Thermal Analysis of Solar Collectors

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Types of solar collectors

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
	Parabolic trough collector (PTC)	Tubular	15-45	60-300
	Cylindrical trough collector (CTC)	Tubular	10-50	60-300
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100-1000	100-500
	Heliostat field collector (HFC)	Point	100-1500	150-2000

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

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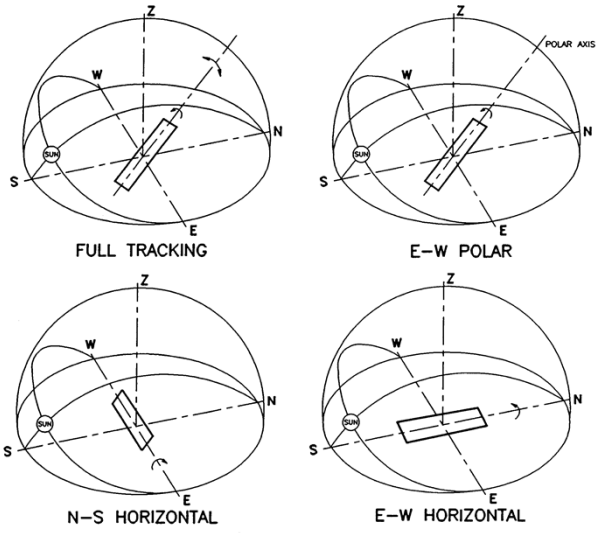

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Comparison of energy absorbed for various modes of tracking

Tracking mode	Solar energy (kWh/m^2)			Percent to full tracking		
	E	SS	WS	E	SS	WS
Full tracking	8.43	10.60	5.70	100.0	100.0	100.0
E-W Polar	8.43	9.73	5.23	100.0	91.7	91.7
N-S Horizontal	6.22	7.85	4.91	73.8	74.0	86.2
E-W Horizontal	7.51	10.36	4.47	89.1	97.7	60.9
Note: E - Equinoxes, SS - Summer Solstice, WS - Winter Solstice						

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Stationary collectors

No concentration

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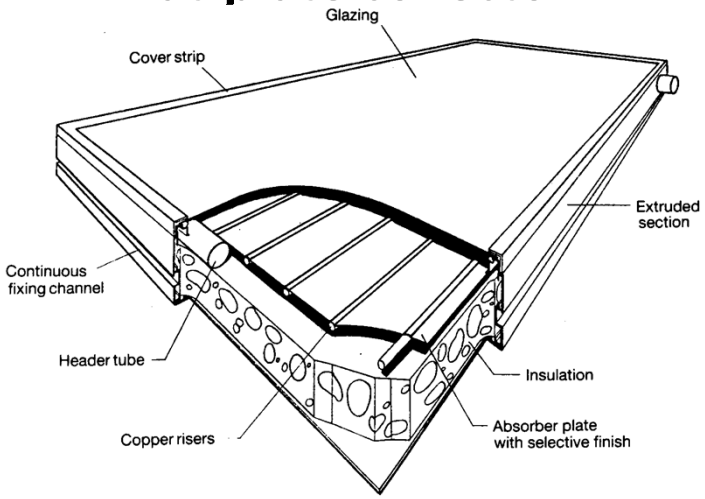
Flat-plate collector



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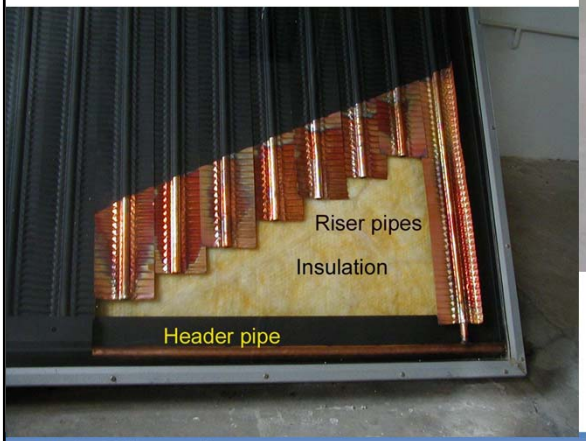
Flat-plate Collector



