SOLAR THERMAL ENERGY

1.2 Thermal Energy

1.2.1 Technology Description

Solar energy can be utilized for various applications in addition to power generation, such as solar thermal systems in which the solar radiation is converted into heat. These systems are used to warm up a heat transfer fluid, which can be air, water, or a specially designed fluid. The heated fluid can be utilized immediately for hot water or space heating/cooling, electricity generation, or a heat exchanger to transfer the thermal energy to the final application. The heat generated can also be kept in a suitable storage tank for use when the sun is not shining.

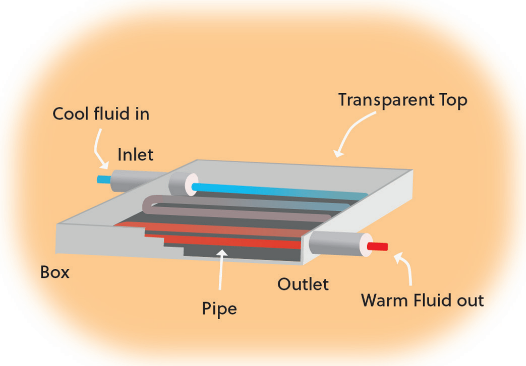


Figure 20: Solar energy-to-heat conversion[25]

Solar thermal collectors are classified as low, medium, or high-temperature collectors. Low-temperature collectors are flat plates generally used to heat swimming pools. Medium-temperature collectors are typically flat-plate collectors used to heat water or air for household and commercial applications. High-temperature collectors, which use mirrors or lenses to focus sunlight, are commonly used to produce electricity.

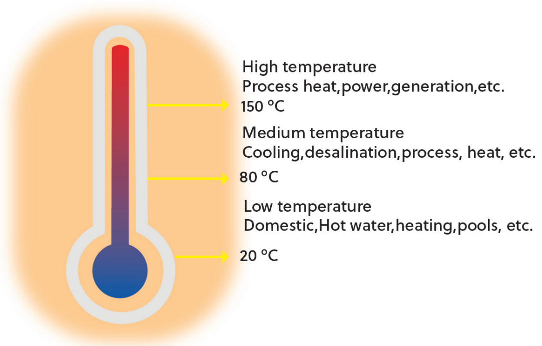


Figure 21: Different Temperatures levels meet different applications[26]

1.2.1. A Solar thermal system components and working principle:

Solar water heating system

The collector array is responsible for absorbing solar radiation and convert it into heat. Most systems have an absorber that also reduces the release of infrared radiation, ensuring as much heat as possible is retained. These are called selective absorbers.

Most non-concentrating collectors have housing, except for unglazed collectors. Both the absorber and the fluid circuit heat exchanger lose less energy to the environment due to this, and both elements are protected from degradation. To allow solar energy to reach the absorber, the part of the housing facing the sun must be transparent.

Types of collectors:

• Unglazed flat plated collector

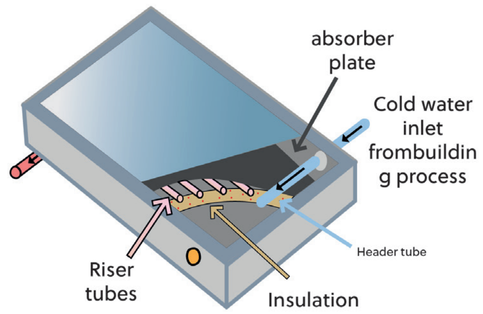
The most basic type of solar collector is the unglazed collector. It comprises a metal or plastic absorber with no glass cover, housing, or thermal insulation, resulting in more thermal loss and lower performance than other types of collectors. It can be used for low-temperature applications.

• Glazed flat plated collector

This collector is thermally insulated and is provided with a transparent cover on the upper surface, in addition to two pipe connections for the supply and return of the heat transfer medium.

• Evacuated tube collectors

The housing of this collector is a glass tube with a vacuum inside; additional evacuation prevents losses through thermal conduction. It has higher efficiency even with low irradiation and significant temperature differences between the collector and the surroundings. It cannot be used for in-roof installation and horizontal installation for heat pipe systems since the inclination must be at least 25°.



