

On the web

- Course webpage!
[http:// solar.fc.ul.pt/PV_course](http://solar.fc.ul.pt/PV_course)
- PV blog
<http://solar-fcul.blogspot.com>
- Group page:
<http:// solar.fc.ul.pt>

On the web

Faculdade Ciências da Universidade de Lisboa
Mestrado Integrado Engenharia da Energia e do Ambiente
Cursos: Engenharia 2008/2009
Prof. Miguel L. Almeida
www.fc.ul.pt/eng/eng-eeam

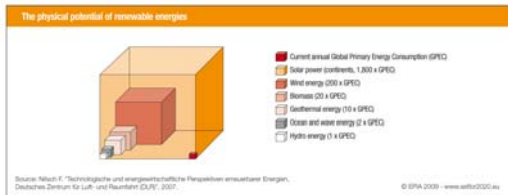
Ordem	Nome	Disciplina	1	2	3
1	10000000	Introdução à Engenharia da Energia e do Ambiente	Engenharia	Eng.	Eng.
2	10000001	Introdução à Engenharia da Energia e do Ambiente	Engenharia	Eng.	Eng.
3	10000002	Introdução à Engenharia da Energia e do Ambiente	Engenharia	Eng.	Eng.
4	10000003	Introdução à Engenharia da Energia e do Ambiente	Engenharia	Eng.	Eng.
5	10000004	Introdução à Engenharia da Energia e do Ambiente	Engenharia	Eng.	Eng.
6	10000005	Introdução à Engenharia da Energia e do Ambiente	Engenharia	Eng.	Eng.
7	10000006	Introdução à Engenharia da Energia e do Ambiente	Engenharia	Eng.	Eng.
8	10000007	Introdução à Engenharia da Energia e do Ambiente	Engenharia	Eng.	Eng.
9	10000008	Introdução à Engenharia da Energia e do Ambiente	Engenharia	Eng.	Eng.
10	10000009	Introdução à Engenharia da Energia e do Ambiente	Engenharia	Eng.	Eng.

Solar resource

- Radiation from the Sun
- Atmospheric effects
- Insolation maps
- Tracking the Sun

Solar resource

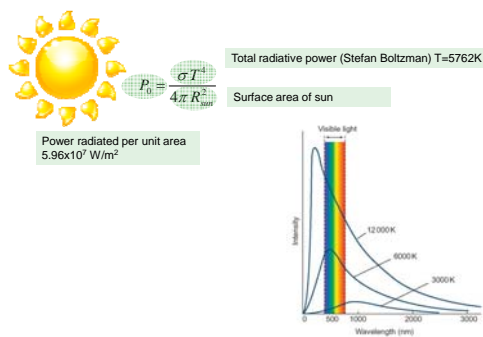
- Solar resource is immense
 - Human energy use: 4.0×10^{14} kWh/year
 - Solar resource on Earth's surface: 5.5×10^{17} kWh/year



Solar resource

- Solar resource is **immense**
 - Human energy use: 4.0×10^{14} kWh/year
 - Solar resource on Earth's surface: 5.5×10^{17} kWh/year
- Solar resource is **global and democratic**
- Solar resource is relatively **constant** but depends on
 - atmospheric effects, including absorption and scattering
 - local variations in the atmosphere, such as water vapour, clouds, and pollution
 - latitude of the location
 - the season of the year and the time of day

Solar resource



Solar resource

$P_0 = \frac{\sigma T^4}{4\pi R_{sun}^2}$

Ratio of surface areas of the 2 spheres

Solar constant average energy flux incident at the Earth's orbit: **1366 W/m²**

$S = \frac{4\pi R_{sun}^2}{4\pi D^2} P_0$

Distance Sun-Earth

Solar resource

$P_0 = \frac{\sigma T^4}{4\pi R_{sun}^2}$

$R_{sun} = 6.96 \times 10^5 \text{ km}$
 $D_{avg} = 1.5 \times 10^8 \text{ km}$
 $R_{Earth} = 6.35 \times 10^3 \text{ km}$

$S = \frac{4\pi R_{sun}^2}{4\pi D^2} P_0$

Energy incident on Earth
Total area of Earth

$\frac{S \times \pi R_{Earth}^2}{4\pi R_{Earth}^2} = \frac{S}{4}$

Average energy incident per unit area of surface of Earth: **342 W/m²**

Solar resource

- Earth-Sun motion

23.7 °

Polar axis

Elliptic plane

365 days and 6 hours

$\frac{H}{S} = 1 + 0.033 \cos\left(\frac{360(n-2)}{365}\right)$

Solar resource

- Earth-Sun motion
 - Solar declination: angle between line joining centres of Earth and Sun and the equatorial plane

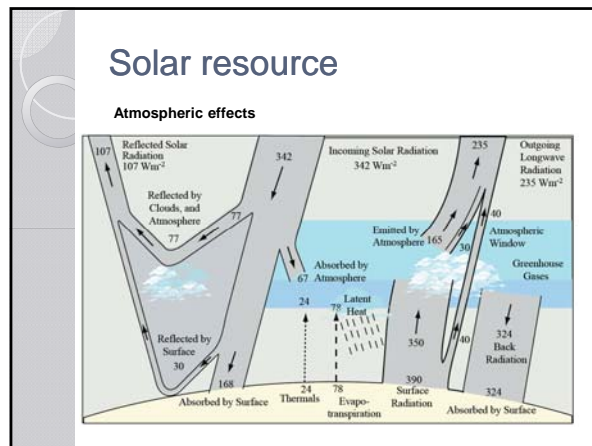
Solar resource

- Earth-Sun motion
 - Solar declination: angle between line joining centres of Earth and Sun and the equatorial plane

Solar resource

- Earth-Sun motion

$$\sin \alpha = \sin \delta \sin \phi + \cos \delta \cos \phi \cos \psi$$
$$\cos \psi = \frac{\sin \alpha \sin \phi - \sin \delta}{\cos \alpha \cos \phi}$$



Solar resource

Atmospheric effects on solar radiation at the Earth's surface:

- a **reduction in the power** of the solar radiation due to absorption, scattering and reflection in the atmosphere;
- a **change in the spectral content** of the solar radiation due to greater absorption or scattering of some wavelengths;
- the **introduction of a diffuse** or indirect component into the solar radiation; and
- local variations in the atmosphere (such as water vapour, clouds and pollution) which have additional effects on the incident power, spectrum and directionality.

Solar resource

- **Air Mass** is a measure of the reduction in the power of light as it passes through the atmosphere and is absorbed by air and dust

The diagram illustrates the concept of Air Mass (AM). It shows two suns at different angles θ relative to the surface. The path length X is the vertical distance, and Y is the slanted distance through the atmosphere. The formula $AM = \frac{1}{\cos \theta}$ is shown.

