RENEWABLE ENERGY TECHNOLOGY

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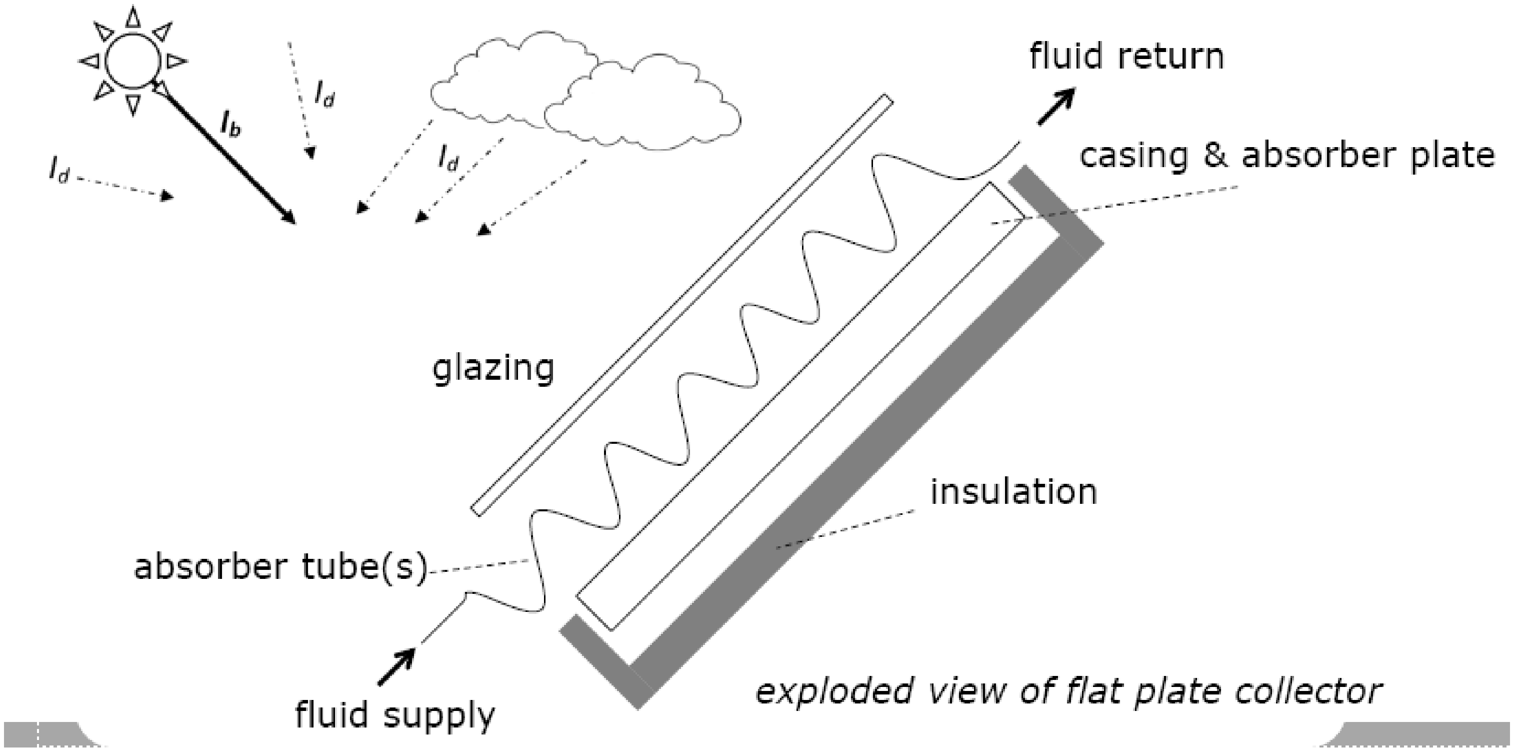
Solar Thermal Collector

- Solar collector is a device that absorbs the incoming solar radiation, converts it into heat, and transfers the heat to a fluid (usually air, water, or oil) flowing through the collector.



Solar Thermal Collector

Motion	Collector type	Absorber type	Concentration ratio	Indicative temperature range (°C)
Stationary	Flat-plate collector (FPC)	Flat	1	30–80
	Evacuated tube collector (ETC)	Flat	1	50–200
	Compound parabolic collector (CPC)	Tubular	1–5	60–240
Single-axis tracking			5–15	60–300
	Linear Fresnel reflector (LFR)	Tubular	10–40	60–250
	Cylindrical trough collector (CTC)	Tubular	15–50	60–300
	Parabolic trough collector (PTC)	Tubular	10–85	60–400
Two-axis tracking	Parabolic dish reflector (PDR)	Point	600–2000	100–1500
	Heliostat field collector (HFC)	Point	300–1500	150–2000

Note: Concentration ratio is defined as the aperture area divided by the receiver/absorber area of the collector.