(25) lba Ramos, et al. 2017. Solar-Thermal and Hybrid Photovoltaic-Thermal Systems for Renewable Heating.
(26) Alba Ramos, et al. 2017. Solar-Thermal and Hybrid Photovoltaic-Thermal Systems for Renewable Heating.

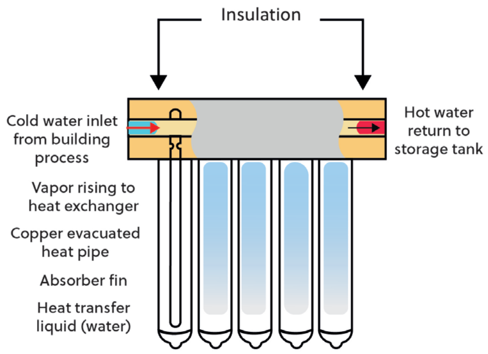


Figure 22: Flat plate collector and evacuated tube collector. Source: Victoria Sustainability

The heat transfer fluid runs across a circuit in all solar thermal systems. The heat exchange efficiency between this circuit and the absorber must be maximized to maximize the system efficiency. The absorber should be directly located on the external surface of the hydraulic circuit to achieve this target.

Solar water heating systems use a heat transfer fluid; When the fluid is used directly in the application, it is called a direct or open-loop system.

On the other hand, it is called an indirect or closed-loop when the heated fluid is used in a heat exchanger to heat the used fluid.

The heat transfer fluid must be transferred through pipelines which must be entirely insulated without gaps and open spots, and the generated solar heat must be stored in a Storage tank.

The heat transfer fluid can be transported by forced circulation using a pump or passively without using pumps. Natural convection is used to transport the fluid from the collector array to the storage tank.

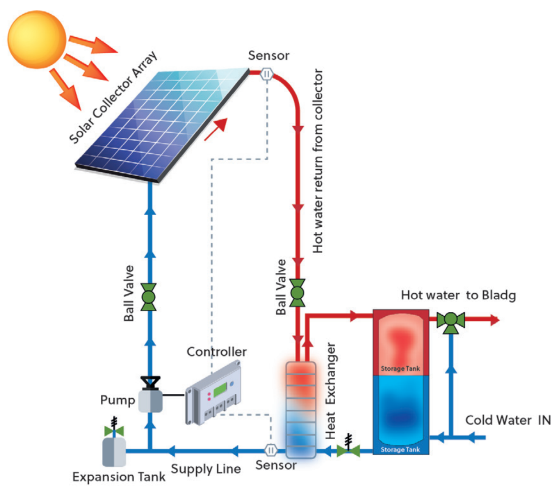


Figure 23: Schematic diagram for solar water heating system[27]

Concentrated Solar power (CSP)

CSP is a High-temperature application where the solar heat is used to raise the temperature of a fluid to be used in a steam turbine to generate electricity. These systems consist of a concentrating collector array, where the solar energy is absorbed.

Types of collectors:

• *Parabolic Trough*

It is composed of a parabola-shaped (or trough-shaped) reflective surface that focuses sunlight onto a receiver pipe. A heat transfer fluid (HTF) circulates through the receiver and is heated by the absorbed sunlight to reach 150-350 degrees Celsius. The steam is generated using the hot fluid, which is then utilized to power a standard steam turbine/generator.

• *Linear Fresnel*

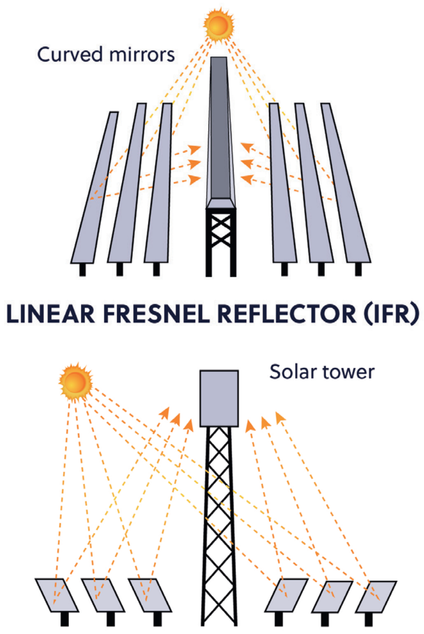
Fresnel concentrators replace the curved surface of a conventional optical lens with a series of flat mirrors which bend the parallel light rays to a typical focal length.

