بسم الله الرحمن الرحيم

Benha University

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Postgraduate (Pre-master) Course

Generation of Electrical Power from Renewable Resources

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Syllabus

1. ***INTRODUCTION.***
2. ***SOLAR PHOTOVOLTAIC POWER SYSTEM.***
3. ***SOLAR THERMAL POWER SYSTEM.***
4. ***WIND POWER SYSTEM.***
5. ***ENERGY STORAGE SYSTEMS.***
6. ***STAND-ALONE SYSTEM.***
7. ***GRID-CONNECTED SYSTEM.***

Solar Thermal Power Plants

History

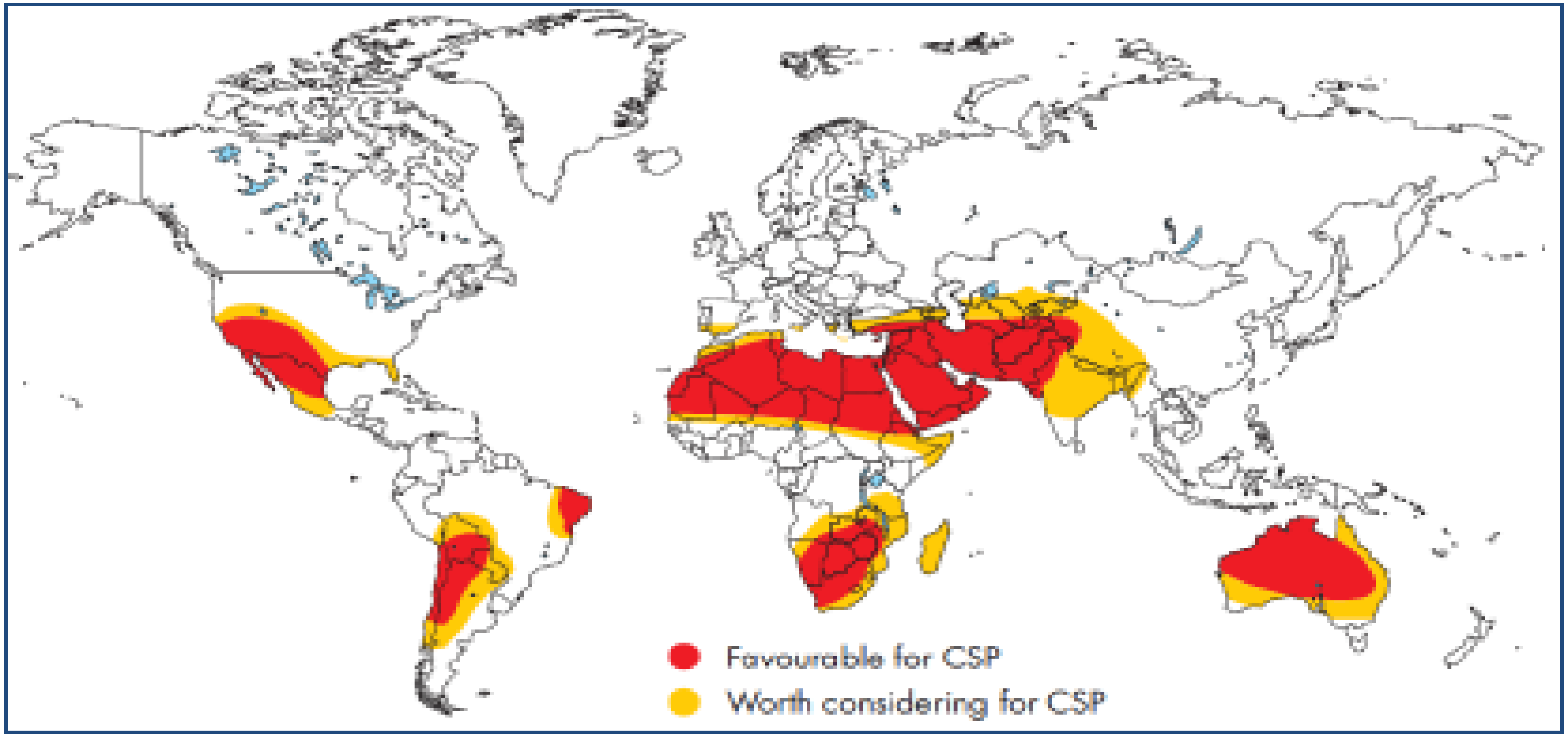
Concentrated Solar Power (CSP) Plants

CSP in Egypt, the history

Frank Shuman parabolic solar collectors, Maadi, Egypt, 1912

[K. Butti and J. Perlin: A golden thread: 2500 years of solar architecture and technology, Cheshire Books, 1980.]

World CSP Map

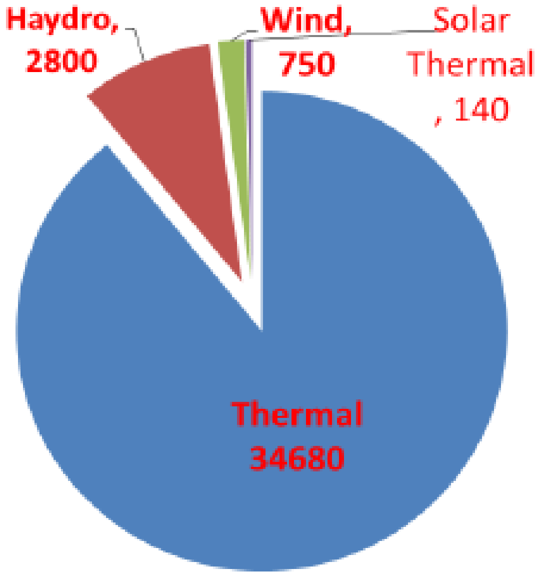


Egypt and the solar belt

Egypt as a part of the solar belt (suitable locations for CSP applications)
2900-3200 annual sunshine hours, 1970- 3200 kWh/m^2 annual DNI