Solar Thermal Collector

Non-concentrating or Stationary

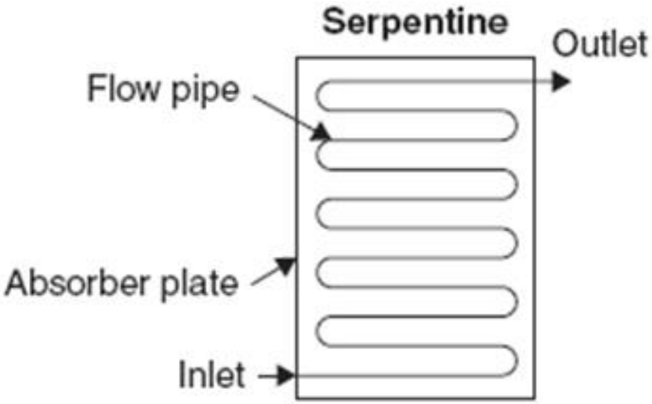
- Flat Plate Collector (FPC)
- Evacuated Tube Collector (ETC)
- Compound Parabolic Collector (CPC) *

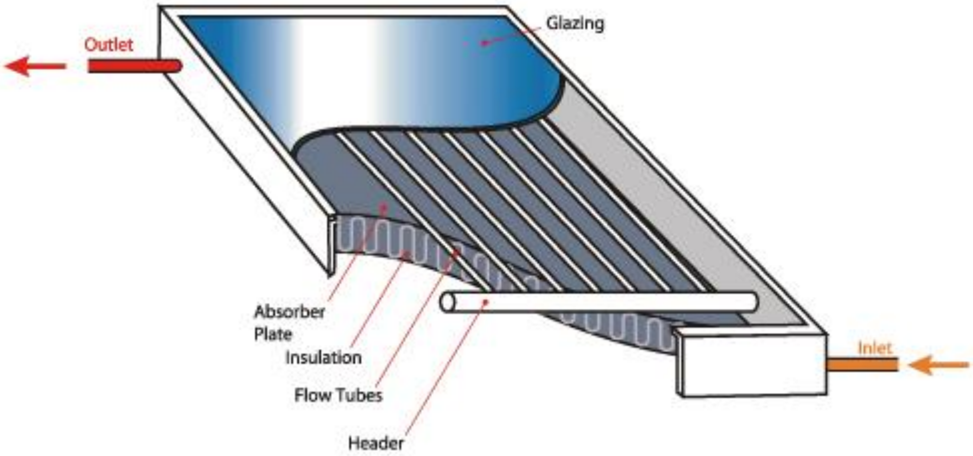
Concentrating

- Single-axis Tracking
  - Linear Fresnel reflector (LFR)
  - Cylindrical trough collector (CTC)
  - Parabolic through collector (PTC)
- Two-axis Tracking
  - Parabolic dish reflector (PDR)
  - Heliostat field collector (HFC)

Solar Thermal Collector

Flat Plate Collector:

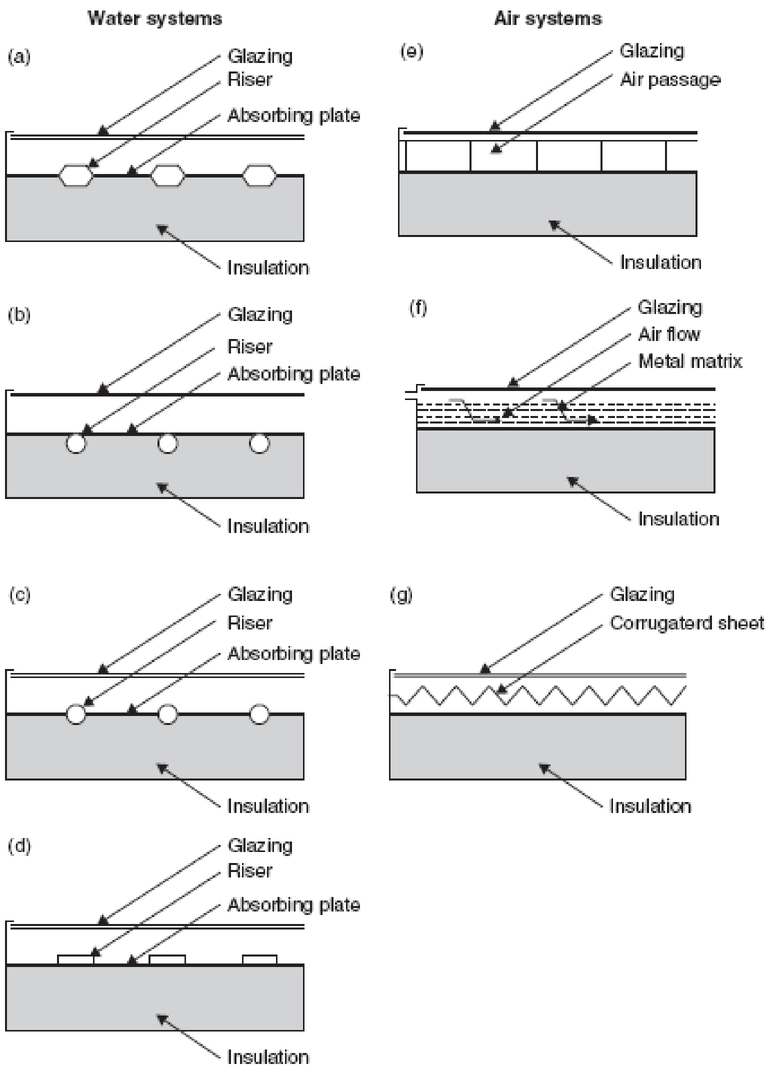




Solar Thermal Collector

Flat Plate Collector:

Various Types of FPC absorber configurations:



- Figure “a” shows a bonded sheet design, in which the fluid passages are integral to the plate to ensure good thermal conduction between the metal and the fluid.
- Figures “b” and “c” show fluid heaters with tubes soldered, brazed, or otherwise fastened to upper or lower surfaces of sheets or strips of copper
- Figure “d” shows the use of extruded rectangular tubing to obtain a larger heat transfer area between tube and plate.
- Copper tubes are used most often because of their superior resistance to corrosion.

The major difference between air and water-based collectors is the need to design an absorber that overcomes the heat transfer penalty caused by lower heat transfer coefficients between air and the solar absorber.

The principal requirement of these designs is a large contact area between the absorbing surface and the air. The thermal capacity of air is much lower than water, hence larger volume flow rates of air are required, resulting in higher pumping power.

Solar Thermal Collector

Flat Plate Collector:

- The collectors should be oriented directly toward the **equator**, facing south in the Northern Hemisphere and north in the Southern Hemisphere
- The optimum tilt angle of the collector is equal to the **latitude of the location**, with angle variations of 10 ° to 15 ° more or less, depending on the application.
  - Solar cooling- optimum angle is (latitude-10°)
  - Space heating- optimum angle is (latitude+10°)
  - Hot water production- optimum angle is (latitude+5°)

Advantages of FPC:

- Inexpensive to manufacture
- Collect both beam and diffuse radiation
- Permanently fixed in position (no tracking required)

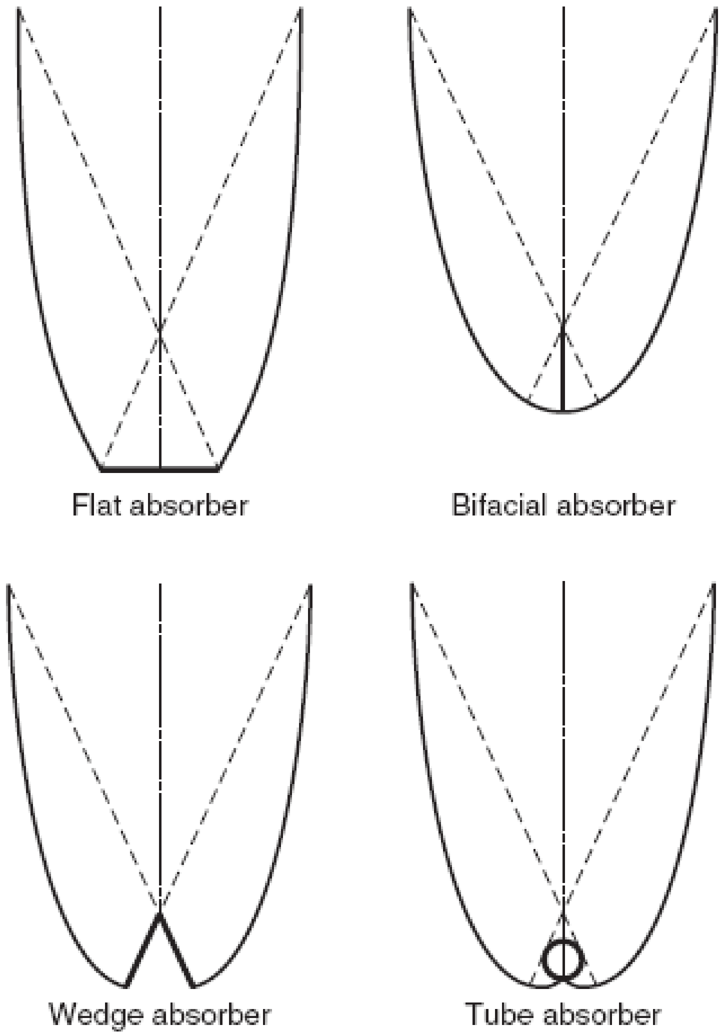
Solar Thermal Collector

Compound Parabolic Collectors:

- Compound parabolic collectors (CPCs) are non-imaging concentrators. They have the capability of reflecting to the absorber all of the incident radiation within wide limits.