• *Dish Stirling*

It comprises a parabolic reflector that directs light to the focal point, where the working fluid absorbs the energy and heats to around 500°C

• *Heliostats*

Heliostat is an array of dual-axis tracking reflectors set around a tower where concentrated sunlight hits a central receiver containing the working fluid, which can be heated to 500 or even 1000 degrees Celsius.



(27) http://www.freehotwater.com/solar-thermal-101-main-components-of-a-solar-hot-water-system

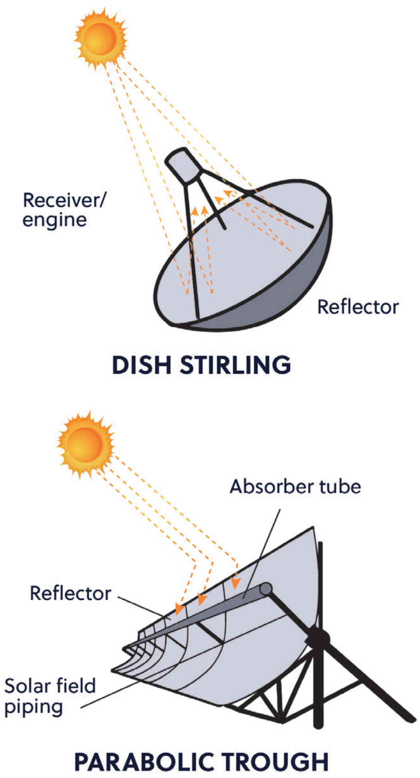


Figure 24: CSP collectors' technologies[28]

Concentrated Solar power (CSP)

The primary advantage of CSP is the ability to add thermal storage efficiently, allowing for the dispatching of electricity over up to 24 hours. According to the current technologies, heat storage is cheaper and more efficient than electricity storage. The storage is used to cover daily and seasonal fluctuations. Heat can be stored using water, solids, or phase-change material. The heat from the fluid generates steam that drives turbines to generate electricity.

Solar cooling

The sun is commonly thought of as a source of heat. There are, however, thermal processes that produce coolness, such as cooling water or air conditioning that is directly driven by heat input. The heat generated by solar thermal collectors is often suitable for use as the primary energy source in these operations.

Types of cooling systems:

- ***Absorption cycle:***

An absorber, a generator, a condenser, and an evaporator are the four main components of an absorption cooling cycle.

The absorber holds an absorbent-refrigerant mixture; using the external solar energy that has been collected through solar collectors, the generator heats the absorbent-refrigerant mix, which turns water into a vapor that flows to the condenser. The condenser liquefies the water vapor, rejecting the heat that the heat sink will collect. The new liquid condensate is then directed towards the evaporator through an expansion valve. The refrigerant evaporation at low pressure causes the evaporator to absorb the heat from the cooled space, creating the cooling effect.

- ***Adsorption cycle***

The main difference between absorption and adsorption cycles is that the refrigerant is adsorbed on the internal surface of highly porous solid material instead of the refrigerant being absorbed by a liquid solution.

Desiccant systems

Repeated Cycles of dehumidification-humidification are used in desiccant cooling systems. It dehumidifies the air by using desiccants which are substances that readily attract water from their surroundings. The role of solar power is to replenish the desiccants in the cycle by transferring the moisture to the air.