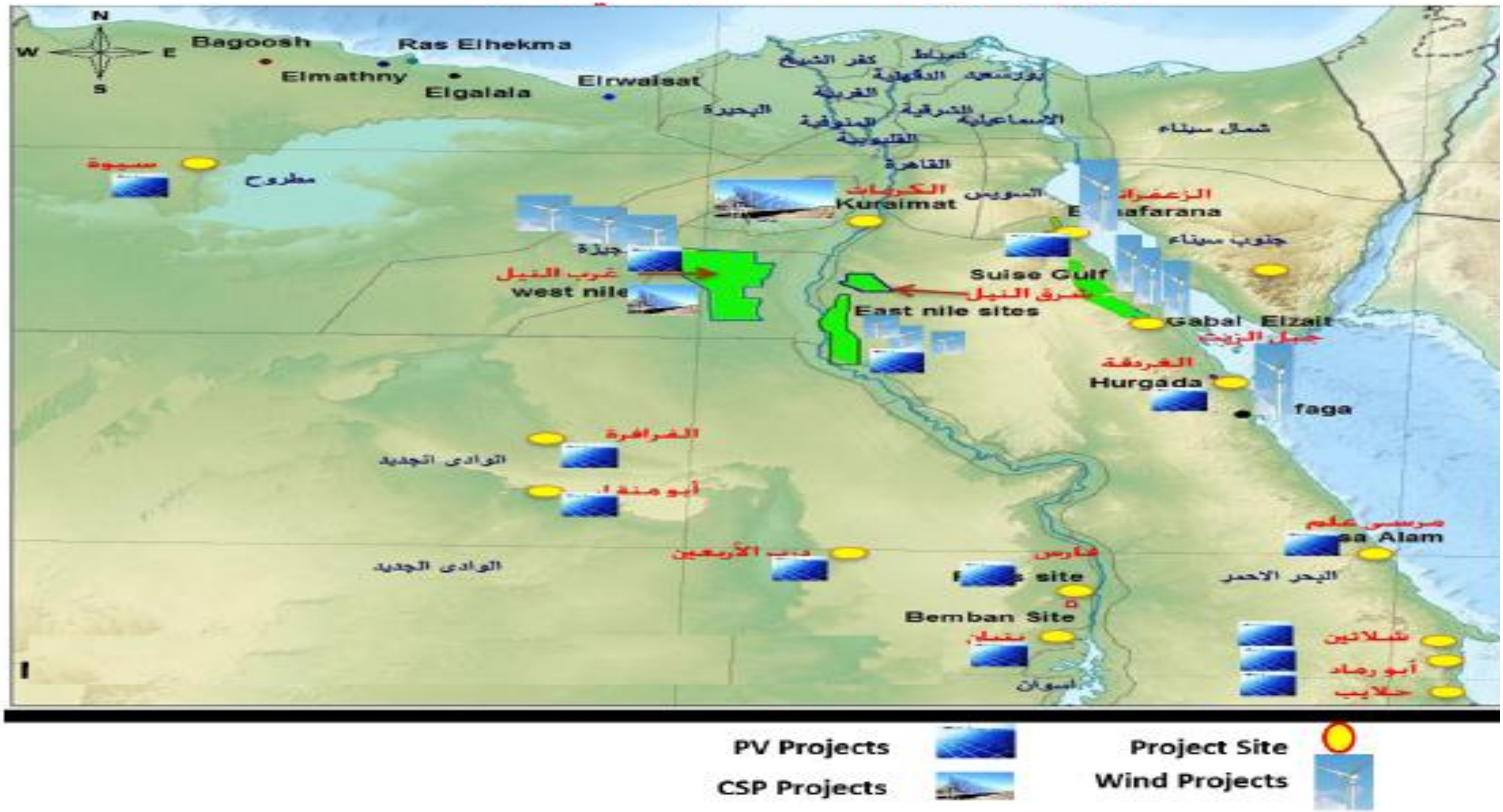
Solar Energy Current & Future in Egypt

- Total installed capacity about 38 GW
  - 34.7 thermal,
  - 2.8 hydro,
  - 0.75 wind,
  - 0.14 CSP
  - 0.03 PV



- Renewable Energy (Wind & solar) represent about 2.5% from the capacity & 0.8% from the electric energy.
- Targeting to reach 20% of the electricity generation by year 2022.

Possible Sites for Renewable Energy projects in Egypt



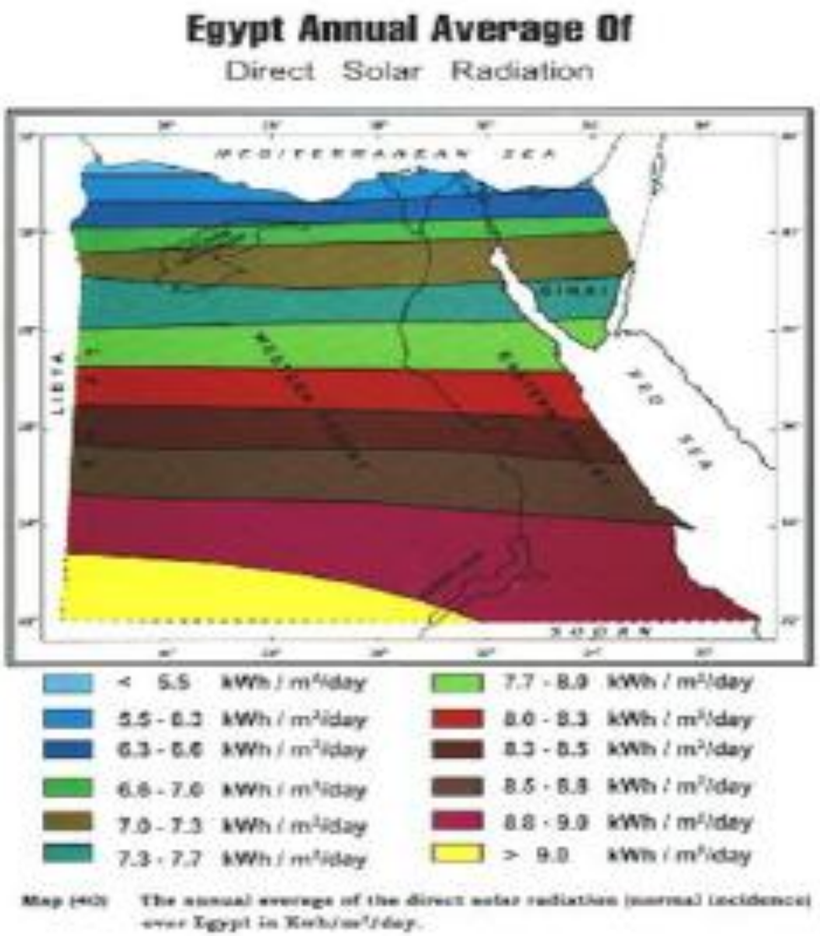
Egyptian National Strategy up to 2022

The Egyptian National Strategy targets to reach 20% of the electricity generation by year 2022 as follows:

