDR
HFC - Molten Salt
HFC - Water/Steam
CPC
CPC - Fresnel Lens
CLFR
LFR
PTC - DSG
PTC-Oil
CPC - Fresnel Lens
LFR
CLFR
HFC - Water/Steam
HFC - Molten Salt
HFC - Air
PDR
CPC
PTC - DSG
PTC-Oil
CLFR
LFR
CPC
CPC - Fresnel Lens
HFC - Water/Steam
PTC - DSG
HFC - Molten Salt
PTC-Oil
HFC - Air
PDR
Efficiency
Collector Efficiency
Ideal Conversion Efficiency
Concentration of Direct Sunlight
Parasitic Load
Heat Transferred
Carnot and Optical Efficiency
Concentration Ratio
1/2 Acceptance Angle
HFC - Air
HFC - Water/Steam
HFC - Molten Salt
PDR
PTC - DSG
PTC-Oil
CLFR
LFR
CPC - Fresnel Lens
CPC
PDR
HFC - Air
HFC - Water/Steam
HFC - Molten Salt
PTC - DSG
PTC-Oil
CLFR
LFR
CPC - Fresnel Lens
CPC
PDR
HFC - Water/Steam
HFC - Molten Salt
HFC - Air
PTC - DSG
PTC-Oil
CLFR
LFR
CPC - Fresnel Lens
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CPC
CPC - Fresnel Lens
HFC - Air
HFC - Molten Salt
HFC - Water/Steam
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PTC - DSG
PTC-Oil
PDR
CPC
CPC - Fresnel Lens
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PTC-Oil
HFC - Air
PTC - DSG
HFC - Molten Salt
HFC - Water/Steam

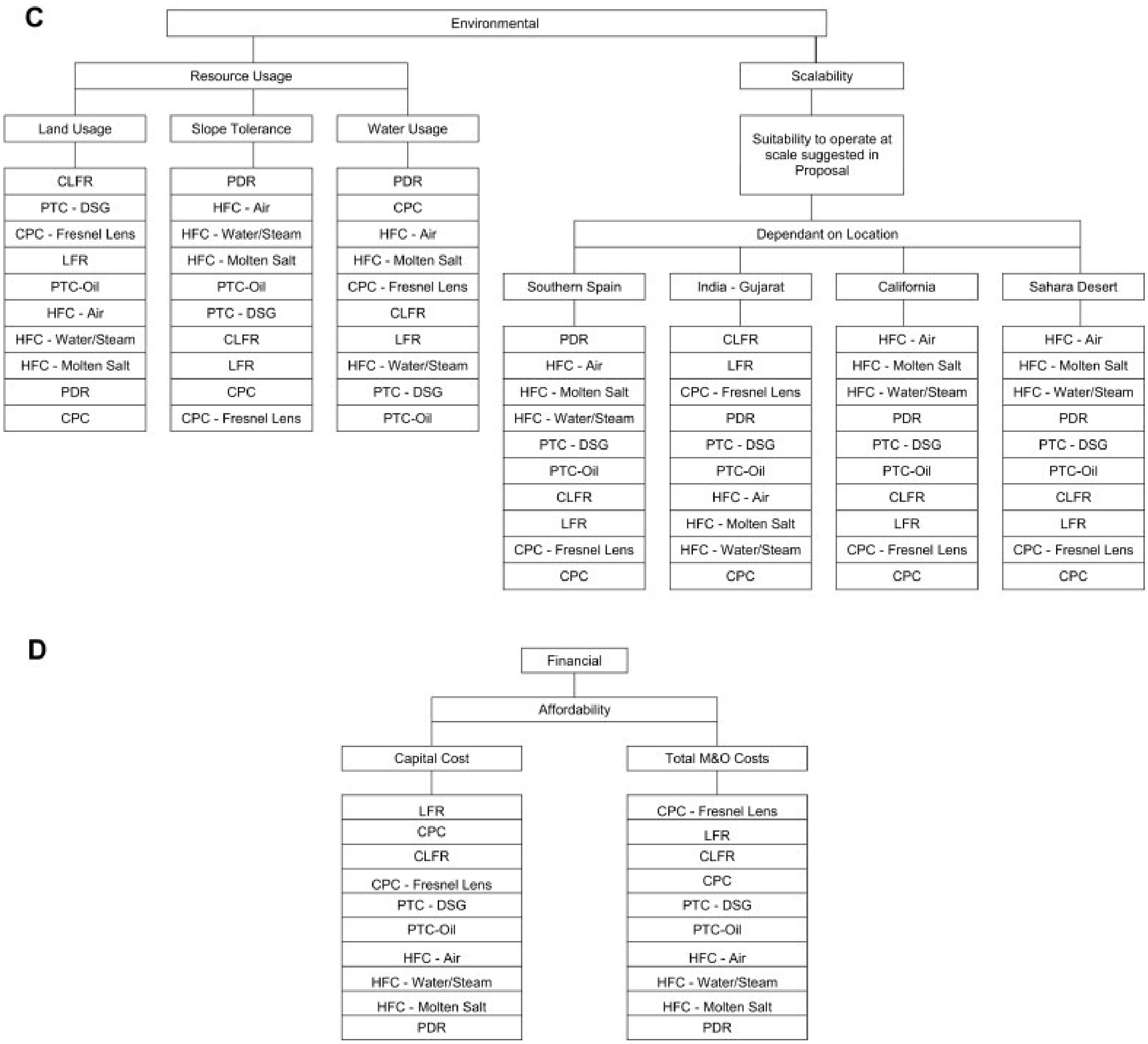


Table 2.4: Advantage of Flat Plate Solar Thermal [7]

2.5 Improvement Parameters and Design Modifications

2.5.1 Absorption Coating

The electromagnetic radiation emitted by the sun displays a wide range of wavelengths. This can be divided into two major regions with respect to the capability of ionizing atoms in radiation-absorbing matter: ionizing radiation (X-rays and gamma-rays) and non-ionizing radiation (UVR, visible light and infrared radiation). Solar radiation is commonly divided into various regions or bands of wavelength as seen in Figure

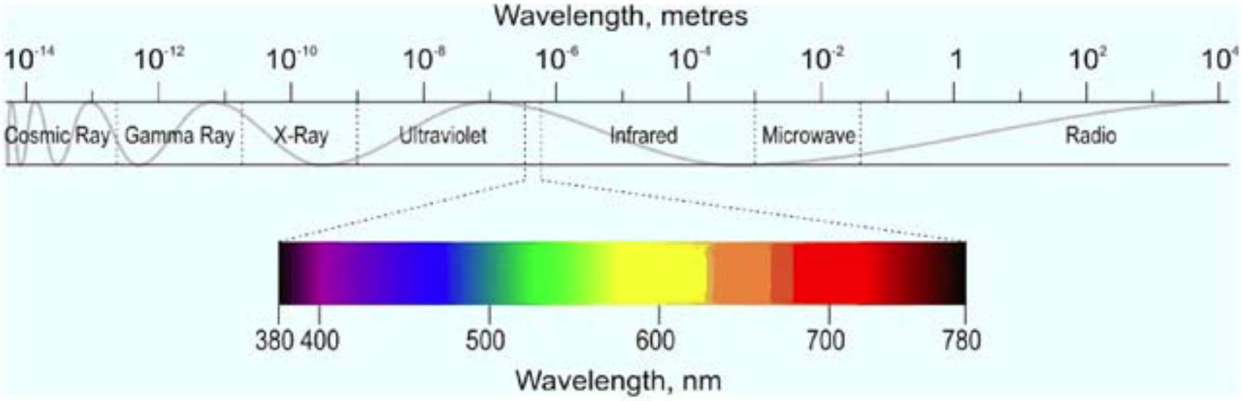


Figure 2.5.1a Solar Radiation Wavelength Bands [8]

An ideal selective surface for solar collectors should absorb electromagnetic radiation (Light) in the visible range and emit a small amount of radiation back in the infra-red Range. So, the maximum amount of energy from the incoming sunlight is used to heat Water.

Silver or aluminum films are deposited on some type of rigid support. Currently, the most commonly used support structures are metallic, glass or plastic tubes. (ii) Absorber tube: The absorber tube is one of the most important components of a trough system. The absorber tube is made of two concentric tubes that lie along the parabolic trough's focal point. The outer tube (made of glass) is separated from the inner tube (mad e of metal) by a vacuum layer. This reduces heat loss and increases the overall efficiency. A working fluid is circulated through the inner tube and absorbs solar radiation energy as heat. (iii) Working fluid: The working fluid varies depending on the trough technology. For lower temperature applications (less than 200 ° C), demineralized water with an ethylene- glycol mixture is used as the working fluid. For higher temperatures, (200 - 450 ° C) synthetic aromatic oil is often used as the working fluid. Direct steam generation (DSG) in parabolic trough collectors eliminates the use of heat exchangers and expensive heat transfer fluids. Therefore, it is a promising option to improve the efficiency and reduce the operating costs of parabolic trough power plants. Newer technologies use molten salts as the working fluid. (iv) Solar tracking system: A parabolic trough power plant's solar field consists of a large, modular array of single-axis tracking parabolic trough solar collectors. Many parallel rows of these solar collectors span across the solar field, usually aligned on a north-south horizontal axis. (v) Support structure: The entire parabolic trough system is supported by a rigid metallic support structure. The structure supports the mirrors and receivers and maintains their optical alignment. It allows the collector to rotate, so that the mirrors and receivers can track the sun. Generally, the support structures are made from galvanized steel or extruded aluminum. Improving the properties of the solar selective coating on the receiver and increasing the solar field operating temperature above 400 ° C can improve the efficiency of a parabolic trough solar power plant and reduce the cost of solar electricity. In order to achieve this, new efficient spectrally selective coatings are needed which have high absorptance (α) in the wavelength range of 0.3-2.5 μ m and low emittance (ε) in the infrared region, at higher operating temperatures (both in air and vacuum). Spectrally selective coatings used on the receiver tubes can be categorized into six types and are shown schematically in Figure 8: (i) intrinsic absorber (ii) absorber-reflector

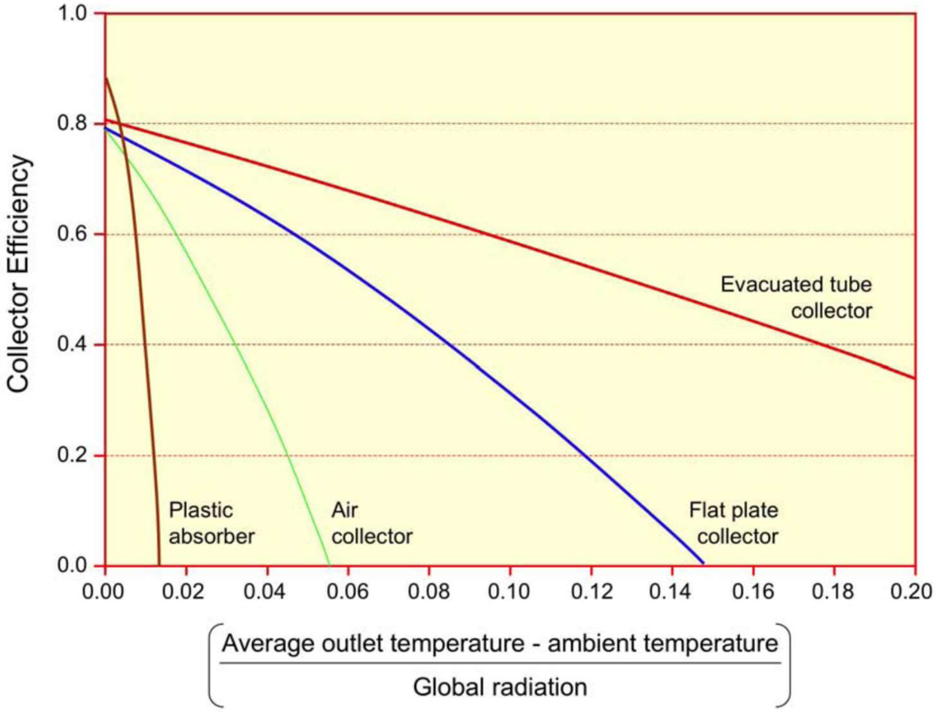


Figure 2.5.1b Hottel - Whillier Bliss Efficiency Curves

Different types of solar selective coatings out-view is as follows-

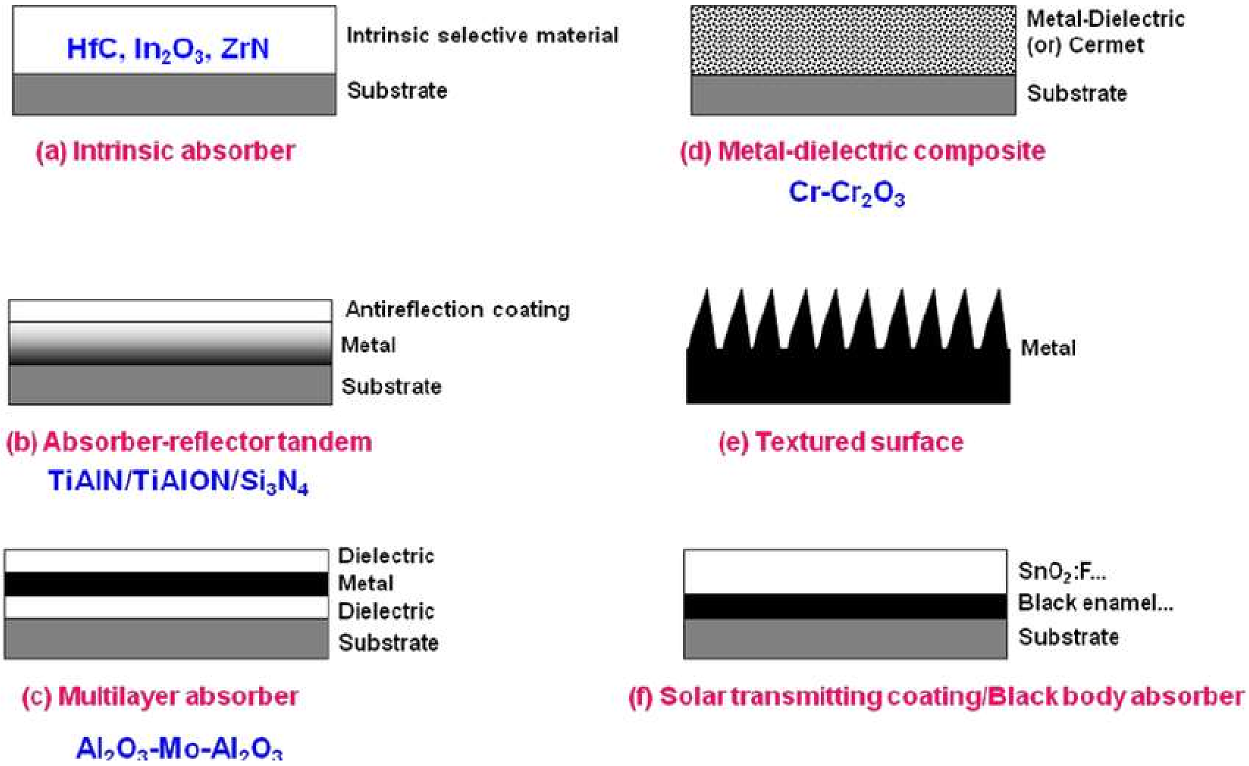


Figure 2.5.1c: Types of Solar Selective Coatings

2.5.2 Glazing

Glass is a good material for glazing flat plate solar collectors as it transmits almost 90% of the received shortwave solar radiation. Types of plastics can also be used as covers as few of them can endure ultraviolet radiation for a long time. Polycarbonate rigid sheet, polycarbonate rigid film and corrugated sheets are plastic products available on the market. The benefit of using plastics is that they cannot be broken by hail or stones and they are flexible and light. A design of the solar window was developed with the expectation to improve the performance of the solar energy collectors at high solar radiation incidences. The solar window was composed of two transparent plastic sheets of acrylic ribbed together. One of the inner surfaces of the solar window has triangular projection pairs separated from the adjacent projection pair by a distance equal to the width of the triangular projection pair at the top.

A transparent cover plate often made of glass reflects around 8% to 10% of the incident solar radiation, so resulting in a reduction in the overall efficiency of the collector.

Antireflective coatings on glass sheets are also a possibility for increasing the efficiency of solar energy systems by reducing the reflection of the incoming light. Studies have shown that the transmittance of glass can be increased by 4% if the glass is equipped with antireflection surfaces and also in return the efficiency of the solar collector can also be increased.

An effective antireflective coating on glass panels was developed for solar applications. The coating solution was prepared by a sol-gel technique. The solgel technique is based on hydrolysis of liquid precursors (i.e. metal chlorides) and formation of colloidal sols. A gel is a state where both liquid and solid are dispersed in each other, which presents a solid network containing liquid components which is applied on the glass by dip-coating. Thus, the sol evolves towards the formation of a gel-like dysphasic system containing both a liquid phase and solid phase whose morphologies range from isolated particles to continuous polymer networks. A wide band antireflective effect leads to an increase of solar transmission from 90% for an ordinary glass up to 96% for an antireflective coated glass. If constant thermal losses are assumed, a 5% increase in solar transmittance could result in as much as a 10% improvement in energy collection efficiency. Other types of antireflective coatings (AR) were tested including various solgels applied to glass and to an embossed treatment of sheet acrylic [34]. Recently, a silica low-reflection coating via a dip-coating process has been developed. The value of the film refractive index that leads to a minimum of reflection on the surface of the glass cover was achieved. A comparison has been made between an uncoated flat-plate solar collector glass cover and one with a porous sol-gel antireflective coating.

2.6 Thermal Energy Storage System

One challenge facing the widespread use of solar energy is reduced or curtailed energy production when the sun sets or is blocked by clouds. Thermal energy storage provides a workable solution to this challenge.

In a concentrating solar power (CSP) system, the sun's rays are reflected onto a receiver, which creates heat that is used to generate electricity that can be used immediately or stored for later use. This enables CSP systems to be flexible, or dispatch able, options for providing clean, renewable energy.

Several sensible thermal energy storage technologies have been tested and implemented since 1985. These include the two-tank direct system, two-tank indirect system, and single-tank thermocline system.

2.6.1 Two Tank Direct System

Solar thermal energy in this system is stored in the same fluid used to collect it. The fluid is stored in two tanks—one at high temperature and the other at low temperature. Fluid from the low-temperature tank flows through the solar collector or receiver, where solar energy heats it to a high temperature and it then flows to the high-temperature tank for storage. Fluid from the high-temperature tank flows through a heat exchanger, where it generates steam for electricity production. The fluid exits the heat exchanger at a low temperature and returns to the low-temperature tank.

Two-tank direct storage was used in early parabolic trough power plants (such as Solar Electric Generating Station I) and at the Solar Two power tower in California. The trough plants used mineral oil as the heat-transfer and storage fluid; Solar Two used molten salt.

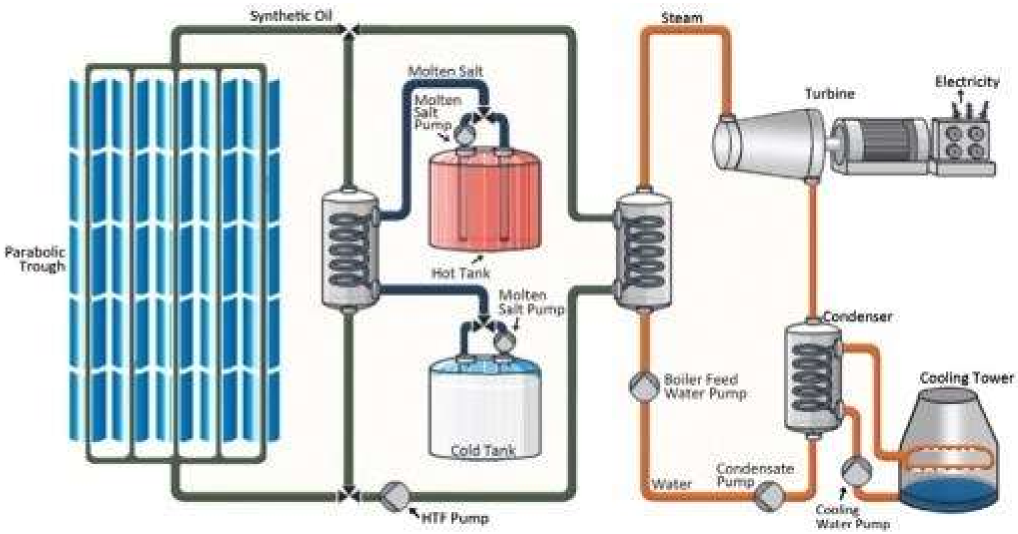


Figure 2.6.1: Two-tank Direct System

2.6.2 Two-tank Indirect System

Two-tank indirect systems function in the same way as two-tank direct systems, except different fluids are used as the heat-transfer and storage fluids. This system is used in plants in which the heat-transfer fluid is too expensive or not suited for use as the storage fluid.

The storage fluid from the low-temperature tank flows through an extra heat exchanger, where it is heated by the high-temperature heat-transfer fluid. The high-temperature storage fluid then flows back to the high-temperature storage tank. The fluid exits this heat exchanger at a low temperature and returns to the solar collector or receiver, where it is heated back to a high temperature. Storage fluid from the high-temperature tank is used to generate steam in the same manner as the two-tank direct system. The indirect system requires an extra heat exchanger, which adds cost to the system.

This system will be used in many of the parabolic power plants in Spain and has also been proposed for several U.S. parabolic plants. The plants will use organic oil as the heat-transfer fluid and molten salt as the storage fluid.