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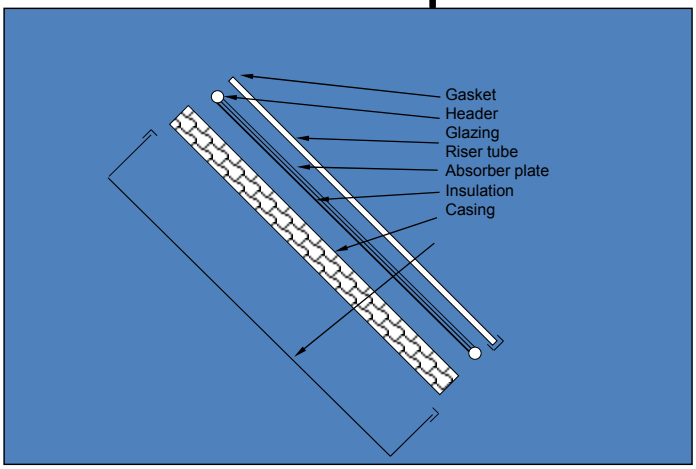
Exploded view of a flat-plate collector



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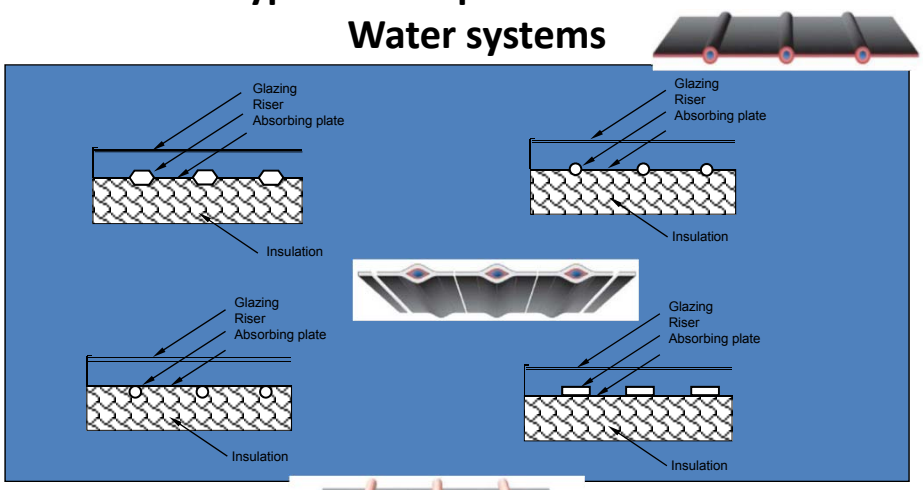
Types of flat-plate collectors

Water systems



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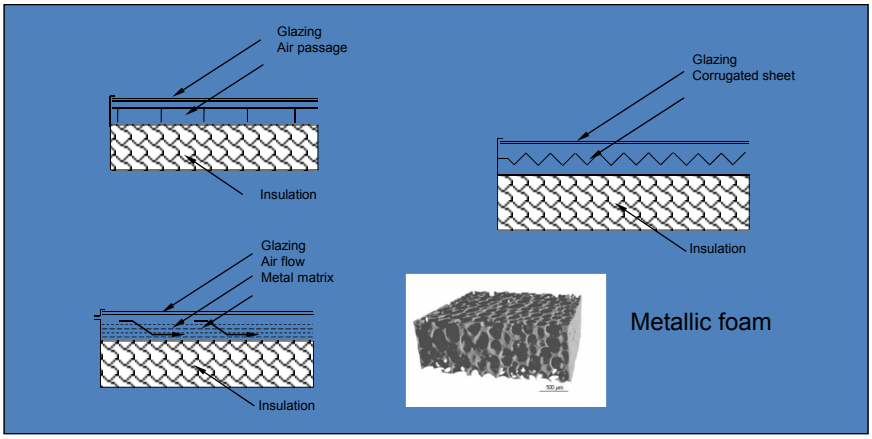
Types of flat-plate collectors
Air systems