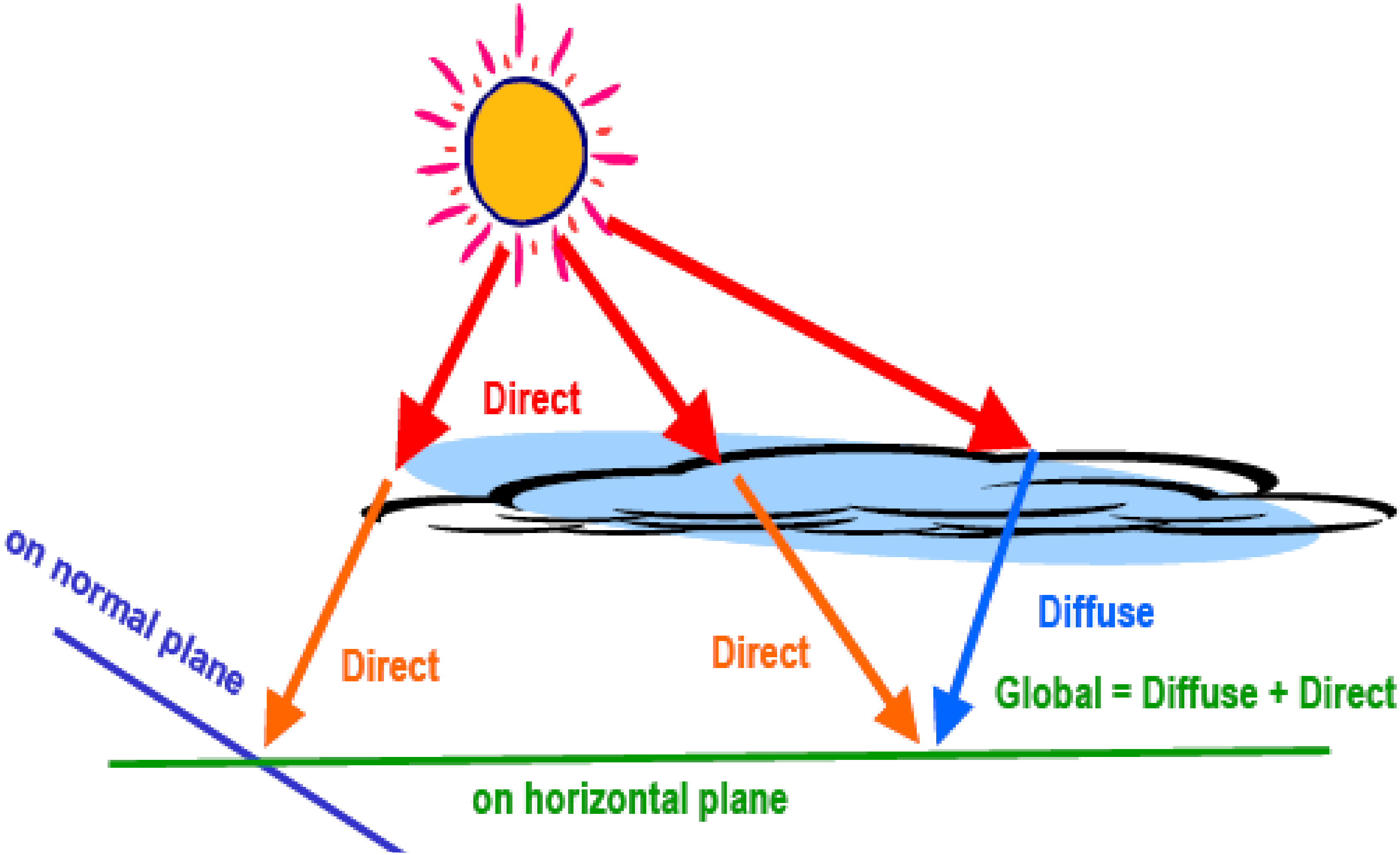
Renewable Energy Source	Capacity (MW)	Energy (TWh) & %
Wind	6810	30.6 (12%)
Solar	2879	2.2 (2%)
Hydro	2800	14 (6%)

Solar resources assessment

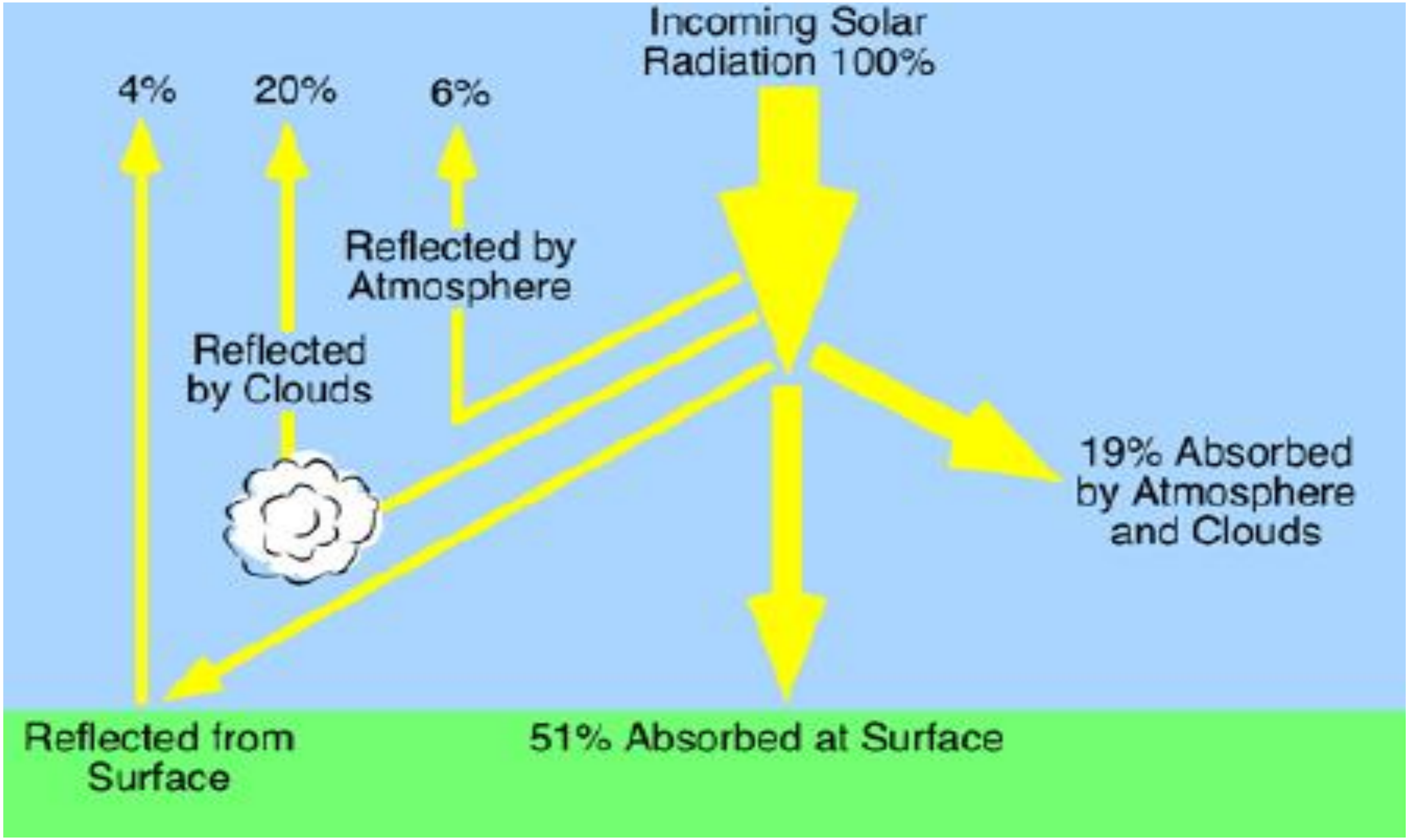
- **Average annual direct normal solar radiation reaches (2000-3200) kWh/m²/year.**
- **Average sun shine duration ranges between 9-11 h/day from North to South, with very few cloudy days.**