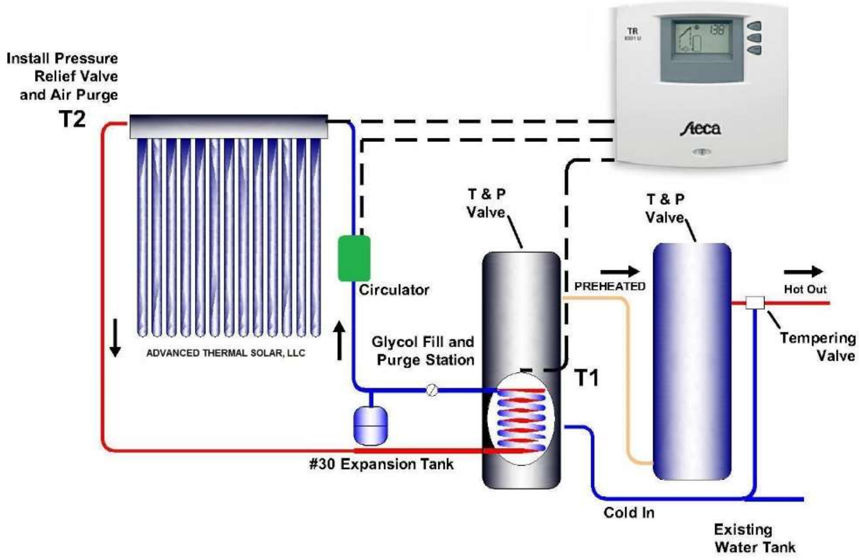


Figure 2.6.2: Two-tank Indirect System

2.6.3 Single Tank Thermocline System

Single-tank thermocline systems store thermal energy in a solid medium—most commonly, silica sand—located in a single tank. At any time during operation, a portion of the medium is at high temperature, and a portion is at low temperature. The hot- and cold-temperature regions are separated by a temperature gradient or thermocline. High-temperature heat-transfer fluid flows into the top of the thermocline and exits the bottom at low temperature. This process moves the thermocline downward and adds thermal energy to the system for storage. Reversing the flow moves the thermocline upward and removes thermal energy from the system to generate steam and electricity. Buoyancy effects create thermal stratification of the fluid within the tank, which helps to stabilize and maintain the thermocline.

Using a solid storage medium and only needing one tank reduces the cost of this system relative to two-tank systems. This system was demonstrated at the Solar One power tower, where steam was used as the heat-transfer fluid and mineral oil was used as the storage fluid. [9]

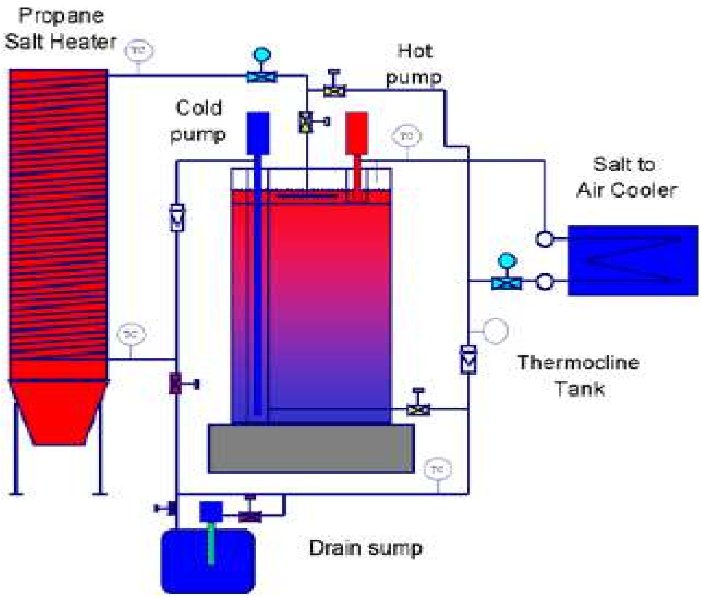


Figure 2.6.3: Single-Tank Thermocline System

Chapter-3

Theoretical Background

This work is based upon strong theoretical background which are elaborately discussed with proper reference sources. All the equations developed are used for deriving experimental calculations. Theories are well revised and are used to measure plant parameters for application. All the associated terms are broadly defined with relative block-diagram logistic terms.

3.1 Assumption

The theoretical model is based on the following assumptions:

1. The system is steady state
2. Uniform fluid flow
3. Heat transfer is one dimensional
4. Temperature drop through cover is negligible
5. The heat transfer from the collector edges is negligible
6. There is no absorption of solar energy by covers in so far it affects losses
7. The covers are opaque to infrared radiation
8. The sky can be considered as a blackbody for long wavelength radiation at an equivalent sky temperature
9. The temperature gradient around the tubes can be neglected
10. The temperature gradients in the direction of flow and between the tubes can be treated independently
11. Properties are independent of temperature
12. Loss through front and back are to same ambient temperature
13. Dust and dirt on the collector are negligible.
14. Shading on the collector plate is negligible.
15. Energy loss due to atmosphere is negligible

3.2 Heat Loss Analysis

The useful energy on the collector will found by the heat balance of the flat plate collector as follow,

$$Q_U=A_c\ (I_n-U_L(T_P-T_A)\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ \text{(i)}$$ [10]

Here,

A_C= Collector area

Q_U= Useful energy

U_L = Over all heat transfer coefficient

I_n= Solar insolation normal to the surface

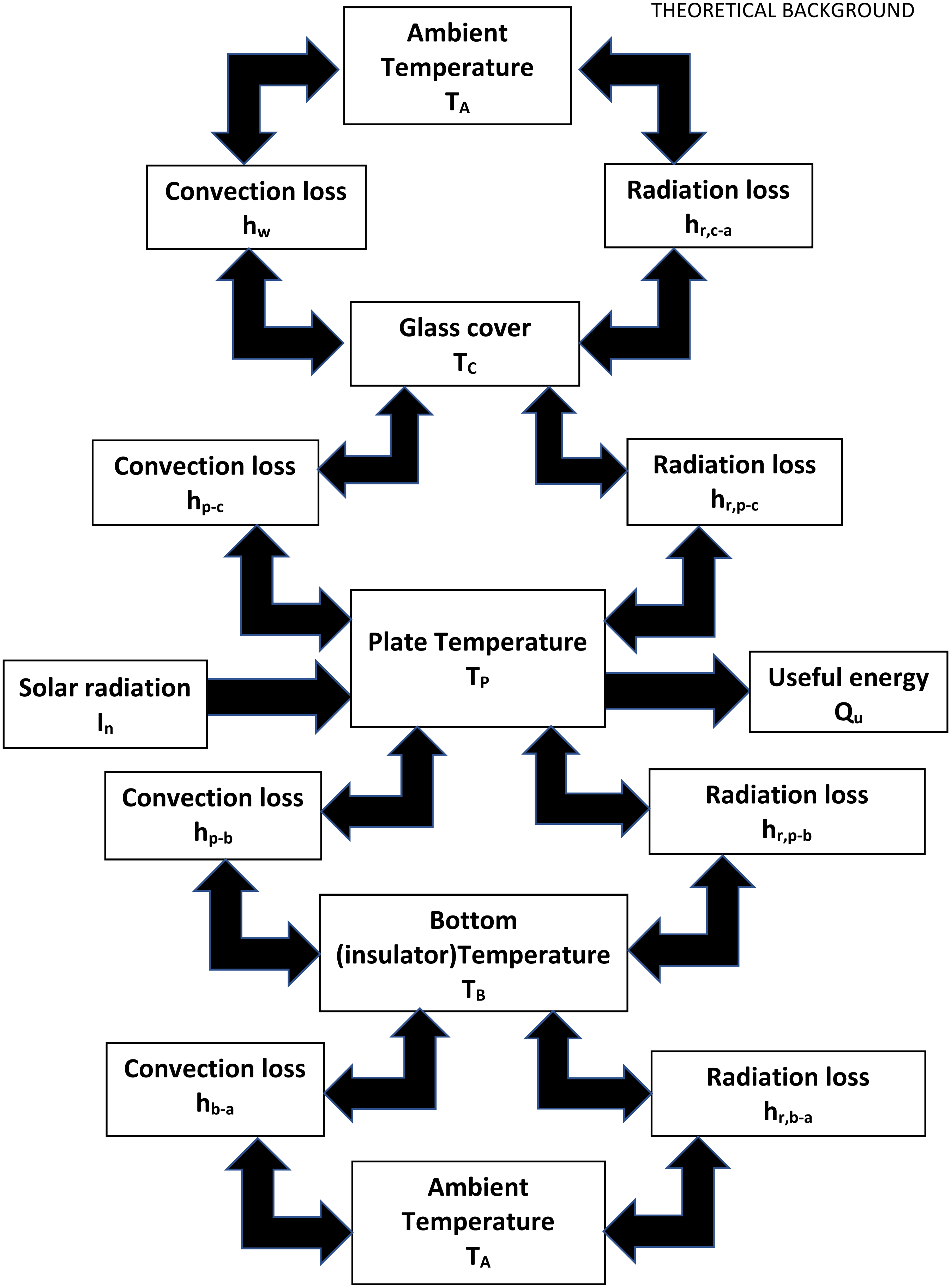
T_P= Plate temperature

T_A= Ambient temperature

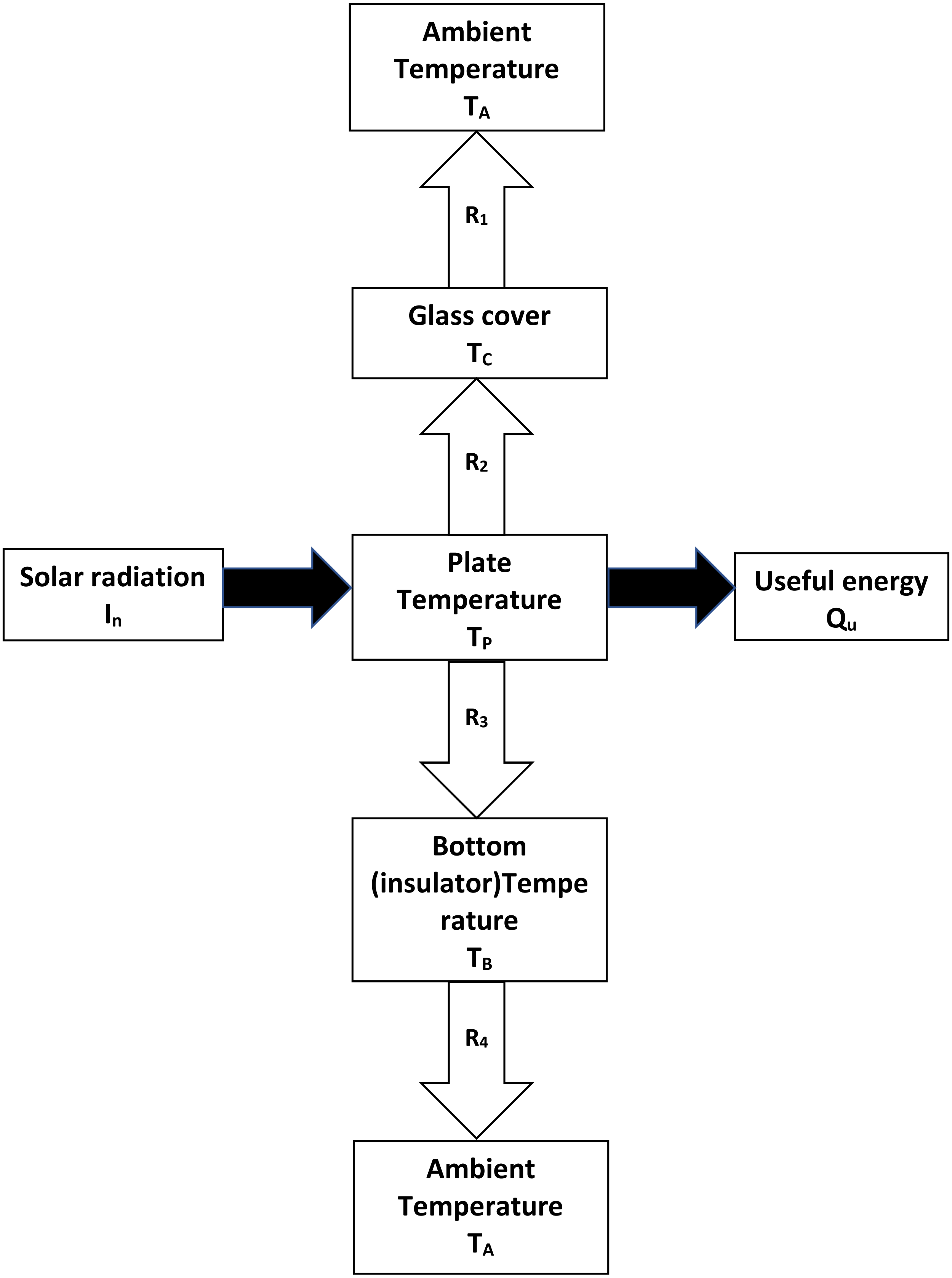
U_L is over all heat transfer coefficient which is calculated by combining all heat transfer coefficient (i.e. conduction, convection and radiation heat transfer coefficient).

To find U_L we should consider heat loss from top and the heat loss from bottom. This heat loss is in terms of conduction, convection and radiation form.

The thermal network analysis for heat balance of the flat plate solar collector is shown in the figure: -


Ambient Temperature T_A
Convection loss h_w
Radiation loss $h_{r,c\text{-}a}$
Glass cover T_C
Convection loss $h_{p\text{-}c}$
Radiation loss $h_{r,p\text{-}c}$
Plate Temperature T_P
Solar radiation I_n
Useful energy Q_u
Convection loss $h_{p\text{-}b}$
Radiation loss $h_{r,p\text{-}b}$
Bottom (insulator)Temperature T_B
Convection loss $h_{b\text{-}a}$
Radiation loss $h_{r,b\text{-}a}$
Ambient Temperature T_A

We can consider this heat loss in terms of thermal resistance as follow:



Here,

R_1= Total thermal resistance in between glass and atmosphere

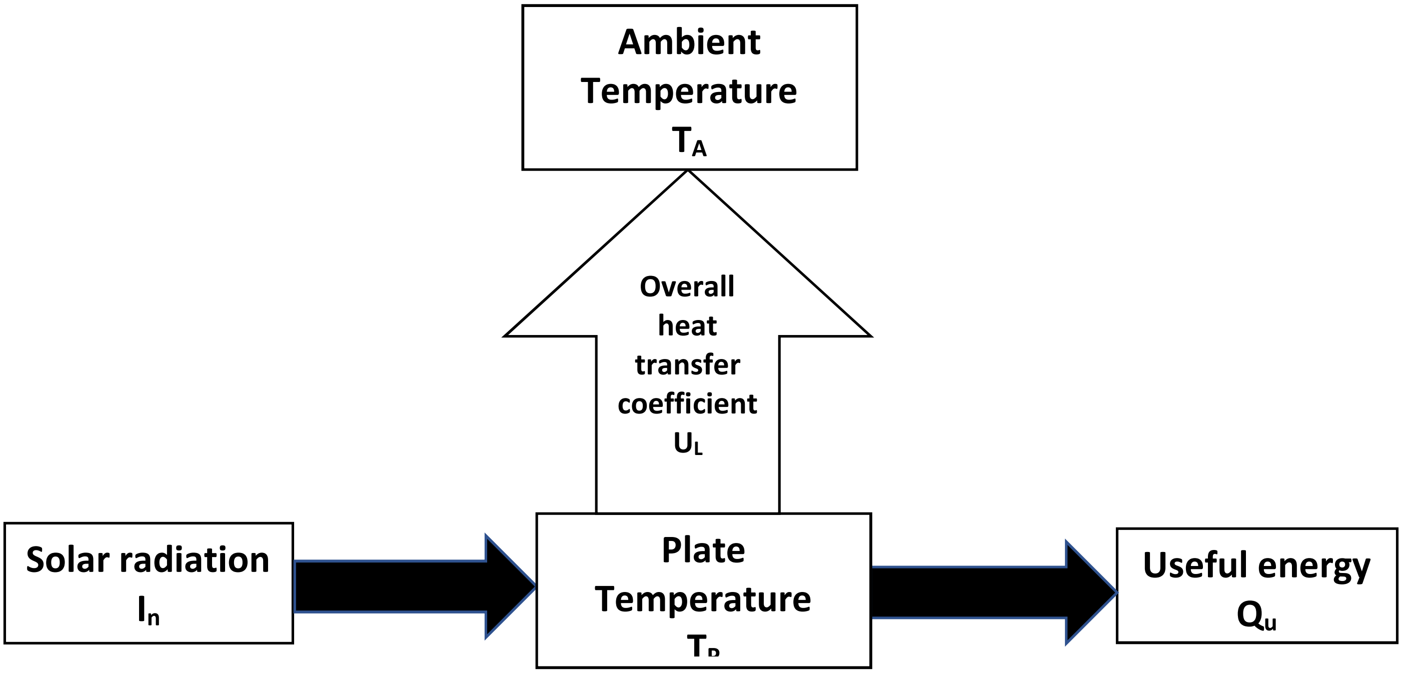
R_2= Total thermal resistance in between glass and absorber plate

R_3= Total thermal resistance in between absorber plate and insulator

R_4= Total thermal resistance in between insulator and atmosphere

By combining R_1, R_2, R_3, R_4 we will get over all heat transfer coefficient, U_L

$$U_L=\frac{1}{R_{1+R_2}}+\frac{1}{R_3+R_4} \quad .... \text{(ii)}$$



3.2.1 Heat Loss by Absorber Plate (Heat loss from top)

Heat loss from top of the absorber plate is done in two stages.

First stage is loss from plate to glass cover.

Second stage is loss from glass cover to atmosphere.

In both stage the loss is in terms of convective and radiative loss

In first stage heat loss, can be calculated as

$$Q_{\text{loss, p-c}} = h_{p\text{-}c}(T_P - T_C) + \frac{\sigma({T_P}^4 - {T_C}^4)}{\frac{1}{\epsilon_P} + \frac{1}{\epsilon_C} - 1}$$

Here,

ϵ_P= Plate emissivity

ϵ_C=Glass cover emissivity

$h_{p\text{-}c}$= Convection heat transfer coefficient in between plate and glass cover

T_P=Plate temperature

T_C= Glass cover temperature.

Top loss can be written as

$$Q_{\text{loss, p-c}} = (h_{p\text{-}c} + h_{r,\,p\text{-}c})(T_P - T_C) \text{ .... (iii)}$$

Where

$h_{r,\,p\text{-}c}$= Radiation heat transfer coefficient between plate and glass cover

$$h_{r,\,p\text{-}c} = \frac{\sigma({T_P}^2 + {T_C}^2)(T_P + T_C)}{\frac{1}{\epsilon_P} + \frac{1}{\epsilon_C} - 1}$$

From (iii)

$$R_2 = \frac{1}{h_{p-c} + h_{r,p-c}} \text{ .... (iv)}$$

3.2.2 Heat Loss by Glass Cover (Heat loss from top)

Now in second stage there will be heat loss between glass cover and atmosphere, this loss will be in terms of radiated heat loss, and convective loss by wind.

This can be calculated as

$$Q_{loss,\,c\text{-}a} = (h_W + h_{r,\,c\text{-}a})\,(T_C\text{-}T_A) \text{ .... (v)}$$

Here,

h_w= Wind heat transfer coefficient.

h_w= 5.7+ 3.8 V (Mc Adams [30], heat transmission 3^{re} Ed. McGraw-hill, 1954))

here h_w is in w/m^2. ^{o}c and V is wind speed in m/s

The radiation loss from the top of the cover takes place to an effective sky temperature and hence the radiative heat transfer coefficient between cover to ambient, $h_{r,\,c\text{-}a}$ is given by

$h_{r,\,c\text{-}a} = \epsilon_c \times \frac{\sigma({T_S}^4 - {T_c}^4)}{(T_C - T_A)}$

Where

T_S= Sky temperature

$T_S = .0552{T_A}^{1.5}$ (Both T_S *and* T_A in ^{o}K)

From (v)

$$R_1 = \frac{1}{h_w + h_{r,c-a}} \text{ .... (vi)}$$

Total heat loss from top of the plate

$$Q_{loss,\,top} = Q_{loss,\,p\text{-}c} + Q_{loss,\,c\text{-}a} \text{ .... (vii)}$$

$$Q_{loss,\,top} = (h_{p\text{-}c} + h_{r,\,p\text{-}c})\,(T_P\text{-}T_C) + (h_W + h_{r,\,c\text{-}a})\,(T_C\text{-}T_A) \text{ .... (viii)}$$

From (viii) Total top heat loss coefficient

$$U_t = \frac{1}{R_1 + R_2} \text{ .... (ix)}$$

3.2.3 Heat Loss by Insulator (Heat loss from bottom)

Heat loss from the bottom of the plate is carried out in two stages

First stage heat loss from absorber plate to insulator

Second stage heat loss from insulator to atmosphere

In first stage heat loss in terms of conduction loss which may calculated as

$$Q_{\text{loss, p-i}} = \frac{K}{L}(T_P - T_b) \text{ ...... (x)}$$

Here

L=Thickness of insulator

K=Conduction heat transfer coefficient of insulator

From (x)

$R_3 = \frac{L}{K}$

In second stage heat loss from bottom of the plate to atmosphere

But it is assumed that $T_b \cong T_A$

So

$Q_{\text{loss, b-a}} = 0$.

Hence

$R_4 = 0$

Now total bottom heat loss

$Q_{\text{loss, bottom}} = Q_{\text{loss, p-b}} + Q_{\text{loss, b-a}}$

$$Q_{\text{loss, bottom}} = \frac{K}{L}(T_P - T_b) \text{ ...... (xi)}$$

From (xi) overall bottom heat loss

$$U_b = \frac{1}{R_3} \text{ .... (xii)}$$

3.2.4 Overall Heat Transfer Co-efficient

Now over all heat transfer coefficient

$U_L = U_t + U_b$

$$U_L = \frac{1}{R_1 + R_2} + \frac{1}{R_3} \text{ .... (xiii).}$$

By subtracting all losses from incident solar energy, we will get the useful energy as solar thermal power.

3.3 Solar Insolation

Solar insolation is a measure of solar radiation energy received on a given surface area in a given time. It is commonly expressed as average irradiance in watts per square meter (W/m2) or kilowatt-hours per square meter per day (kW•h/(m2•day)) (or hours/day).