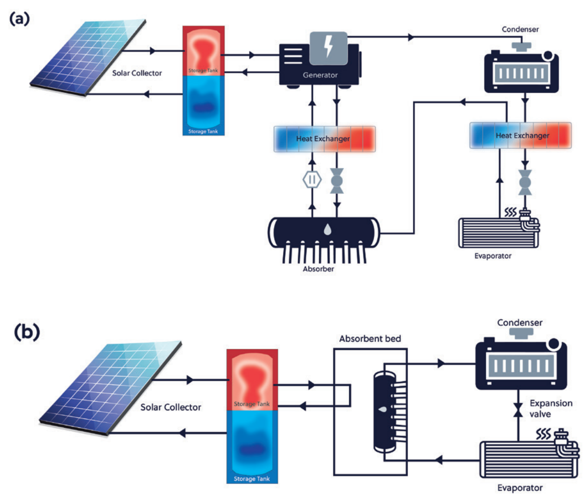


Figure 25: Basic configuration of solar cooling technology: (a) absorption and (b) adsorption system[29]

1.2.2 Design Considerations

The need for backup

Solar thermal systems might need backup, depending upon the yearly amount of heating, cooling, or electricity requirement, in order to provide the necessary energy when the solar power is not sufficient.

The need for backup can be demonstrated using the solar fraction, which describes the ratio of solar

(28) Răboacă, Maria & Badea, Gheorghe & Enache, Adrian & Filote, Constantin & Răsoi, Gabriel & Rata, Mihai & Lavric, Alexandru & Felseghi, Raluca. (2019). Concentrating Solar Power Technologies. Energies.
(29) https://doi.org/10.1177/1687814015586120

heat yield to the total energy requirement for the application—the higher the solar fraction, the lower the amount of energy required for the auxiliary system.

The selection of the heat transfer fluid

Through the different operating conditions, the heat transfer fluid should not freeze or boil. The medium should also have a high specific heat capacity, low viscosity and be non-toxic, inexpensive, and abundant. Water, oils, and air are the most commonly used fluids.

Collector surface area

The collector surface area will depend on the average hot water demand, heating or cooling loads, or electrical load in CSP.

For SWH:

$$\text{Collector Area} = \frac{\text{Solar fraction} \times \text{Operatinal days} \times \text{Hot Water requirment}}{\text{Solar irradiation} \times \text{System efficiency}}$$

Collector Orientation

Similar to PV panels, optimum performance is achieved when the azimuth is equal to 0 degrees. Collectors installed at different angles show a variation in the performance. The collectors' location must be away from any obstacles and possible sources of shading, which also affect the performance drastically. Since the sun's angle relative to the horizon varies between summer and winter, the optimum inclination angle for solar collectors is between them.

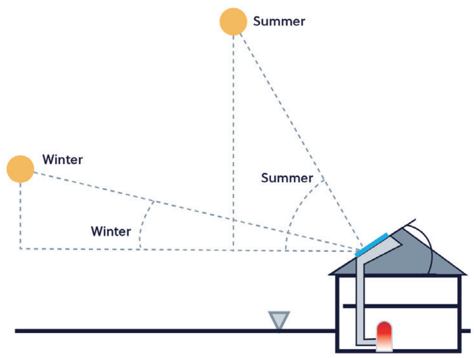


Figure 26: Inclination angle[30]

1.2.3 Advantages & Disadvantages

Advantages	Disadvantages
• Renewable Energy Source. • Environment-friendly. • It helps in reducing the heating bill. • Reduces Fossil Fuel Dependency. • Cheap to Run. • It can be combined with solar PV	• Intermittent source • High upfront cost (capital cost, land, storage, plumping, heat exchange system). • Land and space availability. • Technical barriers in terms of building suitability

1.2.4 Applications:

Solar domestic hot water

Solar Domestic Hot Water Systems are intended to provide 100% of the hot water requirements in the summer and around 40-80% of total annual hot water demand. They come with a backup heater. Smaller (individual) systems are available, whereas bigger (collective) systems offer hot water for multi-family homes, hotels, and office buildings, among other things.

Pool heating

In many climates, pool heating using solar energy is the most cost-effective choice since solar pool heaters are cost-competitive with gas and heat pumps and have very low annual operating costs.

Figure 27: Solar pool heating system for al Hamdan sports complex, UAE [31]

(30) https://firebird.uk.com/wp-content/uploads/2016/06/Guide-to-Solar-Thermal-Systems-Brochure-2012.pdf
(31) https://www.eurostar-solar.com/#projects-5

Hybrid solar heating

The rise of solar panels' temperature lowers the system efficiency. On a hot summer day, solar panels may lose 10 to 25% of their output. By pumping a current of air across the panel, heat is harvested, and the panel is kept cold. Hybrid panels turn this difficulty into an advantage. The solar panel operates at maximum efficiency, and the heat can be piped into the building to prevent heat loss.