Measurement of Solar Radiation



Measurement of Solar Radiation



Solar Radiation Measurement Devices

Global solar radiation

Pyranometer

Diffuse radiation

Pyranometer

Direct solar radiation

pyrheliometer

Thermodynamic conversion efficiency

- **The maximum thermodynamic conversion efficiency that can be theoretically achieved with the hot side temperature T_{hot} and the cold side temperature T_{cold} is given by the Carnot cycle efficiency, which is as follows**

$$\eta_{Carnot} = \frac{T_{hot} - T_{Cold}}{T_{hot}}$$

Applications of Solar Thermal Systems

- **Heating of domestic hot water in small residential applications**

Applications of Solar Thermal Systems

- **Heating of domestic hot water in collective applications (residential, hotels, hospitals, sport centers).**

Applications of Solar Thermal Systems

- **Space heating.**

Applications of Solar Thermal Systems

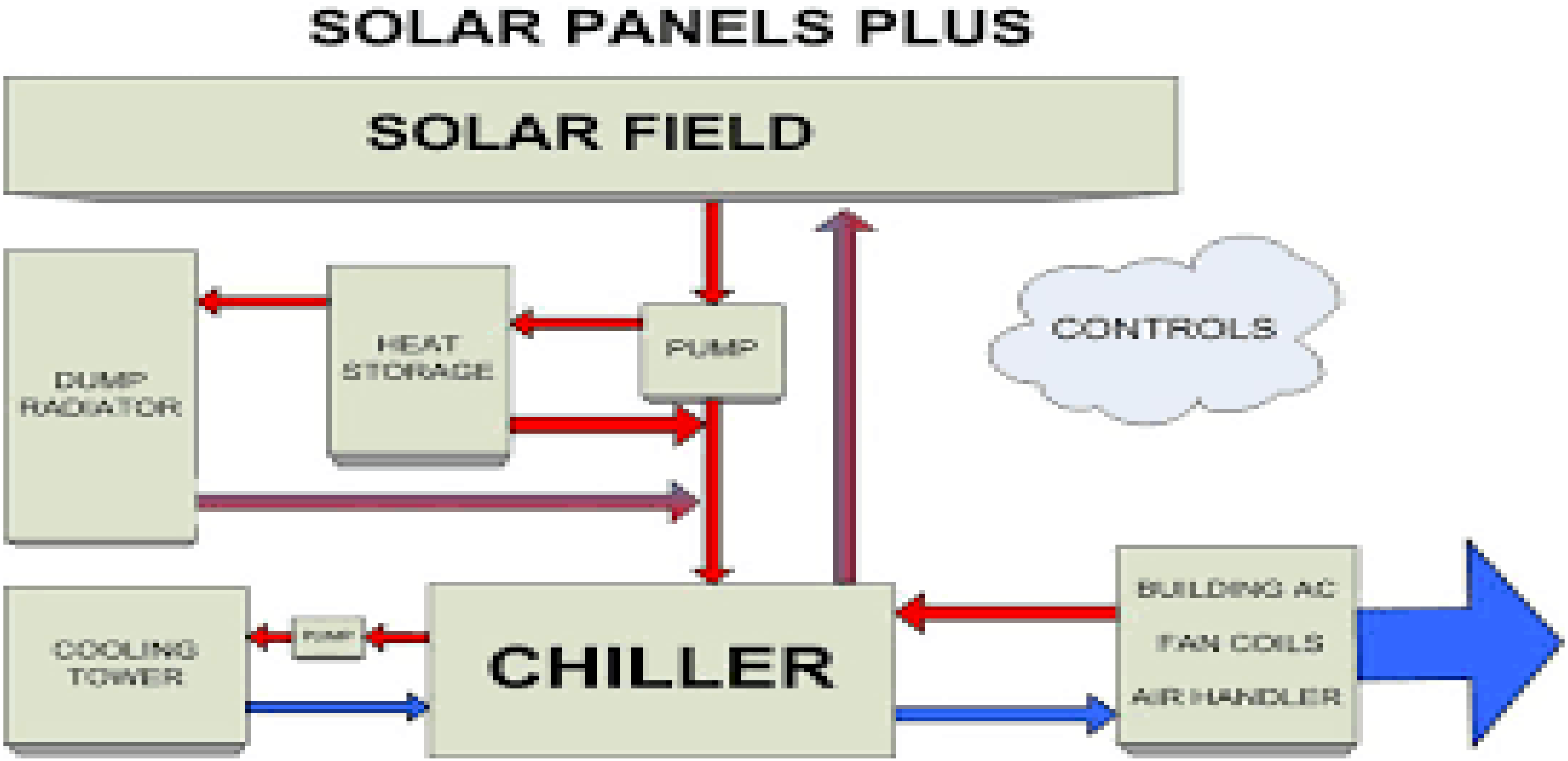
- **Pool heating.**

Applications of Solar Thermal Systems

- **Industrial process heat.**

Applications of Solar Thermal Systems

- **Solar cooling.**

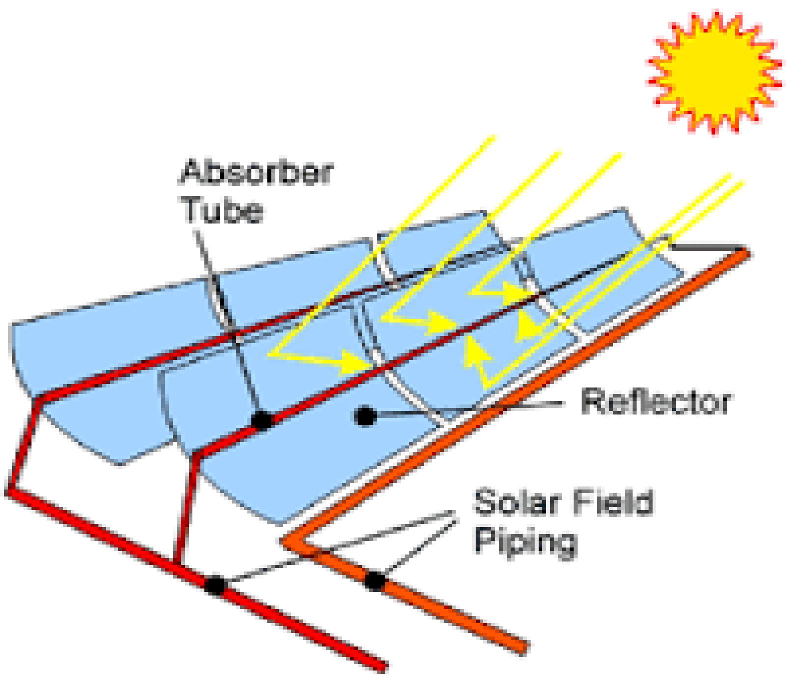


Solar Energy Collection

- **Classification of CSP collectors**

A- Line focusing systems

- Parabolic Trough.