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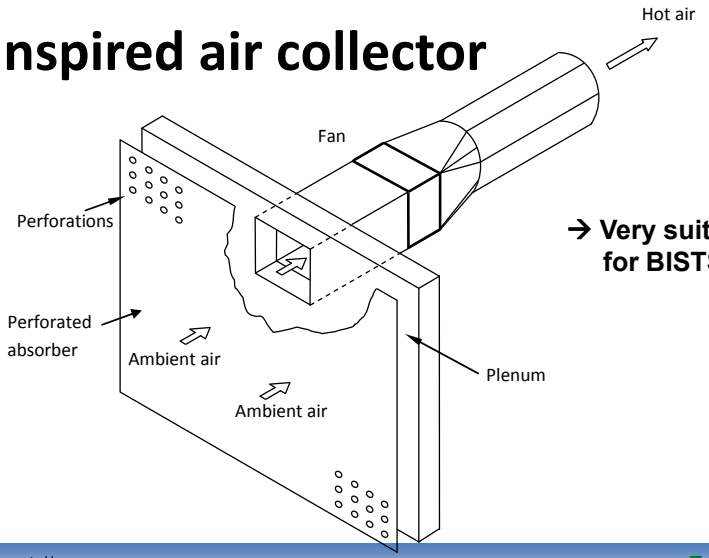
Transpired air collector



→ Very suitable for BISTS

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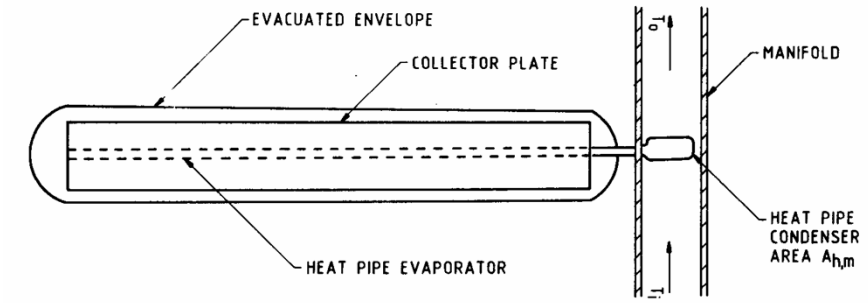
Schematic diagram of an evacuated tube collector



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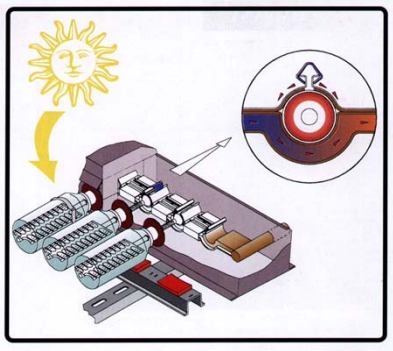
Evacuated tube collectors



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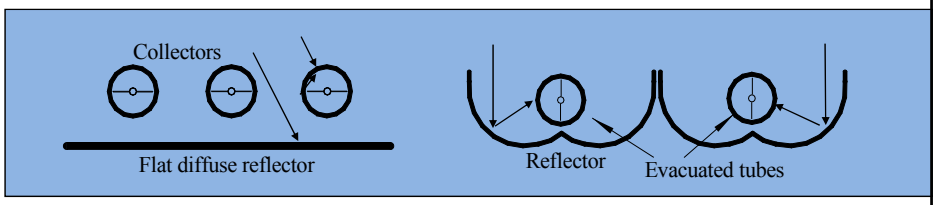
Combination of collectors