Solar Thermal Collector

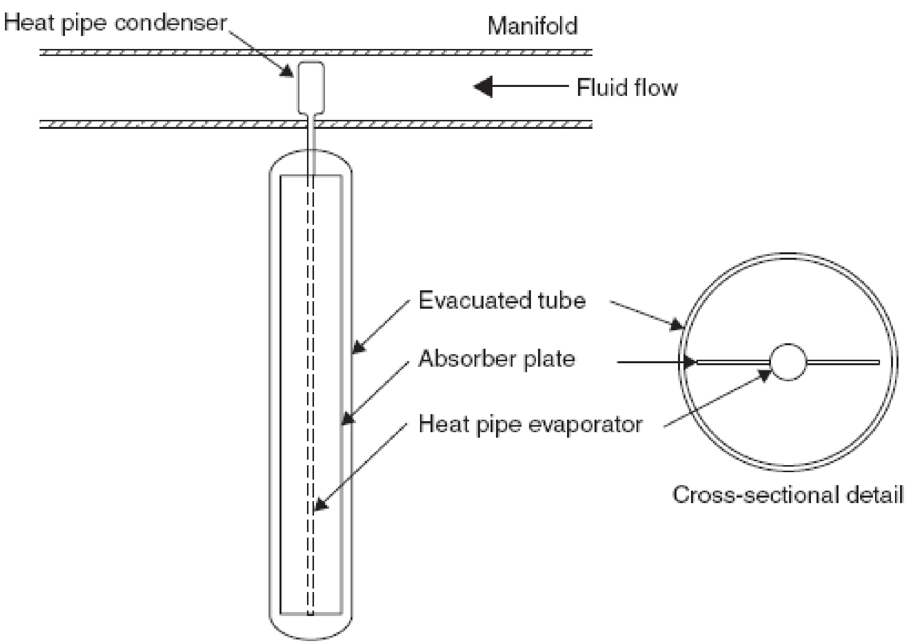
Compound Parabolic Collectors:

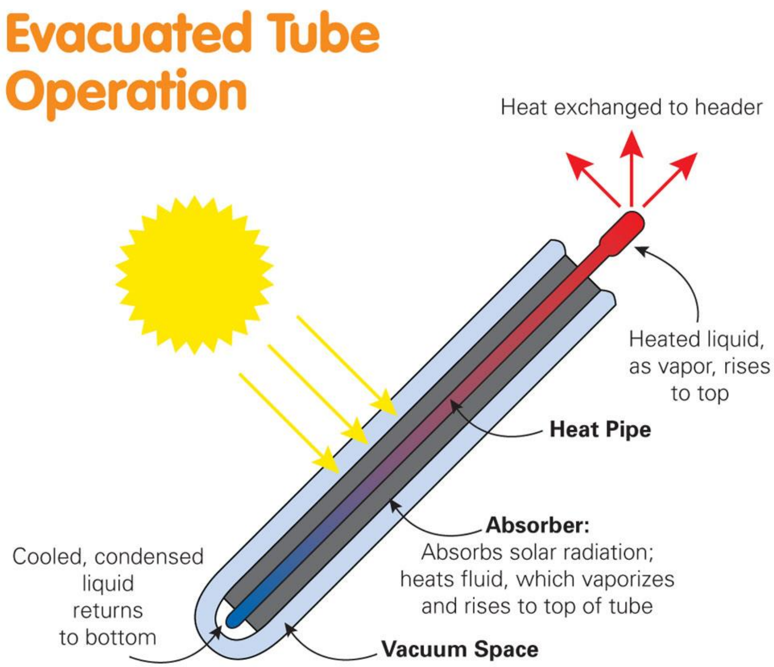


Solar Thermal Collector

Evacuated Tube Collectors**:**

- Conventional simple flat-plate solar collectors were developed for use in sunny, warm climates.
- ETCs consist of a heat pipe inside a vacuum-sealed tube.

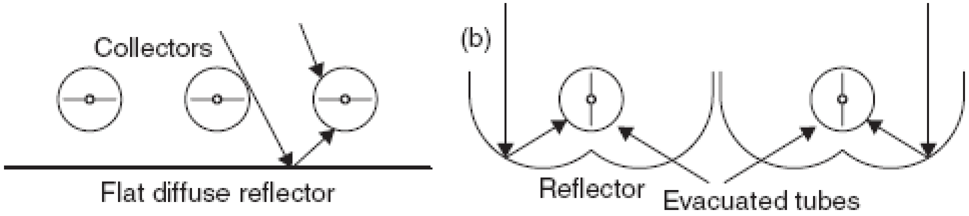




Solar Thermal Collector

Evacuated Tube Collectors:

- Evacuated tube collectors use liquid-vapor phase change materials to transfer heat at high efficiency.
- These collectors feature a heat pipe placed inside a vacuum-sealed tube. The pipe, which is a sealed copper pipe, is then attached to a black copper fin that fills the tube (absorber plate).
- Protruding from the top of each tube is a metal tip attached to the sealed pipe (condenser).
- The heat pipe contains a small amount of fluid (e.g. methanol) that undergoes an evaporating-condensing cycle.
- In this cycle, solar heat evaporates the liquid and the vapor travels to the heat sink region, where it condenses and releases its latent heat.
- The condensed fluid returns to the solar collector and the process is repeated.
- Heat pipe is a highly efficient thermal conductor
- ETCs are relatively expensive
- Number of tubes can be reduced by using reflectors to concentrate the solar radiation onto the tubes.



CONCENTRATED SOLAR THERMAL COLLECTORS

Non-concentrating or Stationary

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- Evacuated Tube Collector (ETC)
- Compound Parabolic Collector (CPC) *

Concentrating

- Single-axis Tracking
  - Linear Fresnel reflector (LFR)
  - Cylindrical trough collector (CTC)
  - Parabolic through collector (PTC)
- Two-axis Tracking
  - Parabolic dish reflector (PDR)
  - Heliostat field collector (HFC)

CONCENTRATED SOLAR THERMAL COLLECTORS

Why Concentrate?

Concentration increases the density of the radiant energy flux, allowing more power to be absorbed for a given surface area

Increased concentration means lowers areas for radiative heat loss, allowing effective receiver operation at higher temperatures

In a concentrating system two surfaces are defined:

- The **solar collector** intercepts the incident solar radiation, concentrates and redirects it
- Collector design fixes the aperture area A_a
- The **receiver**: intercepts the concentrated radiation and converts it to high temperature heat
- Receiver design fixes the receiver area A_r

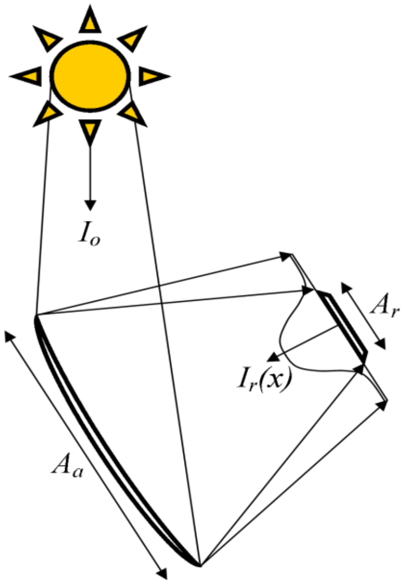

Image Source: J. Spelling, 2011

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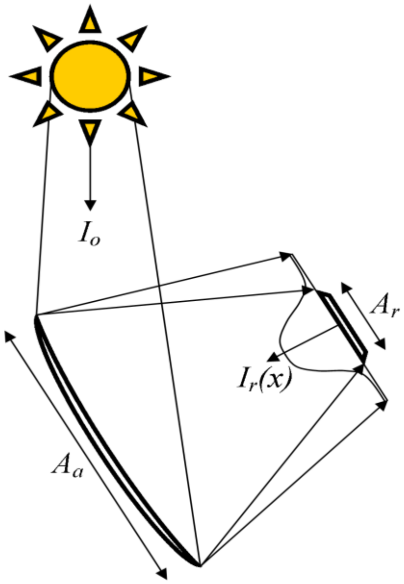
Only **beam radiation** can be harnessed by the solar collector, as the focusing system requires that incident rays have a clearly-defined direction



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CONCENTRATED SOLAR THERMAL COLLECTORS

Concentration Ratio

Concentration increases the density of the radiant energy flux, allowing more power to be absorbed for a given surface area

The key parameter that determines the level of temperature that can be reached is the solar concentration ratio

Two different definitions exist:

- **Geometric Concentration Ratio:** A simple ratio of receiver area to aperture area.

$$CR_g = \frac{A_a}{A_r}$$

- **Optical Concentration Ratio:** A more accurate value based on the intercepted solar flux.