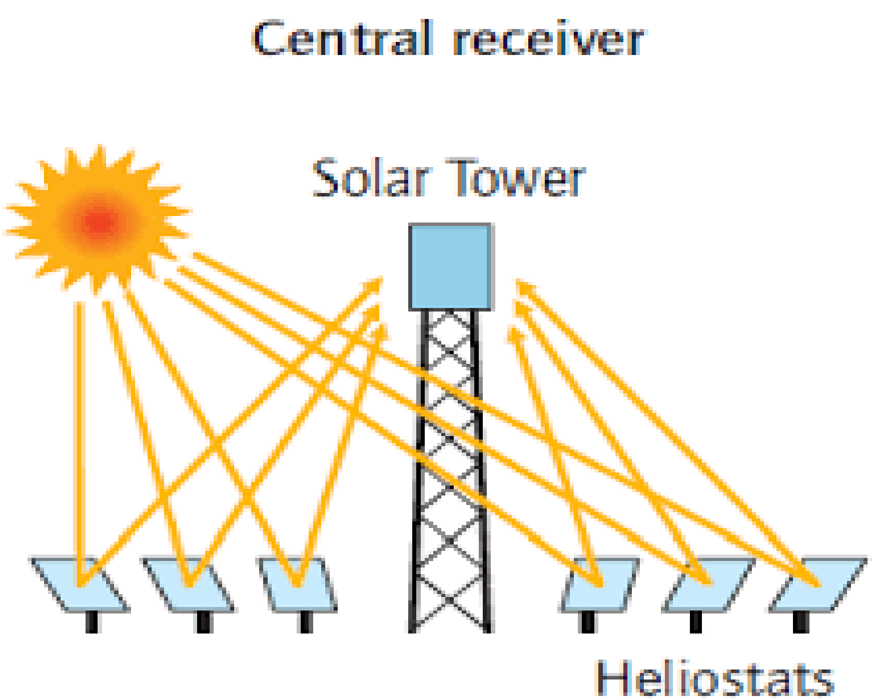


- Linear Fresnel Reflector.

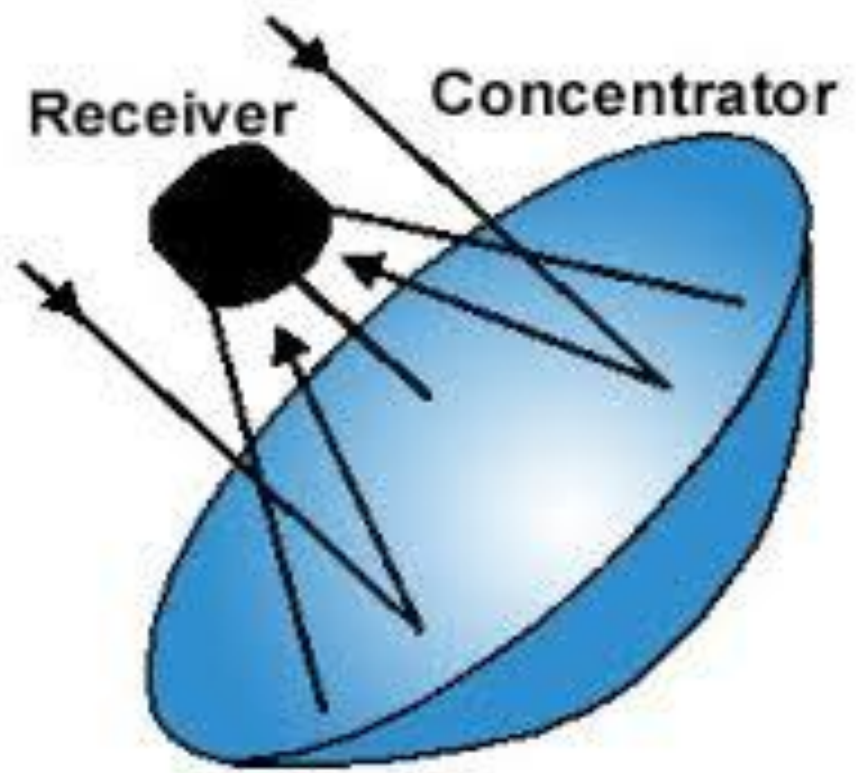
Concentrating Solar Power (CSP)

B- Point focusing systems

- Solar Tower systems.



- Parabolic dish.



Concentrating Solar Power (CSP)

Comparison of Alternative Solar Thermal Power System Technologies

Technology	Solar Concentration (x Suns)	Operating Temperature on the Hot Side	Thermodynamic Cycle Efficiency
Parabolic Trough	100	300 – 500 °C	Low
Central Tower	1000	500 – 1000 °C	Moderate
Dish	3000	800 – 1200 °C	High

Linear Fresnel Solar Concentrator

Augustin Jean Fresnel (1788-1828), French Physicist

Linear Fresnel Solar Concentrator

- **Linear Fresnel reflectors use stretched narrow segments of mirrors to focus sunlight onto a fixed receiver tube that runs axially above the array of reflectors located at a common focal point of the reflectors.**

- **Optimal orientation for maximum gain is north-south, but any orientation is possible.**

Linear Fresnel Solar Concentrator

Incident Concentrated Solar Energy Calculations

The rate of energy incident on the receiver tube can be calculated from the following equation:

$$\dot{Q}_{input} = A_{net} * DNI * \eta_{op,p} * IAM(\theta) * ELF * Clf * TwEf$$

$$DNI = A * Cn * \exp(-pr * br)$$

DNI	= Direct Normal Irradiance.	W/m^2
A_{net}	= The net reflector area.	m^2
$\eta_{op,p}$	= peak optical efficiency.	
ELF	=End Loss Factor	
Clf	=clearance factor	
TwEf	= Twisting Error factor	

Incident Concentrated Solar Energy Calculations

The peak optical efficiency η_{op} of solar concentrators depends on:

- **Reflectivity of the mirrors.** ρ
- **Transparency of the glass cover of the receiver tube.** τ
- **Absorbtivity of the receiver tube.** α
- **Intercept factor.** λ