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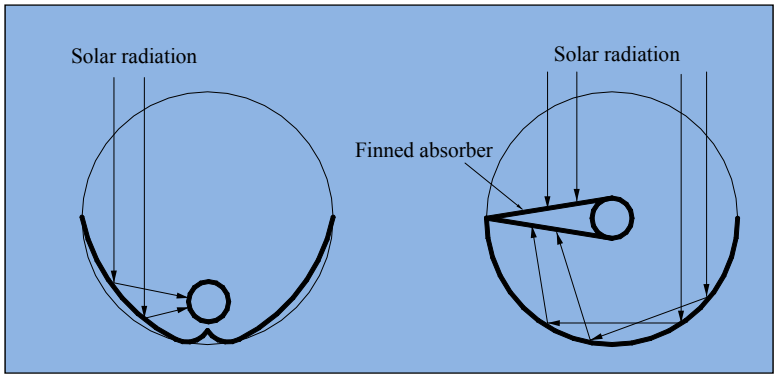
ICPC Collector



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Stationary collectors

Concentrating

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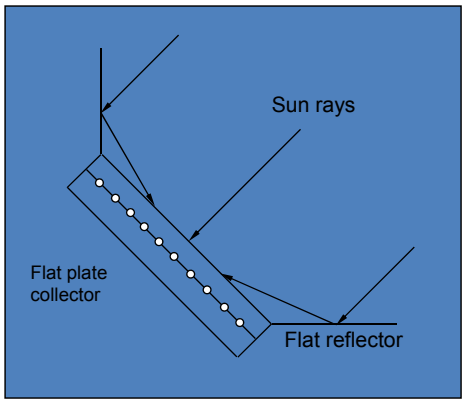
Flat plate collector with flat reflectors



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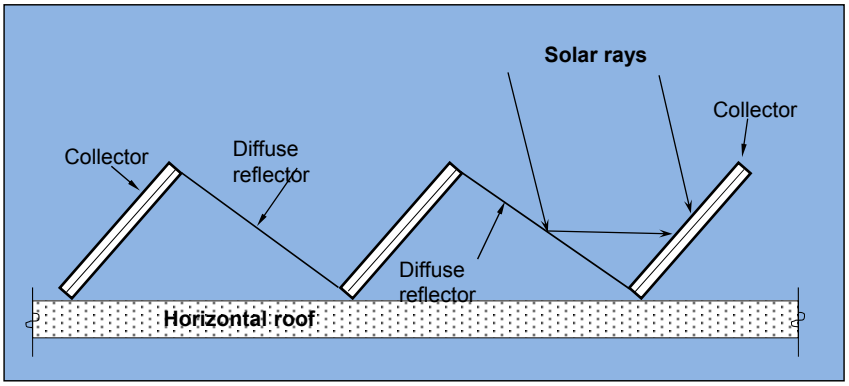
Saw-tooth arrangement



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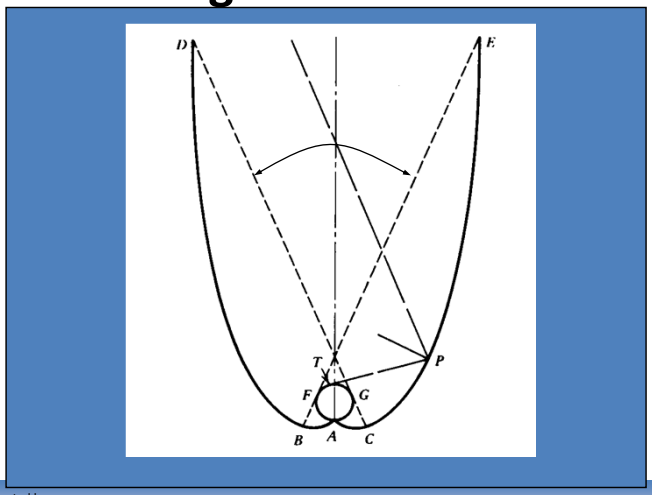
Schematic diagram of a CPC collector



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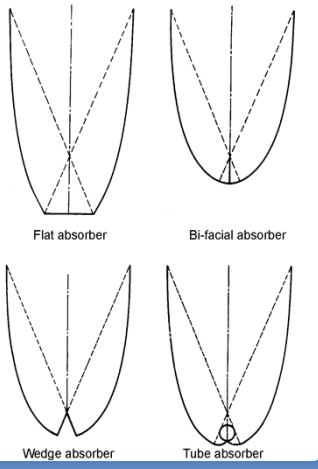
CPC types