The amount of insolation received at the surface of the Earth is controlled by the angle of the sun, the state of the atmosphere, altitude, and geographic location. The insolation into a surface is largest when the surface directly faces the Sun. As the angle increases between the direction at a right angle to the surface and the direction of the rays of sunlight, the insolation is reduced in proportion to the cosine of the angle.

In construction, insolation is an important consideration when designing a solar thermal plant for a particular location setup. It is one of the most important variables for solar thermal energy efficiency. Solar insolation levels are used to determine what size solar collector is needed to efficiently provide adequate levels of hot water. Geographic locations with low insolation levels require larger collectors than locations with higher insolation levels.

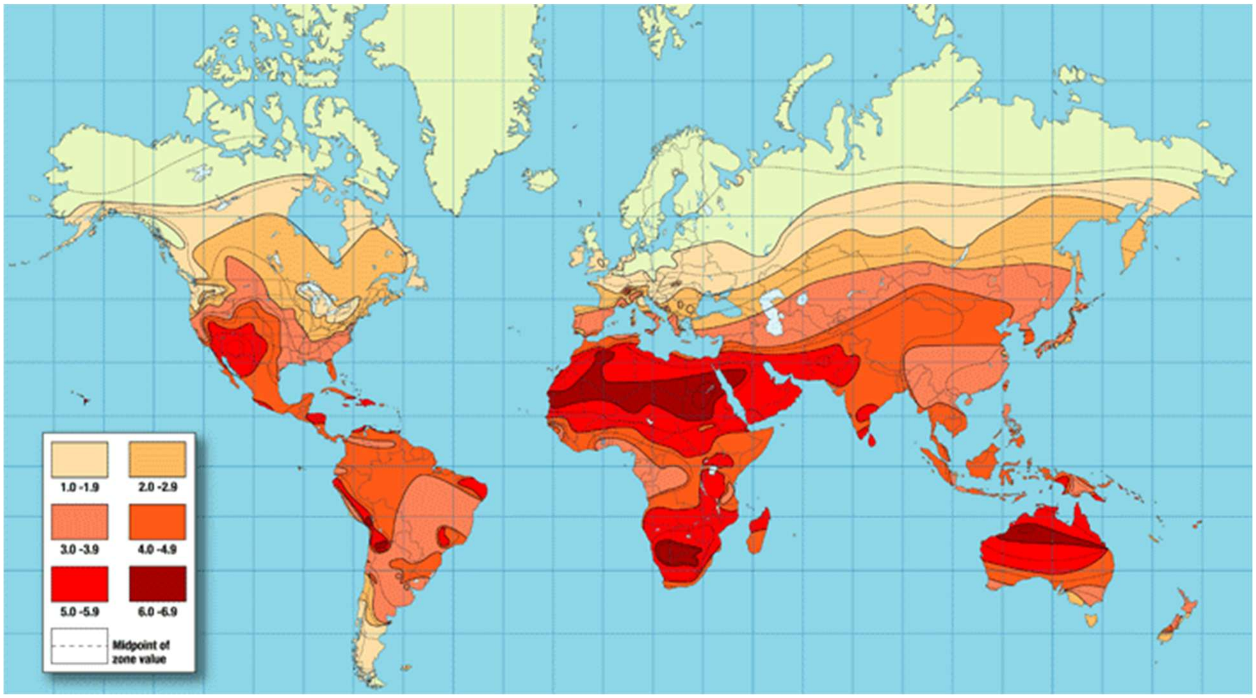


Figure 3.3: Solar Insolation Map of the World

3.3.1 Solar Beam Insolation (I_{bn})

Insolation describes how much sunlight (or solar radiation) a place gets. It is basically a measure of how sunny it is outside. Not all the 1367 W/m^2 ("W/m^2" = "watts per square meter") of sunlight that strikes the earth's outer atmosphere each ("daylight") moment makes it down to those of us living on the ground-floor. About 30% of the solar radiation is reflected back into space by the atmosphere. Of the remaining 1,000 W/m^2 or so, a given spot on the earth's surface might see about all of it or close to none of it.

The main conditions that influence how much solar energy a place gets during the day are sun angle, air mass, day length, cloud coverage and pollution.

The solar radiation receives from the sun without have been scattered by the atmosphere is called solar beam insolation (I_{bn}), this $\mathbf{I_{bn}}$ is obtained by the following formula,

$$I_{bn}=S_C\{1+.033\cos(\frac{360n}{365})\} \text{ ………………(xiv) [10]}$$

Here,

n=number of day counted from 1st January

S_C= solar constant= 1373 W/m^2.

3.3.2 Solar Insolation Normal to the Surface (I_n)

The amount of incident solar energy on the desired surface is called solar insolation normal to the surface (I_n). This I_n is obtained by the following formula-

$$I_n = I_{bn}.\cos\theta \ldots\ldots\ldots\ldots\ldots \text{(xv)}$$

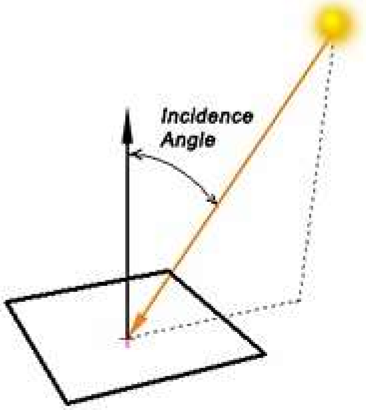
Here

I_n= solar insolation normal to the surface

I_{bn}= solar beam radiation.

θ= angle of incidence.

3.3.3 Angle of Incidence



The angle of incidence is depended on the latitude of the place (φ), angle of declination (δ) of the day, hour angle (ω) and tilt angle (β) of the surface as follow:

$$\cos\theta = \sin(\varphi)\{\sin(\delta)\cos(\beta)+\sin(\beta)\cos(\delta)\cos(\omega)\} + \cos(\varphi)\{\cos(\delta)\cos(\beta)\cos(\omega) - \sin(\delta)\sin(\beta)\} + \cos(\delta)\sin(\beta)\sin(\omega) \ldots\ldots\ldots\ \text{(xvi)}$$

3.3.4 Latitude Angle (φ)

In geography, latitude is a geographic coordinate that specifies the north–south position of a point on the Earth's surface. Latitude is an angle (defined below) which ranges from 0° at the Equator to 90° (North or South) at the poles.

For Dhaka, Bangladesh latitude angle is 24^{o} north

3.3.5 Angle of Declination (δ)

The angle of declination is the angle between the rays of the Sun and the plane of the Earth's equator.

This angle of declination (δ) is obtained by

$$\delta = 23.45\sin\{\frac{360}{365}(284+n)\} \ldots\ldots\ldots\ldots\ \text{(xvii)}$$ [10]

Here,
n=number of day counted from 1^{st} January

3.3.6 Hour Angle (ω)

The angular displacement of the sun east or west of the local meridian due to the rotation of earth on its axis is termed as hour angle.

The value of Hour angle (ω) is 15^{o} per hour from 12pm. Before 12pm (anti-clockwise rotation) hour angle is negative (-ve) and after 12pm (clockwise rotation) hour angle is positive (+ve).

3.3.7 Tilt Angle (β)

The angle between the surface and the horizontal is called tilt angle. To get the most from solar panels, it should be pointed in the direction that captures the most sun. But there are a number of variables in figuring out the best direction. It is suggested that solar energy often give the advice that the tilt should be equal to your latitude, plus 15 degrees in winter, or minus 15 degrees in summer. It turns out that you can do better than this - about 4% better.

3.4 Energy Received by the Surface

The total energy received by the surface

$$Q_{surface} = A_C \times I_n \times \text{time of operation} \text{ .... (xviii)}$$

3.5 Energy Gain by the Working Fluid

The working fluid gain energy from the solar insolation on the surface which may calculate as follow,

$$Q_{fluid} = ms\Delta\theta \text{ .... (xix)}$$

Here,

m= mass of fluid flow

s= specific heat of fluid

$\Delta\theta$=rise in temperature.

3.6 Efficiency of the Collector

Flat plate solar collector efficiency derivation can be calculated by-

Efficiency of the collector, $\eta_{collector} = \frac{heat\ gain\ by\ working\ fluid}{useful\ solar\ energy} = \frac{Q_{fluid}}{Q_{surface}}$ .... (xx)

3.7 Efficiency Factor

Efficiency of the flat plate solar collector depends upon different parameters. Various implementations can be integrated to increase the performance of the solar collector. Use of glazing materials for more absorbance of solar thermal radiation energy, design modifications to maximize area for thermal irradiance harnessing are some of the procedures. Technically these implementations have a great impact for ensuring maximum solar thermal energy utilization by the flat plate collector.

3.7.1 Tubing Formation

There are two types of tubing configuration usually found in flat plate collector namely parallel configuration and serpentine configuration**.**

Parallel configuration:

Most flat plate collector has small parallel tubes connected to a larger main carrier pipes as shown in Figure. These small parallel tubes are called riser tubes because this is where the working fluids would rise in order to harvest the heat from the sun. The parallel tube is designed to transport working fluid from the bottom of the flat plate collector to the top of the flat plate collector. The fluids pressure is higher at the base of the collector and least at the top. If the top and bottom pipes are large, the pressure difference is moderated and the flow rate in each of the parallel pipes is more uniform. Unfortunately, the flow rate is minimal at the center where most of the heat is concentrated. Other problems associated with this configuration are the cost and leaking problems. One small leak can cause catastrophic mess in experimentation and calculation.

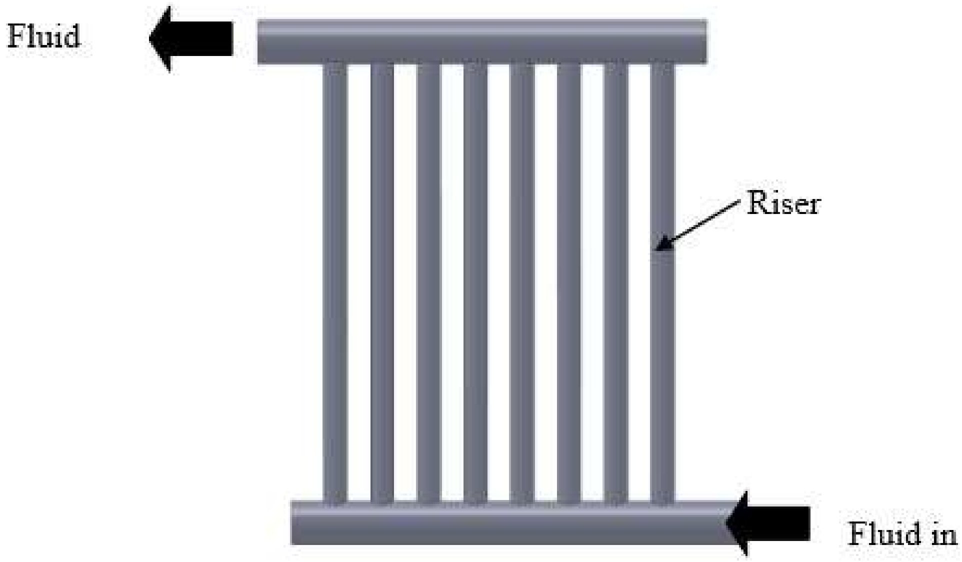


Figure 3.7.1a: Parallel flow configuration.

Serpentine configuration:

The serpentine flow in Figure 2.3 below consists of one long continuous flexible tube so there is no problem with uniform flow rate. The working fluids flow continuously from bottom to the top of the collector. This results in steady heat transfer from the heat absorber to the working fluid. Since the flow rate of the fluid through the serpentine tube is uniform the heat collection process is uniform.

Thus, serpentine configuration is used in this investigation due to uniform fluid flow resulting uniform heat transfer from absorber plate to working fluid. Furthermore, serpentine configuration is easier to construct compare to parallel which have many welding joints. The probability of leaking in parallel configuration is high compare to serpentine configuration.

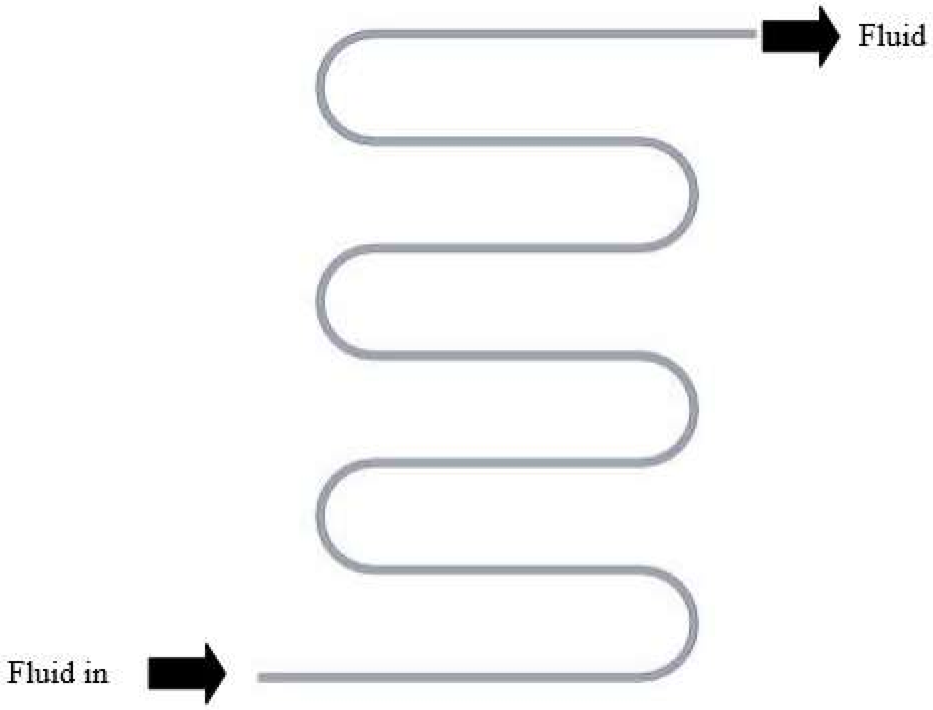


Figure 3.7.1b: Serpentine Flow Configuration

3.7.2 Glazing Material

The purpose of a glazing material is to transmit the shorter wavelength solar radiation and block the longer wavelength reradiating from the absorber plate and reduce the heat loss by convection from the top of the absorber [P. Rushi Prasad, H.V Byregowda, P.B Gangavati, 2010]. Glazing also acts as the cover on the top of the collector casing.

Glass is the most common glazing material because of the low transmittance of the longer wavelength. Glass has the highly desirable property of transmitting as much as 90% of the incoming short-wave radiations while virtually none of the long-wave radiation emitted by the heat absorber plate can escaped outward [P. Rushi Prasad, H.V Byregowda, P.B Gangavati, 2010]. The commercially available window glass will have normal incidence transmittance of about 0.87 to 0.90.

Material	Transmittance (τ)
Crystal glass	0.91
Window glass	0.85
Acrylate, Plexiglass	0.84
Polycarbonate	0.84
Polyester	0.84
Polyamide	0.80

Table 3.7.2: Transmittance of Various Glazing Materials [11]

Crystal clear glass and window glass have highest transmittance of solar radiation. The ability of the glass makes it suitable as heat trap in the collector. Thus, window glass is suitable because it is widely used in local flat plate collector.

3.7.3 Thermal Conductivity of Absorber Plate and Tube Material

The primary function of the heat absorber plate is to absorbed as much as possible of the radiation reaching through the glazing at the same time to lose as little as possible radiation reflecting upward to the atmosphere and downward through the back of the container later transfer the retained heat to the circulating working fluids

In FPC, the heat absorber is usually made of copper, aluminum or steel. In this project, aluminum and copper is used for investigation because both of the material have high thermal conductivity.

Factors that determine the material selection is its thermal conductivity, its durability, easy handling, cost and availability.

Material	Thermal conductivity(k), W/m·°C
Silver	429
Copper	401
Gold	317
Aluminum	237
Iron	80.2

Table 3.7.3a: Thermal Conductivity of Various Materials [12]

Heat absorber plate usually given a surface coating, mainly black, that increases the fraction of available solar radiation absorbed by the plate. Table gives value of absorbance of several colors for plate coating. Flat black color has high absorbance value compare to other color which make it suitable for heat absorber plate coating. The absorbance (α) for black paint ranges from 0.92 to 0.98. The black paint is applied by spraying on the plate. Some are heat treated to evaporate solvents and improve adherence. These surfaces must be able withstand repeated and prolonged exposure to the relatively high temperature.

Material color	Absorbance (α)
White	0.07
Fresh snow	0.13
White enamel	0.35
Green paint	0.50
Red brick	0.55
Grey paint	0.75
Black tar	0.93
Flat black	0.98
Granite	0.55

Table 3.7.3b: Absorbance Value for Several Commonly Used Colors [11]

Chapter: 4

Experimental Work

4.1 Experimental Data

Solar beam insolation, angle of declination varies for each day. We have taken different observation values through-out the month of October, November and December. As described in the theoretical background we have calculated the Solar Beam Insolation by equation no (xiv)

$$I_{bn}=S_C\{1+.033\cos\left(\frac{360n}{365}\right)$$

And by equation (xv)

$$I_n= I_{bn}.\cos\theta$$

Angle of declination derived from the equation (xvii)

$$\delta = 23.45\sin\{\frac{360}{365}(284+n)\}$$

Data's are illustrated in tabular form for each month.

For the month of October:

Date	No of day from 1st January, n	Solar beam insolation, I_{bn}	Angle of declination, δ
2	276	1374.75	-3.82
9	283	1380.18	-7.72
13	287	1383.25	-9.23
16	290	1385.51	-10.33
17	291	1386.26	-10.69
20	294	1388.48	-11.75
21	295	1389.21	-12.10
25	299	1392.08	-13.46

Date: 02/10/2016

Time	Hour angle, ω	$\cos\theta$ θ= Angle of declination	Solar insolation normal to the surface, I_n
1100	-15	0.85	1368.54
1120	-10	0.87	1196.03
1140	-5	0.88	1209.78
1200	00	0.88	1209.78
1220	05	0.88	1209.78
1240	10	0.87	1196.03
1400	30	0.76	1044.81
1420	35	0.72	989.82
1440	40	0.67	921.08
1500	45	0.62	852.35
1520	50	0.56	769.86
1540	55	0.50	687.38

Date: 09/10/2016

Time	Hour angle, ω	$\cos\theta$ θ= Angle of declination	Solar insolation normal to the surface, I_n
1100	-15	0.82	1131.75
1120	-10	0.84	1159.35
1140	-5	0.85	1173.15
1200	00	0.85	1173.15
1220	05	0.85	1173.15
1240	10	0.84	1159.35
1400	30	0.73	1007.53
1420	35	0.69	952.32
1440	40	0.64	883.32
1500	45	0.59	814.31
1520	50	0.53	731.5
1540	55	0.46	634.88

Date: 13/10/2016

Time	Hour angle, ω	$\cos\theta$ θ= Angle of declination	Solar insolation normal to the surface, I_n
1100	-15	0.81	1120.43
1120	-10	0.82	1134.27

1140	-5	0.83	1148.1
1200	00	0.84	1161.93
1220	05	0.83	1148.1
1240	10	0.82	1134.27
1400	30	0.72	995.94
1420	35	0.67	926.78
1440	40	0.63	871.45
1500	45	0.57	788.45
1520	50	0.51	705.46
1540	55	0.45	622.46

Date: 16/10/2016

Time	**Hour angle, ω**	**$\cos\theta$ θ= Angle of declination**	**Solar insolation normal to the surface, I_n**
1100	-15	0.80	1108.41
1120	-10	0.81	1122.26
1140	-5	0.82	1136.12
1200	00	0.83	1149.97
1220	05	0.82	1136.12
1240	10	0.81	1122.26
1400	30	0.71	983.71
1420	35	0.66	914.44
1440	40	0.62	859.02
1500	45	0.56	775.89
1520	50	0.50	692.76
1540	55	0.44	609.62

Date: 17/10/2016

Time	**Hour angle, ω**	**$\cos\theta$ θ= Angle of declination**	**Solar insolation normal to the surface, I_n**
1100	-15	0.79	1095.15
1120	-10	0.81	1122.87
1140	-5	0.82	1136.73
1200	00	0.82	1136.79
1220	05	0.82	1136.73
1240	10	0.81	1122.87
1400	30	0.85	1178.32
1420	35	0.81	1122.87

1440	40	0 .76	1053.56
1500	45	0.71	984.24
1520	50	0.65	901.07
1540	55	0.59	817.89

Date: 20/10/2016

Time	**Hour angle, ω**	**$\cos\theta$ θ= Angle of declination**	**Solar insolation normal to the surface, I_n**
1100	-15	0.78	1083.01
1120	-10	0.80	1110.78
1140	-5	0.81	1124.67
1200	00	0.81	1124.67
1220	05	0.81	1124.67
1240	10	0.80	1110.78
1400	30	0.86	1194.09
1420	35	0.82	1138.55
1440	40	0.77	1069.13
1500	45	0.72	999.71
1520	50	0.67	930.28
1540	55	0.60	833.09

Date: 21/10/2016

Time	**Hour angle, ω**	**$\cos\theta$ θ= Angle of declination**	**Solar insolation normal to the surface, I_n**
1100	-15	0.78	1083.58
1120	-10	0.79	1097.84
1140	-5	0.80	1111.37
1200	00	0.81	1125.26
1220	05	0.80	1111.37
1240	10	0.79	1097.84
1400	30	0.69	958.55
1420	35	0.65	902.99
1440	40	0.60	833.53
1500	45	0.55	764.07
1520	50	0.49	680.71
1540	55	0.43	597.36

Date: 25/10/2016

Time	Hour angle, ω	$\cos\theta$ θ= Angle of declination	Solar insolation normal to the surface, I_n
1100	-15	0.76	1057.98
1120	-10	0.78	1085.82
1140	-5	0.79	1099.74
1200	00	0.79	1099.74
1220	05	0.79	1099.74
1240	10	0.78	1085.82
1400	30	0.67	932.69
1420	35	0.63	877.01
1440	40	0.59	821.33
1500	45	0.53	737.80
1520	50	0.48	668.2
1540	55	0.42	584.67

For the month of November:

Date	No of day from 1st January, n	Solar beam insolation, I_{bn}	Angle of declination, δ
2	307	1397.54	-15.96
3	308	1398.19	-16.26
7	312	1400.72	-17.38
9	314	1401.94	-17.91
13	318	1404.27	-18.91
14	319	1404.83	-19.14
15	320	1405.38	-19.38
16	321	1405.92	-19.60
17	322	1406.45	-19.82

Date: 02/11/2016

Time	Hour angle, ω	$\cos\theta$ θ= Angle of declination	Solar insolation normal to the surface, I_n
1100	-15	0.74	1034.18
1120	-10	0.75	1048.16

1140	-5	0.76	1062.13
1200	00	0.76	1062.13
1220	05	0.76	1062.13
1240	10	0.75	1048.16
1400	30	0.65	908.4
1420	35	0.61	852.5
1440	40	0.56	782.62
1500	45	0.51	712.75
1520	50	0.45	628.89
1540	55	0.39	545.04

Date: 03/11/2016

Time	**Hour angle, ω**	**$\cos\theta$ θ= Angle of declination**	**Solar insolation normal to the surface, I_n**
1100	-15	0.73	1020.68
1120	-10	0.75	1048.64
1140	-5	0.76	1062.62
1200	00	0.76	1062.62
1220	05	0.76	1062.62
1240	10	0.75	1048.64
1400	30	0.65	908.82
1420	35	0.61	852.9
1440	40	0.56	782.99
1500	45	0.51	713.08
1520	50	0.45	629.19
1540	55	0.39	545.29

Date: 07/11/2016

Time	**Hour angle, ω**	**$\cos\theta$ θ= Angle of declination**	**Solar insolation normal to the surface, I_n**
1100	-15	0.72	1008.52
1120	-10	0.74	1036.53
1140	-5	0.75	1050.54
1200	00	0.75	1050.54
1220	05	0.75	1050.54
1240	10	0.74	1036.53

1400	30	0.63	882.45
1420	35	0.59	826.42
1440	40	0.55	770.4
1500	45	0.49	686.35
1520	50	0.44	616.32
1540	55	0.38	532.27

Date: 10/11/2016

Time	**Hour angle, ω**	$\cos\theta$ **θ= Angle of declination**	**Solar insolation normal to the surface, I_n**
1100	-15	0.71	995.38
1120	-10	0.73	1023.42
1140	-5	0.74	1037.44
1200	00	0.74	1037.44
1220	05	0.74	1037.44
1240	10	0.73	1023.42
1400	30	0.62	869.20
1420	35	0.58	813.13
1440	40	0.54	757.05
1500	45	0.48	672.93
1520	50	0.43	602.83
1540	55	0.37	518.72

Date: 13/11/2016

Time	**Hour angle, ω**	$\cos\theta$ **θ= Angle of declination**	**Solar insolation normal to the surface, I_n**
1100	-15	0.70	982.99
1120	-10	0.72	1011.07
1140	-5	0.73	1025.12
1200	00	0.73	1025.12
1220	05	0.73	1025.12
1240	10	0.72	1011.07
1400	30	0.62	870.65
1420	35	0.58	814.48
1440	40	0.53	744.26
1500	45	0.48	674.05
1520	50	0.42	589.8
1540	55	0.36	505.54

Date: 14/11/2016

Time	Hour angle, ω	$\cos\theta$ θ= Angle of declination	Solar insolation normal to the surface, I_n
1100	-15	0.70	983.38
1120	-10	0.72	1011.48
1140	-5	0.73	1025.53
1200	00	0.73	1025.53
1220	05	0.73	1025.53
1240	10	0.72	1011.48
1400	30	0.61	856.95
1420	35	0.57	800.75
1440	40	0.53	744.56
1500	45	0.48	674.32
1520	50	0.42	590.03
1540	55	0.36	505.74

Date: 15/11/2016

Time	Hour angle, ω	$\cos\theta$ θ= Angle of declination	Solar insolation normal to the surface, I_n
1100	-15	0.70	983.77
1120	-10	0.71	997.82
1140	-5	0.72	1011.87
1200	00	0.73	1025.93
1220	05	0.72	1011.87
1240	10	0.71	997.82
1400	30	0.61	587.28
1420	35	0.57	801.07
1440	40	0.53	744.85
1500	45	0.47	660.53
1520	50	0.42	590.26
1540	55	0.36	505.94

Date: 16/11/2016

Time	Hour angle, ω	$\cos\theta$ θ= Angle of declination	Solar insolation normal to the surface, I_n
1100	-15	0.69	970.08
1120	-10	0.71	998.2
1140	-5	0.72	1012.26
1200	00	0.72	1012.26
1220	05	0.72	1012.26
1240	10	0.71	998.2
1400	30	0.61	857.61
1420	35	0.57	801.37
1440	40	0.52	731.08
1500	45	0.47	660.78
1520	50	0.42	590.49
1540	55	0.36	506.13

Date: 17/11/2016

Time	Hour angle, ω	$\cos\theta$ θ= Angle of declination	Solar insolation normal to the surface, I_n
1100	-15	0.69	970.45
1120	-10	0.71	998.58
1140	-5	0.72	1012.64
1200	00	0.72	1012.65
1220	05	0.72	1012.64
1240	10	0.71	998.58
1400	30	0.61	857.93
1420	35	0.57	801.68
1440	40	0.52	731.35
1500	45	0.47	661.03
1520	50	0.42	590.71
1540	55	0.36	506.32

For the month of December:

Date	No of day from 1st January, n	Solar beam insolation, I_{bn}	Angle of declination, δ
17	352	1417.18	-23.42
19	354	1417.5	-23.45
20	355	1417.64	-23.45
21	356	1417.77	-23.44

Date: 17/12/2016

Time	Hour angle, ω	$\cos\theta$ θ= Angle of declination	Solar insolation normal to the surface, I_n
1100	-15	0.65	921.17
1120	-10	0.66	935.34
1140	-5	0.67	949.51
1200	00	0.68	969.68
1220	05	0.67	949.51
1240	10	0.66	935.34
1400	30	0.56	793.62
1420	35	0.53	751.11
1440	40	0.48	680.25
1500	45	0.43	609.39
1520	50	0.38	538.53
1540	55	0.32	453.5

Date: 19/12/2016

Time	Hour angle, ω	$\cos\theta$ θ= Angle of declination	Solar insolation normal to the surface, I_n
1100	-15	0.65	921.38
1120	-10	0.66	935.55
1140	-5	0.67	949.73
1200	00	0.68	963.9
1220	05	0.67	949.73
1240	10	0.66	935.55
1400	30	0.56	793.8
1420	35	0.52	737.1
1440	40	0.48	680.4

Time	Hour angle, ω	$\cos\theta$ θ= Angle of declination	Solar insolation normal to the surface, I_n
1500	45	0.43	609.53
1520	50	0.38	538.65
1540	55	0.31	439.43

Date: 20/12/2016

Time	Hour angle, ω	$\cos\theta$ θ= Angle of declination	Solar insolation normal to the surface, I_n
1100	-15	0.65	921.47
1120	-10	0.66	935.64
1140	-5	0.67	949.82
1200	00	0.68	964
1220	05	0.67	949.82
1240	10	0.66	935.64
1400	30	0.56	739.88
1420	35	0.52	737.17
1440	40	0.48	680.47
1500	45	0.43	609.59
1520	50	0.38	538.70
1540	55	0.31	439.46

Date: 21/12/2016

Time	Hour angle, ω	$\cos\theta$ θ= Angle of declination	Solar insolation normal to the surface, I_n
1100	-15	0.65	921.55
1120	-10	0.66	935.73
1140	-5	0.67	949.91
1200	00	0.68	964.08
1220	05	0.67	949.91
1240	10	0.66	935.43
1400	30	0.56	739.95
1420	35	0.52	737.24
1440	40	0.48	680.53
1500	45	0.43	609.64
1520	50	0.38	538.75
1540	55	0.31	439.51

4.1.1 Model Calculation

Using all the theories as described in **Theoretical Background** section we have illustrated a model calculation by which all the data tables have been formatted. We have used this same model procedure to derive the efficiency and temperature calculation.

Some model assumptions used here are,

1. Heat loss from the sides are neglected as surface volume is negligible
2. Uniform heating is considered
3. One dimensional heat transfer
4. Steady state system
5. Water stored for "Ten Minutes" durational time

For 02/10/2016

Observation no: 06

Time of observation: 1240

Time variation: 10 minutes

Water inlet,$\theta_1 = 32\ ℃$

Water outlet,$\theta_2 = 64\ ℃$

$\Delta\theta = \theta_2 - \theta_1 = 64 - 32 = 32\ ℃$

Solar beam radiation

$$I_{bn}=S_C\{1+.033\cos(\frac{360n}{365})\}$$

Solar constant S_C=1373 w/m^2

No of day from 1st January, n=276

∴ I_{bn}=1374.75 w/m^2

Angle of incidence (θ)

$$\cos\theta = \sin\varphi(\sin\delta\cos\beta + \sin\beta\cos\delta\cos\omega) + \cos\varphi(\cos\delta\cos\beta\ \cos\omega - \sin\delta\ \sin\beta) + \cos\delta\ \sin\beta\sin\omega)$$

Latitude angle for Dhaka, Bangladesh, φ =24° north

Tilt angle, $\beta = 0°$

Hour angle for 1240, $\omega = 10°$

Angle of declination,

$$\delta = 23.45 \sin\{\frac{360}{365} \times (284 + \mathrm{n})\}$$

$$\therefore \ \delta = -3.82°$$

From the equation of incidence angle,

$$\therefore \cos\theta = .87$$

Solar insolation normal to the surface,

$$I_n = I_{bn} \cos\theta$$

$$\therefore I_n = 1196.03 \text{ w/m}^2$$

Total incident solar energy on the surface,

$$Q_{\text{surface}} = I_n \times A_C \times \text{time of operation}$$

A_C=area of the collector= 1.15 m^2

Time of operation = 10 minutes = 600 seconds

$\therefore$ Q_{surface}=825260.7 j

Energy gain by water:

$$Q_{\text{water}} = ms\Delta\theta$$

S= specific heat of water = 4200 j/kg. ℃

Mass of water, m= volume (V) × density (ρ)

Volume of the tube,

$$V = \frac{\pi}{4} \times D^2 \times L$$

Here

Diameter of the pipe D= 1 inch=.03m

Length of the pipe L= 16 foot= 4.88m

$\therefore$ $V = 3 \times 10^{-3}$ m^3

Density of water, ρ=1000 kg/m^3

∴ Mass of water, m = 3kg (approximately)

∴ Q_{water}= 403200 j

Efficiency of the collector,

$$\eta = \frac{Q_{water}}{Q_{surface}} \times 100\%$$

$$\therefore \eta = 48.86\%$$

4.1.2 Observed Data

By applying the theoretical implications on the experimented data's, we have observed and calculated various values of efficiency. We have separated the observations month-wise for the month of October, November and December. Sufficient data were taken and individually experimented to derive temperature difference of inlet and outlet. Efficiency for each of the observation is showed in form of data table and represented in form of graph as per same for better understanding.

Date: 02/10/16

Day: Sunday

Day temperature: 30°c

Time Range: 1100 to 1300 hours

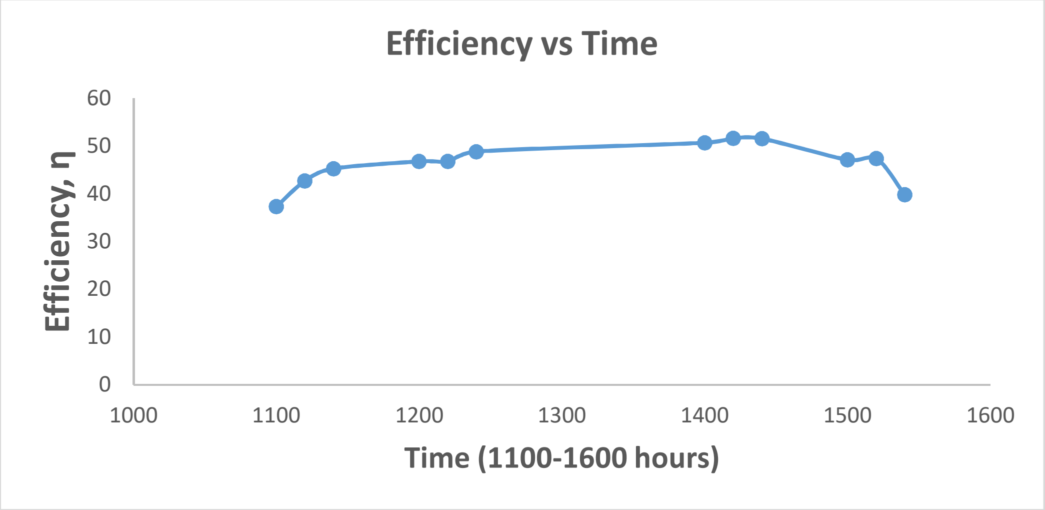
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1100	29	57	28	37.36
2	1120	30	58	28	42.75
3	1140	30	60	30	45.28
4	1200	31	62	31	46.79
5	1220	31	62	31	46.79
6	1240	32	64	32	48.86

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1400	32	61	29	50.69
2	1420	32	60	28	51.66
3	1440	31	57	26	51.55
4	1500	30	52	22	47.13
5	1520	29	49	20	47.44
6	1540	29	44	15	39.85



Date: 09/10/16

Day: Sunday

Day temperature: 30°c

Time Range: 1100 to 1300 hours

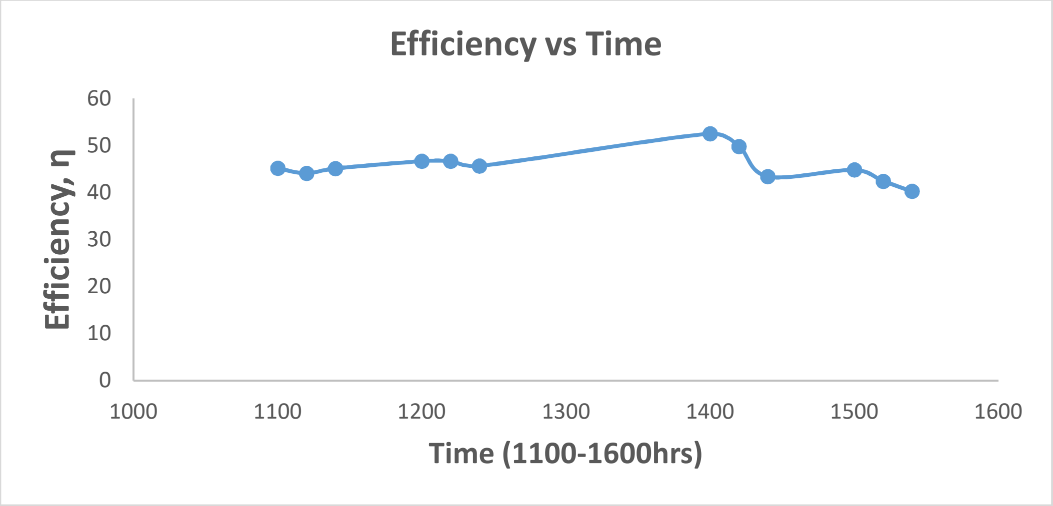
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1100	29	57	28	45.18
2	1120	30	58	28	44.10
3	1140	31	60	29	45.14
4	1200	31	61	30	46.7
5	1220	32	62	30	46.7
6	1240	33	62	29	45.68

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1400	32	61	29	52.56
2	1420	34	60	26	49.86
3	1440	34	55	21	43.41
4	1500	33	53	20	44.85
5	1520	31	48	17	42.44
6	1540	30	46	16	40.27



Date: 13/10/16

Day: Saturday

Day temperature: 32°c

Time Range: 1100 to 1300 hours

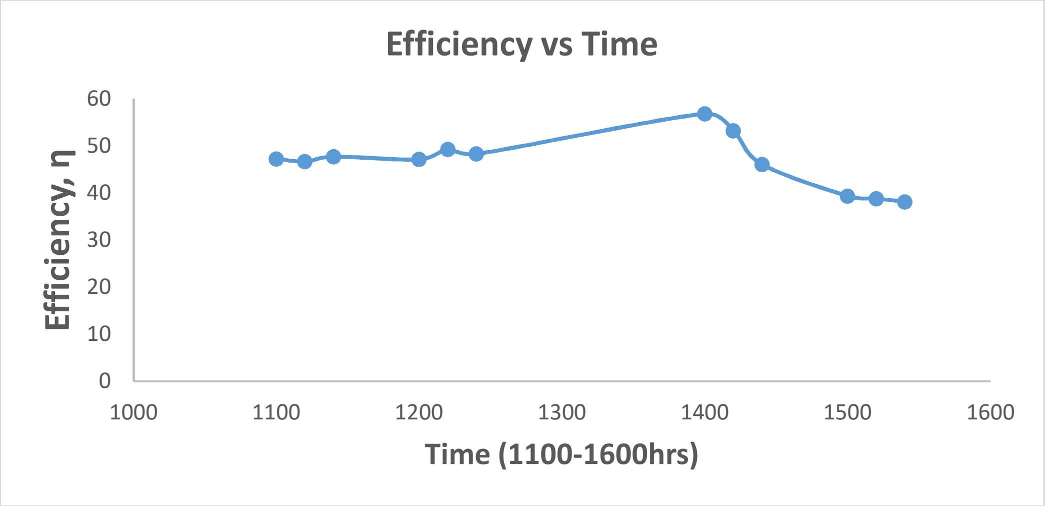
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1100	31	60	29	47.26
2	1120	31	60	29	46.69
3	1140	32	62	30	47.72
4	1200	31	61	30	47.15
5	1220	33	64	31	49.31
6	1240	33	63	30	48.3

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1400	34	65	31	56.84
2	1420	35	52	27	53.2
3	1440	36	58	22	46.1
4	1500	35	52	17	39.37
5	1520	33	48	15	38.83
6	1540	32	45	13	38.14



Date: 16/10/16

Day: Sunday

Day temperature: 33°c

Time Range: 1100 to 1300 hours

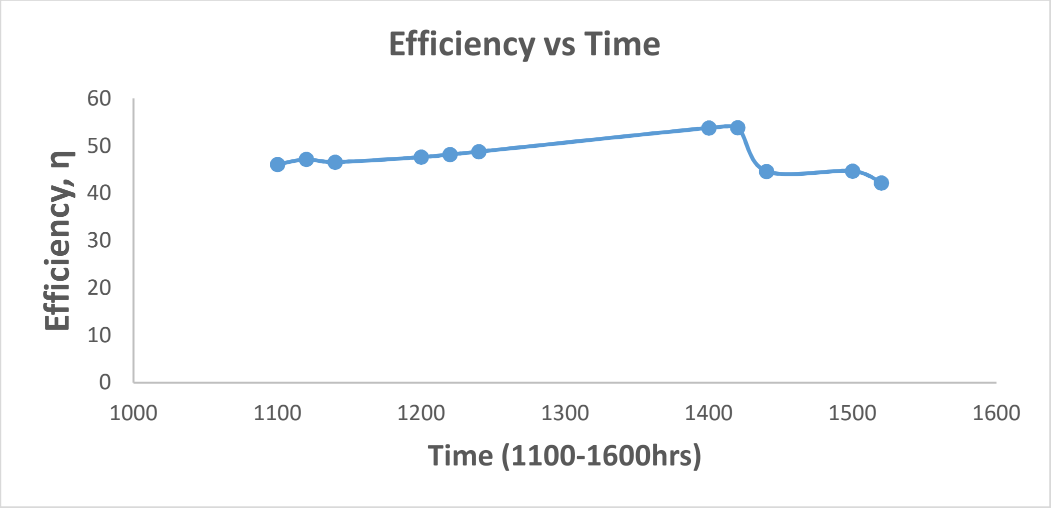
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1100	31	59	28	46.13
2	1120	32	61	29	47.19
3	1140	33	62	29	46.61
4	1200	34	64	30	47.64
5	1220	34	64	30	48.22
6	1240	35	65	30	48.81

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1400	35	64	29	53.83
2	1420	37	64	27	53.91
3	1440	36	57	21	44.64
4	1500	35	54	19	44.71
5	1520	33	49	16	42.18
6	1540	32	44	12	35.95



Date: 17/10/16

Day: Monday

Day temperature: 34ºc

Time Range: 1100 to 1300 hours

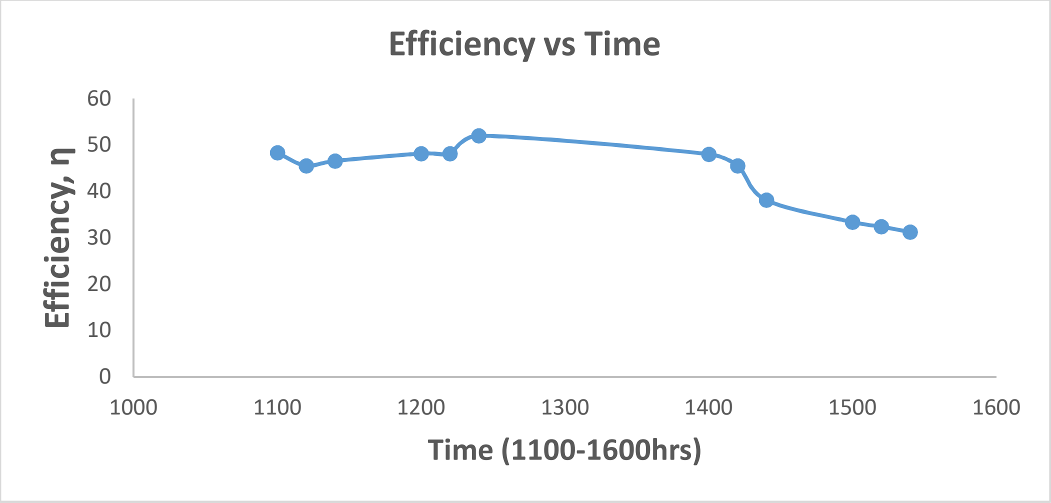
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C), θ_1	Water outlet (°C), θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1100	32	61	29	48.36
2	1120	33	61	28	45.54
3	1140	33	62	29	46.59
4	1200	34	64	30	48.19
5	1220	35	65	30	48.19
6	1240	34	66	32	52.04