$$\eta_{op,p} = \rho * \tau * \alpha * \lambda$$

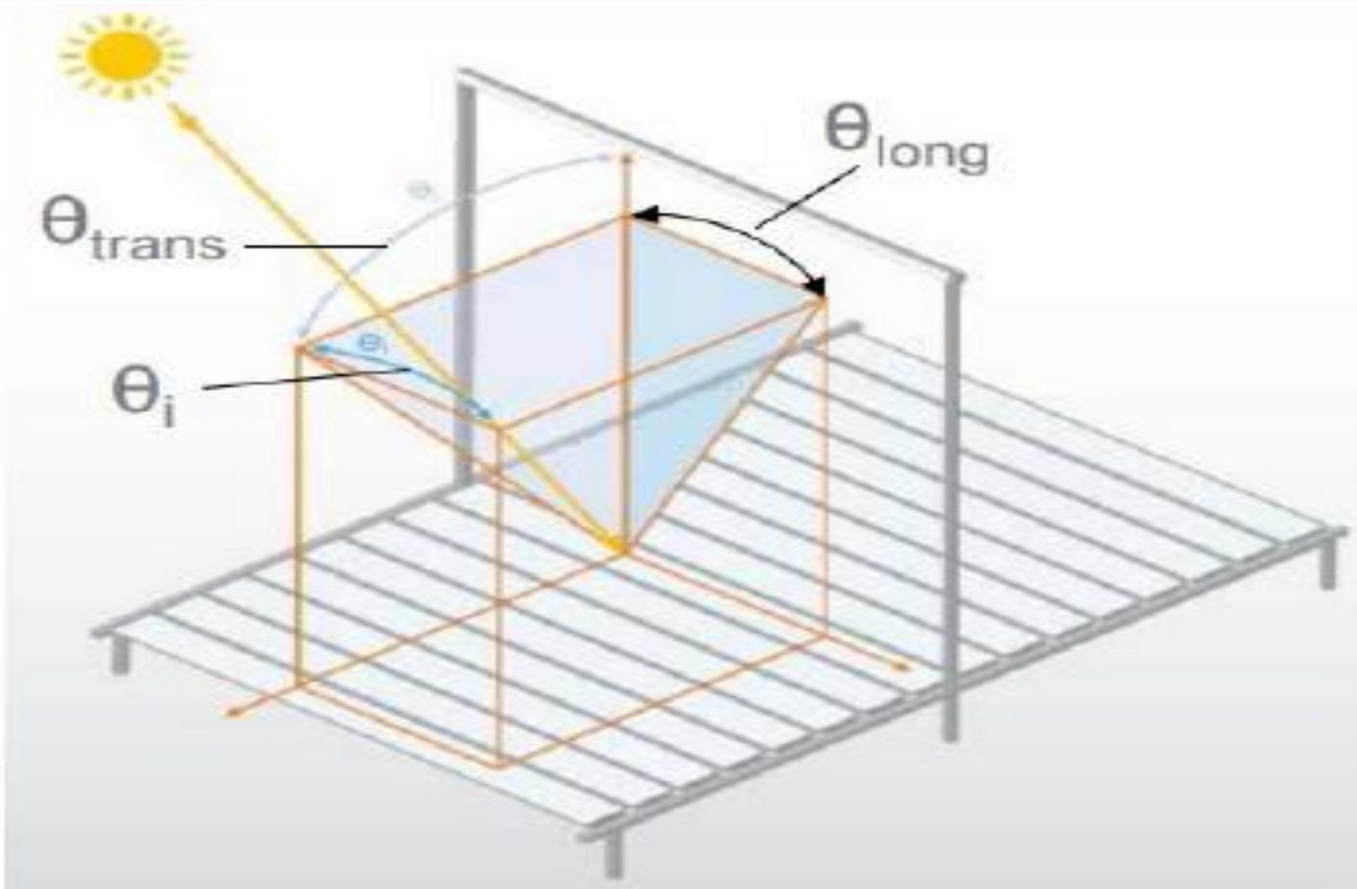
Incident Concentrated Solar Energy Calculations

- When the angle of incidence (θi) is greater than zero, there are optical losses due to the difference in the optical properties (tansmissivity , absorptivity and reflectivity).

- The optical properties effected by the incident angle of the solar beam (θi).

- The optical properties decrease with increasing the incident angle (θi). It is determined experimentally for each collector.

Incident Concentrated Solar Energy Calculations



The incidence angle θ_i of the sunrays is divided into 2 angles

Incident Concentrated Solar Energy Calculations

Transversal and incidence angles are used to characterize optical behavior of LFC (IAM)

Transversal angle	θ_{trans}	Angle between zenith and projection of straight line to the sun into the transversal plane.
Longitudinal angle	θ_{long}	Angle between zenith and projection of straight line to the sun into the longitudinal plane .
Incidence angle	θi	Angle between straight line to the sun and section line of intersection between incidence plane and transversal plane

Incident Concentrated Solar Energy Calculations

The incidence angle modifier IAM(θi) is approximated by multiplying IAM in the longitudinal direction $IAM_L(\theta_i)$ with the IAM in transversal direction $IAM_T(\theta_T)$.

$$IAM(\theta) = IAM_L(\theta_i) * IAM_T(\theta_T)$$

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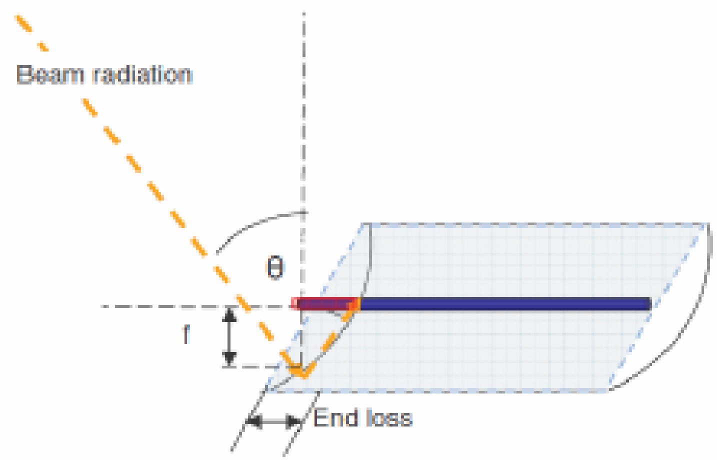
Incident Concentrated Solar Energy Calculations

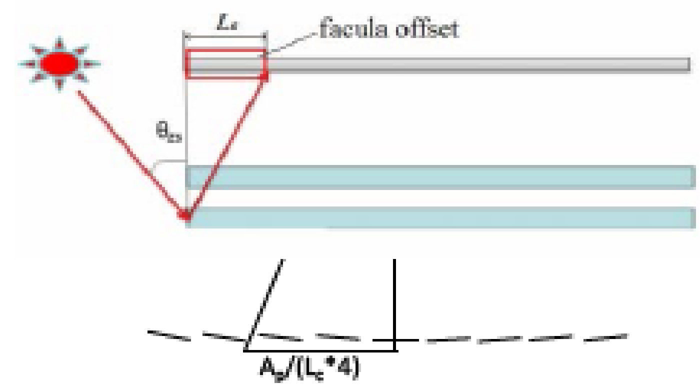
- **The End Loss Factor ELF**



$$ELF = 1 - \frac{f \tan\theta}{L_{sc}}$$

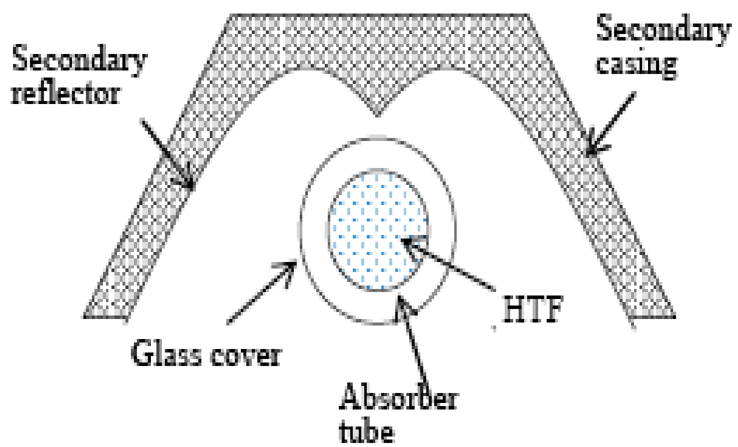
- End Losses Factor (ELF) depends on the collector length (L_{sc}), incident angle (θ) and the focal length (f).