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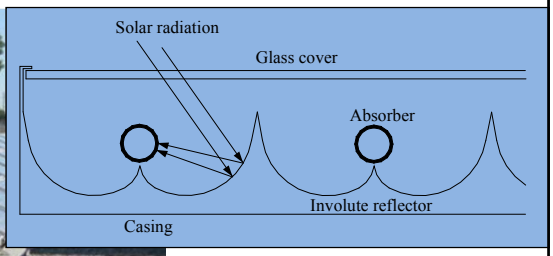
Application as flat plate collector



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Sun tracking collectors

Concentrating

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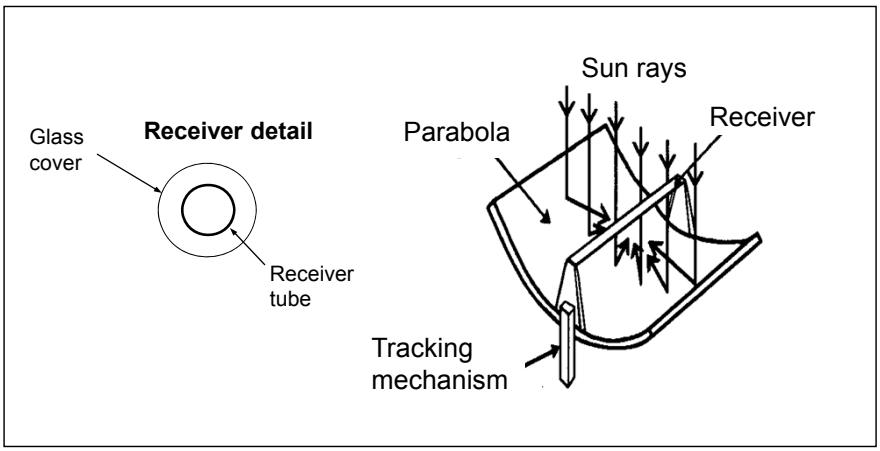
Schematic of a parabolic trough collector



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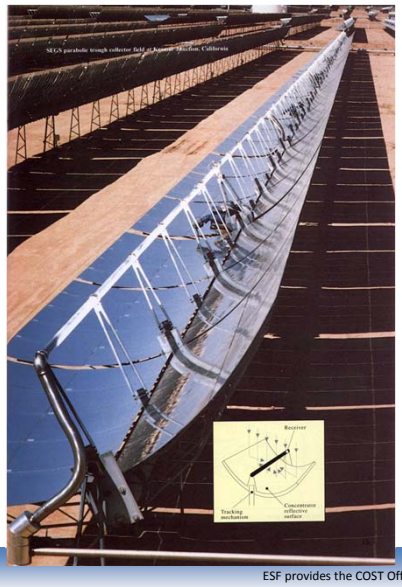
Parabolic trough collectors



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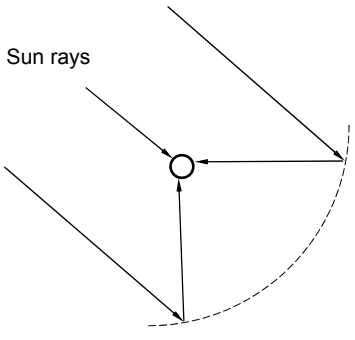
Fresnel type parabolic trough collector



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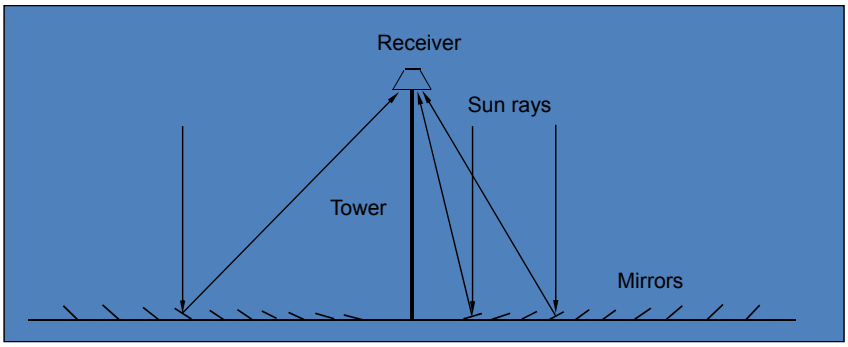
Schematic diagram of a downward facing receiver illuminated from a Linear Fresnel Reflector (LFR) field