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C), θ_1	Water outlet (°C), θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1400	36	67	31	48.04
2	1420	35	66	28	45.54
3	1440	36	58	22	38.13
4	1500	36	54	18	33.4
5	1520	35	51	16	32.43
6	1540	32	46	14	31.26



Date: 20/10/16

Day: Thursday

Day temperature: 36°c

Time Range: 1100 to 1300 hours

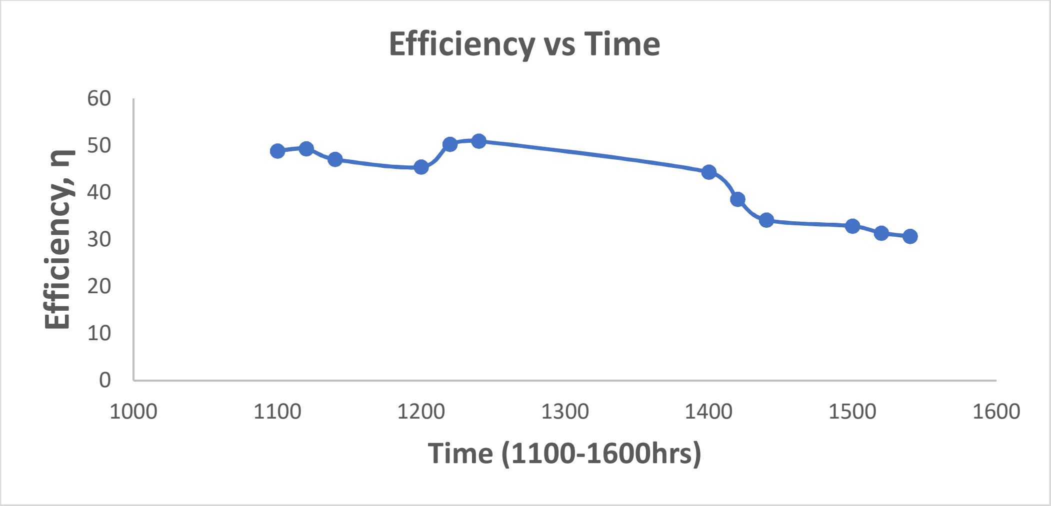
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1100	34	63	29	48.9
2	1120	34	64	30	49.32
3	1140	35	64	29	47.09
4	1200	35	63	28	45.46
5	1220	36	67	31	50.33
6	1240	34	65	31	50.96

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1400	36	65	29	44.35
2	1420	38	62	24	38.59
3	1440	39	59	20	34.16
4	1500	38	56	18	32.88
5	1520	36	52	16	31.41
6	1540	35	49	14	30.69



Date: 21/10/16

Day: Friday

Day temperature: 34°c

Time Range: 1100 to 1300 hours

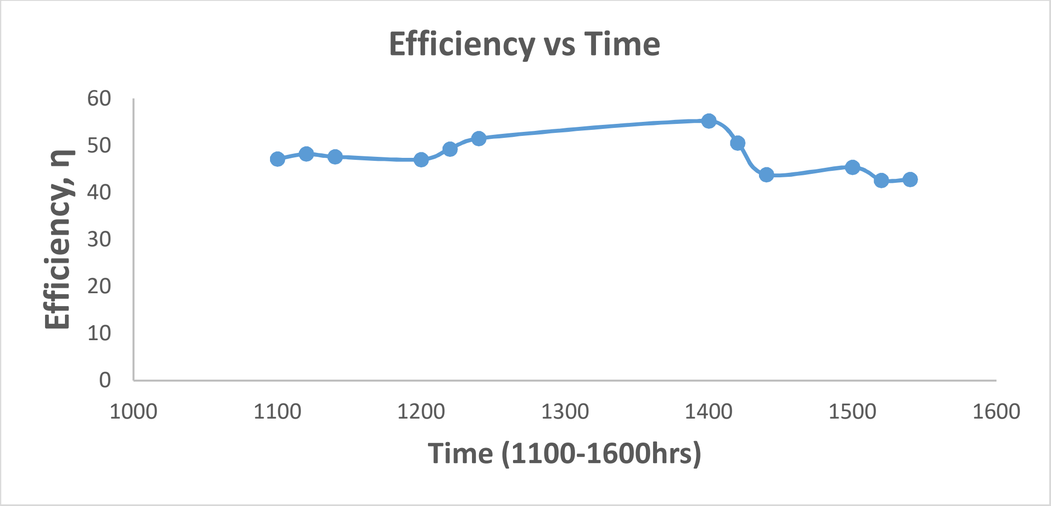
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1100	33	61	28	47.19
2	1120	34	63	29	48.24
3	1140	34	63	29	47.65
4	1200	35	64	29	47.06
5	1220	35	65	30	49.29
6	1240	35	66	31	51.56

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1400	37	66	29	55.25
2	1420	38	63	25	50.56
3	1440	37	57	20	43.82
4	1500	36	55	19	45.41
5	1520	34	50	16	42.62
6	1540	33	47	14	42.8



Date: 25/10/16

Day: Tuesday

Time Range: 1100 to 1300 hours

Day temperature: 33°c

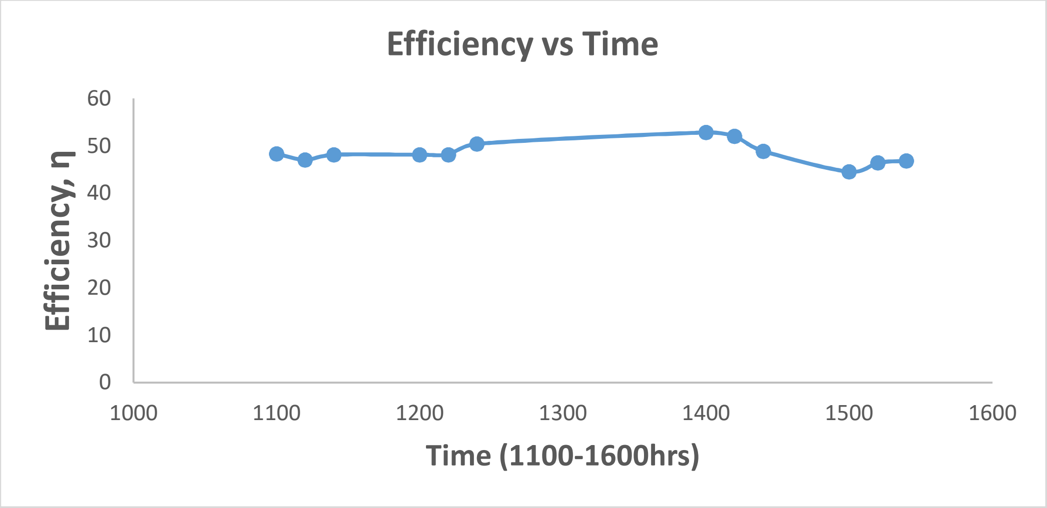
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1100	32	60	28	48.33
2	1120	32	60	28	47.09
3	1140	33	62	29	48.15
4	1200	33	62	29	48.15
5	1220	34	63	29	48.15
6	1240	34	64	30	50.45

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1400	35	62	27	52.86
2	1420	36	61	25	52.05
3	1440	36	58	22	48.91
4	1500	34	52	18	44.55
5	1520	33	50	17	46.45
6	1540	33	48	15	46.85



Date: 02/11/16

Day: Wednesday

Day temperature: 30^{o}c

Time Range: 1100 to 1300 hours

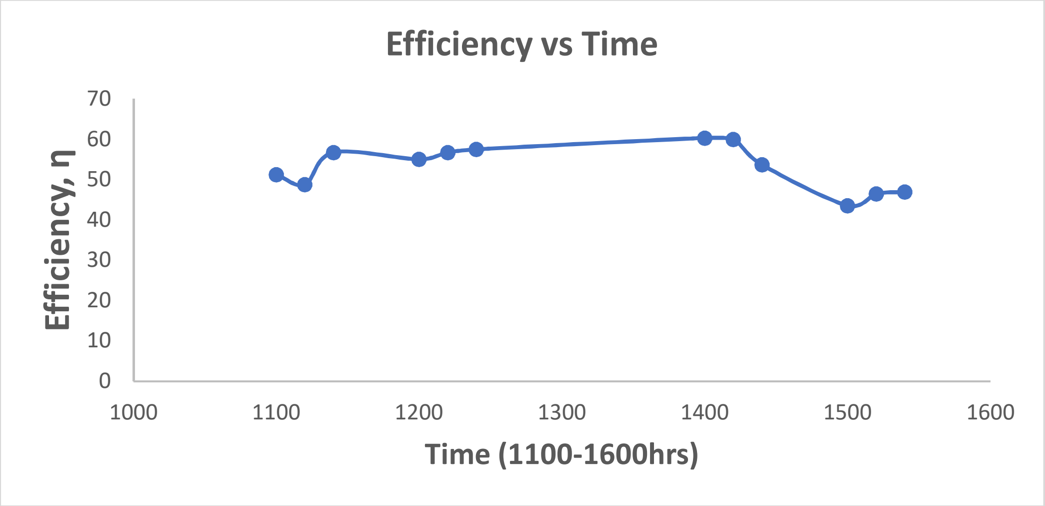
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1100	26	55	29	51.21
2	1120	26	54	28	48.78
3	1140	28	61	33	56.74
4	1200	27	59	32	55.02
5	1220	27	60	33	56.74
6	1240	27	60	33	57.49

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1100	31	61	30	60.31
2	1120	29	57	28	59.98
3	1140	28	51	23	53.67
4	1200	26	43	17	43.55
5	1220	26	42	16	46.46
6	1240	25	39	14	46.91



Date: 03/11/16

Day: Thursday

Day temperature: 32°c

Time Range: 1100 to 1300 hours

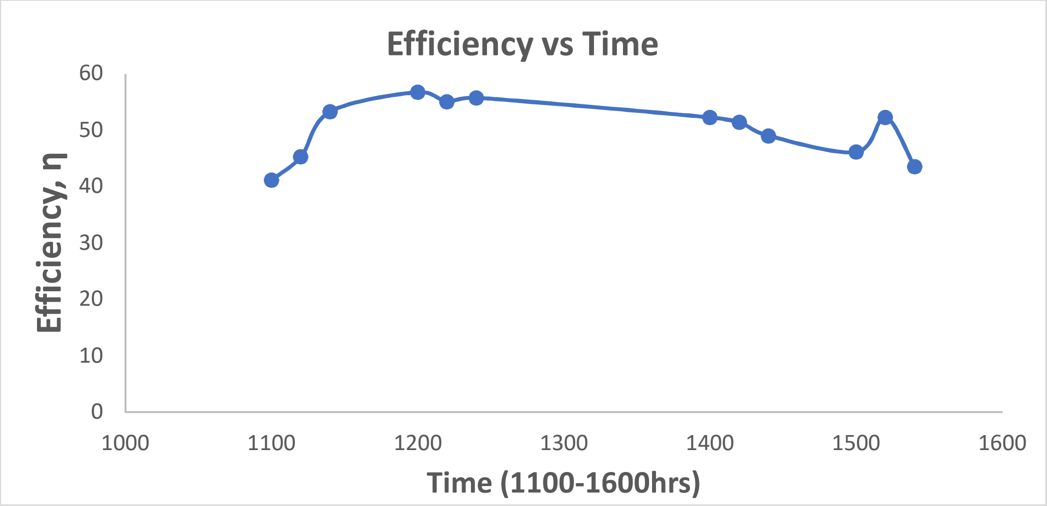
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1100	28	51	23	41.15
2	1120	29	55	26	45.28
3	1140	29	60	31	53.27
4	1200	28	61	33	56.71
5	1220	28	60	32	55
6	1240	26	59	32	55.72

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1400	32	58	26	52.24
2	1420	30	54	24	51.39
3	1440	29	50	21	48.98
4	1500	28	46	18	46.1
5	1520	27	45	18	52.24
6	1540	27	40	13	43.53



Date: 07/11/16

Day: Monday

Day temperature: 26°c

Time Range: 1100 to 1300 hours

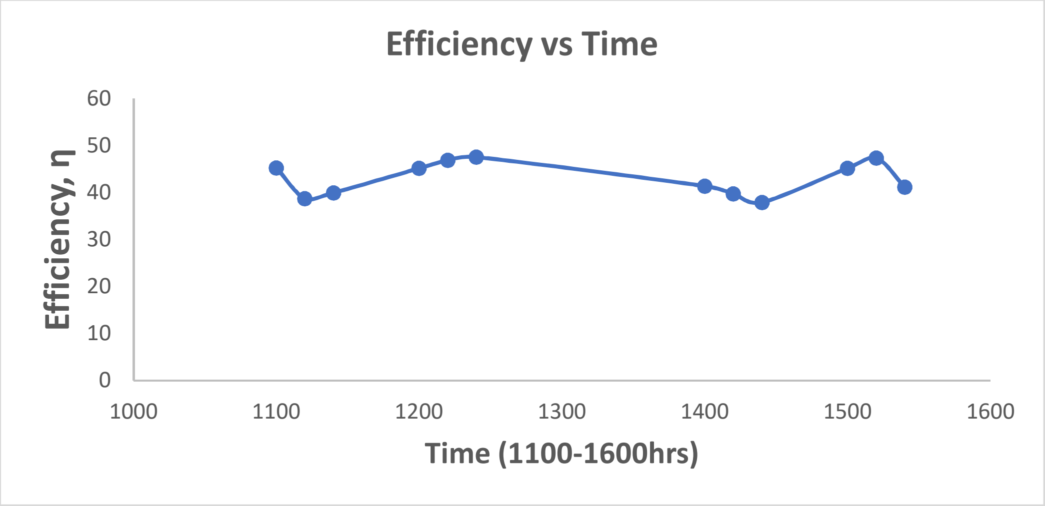
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1100	26	51	25	45.27
2	1120	25	47	22	38.76
3	1140	27	50	23	39.98
4	1200	26	52	26	45.19
5	1220	26	53	27	46.93
6	1240	27	54	27	47.57

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1400	30	50	20	41.39
2	1420	30	48	18	39.77
3	1440	27	43	16	37.93
4	1500	26	43	17	45.23
5	1520	26	42	16	47.41
6	1540	25	40	12	41.17



Date: 10/11/16

Day: Thursday

Day temperature: 30^{o}c

Time Range: 1100 to 1300 hours

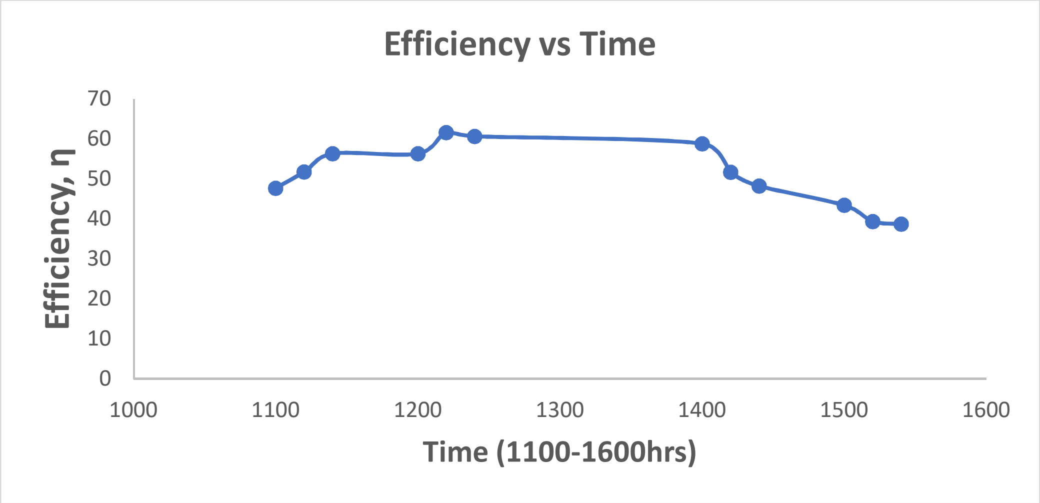
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1100	27	53	26	47.67
2	1120	26	55	29	51.72
3	1140	27	59	32	56.30
4	1200	27	59	32	56.30
5	1220	28	63	35	61.58
6	1240	27	63	34	60.64

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1400	33	61	28	58.78
2	1420	32	55	23	51.63
3	1440	30	47	20	48.22
4	1500	27	43	16	43.4
5	1520	27	40	13	39.36
6	1540	26	37	11	38.70



Date: 13/11/16

Day: Sunday

Day temperature: 29°c

Time Range: 1100 to 1300 hours

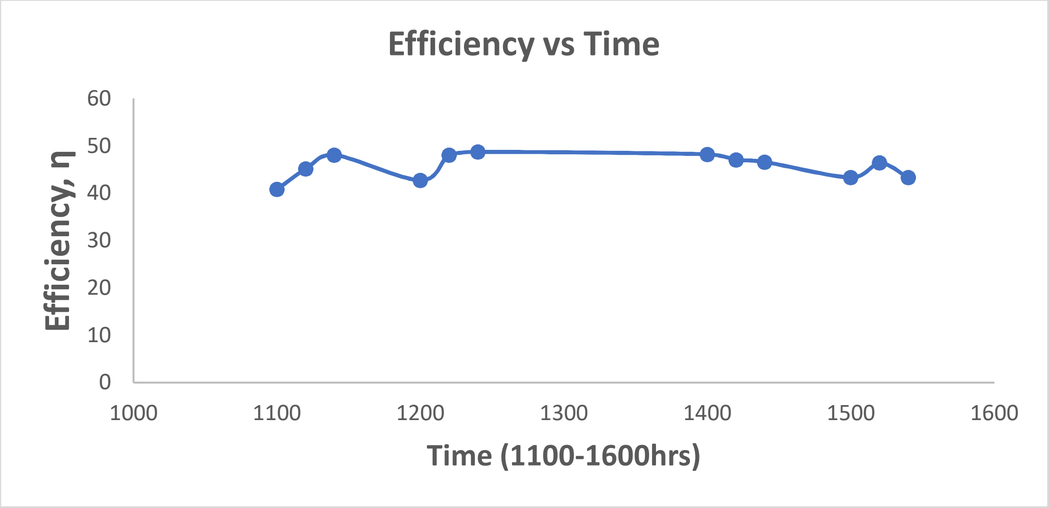
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1100	25	47	22	40.87
2	1120	24	49	25	45.15
3	1140	25	52	27	48.1
4	1200	26	50	24	42.75
5	1220	26	53	27	48.1
6	1240	26	53	27	48.76

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1400	30	53	23	48.24
2	1420	29	50	21	47.08
3	1440	28	47	19	46.62
4	1500	26	42	16	43.35
5	1520	25	40	15	46.44
6	1540	25	37	12	43.35



Date: 14/11/16

Day: Monday

Day temperature: 30^{o}c

Time Range: 1100 to 1300 hours

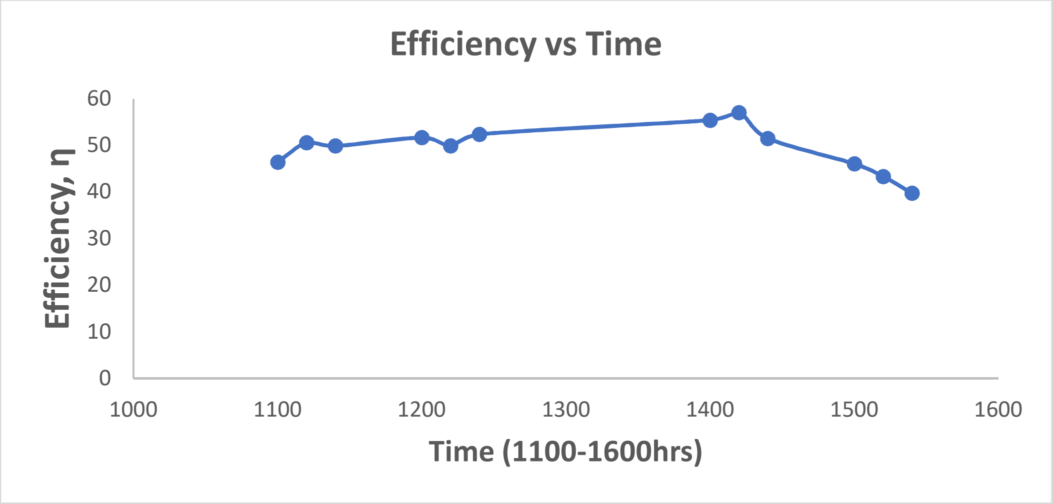
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1100	27	52	25	46.42
2	1120	26	54	28	50.55
3	1140	25	53	28	49.86
4	1200	25	54	29	51.64
5	1220	26	54	28	49.86
6	1240	25	54	29	52.36

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1400	32	58	26	55.40
2	1420	32	57	25	57.01
3	1440	27	48	21	51.50
4	1500	27	44	17	46.04
5	1520	25	39	14	43.33
6	1540	25	36	11	39.72