- The focal length f can be substituted by an effective focal length f_{eff} in the LFC.



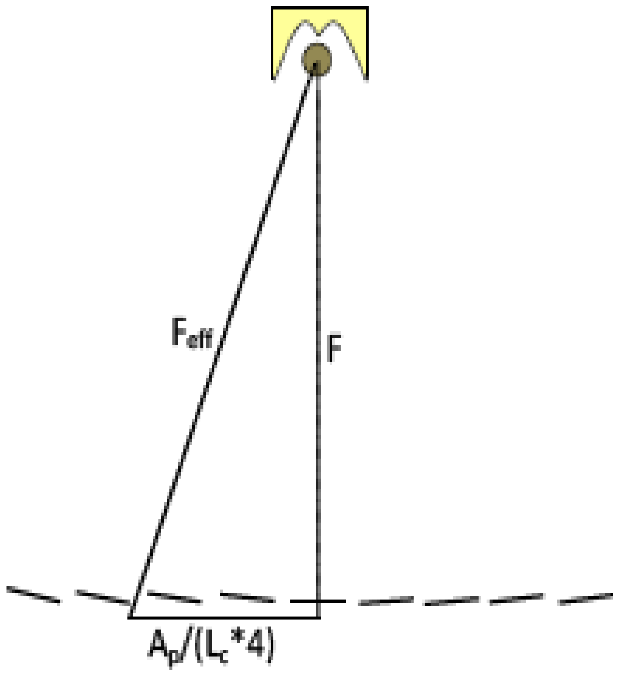
Incident Concentrated Solar Energy Calculations

The focal area contains a secondary compound parabolic reflector



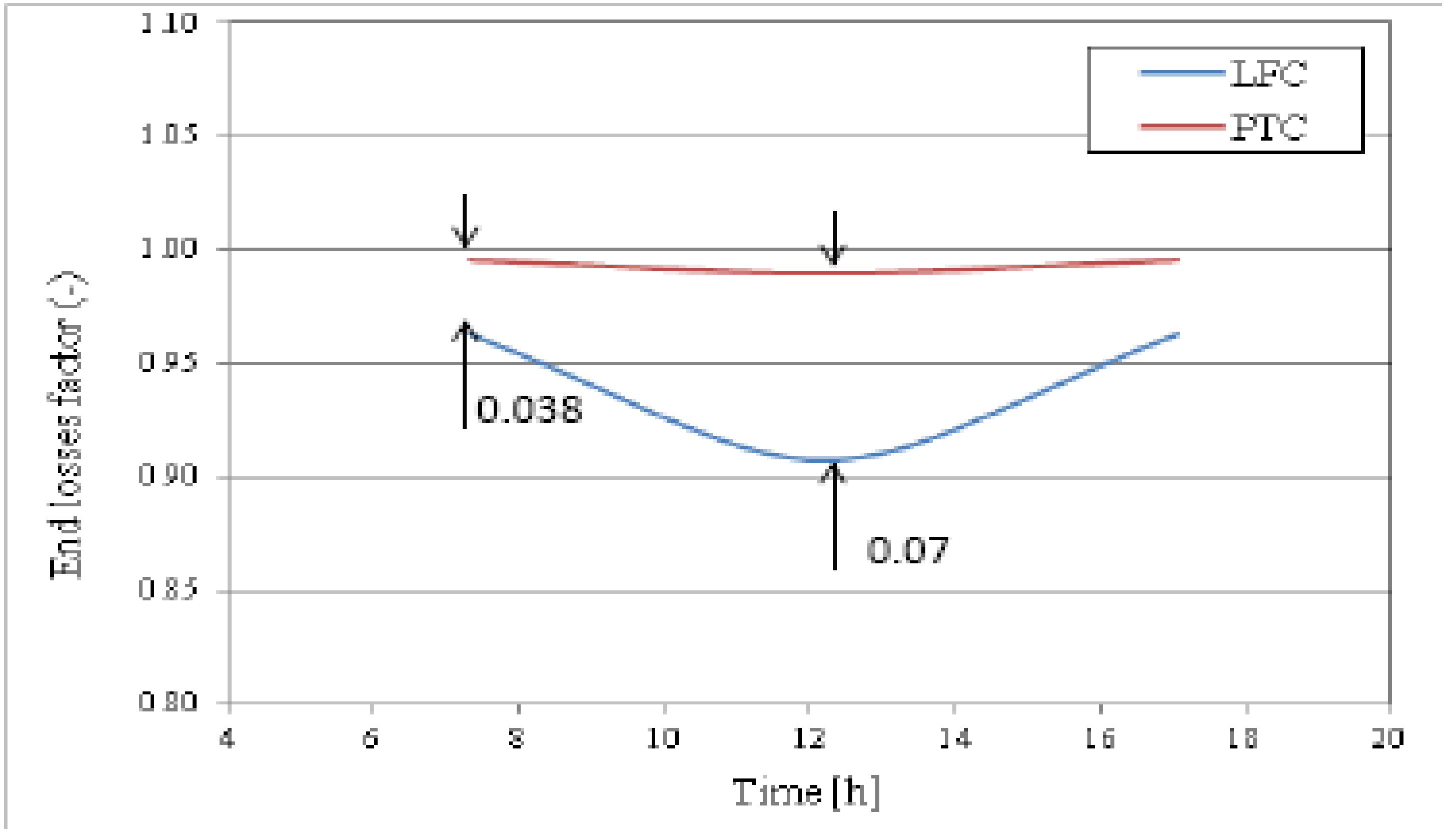
The construction of the heat collecting element (HCE)