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Schematic diagram showing interleaving of mirrors in a CLFR with reduced shading between mirrors

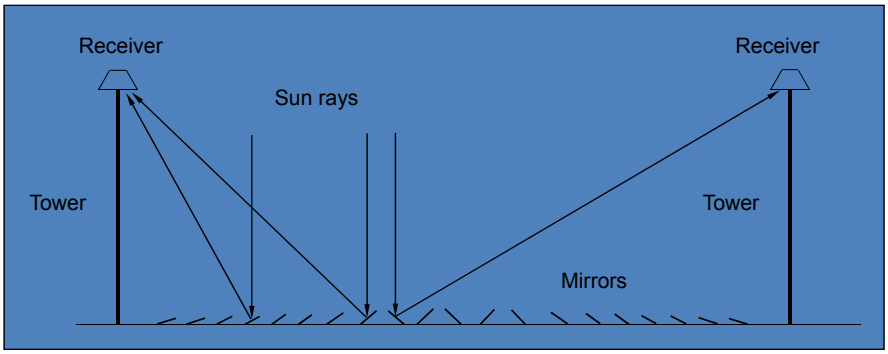

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Photo of Fresnel system

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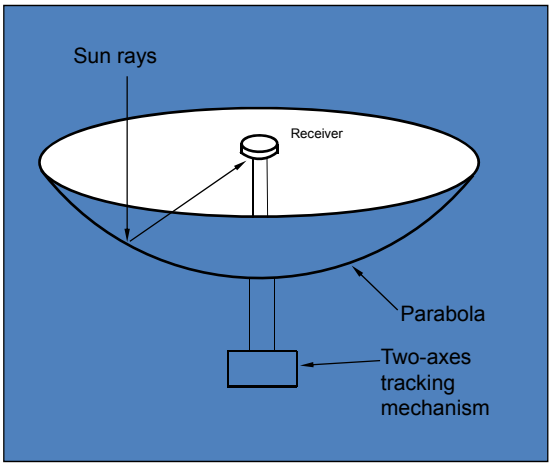
Schematic of a parabolic dish collector



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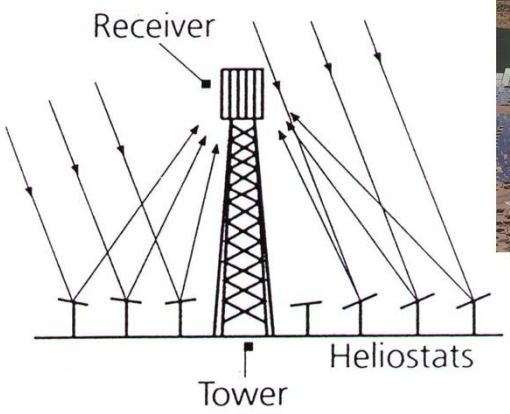
Schematic of central receiver system



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Thermal analysis of collectors

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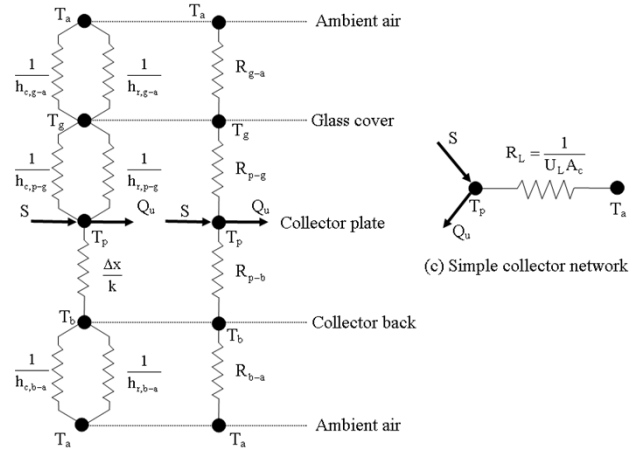
Flat-plate collector thermal losses