Figure 28: Hybrid Solar Panel(32)

Water Desalination

Solar desalination removes salt from the water that uses a specifically developed still that uses solar energy to heat seawater and trap the resulting steam, which is then cooled and condensed into pure freshwater. In the still, salt and other contaminants are left behind.

Solar Refrigerator/ Fridge

it is an absorptive device, which takes a heat source and uses thermal energy to convert the refrigerant solution into liquid. As a result, energy is produced, and it can sustain itself and the contents within it.

Underfloor Space Heating

Underfloor heating is a system whereby a pipe circuit is installed below the floor of a home. Hot water from solar collectors is circulated through it.

Figure 29: Underfloor heating(33)

The main advantage over other conventional heating systems is that it is unnecessary to install wall radiators so that the walls are accessible.

Another advantage of this system is distributing the temperature in a more uniform way which does not require that the fluid have a high temperature. This feature makes it possible for solar thermal energy to fit this application.

Solar Oven

A solar oven is an energy concentrator that directs solar radiation onto a focal area where the cooking vessel is located. It might also consist of an insulated box painted black internally and double glazed to avoid heat loss. To enhance solar gain, plane sheet reflectors (single or multiple) may be employed.

In industrial applications, parabolic mirrors or heliostats concentrate light at the focal point. The temperature can reach 3,500 ° C (6,330 ° F), and this heat can be used to melt steel and produce hydrogen fuel or nanomaterials.

Figure 30: Bander Bayla is Somalia's first solar cooking village with approximately 950 solar ovens(34)

Trombe wall

Trombe or solar wall is a system that can be installed in homes to heat the building passively; it consists of an air channel sandwiched between a window and a sun-facing thermal mass. The heat is stored in the thermal mass and warms the air channel causes circulation to occur at the upper and lower parts of the wall. It can be used for cooling using a heat-driven absorption or adsorption chiller.

Figure 31: Trombe Wall(35)

(32) http://www.reuk.co.uk/wordpress/solar/virtu-hybrid-solar-pv-water-heating/
(33) https://ambienteufh.co.uk/underfloor-heating-retrofitting-complete-guide
(34) https://solarcooking.fandom.com/wiki/Somalia
(35) https://deepgreenmovie.com/watch/deep-green-chapter-edition-green-building

1.2.5 Projects

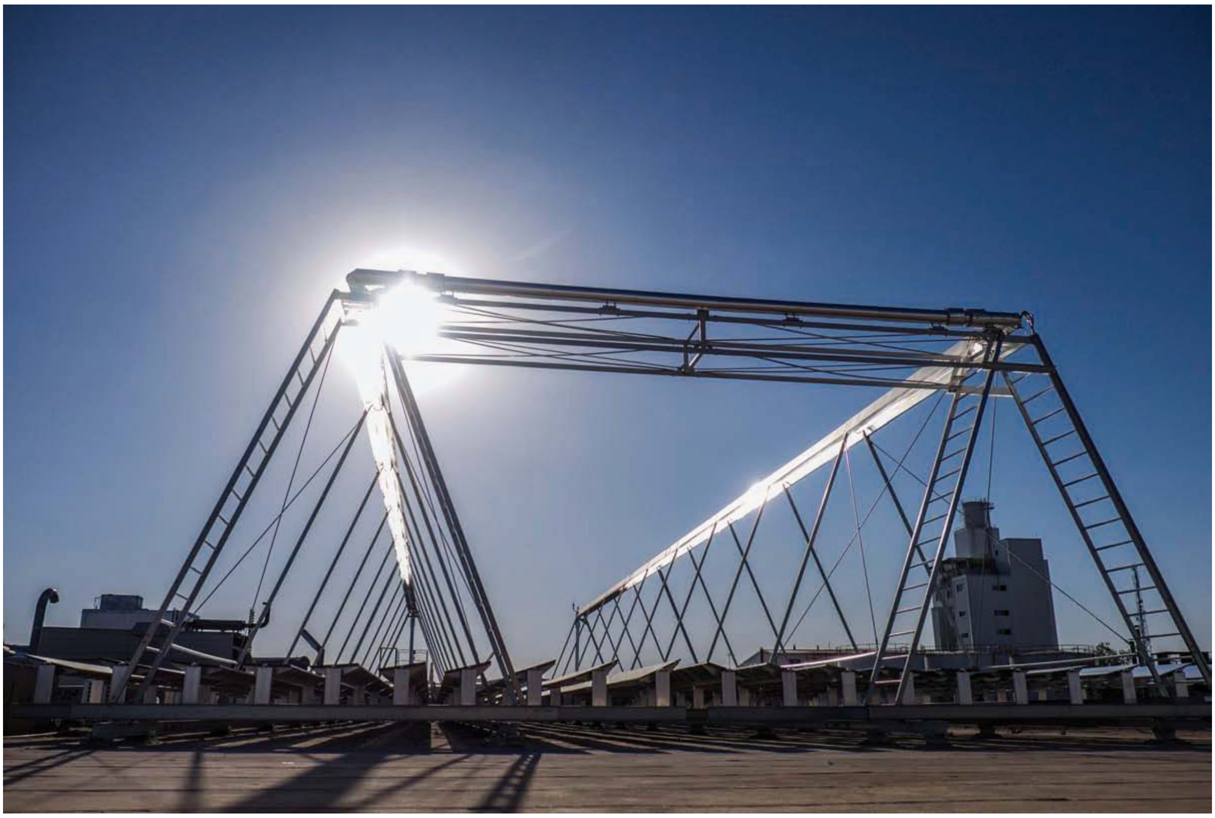
Industrial process heat Project (36)