The focal length F can be substituted by an effective focal length F_{eff}



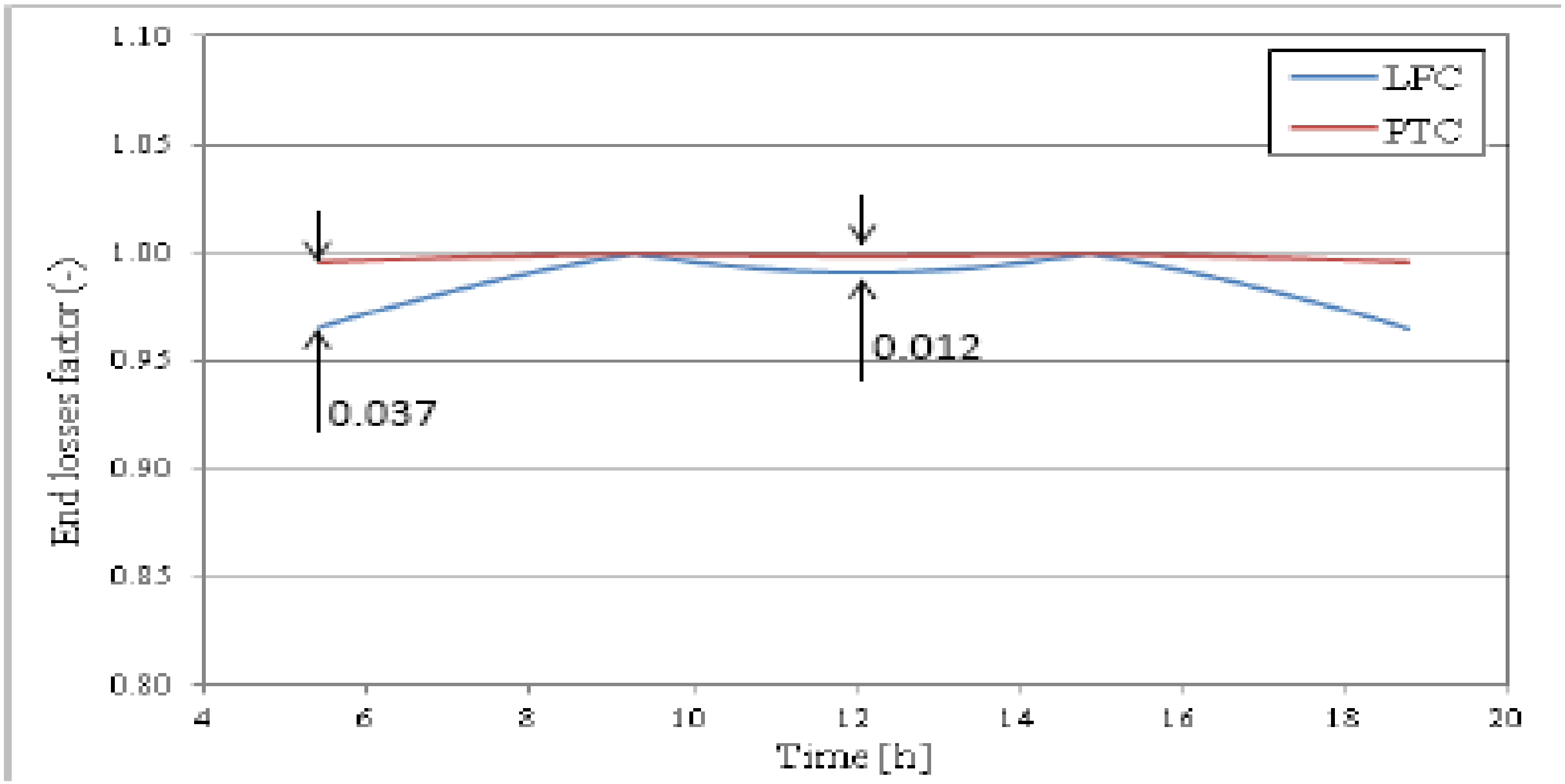
The effective focal length of the LFC

Incident Concentrated Solar Energy Calculations



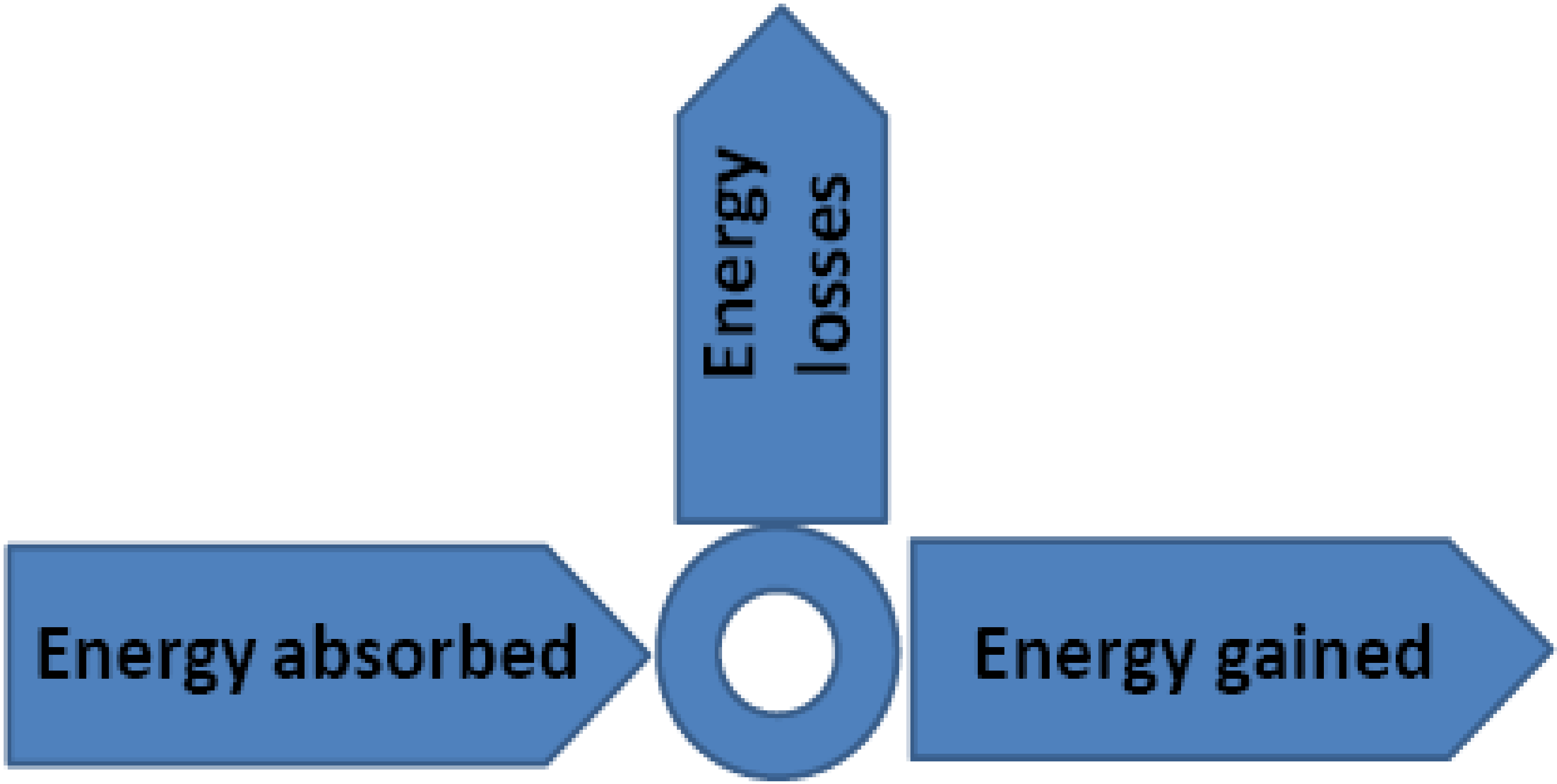
The End losses factor for the LFC and PTC in January

Incident Concentrated Solar Energy Calculations



The End losses factor for the LFC and PTC in June

The useful energy



Thank You

For Your Attention