$$CR_o = \frac{\frac{1}{A_r}\int I_r \, dA_r}{I_a}$$

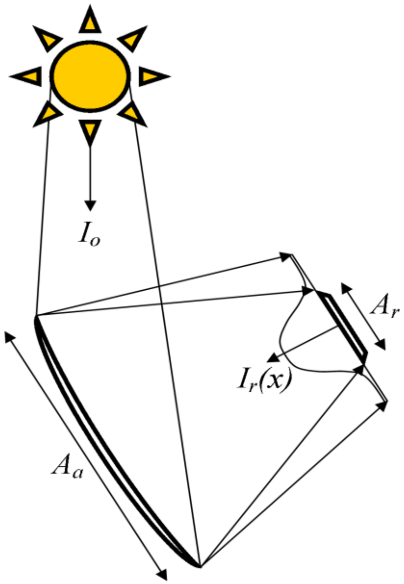


Image Source: J. Spelling, 2011

CONCENTRATED SOLAR THERMAL COLLECTORS

Energy Balance at the Receiver

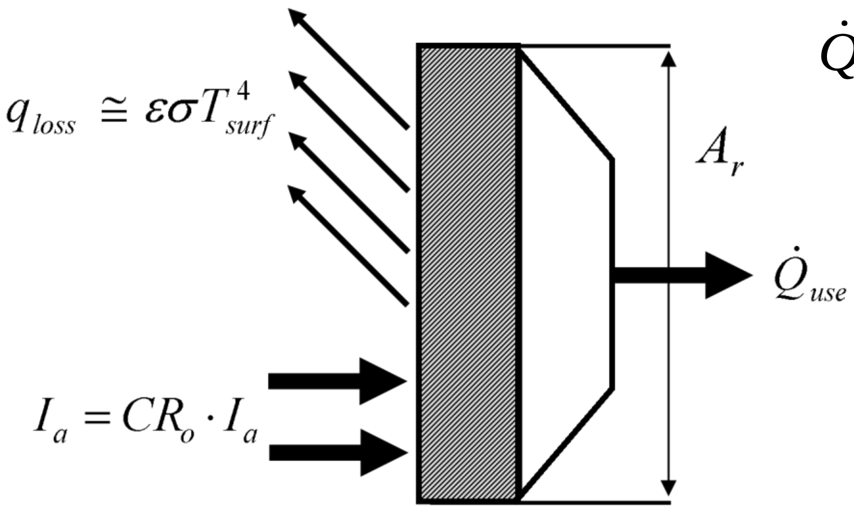
The energy balance at the receiver can be established as function of the operating temperature of the receiver

At higher temperatures the key losses will be by radiation from the surface of the receiver

The useful energy extracted is function of the temperature, the concentration ratio, the incident flux and some material properties:

$$\dot{Q}_{use} = A_r \alpha I_r - A_r \varepsilon \sigma T_{surf}^4$$

$$\dot{Q}_{use} = A_r \left(\alpha C R_o I_a - \varepsilon \sigma T_{surf}^4 \right)$$



α: *surface absorptivity* [-]
ε: *surface emissivity* [-]
σ: *Stephan-Boltzmann constant*
T_{surf}: *surface temperature* [K]
A_r: *receiver surface area* [m²]

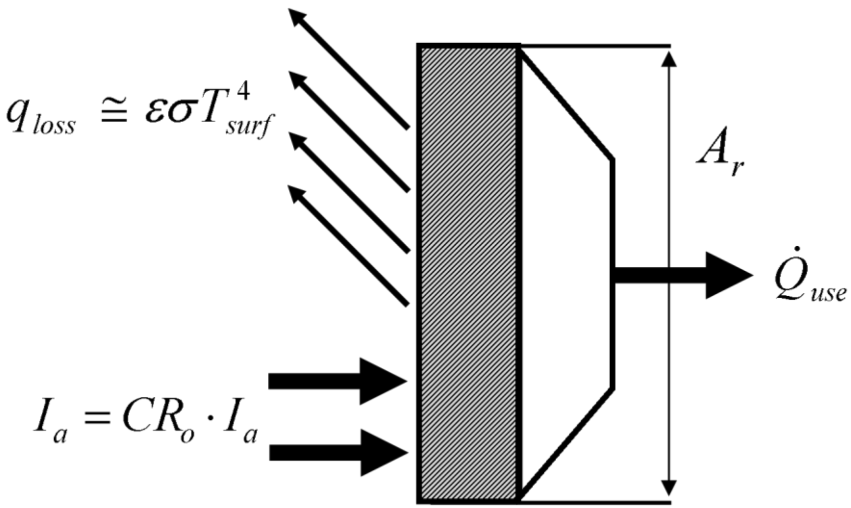
Image Source: J. Spelling, 2011

CONCENTRATED SOLAR THERMAL COLLECTORS

Maximum Temperature

- The maximum temperature that can be reached is when the useful energy extracted from the receiver is equal to zero
- The incident solar flux is dissipated by the radiation losses
- From the energy balance equation this gives:

$$\dot{Q}_{use} = A_r \alpha C R_o I_a - A_r \varepsilon \sigma T_{surf}^4 = 0$$



$$I_a = \eta_{opt} I_o$$

With $I_a = \eta_{opt} I_o$ (Optical efficiency)

Re-arranging, $\mathbf{T_{max}}$ can be found:

$$T_{max} = \sqrt[4]{\eta_{opt} \frac{\alpha}{\varepsilon} \frac{CR_o}{\sigma} I_o}$$