Location: Jordan

Capacity: 700 kWth

Project Brief:
- A Fresnel collector field with an aperture capacity of 1,254 m^2
- Direct steam generation is used for solar process heating and solar thermal cooling with an absorption chiller.

Status: Operational



1.2.6 Further Reading:

Technology
D. Yogi Goswami.2014. Principles of Solar Engineering. Taylor & Francis Group
Link: https://www.advan-kt.com/principlesofsolarengi.pdf

John A. Duffie, William A. Beckman. 2013. Solar Engineering of Thermal Processes. John Wiley & Sons, Inc., Hoboken, New Jersey
Link: https://www.sku.ac.ir/Datafiles/BookLibrary/45/John%20A.%20Duffie,%20William%20A.%20Beckman(auth.)-Solar%20Engineering%20of%20Thermal%20Processes,%20Fourth%20Edition%20(2013).pdf

(36) https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2018.pdf

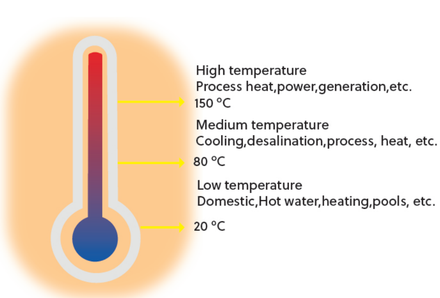
RENEWABLE ENERGY TECHNOLOGY

SOLAR THERMAL ENERGY

TECHNOLOGY DESCRIPTION

Solar energy can be utilized for various applications in addition to power generation, such as solar thermal systems in which the solar radiation is converted into heat.

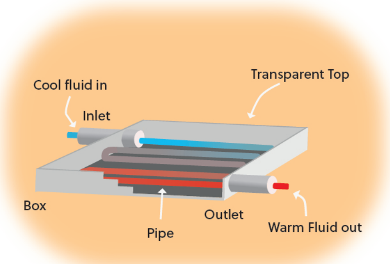
Solar thermal collectors are classified as low, medium, or high-temperature collectors. Low-temperature.