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Flat-plate collector thermal losses

- From the simple thermal network the collector thermal losses are:

$$Q_{loss} = \frac{T_p - T_a}{R_L} = U_L A_c (T_p - T_a)$$

- The total heat loss coefficient U_L is given by:

$$U_L = U_t + U_b + U_e \qquad \text{(top, back, edges)}$$

- The various relations can be obtained from basic heat transfer analysis

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Empirical relation

- This relation gives adequate accuracy:

$$U_t = \frac{1}{\frac{N_g}{\frac{C}{T_p}\left[\frac{T_p - T_a}{N_g + f}\right]^{0.33}} + \frac{1}{h_w}} + \frac{\sigma\left(T_p^2 + T_a^2\right)\left(T_p + T_a\right)}{\frac{1}{\varepsilon_p + 0.05N_g\left(1-\varepsilon_p\right)} + \frac{2N_g + f - 1}{\varepsilon_g} - N_g}$$

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- Where:

$$f = \left(1 - 0.04h_w + 0.0005h_w^2\right)\left(1 + 0.091N_g\right)$$

$$C = 365.9\left(1 - 0.00883\beta + 0.0001298\beta^2\right)$$

$$h_w = \frac{8.6V^{0.6}}{L^{0.4}}$$

- The minimum value of wind heat loss coefficient, h_w for still air is 5 W/m^{2}K, so if above equation gives a lower value we use this value as a minimum.

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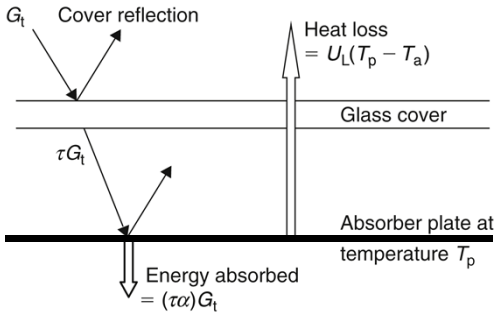
Useful energy collected from a flat plate collector



- In the form of equation this is given by:

$$Q_u = A_c\left[G_t(\tau\alpha) - U_L\left(T_p - T_a\right)\right] = \dot{m}c_p\left[T_o - T_i\right]$$

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Useful energy collected from a collector-Flat plate

- General formula:

$$Q_u = A_c\left[G_t(\tau\alpha) - U_L\left(T_p - T_a\right)\right] = mc_p\left[T_o - T_i\right]$$

- by substituting inlet fluid temperature (T_i) for the average plate temperature (T_p):

$$Q_u = A_c F_R\left[G_t(\tau\alpha) - U_L\left(T_i - T_a\right)\right]$$

  - Where F_R is the heat removal factor

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Heat removal factor

- Heat removal factor represents the ratio of the actual useful energy gain that would result if the collector-absorbing surface had been at the local fluid temperature.
- Equation:

$$F_R = \frac{\dot{m}c_p}{A_c U_L}\left(1 - \mathrm{Exp}\left[-\frac{U_L F' A_c}{\dot{m}c_p}\right]\right)$$

F′=collector efficiency factor

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Collector efficiency

- Finally, the collector efficiency can be obtained by dividing Q_u by (G_t A_c). Therefore:

$$\eta = F_R\left[(\tau\alpha) - \frac{U_L(T_i - T_a)}{G_t}\right]$$

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Concentration ratio

- The concentration ratio (C) is defined as the ratio of the aperture area to the receiver/absorber area, i.e.:

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

- For flat-plate collectors with no reflectors, C=1. For concentrators C is always greater than 1. For a single axis tracking collector the maximum possible concentration is given by:

$$C_{\max} = \frac{1}{\sin(\theta_m)}$$

- and for two-axes tracking collector:

$$C_{\max} = \frac{1}{\sin^2(\theta_m)}$$

where θ_m is the half acceptance angle limited by the size of the sun's disk, small scale errors and irregularities of the reflector surface and tracking errors.