Date: 15/11/16

Day: Tuesday

Day temperature: 29^{o}c

Time Range: 1100 to 1300 hours

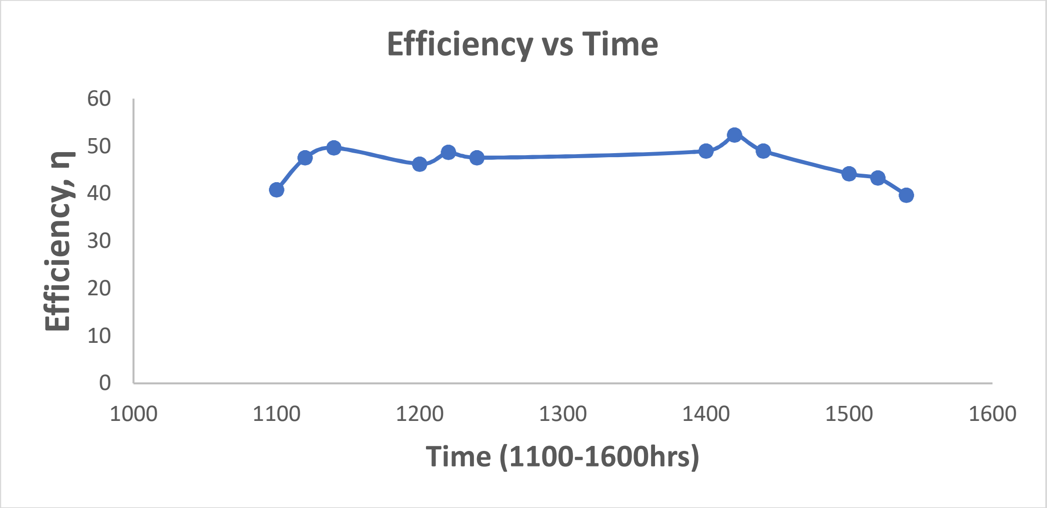
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1100	26	48	22	40.84
2	1120	25	51	26	47.58
3	1140	27	49	22	49.7
4	1200	26	52	26	46.28
5	1220	26	53	27	48.73
6	1240	27	53	26	47.58

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1400	31	54	23	49
2	1420	30	53	23	52.43
3	1440	25	45	20	49.03
4	1500	23	39	16	44.23
5	1520	23	37	14	43.31
6	1540	22	33	11	39.7



Date: 16/11/16

Day: Wednesday

Day temperature: 30°c

Time Range: 1100 to 1300 hours

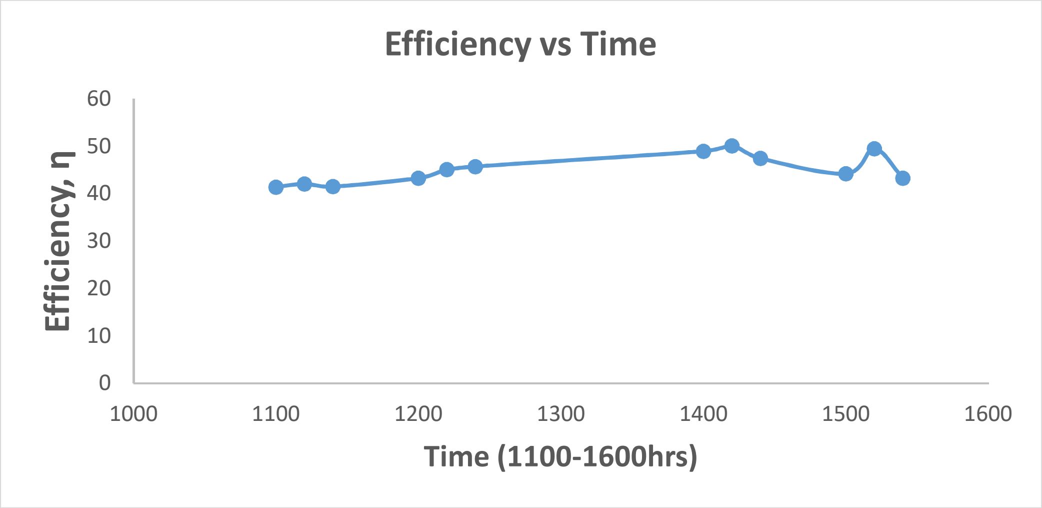
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1100	28	50	22	41.41
2	1120	28	51	23	42.08
3	1140	27	50	23	41.5
4	1200	27	51	24	43.3
5	1220	28	53	25	45.1
6	1240	27	52	25	45.73

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1400	30	53	23	48.97
2	1420	30	52	22	50.13
3	1440	24	43	19	47.46
4	1500	24	40	16	44.22
5	1520	22	38	16	49.48
6	1540	20	32	12	43.29



Date: 17/11/16

Day: Thursday

Day temperature: 30°c

Time Range: 1100 to 1300 hours

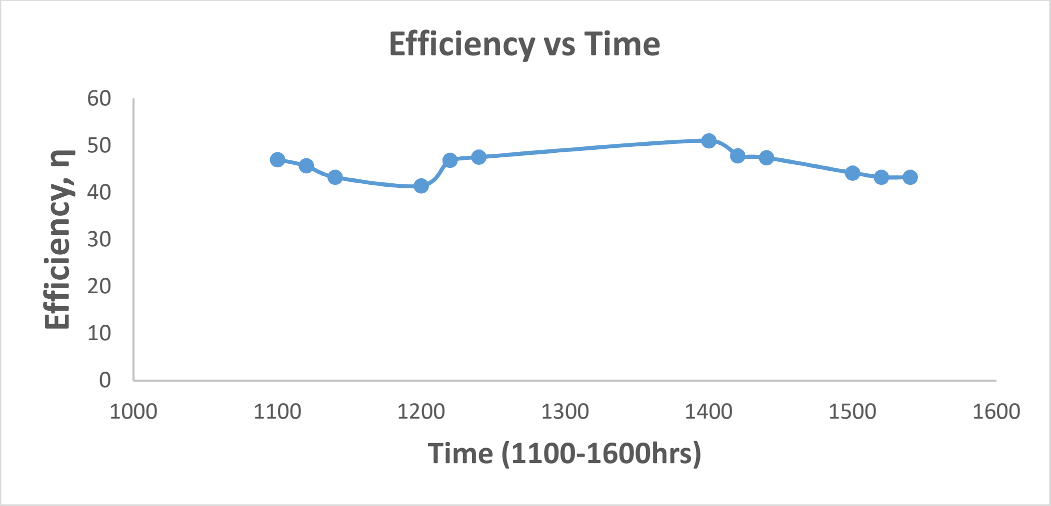
Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1100	28	53	25	47.04
2	1120	28	53	25	45.72
3	1140	26	50	24	43.28
4	1200	26	49	23	41.47
5	1220	27	53	26	46.89
6	1240	27	53	26	47.55

Time Range: 1400 to 1600 hours

Time variation: 10 minutes

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1)$	Efficiency η
1	1400	31	55	24	51.08
2	1420	30	51	21	47.83
3	1440	28	47	19	47.44
4	1500	25	41	16	44.2
5	1520	23	37	14	43.28
6	1540	23	35	12	43.27



Date: 17/12/16

Day: Saturday

Time Range: 11.00am to 1.00pm

Day temperature: 25^{o}c

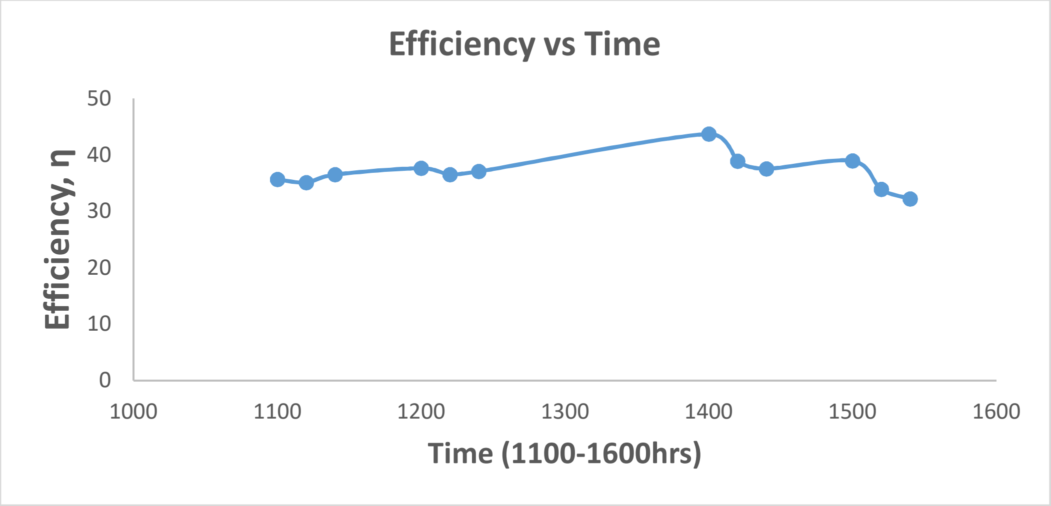
Time variation: 10 mins

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1100	23	41	18	35.68
2	1120	22	40	18	35.14
3	1140	22	41	19	36.54
4	1200	23	43	20	37.66
5	1220	23	42	19	36.54
6	1240	23	42	19	37.09

Time Range: 2.00pm to 4.00pm

Time variation: 10 mins

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1400	24	43	19	43.72
2	1420	24	40	16	38.9
3	1440	23	37	14	37.58
4	1500	22	35	13	38.96
5	1520	21	31	10	33.91
6	1540	21	29	8	32.21



Date: 19/12/16

Day: Monday

Time Range: 11.00am to 1.00pm

Day temperature: 25^{o}c

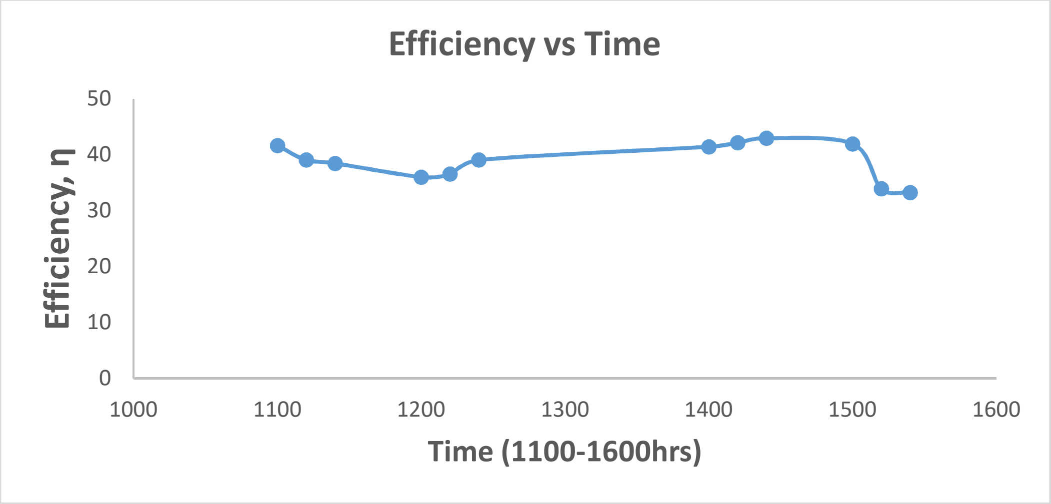
Time variation: 10 mins

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1100	23	44	21	41.62
2	1120	22	42	20	39.04
3	1140	22	42	20	38.45
4	1200	21	40	19	36
5	1220	22	41	19	36.53
6	1240	22	42	20	39.04

Time Range: 2.00pm to 4.00pm

Time variation: 10 mins

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1400	23	41	18	41.41
2	1420	23	40	17	42.12
3	1440	21	37	16	42.94
4	1500	20	34	14	41.94
5	1520	19	29	10	33.9
6	1540	19	27	8	33.24



Date: 20/12/16

Day: Tuesday

Time Range: 11.00am to 1.00pm

Day temperature: 25°c

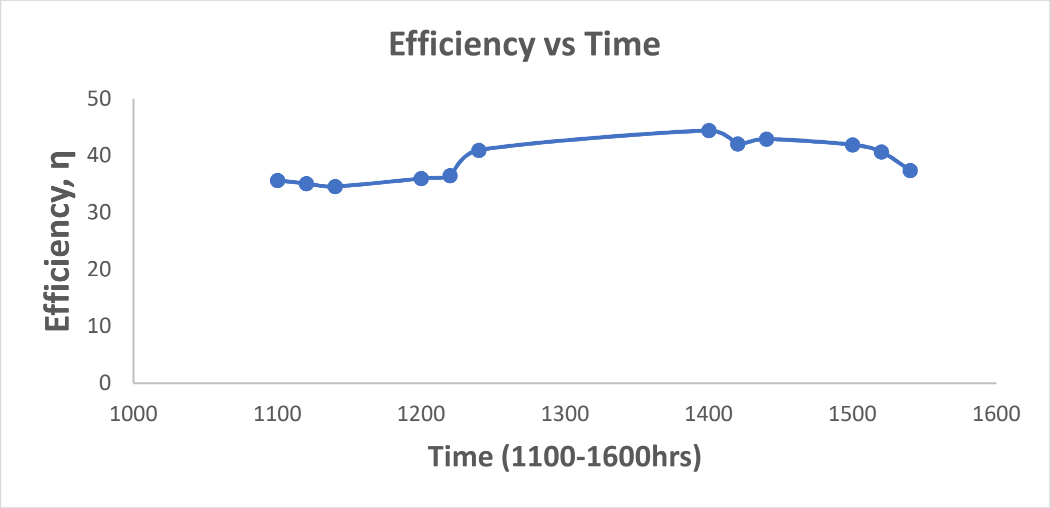
Time variation: 10 mins

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1100	21	39	18	35.67
2	1120	22	40	18	35.13
3	1140	22	40	18	34.61
4	1200	23	42	19	36
5	1220	23	42	19	36.53
6	1240	23	44	21	40.99

Time Range: 2.00pm to 4.00pm

Time variation: 10 mins

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1400	23	41	18	44.43
2	1420	23	40	17	42.11
3	1440	21	37	16	42.94
4	1500	21	35	14	41.94
5	1520	20	32	12	40.68
6	1540	20	29	9	37.4



Date: 21/12/16

Day: Wednesday

Time Range: 11.00am to 1.00pm

Day temperature: 26^{o}c

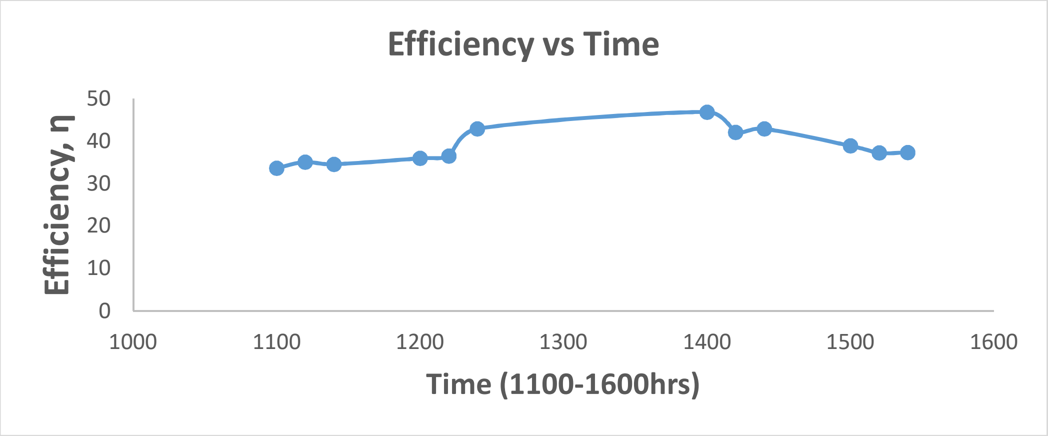
Time variation: 10 mins

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1100	22	39	17	33.69
2	1120	23	41	18	35.13
3	1140	24	42	18	34.6
4	1200	23	42	19	35.99
5	1220	23	42	19	36.53
6	1240	24	46	22	42.95

Time Range: 2.00pm to 4.00pm

Time variation: 10 mins

Observation no	Time of observation	Water inlet (°C),θ_1	Water outlet (°C),θ_2	$\Delta\theta = (\theta_2 - \theta_1$	Efficiency η
1	1400	23	42	19	46.89
2	1420	23	40	17	42.11
3	1440	21	37	16	42.93
4	1500	21	34	13	38.94
5	1520	20	31	11	37.28
6	1540	20	29	9	37.4



Chapter 5

Solar Thermal Prospects

5.1 World Wide

5.1.1 Solar Thermal Energy Potential

Solar thermal heating and cooling attracts less media attention and R&D funding than the more glamorous "high-tech" solar PV. Yet, this low-profile player dominates the solar renewables market, accounting for 84%- as opposed to solar PV's 14%- according to Jes Donneborg, ceo of Denmark's Arcon Solvarme A/S.

Although solar gets most of the attention, solar thermal (ST) for heating and cooling has been the more affordable technology for the domestic and small business sectors - that have been its majority adopters. ST's direct mode of heating, without requiring an electrical intermediary, suits these users, avoiding issues of electrical power management, grid integration etc.

Because much of humankind's power demand is associated with keeping people comfortable – warm or cool – in buildings, there is a large market for solar thermal in hot water, space heating, swimming pool and district heating applications, plus air conditioning and cooling. This accessible technology lends itself to both retrofitting and incorporation in to new buildings.

National and local Government incentives have supported substantial market penetration in such regions as Scandinavia, the Netherlands, Germany and Austria, much of the Mediterranean and parts of the USA. An outstanding example is that of Israel which, because it has actively embraced solar thermal technology since as far back as the 1950s and provided commensurate funding, now has ST heating in over 90% of its homes.

Legislation can help too. Spain has made solar an obligation for new buildings nationwide, and cities like Barcelona and Murcia have added ordinances making such provision part of local planning procedures. A European movement, ProSTO, is encouraging the more widespread use of such ordinances to accelerate take-up of ST throughout the European Union.

Another plus for solar thermal is that, although often thought of in terms of individual premises, it has proved no less scalable than solar PV. Some of the world's largest ST installations are block and district heating schemes in Denmark, where a 12.9 thermal megawatt (MWth) scheme is one of three major systems on the island of Aeroe, and in Sweden and Germany.

Europe's SOLAGE program recognizes the value of economies of scale by encouraging the development of collective systems where arrays on numbers of premises share common heat exchange circuitry and other functions. China, a massive adopter and producer of solar technology, also has large-scale schemes.

Although a basic technology, ST benefits just as much as solar PV from progressive engineering and design refinement. Products available today are more effective and durable than those of the industry's early days. The present state of evolution can be illustrated by reference to the latest products from GREENoneTEC (there are many reputable collector producers but the Austrian company is one of the biggest, with a wide product range.)

The HP160 Easy heat pipe system, which received its public debut at ISH 2009, Frankfurt, is a flat-panel roof-mounted product aimed at the domestic hot water market. The collector is integral with a water tank and, in contrast to the many thermo-siphon units seen in Mediterranean countries, the tank is well hidden by the collector so that the product is aesthetically acceptable.

High engineering standards are manifested in the 160-litre double-walled tank, the UV-resistant two-component adhesive used to bond all the joints, the design of the aluminum-coated absorber and the laser welding that ensures maximum transmission of heat between the absorber plate and the heater tubes. Spokesperson Dr. Claudia Koenig states that the new product requires negligible maintenance and offers a yield 15% greater than that of a good thermo-siphon design. The aluminum frame is manufactured in-house on a robotic assembly line. Installing the device is a matter of folding out the frame, placing the system in the desired location and connecting up the hot and cold water lines.

The FK8231 Mediterrano Frame Collector is optimized for use in Mediterranean countries where both maritime and desert conditions pertain. It has a corrosion-resistant absorber, a selective coating that resists attack by sea air and an optimized ventilation concept to keep out blown sand. Polypropylene glycol included in the water heat transfer medium prevents freezing. A front glazing of tempered, low-iron solar safety glass protects the absorber system. With its aluminum frame, the product is engineered to resist 150 kph winds and 1.25 kN/sq m snow loadings.

To ensure reliability and consistent quality, the Mediterrano is based on a minimum number of individual components and is assembled on a robotic production line. A modular mounting system enables the collector to be used on both flat and pitched roofs. Collector area per module is 2.34 sq m with an absorber area of 2.14 sq m. The system weighs 82 kg and is 73 mm high.

A good product spread caters for multiple needs. An alternative to high end aluminum frames is to have wooden frames. The company produces these in two sizes.1.25 sq m and 2.5 sq m. Another frame model has 50mm thick mineral wool rear insulation. FK7000 is a tray collector series featuring an aluminum tray with positive-fit glass cover strips and silicone-free dry sealing to ensure long leak-tight service life. Façade collectors are designed for integration into building facades and do not require rear ventilation.

Where large ST surfaces are envisaged, customers can opt for GK3000 series collectors with standard dimensions of 5 sq m and 10 sq m. These larger sizes simplify roof connections and reduce installation workload, though a crane lift would typically be required for roof placement. The company also produces a traditional roof-mounted thermo-siphon model in which the collector is attached to 140 liters or 280 liters' accumulator tanks.

The extent to which solar thermal's contribution to the global energy supply dwarfs that of solar PV is often underestimated by energy policy makers. Moreover producing, installing and maintaining ST systems employ over 200,000 people worldwide. Will solar thermal emerge from the PV shadow and, Cinderella-like; begin to steal the attention that the hitherto more glamorous sister has attracted? Activity in terms of large utility scale concentrator projects that are outside the scope of this article (but see renewable focus May/June issue), suggests some progress in this direction. This may extend to lower-temperature collector technology as block and district heating schemes attain headline-grabbing size, helped by economies of scale.

However, it seems likely that mainstream low and medium-temperature collection technology applied to buildings will just keep moving steadily ahead, particularly as the industry improves its act and the recession completes its course. Given determination and vision, the ST sector should maintain its low-profile winning ways. [13]

5.1.2 Solar Heat Worldwide

Total installed capacity in operation worldwide by the end of 2014

By the end of 2014, an installed capacity of 410.2 GWth, corresponding to a total of 586 million square meters of collector area was in operation worldwide.

The vast majority of the total capacity in operation was installed in China (289.5 GWth) and Europe (47.5 GWth), which together accounted for 82.1%of the total installed capacity. The remaining installed capacity was shared between the United States and Canada (18.0 GWth), Asia w/o China (10.7 GWth), Latin America (10.0 GWth), the MENA2 countries Israel, Jordan, Lebanon, Morocco, the Palestinian Territories and Tunisia (6.6 GWth), Australia and New Zealand (6.2 GWth), and Sub-Sahara African countries Lesotho, Mauritius, Mozambique, Namibia, South Africa and Zimbabwe (1.3 GWth). The market volume of “all other countries” is estimated to amount for 5%of the total installations (20.5 GWth).