SOLAR WATER HEATING

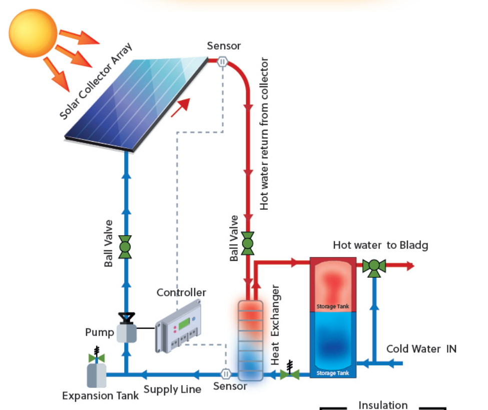
WORKING PRINCIPLE

Solar Thermal systems are used to warm up a heat transfer fluid, which can be air, water, or a specially designed fluid. The heated fluid can be utilized immediately for hot water or space heating/cooling, electricity generation, or a heat exchanger to transfer the thermal energy to the final application. The heat generated can also be kept +in a suitable storage tank for use when the sun is not shining.



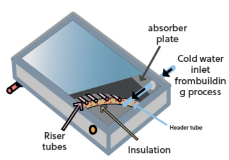
SYSTEM COMPONENTS

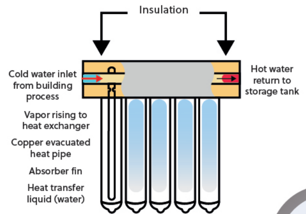
- **The collector array** is responsible for absorbing solar radiation and convert it into heat.
- **Housing;** for both the absorber and the fluid heat exchanger to minimize heat loss and degradation.
- **Heat transfer fluid;** can be used directly in the application for the direct or open-loop system. Or indirectly for the closed-loop system.
- **Circuit** to run the heat transfer fluid across the different parts of the system.
- **Storage tank** to store generated solar heat.



TYPES OF COLLECTORS

- UNGLAZED FLAT PLATED COLLECTOR
- GLAZED FLAT PLATED COLLECTOR
- EVACUATED TUBE COLLECTORS

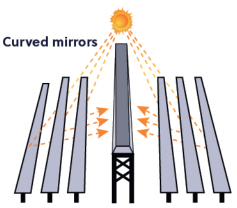




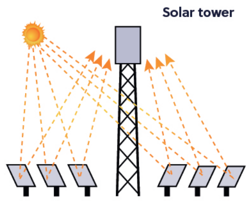
CONCENTRATED SOLAR POWER

Csp Is A High-temperature Application Where The Solar Heat Is Used To Raise The Temperature Of A Fluid To Be Used In A Steam Turbine To Generate Electricity.

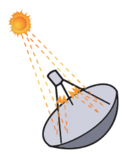
TYPES OF COLLECTORS:



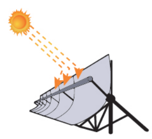
LINEAR FRESNEL REFLECTOR (IFR)



HELIOSTATS



DISH STIRLING



PARABOLIC TROUGH

SOLAR COOLING

The heat generated by solar thermal collectors is often suitable as the primary energy source for cooling water or air conditioning.

TYPES OF COOLING SYSTEMS:

- Absorption cycle
- Adsorption cycle
- Desiccant systems

DESIGN CONSIDERATIONS

The need for backup

The solar fraction describes the ratio of solar heat yield to the total energy requirement for the application—the higher the solar fraction, the lower the amount of energy required for the auxiliary system.

The selection of the heat transfer fluid

the heat transfer fluid should not freeze or boil. The medium should also have a high specific heat capacity, low viscosity and be non-toxic, inexpensive, and abundant.

Collector surface area

The collector surface area will depend on the average hot water demand, heating or cooling loads, or electrical load in CSP.

For SWH: Collector Area =

(Solar fraction x Operatinal days x Hot Water requirment)

(Solar irradiation x System efficiency)

Collector Orientation

The optimum performance is achieved when the azimuth is equal to 0 degrees.

ADVANTAGES	POINTS TO CONSIDER
• Renewable Energy Source. • Environment-friendly. • It helps in reducing the heating bill. • Reduces Fossil Fuel Depen dency • Cheap to Run • It can be combined with solar PV	• Intermittent source • High upfront cost (capital cost, land, storage, plumping, heat exchange system) • Land and space availability • Technical barriers in terms of building suitability

APPLICATIONS

- Solar domestic hot water
- Pool heating
- Hybrid solar heating
- Water Desalination
- Solar Oven
- Trombe wall
- Solar Refrigerator / Fridge
- Underfloor Space Heating

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