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Maximum concentration

- For a perfect collector and tracking system C_{max} depends only on the sun's disk which has a width of 0.53° (32′). Therefore:
- For single axis tracking:

  $C_{max} = 1/\sin(16') = 216$
- For full tracking:

  $C_{max} = 1/\sin^2(16') = 46{,}747$

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Concentrating collectors

- The useful energy delivered from a concentrator is:

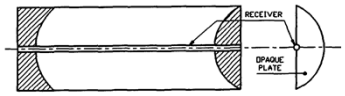
$$Q_u = G_b \eta_o A_a - A_r U_L \left(T_r - T_a\right)$$

- Where n_o is the optical efficiency given by:

$$\eta_o = \rho\tau\alpha\gamma\left[\left(1 - A_f \tan(\theta)\right)\cos(\theta)\right]$$

- And A_f is the geometric factor given by:

$$A_f = \frac{2}{3} W_a h_p + f W_a \left[1 + \frac{W_a^2}{48 f^2}\right]$$



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Concentrating collectors efficiency

- Similarly as for the flat-plate collector the heat removal factor can be used:

$$Q_u = F_R\left[G_b \eta_o A_a - A_r U_L \left(T_i - T_a\right)\right]$$

- And the collector efficiency can be obtained by dividing Q_u by $(G_b A_a)$:

$$n = F_R\left[\eta_o - U_L\left(\frac{T_i - T_a}{G_b C}\right)\right]$$

Note C in the denominator

PERFORMANCE OF SOLAR COLLECTORS

- The thermal performance of the solar collector is determined by obtaining:
  - values of instantaneous efficiency for different combinations of incident radiation, ambient temperature, and inlet fluid temperature.
  - the transient thermal response characteristics of the collector (time constant).
  - the variation of steady-state thermal efficiency with incident angles between the direct beam and the normal to collector aperture area at various sun and collector positions (incidence angle modifier).

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Collector efficiency

- For flat-plate collectors:

$$\eta = F_R(\tau\alpha) - F_R U_L \left(\frac{T_i - T_a}{G_t} \right)$$

- For concentrating collectors:

$$\eta = F_R \eta_o - \frac{F_R U_L}{C} \frac{(T_i - T_a)}{G_b}$$

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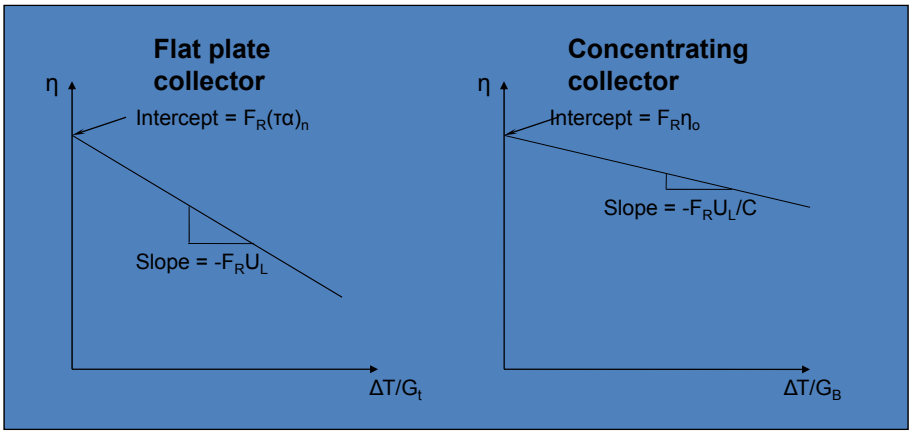
Efficiency plots

More details on a special presentation



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Thank you for your attention,

any questions please….

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