The breakdown of the cummulated capacity in operation in 2014 by collector type is 22.1%glazed flat-plate collectors, 71.1%evacuated tube collectors, 6.3% unglazed water collectors, and 0.4%glazed and unglazed air collectors.

The leading countries in cumulated unglazed and glazed water collector capacity in operation in 2014 per 1,000 inhabitants were Austria (419 kWth/1,000 inhabitants), Cyprus (412 kWth/1,000 inhabitants), Israel (400 kWth/1,000 inhabitants), Barbados (318 kWth/1,000 inhabitants), Greece (278 kWth/1,000 inhabitants), the Palestinian territories (275 kWth/1,000 inhabitants), Australia (260 kWth/1,000 inhabitants), China (213 kWth/1,000 inhabitants), Turkey (162 kWth/1,000 inhabitants) and Germany (158 kWth/1,000 inhabitants).

New installed capacity worldwide in 2014

In the year 2014, a total capacity of 46.7 GWth, corresponding to 66.7million square meters of solar, was installed worldwide.

The main markets were in China (36.7 GWth) and Europe (3.4 GWth), which together accounted for 85.9% of the overall new collector installations in 2014. The rest of the market was shared between Latin America (1.3 GWth), Asia w/o China (1.0 GWth), the United States and Canada (0.8 GWth), the MENA region represented by Israel, Jordan, Lebanon, Morocco, the Palestinian Territories and Tunisia (0.5 GWth), Australia (0.5 GWth), and the Sub-Sahara African countries Lesotho, Mauritius, Mozambique, South Africa and Zimbabwe (0.1 GWth). The market volume of "all other countries" is estimated to amount for 5%of the new installations (2.3 GWth).

Compared to the year 2013 the new collector installations worldwide decreased by 15.2%. By contrast, the world market growth in the period 2012/2013 amounted to 1.9%and in the period 2011/2012 to 6.7%. This indicates a trend change. This is the first time a shrinking world market has been observed. Based on data already available for 2015 this trend seems to continue.

From the top*10 markets* in 2014 positive market development was reported in Brazil (+4.5%), India (+7.0%), the United States (+0.9%), Mexico (+18.2%) and Greece (+19.1%). The other major solar thermal markets within the top 10 countries: namely China (–17.6%), Turkey (–0.8%), Germany (–9.8%), Australia (–21.1%) and Israel (–13.4%) suffered market declines.

Latin America shows the most steady and dynamic upward trend of all economic regions. The dominant Brazilian, but also the large Mexican market as well as the evolving markets such as

Chile are responsible for the positive growth rates for the sixth year in a row. In 2014 these markets grew by 8.1%.

The breakdown of the new installed capacity in 2014 by collector type is 18.5%glazed flat-plate collectors, 77.9% evacuated tube collectors, 3.5%unglazed water collectors and 0.2%glazed and unglazed air collectors.

In terms of new installed *solar thermal* capacity per 1,000 inhabitants in 2014, Israel took the lead once again, ahead of China and Palestinian territories(West Bank and Gaza Strip).Due to outstanding achievements in the field of solar district heating in the last couple of years Denmark is ranked fourth in this respect, even ahead of mature solar thermal markets such as Greece, Turkey and Austria.

Contribution to the energy supply and CO2 reduction

The annual collector yield of all water-based solar thermal systems in operation by the end of 2014 in the 61 recorded countries was 335 TWh (= 1,208 PJ). This corresponds to a final energy savings equivalent of 36.1 million tons of oil and 116.4 million tons of CO2. The calculated number of different types of solar thermal systems in operation was around 101 million.

In 2014, 94%of the energy provided by solar worldwide was used for heating domestic hot water, mainly by small-scale systems in single-family houses (68%) and larger applications attached to multi-family houses, hotels, schools, etc. (27%). Swimming pool heating held a share of 4%in the contribution to the energy supply and CO2 reduction and the remaining 2% was met by solar combined systems.

Distribution of systems by system type and application

The thermal use of the sun’s energy varies greatly from region to region and can be roughly distinguished by the type of solar thermal collector used (unglazed water collectors, evacuated tube collectors, flat plate collectors, glazed and unglazed air collectors, concentrating collectors), the type of system operation (pumped solar thermal systems, thermo siphon systems) and the main type of application (swimming pool heating, domestic hot water preparation, space heating, others such as heating of industrial processes, solar district heating or solar thermal cooling).

For unglazed and glazed water collectors, the evacuated tube collector dominated with a 71%share of the cumulated capacity in operation and a 78%share of the new installed capacity. In China, vacuum tube collectors played an important role, and since this was by far the largest market, the worldwide figures tend towards a higher share of this type of solar thermal collector Unglazed water collectors accounted for 6% of the cumulated water collectors installed worldwide and the share tended to decrease. In 2014, the share of unglazed water collectors was 3%of the new installed capacity.

Worldwide, more than three quarters of all solar thermal systems installed are thermo siphon systems and the rest are pumped solar. Similar to the distribution by type of solar collector in total numbers the Chinese market influenced the overall figures most, and in 2014 90%of the new installed systems were estimated to be thermo siphon systems while pumped systems only accounted for 10%.

In general, thermo siphon systems are more common in warm climates such as in Africa, South America, southern Europe and the MENA region. In these regions thermo siphon systems are more often equipped with flat plate collectors, while in China, the typical thermo siphon system for domestic hot water preparation is equipped with evacuated tubes.

The calculated number of water-based solar thermal systems in operation was approximately 101 million by the end of 2014. The breakdown is 6%used for swimming pool heating, 63%used for domestic hot water preparation in single-family houses and 28%attached to larger domestic hot water systems for multifamily houses, hotels, hospitals, schools, etc. Around 2% of the worldwide installed capacity supplied heat for both domestic hot water and space heating (solar combined systems). The remaining systems accounted for around 1%and delivered heat to other applications such as district heating networks, industrial processes or thermally driven solar cooling applications.

Compared to the cumulated installed capacity, the share of swimming pool heating was less for new installations (6%of total capacity and 4%of new installed capacity). A similar trend can be seen for domestic hot water systems in single-family homes: 63%of total capacity in operation and 43%of new installations in 2014 make this kind of systems the most common application worldwide, but with a decreasing tendency.

By contrast, the share of large-scale domestic hot water applications grew (28%of total capacity and 50% of new installed capacity). It can be assumed that this market segment took over some of the market shares from both swimming pool heating and domestic hot water systems in single-family homes.
The share of solar combined systems as well as other applications, such as solar district heating, solar process heat or solar cooling remained at a low level of 3–4%and no real trend can be identified in a global context.

Leveled cost of solar thermal generated heat

Lowest leveled costs for solar thermal generated heat range between ~1 €-ct/kWh for pool heating systems (Australia, Brazil), 2–5 €-ct/kWh for small thermo siphon domestic hot water systems (Brazil, India, Israel, Turkey), 7–8 €-ct/kWh for small pumped domestic hot water systems (Australia, China) and 2–6 €-ct/kWh for large pumped domestic hot water and/or space heating systems (Brazil, China, India, South Africa).

Highest leveled costs for solar thermal generated heat range between ~2 €-ct/kWh for pool heating systems (Canada, Israel), 7–12 €-ct/kWh for small thermo siphon domestic hot water systems (Australia, China, South Africa), 12–20 €-ct/kWh for small pumped domestic hot water systems (Australia, Austria, Canada, Denmark, France), 8–14 €-ct/kWh for large pumped domestic hot water systems (Austria, Canada, Denmark, France) and 11–19 €-ct/kWh for small combined hot water and space heating systems (Austria, China, Denmark, South Africa).

Employment and Turnover

Based on a comprehensive literature survey and data collected from detailed country reports, the number of jobs in the fields of production, installation and maintenance of solar is estimated to be 730,000 worldwide in 2014.

The worldwide turnover of the solar industry in 2014 is estimated at € 21 billion (US$ 24 billion).

Development of global solar thermal capacity in operation and energy yields 2000–2015

Global solar thermal capacity of unglazed and glazed water collectors in operation grew from 62 GWth (89 million square meters) in 2000 to 435 GWth (622 million square meters) in 2015. The corresponding annual solar thermal energy yields amounted to 51 TWh in 2000 and to 357 TWh in 2014. [14]

5.2 For Bangladesh

5.2.1 Current Aspect of the Country

Bangladesh has an average annual solar radiation of nearly 1,900kWh/m2, which is sufficient to operate a CSP plant. Studies foreseen that by 2015 the capital costs of the plant would become $3,800/kW

The solar thermal energy is used in conventional ways for drying of washed clothes, food grains, fish, vegetable, raw jute etc. for centuries in Bangladesh. Locally this energy is also used for evaporation of saline water for salt production in the coastal region. The long term average sunshine data indicates that the bright sunshine is available for 3 to 11 hours daily in the coastal region of Bangladesh. The solar radiation varies from 3.8 $kWh/m^2/day$ to 6.4 $kWh/m^2/day$ throughout the country. According to these data, Bangladesh has high potential of solar thermal and photovoltaic applications. This immense potential of solar energy provides an opportunity for off-grid rural electrification through utilization of photovoltaic technology. The conventional solar thermal applications are cooking, drying, hot water production and others.

Bangladesh is endowed with rich solar potential, and sunlight is available throughout the year. Bangladesh receives 900 X 1018 joules of solar energy annually and the availability of solar energy per square meter is 193 W whereas the consumption per square meter is only 0.17 W (Haq et al., 2005, p.3). This implies the abundance of solar energy in Bangladesh. The monthly solar radiation in different locations of Bangladesh is given in table

Month	**Dhaka**	**Rajshahi**	**Sylhet**	**Bogra**	**Barisal**	**Jessore**
January	4.03	3.96	4	4.01	4.17	4.25
February	4.78	4.47	4.63	4.69	4.81	4.85
March	5.33	5.88	5.2	5.68	5.3	4.5
April	5.71	6.24	5.24	5.87	5.94	6.23
May	5.71	6.17	5.37	6.02	5.75	6.09
June	4.8	5.25	4.53	5.26	4.39	5.12
July	4.41	4.79	4.14	4.34	4.2	4.81
August	4.82	5.16	4.56	4.84	4.42	4.93
September	4.41	4.96	4.07	4.67	4.48	4.57
October	4.61	4.88	4.61	4.65	4.71	4.68
November	4.27	4.42	4.32	4.35	4.35	4.24
December	3.92	3.82	3.85	3.87	3.95	3.97
Average	4.73	5	4.54	4.85	4.71	4.85

Table 5.2.1: Monthly Solar Insulation at different locations of Bangladesh (in kWh/m^2/day) [15] [16]

Reasons for Slow growth of Solar Energy System in Bangladesh: Solar power is not new to Bangladesh, since 1996 different companies have tried to market solar energy systems to the public. Yet in a technologically backward country like Bangladesh the idea took a fair while to gestate. Grameen Shakti likes to think of itself as one of the solar pioneers in Bangladesh, having started operations in 1996 they found the reality of solar energy difficult to deal with. The main hindrance behind slow expansion of the PV program is the very high cost of the systems.

Obstacles of Expansion of PV Technology in Rural Areas:

- The major obstacles of rapid expansion of Solar Thermal systems are as follows:
- The problem with this technology is that the expectations almost always outweigh what the systems could achieve. Most thought a simple system could power an entire household quite easily. But after everything was explained thoroughly the main problem of solar energy was its price.
- The lack of awareness about the Renewable technology requires long time, effort and money to familiarize the Solar Thermal technology to the rural areas.
- Private sector companies and NGOs may find it very difficult to cover the initial cost of dissemination of the technology, the main hindrance bring the high cost of system due to high price of the PV module and Solar Thermal Setup in international market and imposition of government taxes.
- An alternative to reach large number of rural households could have been developed with an easy financing system so that the buyers can pay the system price over a longer period of time (for example, 5 to 7 years). The implementing agency automatically requires soft fund to finance the customers, but source of soft finance is so far nonexistent.

5.3 Future Visions for Solar Thermal Development

Solar Home System Potential in Bangladesh

Bangladesh is situated between20.30-20.38 degrees north latitude and 88.04-92.44 degrees east which an ideal area for solar energy is. Utilization of solar energy potential is very important for the impact analysis of SHS in our country. Daily average solar radiation varies between 4-6.5 KWh per square meter [8]. We can get maximum amount of radiation on March-April and minimum from December –January. According to recent studies, yearly average insolation availability in Dhaka is 1.73MWh per square meter on a horizontal surface and 1.86MWh per square meter on a tilted surface. Again, the annual amount of radiation is varying from 1840-1575 KWh/m2 which is 50-100% more than the Europe. Taking an average solar radiation of 1900 KWh per square meter, total annual solar radiation in Bangladesh is equivalent to 1010*1018 J. Present total yearly consumption of energy is about 700* 1018 J. It shows that even if 0.07% of the incident radiation can be utilized, total requirement of our energy can be met [8]. At present energy utilization in Bangladesh is about 0.15 Watt/sq. meter land area, whereas the availability is above 208 Watt/sq. This shows the enormity of the potentiality of SHS in Bangladesh by using this huge solar energy [9]. What fraction of it can be used for our use will depend on the availability of the technologies suited to local conditions [10].

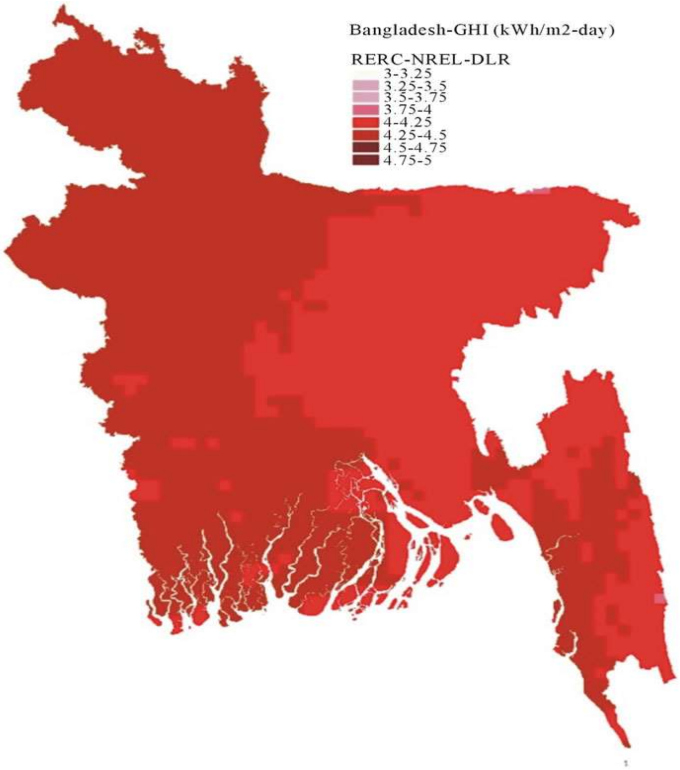
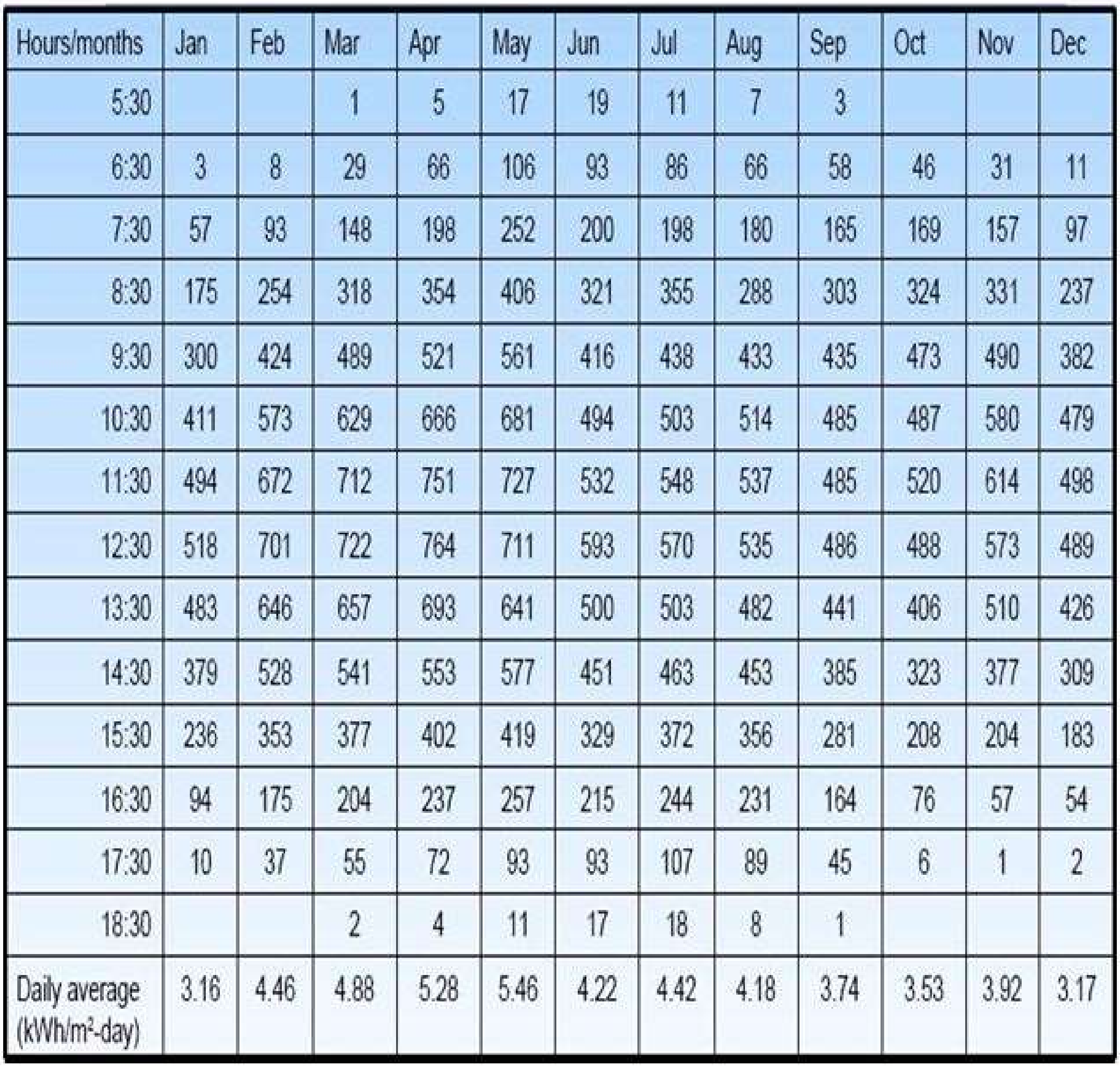


Figure 5.3: Solar Radiation in Bangladesh

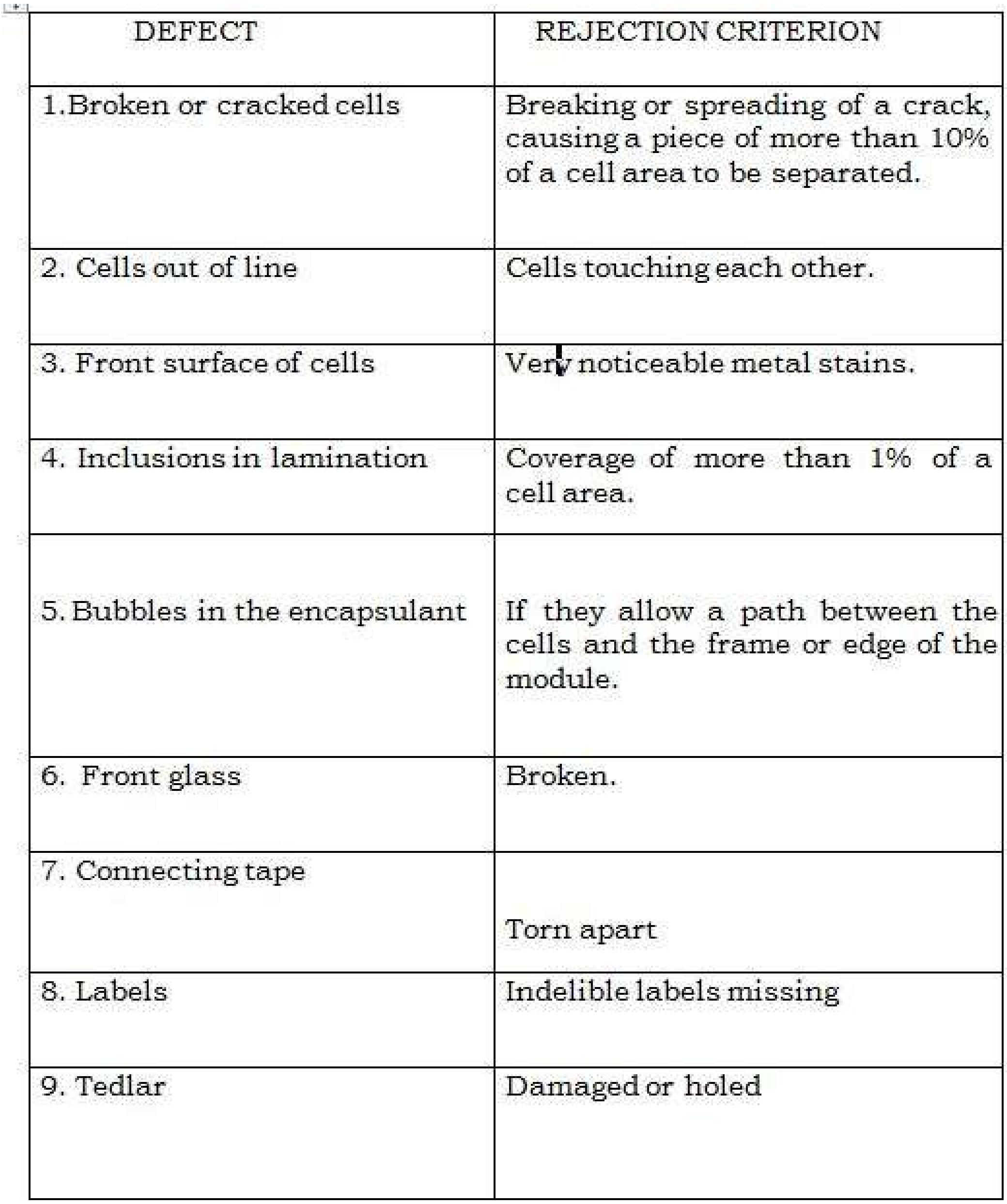


Hours/months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5:30			1	5	17	19	11	7	3			
6:30	3	8	29	66	106	93	86	66	58	46	31	11
7:30	57	93	148	198	252	200	198	180	165	169	157	97
8:30	175	254	318	354	406	321	355	288	303	324	331	237
9:30	300	424	489	521	561	416	438	433	435	473	490	382
10:30	411	573	629	666	681	494	503	514	485	487	580	479
11:30	494	672	712	751	727	532	548	537	485	520	614	498
12:30	518	701	722	764	711	593	570	535	486	488	573	489
13:30	483	646	657	693	641	500	503	482	441	406	510	426
14:30	379	528	541	553	577	451	463	453	385	323	377	309
15:30	236	353	377	402	419	329	372	356	281	208	204	183
16:30	94	175	204	237	257	215	244	231	164	76	57	54
17:30	10	37	55	72	93	93	107	89	45	6	1	2
18:30			2	4	11	17	18	8	1			
Daily average (kWh/m^2-day)	3.16	4.46	4.88	5.28	5.46	4.22	4.42	4.18	3.74	3.53	3.92	3.17

Table 5.3: Monthly average hourly GHI* (Wh/m2) data

Use of CSP over PV:

After having the PV module in the hand, there are some visual inspections which should be done. By having visual inspections outer damage and others things can be identified. Table I lists the different aspects to be inspected, as well as defects leading to a PV module rejection



DEFECT	REJECTION CRITERION
1.Broken or cracked cells	Breaking or spreading of a crack, causing a piece of more than 10% of a cell area to be separated.
2. Cells out of line	Cells touching each other.
3. Front surface of cells	Very noticeable metal stains.
4. Inclusions in lamination	Coverage of more than 1% of a cell area.
5. Bubbles in the encapsulant	If they allow a path between the cells and the frame or edge of the module.
6. Front glass	Broken.
7. Connecting tape	Torn apart
8. Labels	Indelible labels missing
9. Tedlar	Damaged or holed

CSP (Concentrating Solar Power): Concentrating Solar Power (CSP) is a promising technology for power generation in which the solar radiation i.e. direct normal irradiance (DNI) is concentrated to generate high temperature (400ºC to 1000ºC) for producing steam in a solar thermal power plant. This technology has been in use from the 1960’s for large scale power generation as in solar power plants. This technology uses lenses or mirrors and tracking systems to focus a large area of sunlight onto a small area. The concentrated sunlight is focused onto either high efficiency photovoltaic chips or onto a heat transfer medium as in a conventional thermal power plant. The steam produced is in turn used to rotate a turbine coupled to an electric power generator. CSP systems work best at about 5.5kWh/m2/day. Currently the cost of generating power using CSP technology is around15 to 23 BDT per watt [3]. Some of the concentrating technology even offers storage facilities since normal operation at night time is not possible.