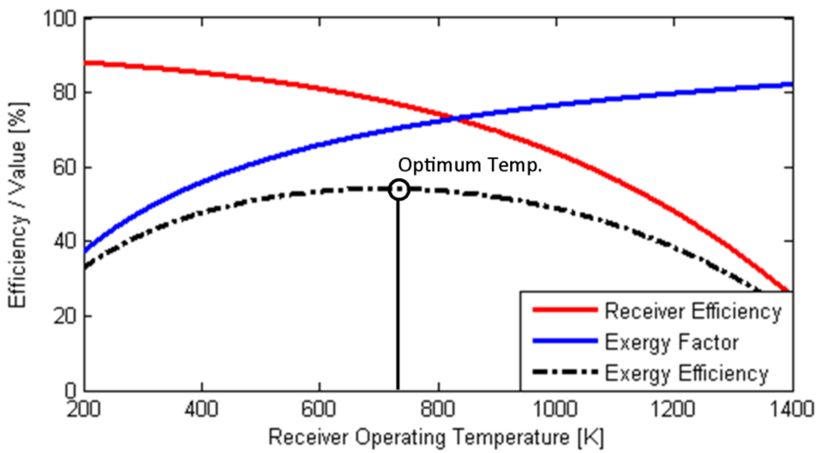
Image Source: J. Spelling, 2011

CONCENTRATED SOLAR THERMAL COLLECTORS

Optimum Temperature

- The optimum (thermodynamic) operating temperature for the receiver is the one which maximizes the useful exergy output of the solar receiver system
- The exergy output of the receiver is given by:

$$\dot{E}_q = \dot{Q}_{use}\left(1 - \frac{T_a}{T_{out}}\right) = A_r\left(\alpha\eta_{opt}CR_o I_o - \varepsilon\sigma T_{surf}^4\right)\left(1 - \frac{T_a}{T_{out}}\right)$$



The Optimum temperature strongly depends on the **Concentration ratio**

Example Graph has following data:

I_0 = 850 W/m^2, CR_O= 1000, n_{opt}= 0.9, *ε=α=0.85*

Image Source: J. Spelling, 2011

CONCENTRATED SOLAR THERMAL COLLECTORS

Solar Concentrator Systems

The achievable concentration ratio depends on whether 2D or 3D concentration is employed.

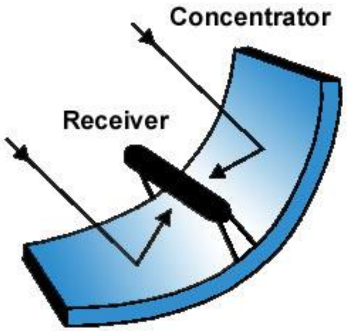
The upper limit is a result of the angle $\boldsymbol{\varepsilon}_s$ to which the sun subtends when viewed from the earth, limiting the minimum size of receiver.

Line Focusing Concentration

- Two-dimension concentration
- Operate with tracking rotation about only one axis

$$C_{2D}^{\max} = \frac{1}{\sin \varepsilon_s} \approx 212$$

- Real systems generally produce concentration ratios between 30 and 100

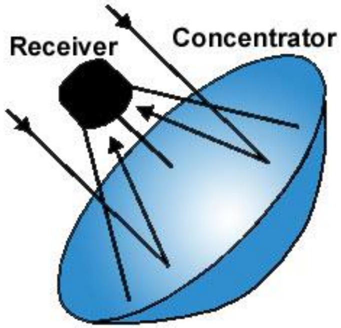


Point Focusing Concentration

- Three-dimensional concentration
- Require two-axis tracking to be effective

$$C_{3D}^{\max} = \frac{1}{\sin^2 \varepsilon_s} \approx 45000$$

- Real systems can produce concentration ratios above 1000



CONCENTRATED SOLAR THERMAL COLLECTORS

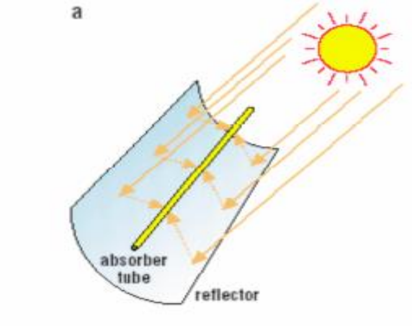
Line Focusing Systems

- Line focusing systems employ single-axis tracking and reach medium temperatures (between 120°C and 450°C)
- They can be used for both power production as well as high-temperature process heat in industrial applications.