Bangladesh receives an average annual DNI of nearly 1,900kWh/m2which is sufficient to operate a CSP plant. Studies show that by the year 2015 the capital cost of CSP plant will become $3800/kWe [4]. As no fuel is required in CSP, this can be an attractive choice to minimize the power crisis of Bangladesh.

Based on the process of collecting and concentrating solar radiation, the CSP can be categorized into four major technologies: i) Parabolic Trough ii) Solar Tower or Central Receiver iii) Parabolic Dish and iv)Linear Fresnel Reflector (LFR).

Use of Flat Plate Solar Collector:

Installing a Flat Plate Solar Collector plant in Bangladesh would serve a great purpose. As we can harness a great amount of solar irradiance due to our global advantageous position, it is high time we started considering the future possibilities of harnessing solar thermal energy. Some of the suggested locations where these kinds of plant can be installed are suggested below-

1. Teknaf
2. Cox's Bazar
3. Sylhet
4. Lalpur
5. Paksei
6. Bheramara
7. Nawabganj
8. Jamalpur

These locations receive solar irradiance as well as water source is very near to the points which are suggested. Another criterion point is that, many of the power generation industries are situated in the above pointed places. Usage of the Flat Plate Solar Collector can go a long way to meet up the power demand and compel the Millennium Development Goal (MDG) of renewable energy so that Bangladesh can prosper to be in the same level as the developed countries. **[17]**

Chapter 6

Integration with Other Power Sources

6.1 Wind Tower

Present wind power is intermittent and cannot be used as the baseload energy source. Concept study of wind power utilizing direct thermal energy conversion and thermal energy storage named Wind powered Thermal Energy System (WTES) is conducted. The thermal energy is generated from the rotating energy directly at the top of the tower by the heat generator, which is a kind of simple and light electric brake. The rest of the system is the same as the tower type concentrated solar power (CSP). The cost estimation suggests that the energy cost of WTES is less than that of the conventional wind power, which must be supported by the backup thermal plants and grid enhancement. The light heat generator reduces some issues of wind power such as noise and vibration.

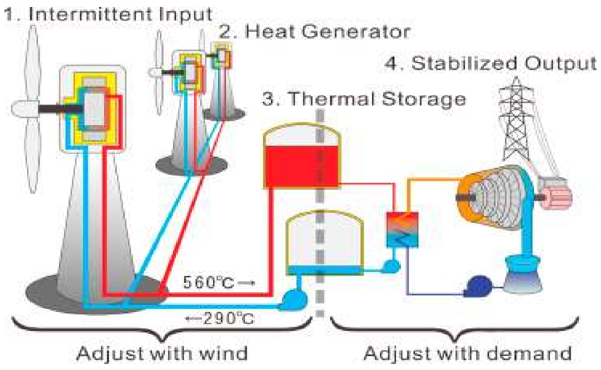


Figure 6.1a: Wind Powered Thermal Energy System (WTES)

Basic configuration

WTES, which employs low cost thermal energy storage system and light and low cost heat generator, could be a better solution than the combination of wind power and thermal plant. The possibility of becoming the low cost stable power generation is studied comparing the combination of the conventional wind with thermal backup and battery supported system.

Basic configuration of WTES is already shown in fig. The heat generator explained in the following section is employed to convert the rotating energy to the thermal energy. The heat generator has lighter weight and lower cost than that of the electric generator since the heat generator is a kind of simple brake in principle. This is important point when it comes to the gearless system, which has less breakdown possibility. The gearless system requires a heavy direct driven slow speed rotating machine.

The heat energy produced at the top of the tower is transferred to the bottom utility by the circulation of HTF. The heated HTF is stored in the thermal storage tank and brought out according to the demand to produce electricity using steam turbine. The technology of HTF circulation over 100 m is already industrialized in the tower type CSP plant, which has 140 m height with 565 Celsius maximum temperature. Even 275 m height plant is under consideration. WTES is easy to be combined with other thermal plant such as CSP, geo-thermal plant and bio-mass since the energy storage and power block parts can be shared. It is, therefore, WTES is not a competing technology but a synergy technology with these technologies.

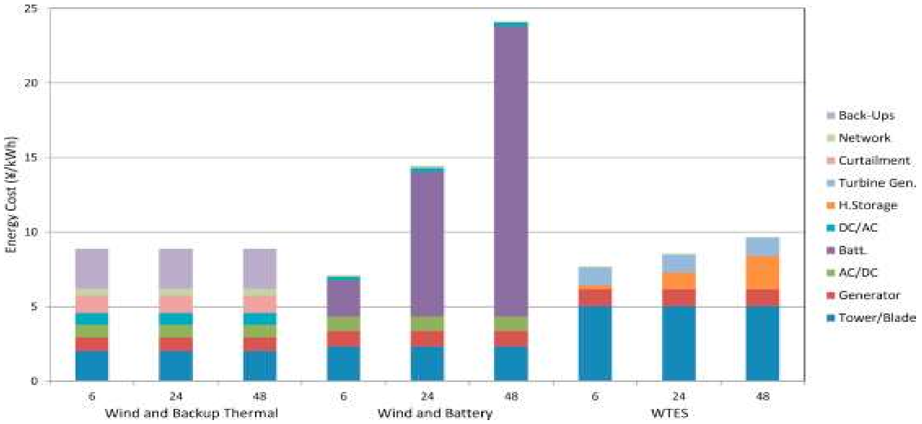


Figure 6.1b: Estimated Energy Cost. Different repetition time of 6, 24, 48 h

The backup thermal plants or some kind of energy storage systems are essential when considerable amount of wind power is introduced to the grid. The energy costs of the wind with backup thermal, the wind with battery energy storage and Wind Powered Thermal Energy System (WTES), which employs heat generator and thermal energy storage system, are compared first-ever. It seems WTES becomes the most economical system in these three systems although the estimation is in the initial stage. WTES becomes much more attractive when it is constructed besides CSP and/or bio-mass plant since many parts of elements can be shared. The configuration of WTES has many variations. Employment of the electric and heat generator enables flexible operation. It can even absorb surplus energy in the grid. Employment of the superconducting heat generator realizes high working temperature, i.e., high thermal to electric conversion efficiency. Those variations including simple thermal specialized type have lots of room to be investigated. [18]

6.2 Thermal Chimney

The heat losses within exhaust gases are an unavoidable part of operating any fuel-fired system. The flue gases still hold considerable thermal energy, which is exhausted to the atmosphere as waste heat and contributes to global warming. This paper presents a developed technique to enhance the performance of low temperature solar thermal systems by utilization of thermal energy recovery of flue gases. A CFD model was established based on the energy, momentum and mass conservation and the state equation in 2-D, steady assumption with k - epsilon for the turbulence modelling using FLUENT – version 6.2.16 software. The model simulates the thermal and fluids flow processes in an inclined modified solar chimney. The flue inlet temperature was varied as, $T_{f\ g}$= 603K, 843K, and 983K. The simulation results were validated by comparison with experimental results obtained from a lab scale model, and acceptable agreement was gained. When the flue temperature is increased from 605K to 843K, the performance is enhanced by 75%. The interesting find is that the efficiency of heat collection tends to increase as the absorber length increases up to a certain length, and then starts to decrease. In this study, the suitable dimension for solar- flue gas collector is about 2.5 m.

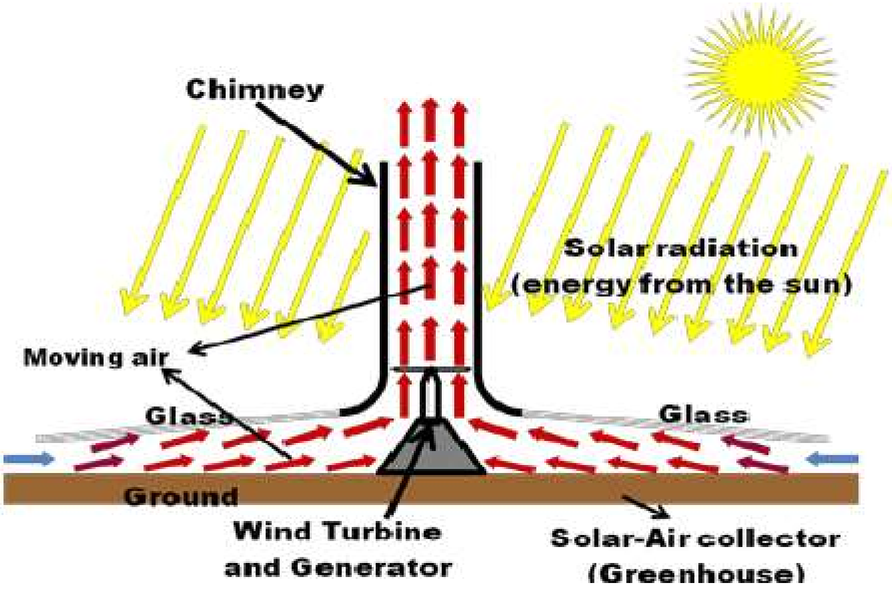


Figure 6.2a: Schematic of a Solar Chimney Power Plant

Operational principles of solar-flue chimney:

The schematic of the proposed solar-flue gas chimney is shown in Figure 2. The transparent cover, absorber plate and insulated back form the thermal unit of the system. Solar radiation penetrates the transparent cover and strike the absorber plate, which is made of corrugated shape to enhance heat absorbing efficiency. At the same time, flue gas from the combustion unit is forced into a channel between the absorber plate and an insulated back. Consequently, the absorber plate gains heat from both solar radiation and flue gas. The heat energy transfers to the adjacent air particles within the air channel. Due to the pressure difference between the outlet and inlet of the channel, an air stream is generated under the buoyancy effect, similar to the working principle of the traditional solar chimney power plant. The kinetic energy of the moving air turns a wind rotor installed at the base of the chimney to produce mechanical output, which is subsequently converted to electricity by an electric generator.

The chimney helps to create upward buoyancy force for additional power to rotate the wind rotor. The energy conversions are illustrated by a block diagram in Figure

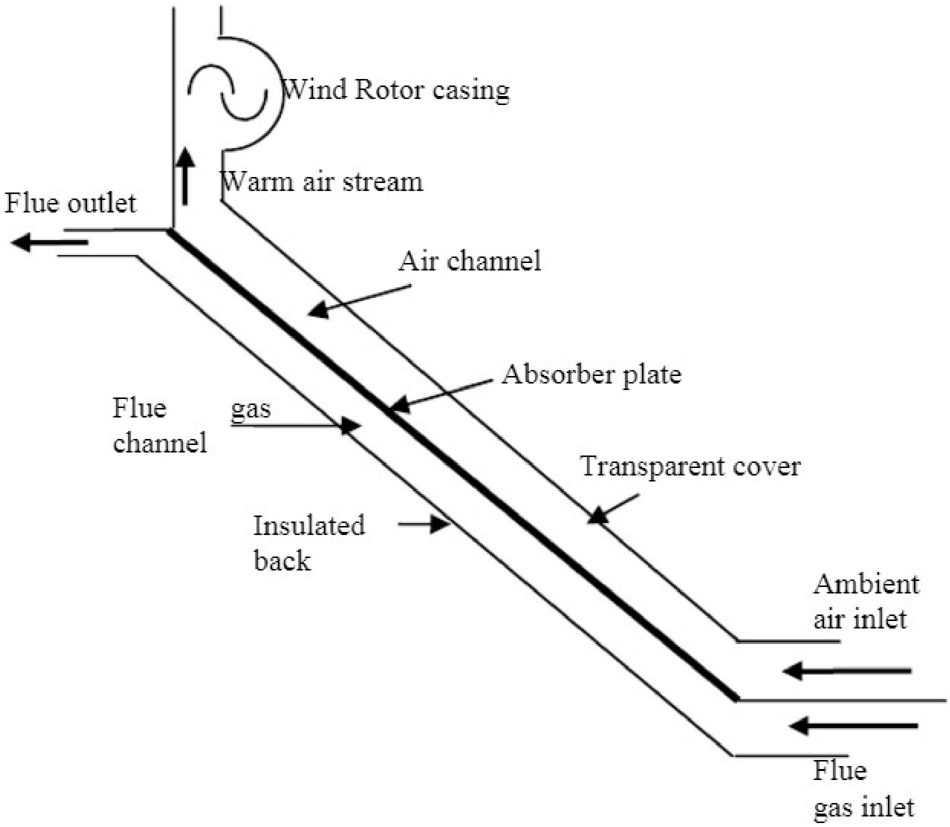


Fig 6.2b: Schematic of the Solar-flue Chimney Power Plant [19]

6.3 Solar Thermal Desalination Plant

With the current strong development of solar energy projects around the world, concentrating solar power and desalination (CSP+D) could be the next significant technological breakthrough. The main reason for this is that it is internationally recognized that power and water supply will be two major issues mankind will have to face and solve during the present 21st century. During the coming decades, the oil era will come to an end, and it is not yet clear today which source of energy will replace it. At the same time, water scarcity is already a global problem which will become crucial during the first half of this century, seawater desalination often being the only alternative source for this element essential to life. Despite the advances in energy efficiency during the last decade, seawater desalination continues to be an intensive fossil-energy consumer. In a context of an oncoming energy crisis due to the end of the oil era, water problems are expected to substantially worsen. And vice versa, due to the close relationship between water and energy issues, water shortages are also expected to contribute to increasing power problems. In addition to all this, environmental considerations such as global warming will surely add significant pressure. In this scenario, renewable energies are rapidly increasing their contribution to the global mix, in which solar energy is clearly the one with highest potential.

Therefore, the integration of solar desalination in solar thermal power plants makes complete sense as it is extremely probable that anywhere there is high enough solar radiation to justify a CSP plant, water would be a more valuable and necessary product than power. Although use of the electricity generated to drive a conventional reverse osmosis (RO) process is possible, multi-effect distillation (MED) seems to be an even more suitable process for integration in CSP plants, using the exhaust steam from the turbine to drive the MED process, part of it as the power cycle cooling system and, potentially, significantly increasing overall efficiency.

The objectives of this Subtask are:

1. To collect existing knowledge and experience on hybrid power and desalination plants for application to hybrid solar power and desalination plants of MW-size;
2. To analyze and determine the main technological characteristics of hybrid solar power and desalination plants;
3. To promote collaborative initiatives in specific assessment of technical and economic feasibility of hybrid solar power and desalination plants, and also identify potential follow-up demonstration case studies.

Fig 6.3: Solar Thermal Desalination Plant in California [20]

6.4 Solar Thermal Greenhouse Conduit

Building a structural system with such a schematic design that integrates looped copper-tubes just below the glass-through medium. This design will aid the copper tubes to receive the solar thermal energy from solar irradiance and heat-up the looped structure to procure heated water. The normal derivational heat for the plants will naturally be received without any hindrance.

This is just a theoretical assumption which has a strong base of compliance. Especially this medium can serve a great purpose for the northern Europe countries having cold weather.

Chapter 7

Conclusion and Recommendation

Conventional energy sources are becoming inefficient for the ever-expanding demand of power of the advancing era. Top priority is given to the research and development sectors to enhance the possibility of harnessing renewable energy sources. Not only has it contributed to the power demand but also its eco-friendly in nature which surmises the prospect of green world improving state of global environment. This study served the purpose to unfold the possibility of improvising the most effective and efficient mean of utilizing renewable source in form of solar thermal energy.

This experimental study was conducted upon flat plate solar collector using Concentrated Solar Power (CSP) as solar thermal energy source to pre-heat water. Experimental aim was to evaluate efficiency by calculating solar irradiance energy falling upon the copper tubes and aluminum absorber plate. Thus, utilize this energy to heat up the circulating fluid (water). This preheated water can be used for space heating, steam generation for power production and other purposes. Efficiency calculation for varies data on different dates were taken into account and showed in graphical representation based on equation governed calculation.

Solar irradiance value taken for this equation is differentiated from formula for each separated day account. Out view of the used formulas are discussed in the **Theoretical Background** chapter with proper reference. Computed values are shown in elaborated formation in the **Experimental Conduction Procedure** chapter. Numerous data are represented along with graphical presentation for proper understanding and thus firms the base of this experimental procedure.

Overall comment can be outlined as the system to be a reflection of thoroughly carried out proper procedural work of experiment with strong theoretical background and proper supervision of expert personals on this domain. This thesis submission can be proven as a great asset for the cause of any power plant installment of this criterion as it can give a full modeled review for predetermination with proper recommendation.

Shortcomings

The utmost importance and whole-hearted dedication was given to complete this thesis without any experimental evaluated drawbacks. Still for some undesirable and technical limitations prevailed which had minor impact on this work. Overcoming and modifying these frailties would ensure higher efficient and more perfect form of data conduction.

- **Lack of sufficient time:** For some academic unwanted circumstances we were unable to conduct procedural works from the beginning of the year.
- **Inadequate funding aid:** Completion of this thesis project work of physical infrastructure demanded a huge capital to ensure higher performance outcome. Due to shortage of funding some modification in the applicable design were made. It had an impact which in some percentage deflected from the design that could have guaranteed better improvisation.
- **Technical limitations:** There were some technical prospects where we had faced problems. Major drawback was the incompetence of the usage of bent copper tubes. 9mm copper tubes are mostly available in market which cannot be bent by “Hydraulic Press” or “Heat Treatment “. As the tube thickness is not capable of withstanding bending force or is unable to contradict heat deformation. As a countermeasure we had to use copper elbow joints by welding them with straight copper tubes. It creates friction and also water hammer effect lessening the efficiency.

  Nickel or Chromium based absorber paintings which are suitable for absorber plate and copper tubes are not available in market. So we couldn’t use absorber paint coati

Recommendation

Improvisation and modification of the design in different sections can ensure a better result. Also if the experienced and present prevailed limitations are dealt with appropriate steps then it is thoroughly believed that this very same work can be relied for high performance outcome. Improvement and modification criterion can be based upon the facts-

1. **Technical Features:** Change of technical features that can enhance performance
    - **<u>Using bent copper tubes</u>:** Using bent copper tubes in place of welded copper elbows can minimize friction and cancel out the water hammer effect.
    - **<u>Using copper absorber plate</u>:** Copper possess the highest heat conductivity property of all materials. So, using copper absorber plate in place of aluminum can assure high conduction of heat to the copper tubes and thus result in greater performance.
    - **<u>Applying absorber painting</u>:** If the copper tubes are applied with absorber paintings in their surface that more solar energy will be absorbed which is theoretically approved and experimentally proven.
    - **<u>Using Sun Tracker actuatable base</u>:** Solar irradiance can be utilized at its highest peak if sun tracker solar base is integrated.
    - **<u>Increasing number of loops</u>:** Increase of loops mean more amount of water will be present over a time for solar energy heat receiving process.
    - **<u>Better insulation medium</u>:** Aluminum net or refrigeration felt can ensure better insulation. Also, application of metallic foam can contribute to this fact.
2. **Selection of suitable place:** Selection of a suitable place for experimental conduction can also play a vital role. By using the solar irradiance map and water source availability with other parameters geographical advantage can be ensured for better result outcome.
3. **System Automation:** By using motor run pump for water loop circulation and thermal sensors in the inlet and outlet sections can derive better performance results.

Chapter 8

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