Parabolic Trough Concentrators

- Fully parabolic in one axis to provide high optical efficiency
- Parabolic shape requires complex molding increasing cost
- Large mirror surface results in high wind loading, thus stronger structures

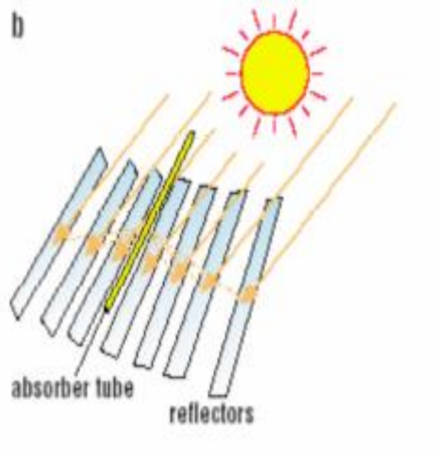
a



Linear Fresnel Concentrators

- A number of linear mirrors approximate parabolic concentration resulting in lower optical efficiencies
- Planar mirrors are simple and cheap to manufacture
- Gaps between mirrors, coupled with a lower centre of gravity result in lower loading and lighter structures

b

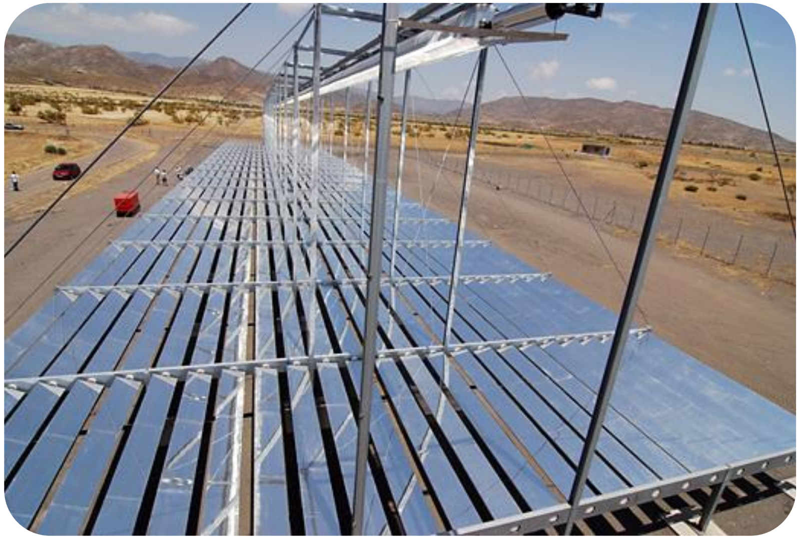


CONCENTRATED SOLAR THERMAL COLLECTORS

Line Focusing Systems

Parabolic Trough Concentrators

Linear Fresnel Concentrators



CONCENTRATED SOLAR THERMAL COLLECTORS

Point Focusing Systems

- Point focusing systems employ dual-axis tracking and can reach high temperatures (between 600°C and 2000°C)
- They are used mainly for power production, as well as solar chemistry and high-temperature materials testing

Heliostat Field Concentrators

- Many planar mirrors focus to a small receiver area, approximating full 3D concentration
- Large number of mirrors can be focused to one receiver, allowing multi-MW systems to be designed
- Planar mirrors are cheap to mass-produce
- Central power system benefits from economies of scale

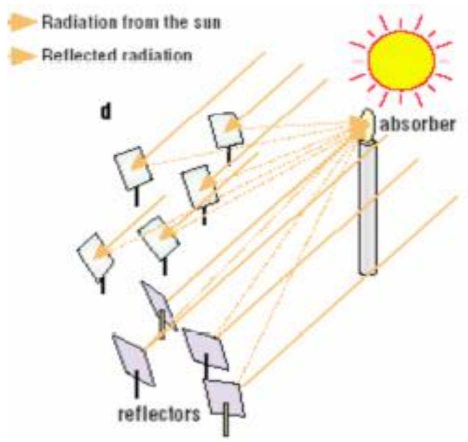
Parabolic Dish Concentrators

- True parabolic shape gives 3D concentration at high concentration ratios and high efficiencies
- Power output limited to ~25 kW_e by maximum dish diameter of ~15m due to optical precision and support
- Parabolic dish is a complex 3D geometry which is expensive to manufacture
- Dishes can be deployed modularly to increase the power output

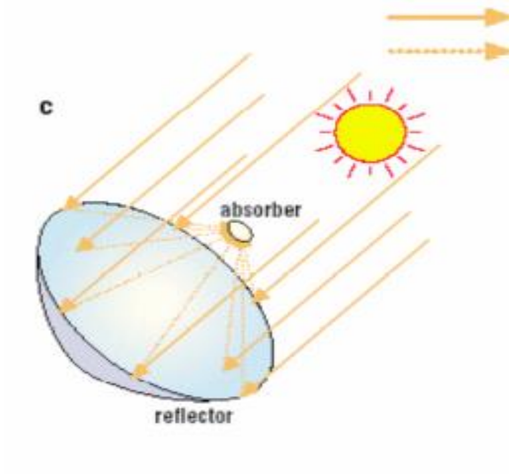
CONCENTRATED SOLAR THERMAL COLLECTORS

Point Focusing Systems

Heliostat Field Concentrators



Parabolic Dish Concentrators



Renewable Energy Technology

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