

The Solar Resource

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Keywords: Sun as source of solar radiation. Solar radiation at the surface of the earth. Solar radiation on tilted surfaces. Meteorological data and simulation tool. Solar radiation and solar applications.

1. Sun as source of solar radiation

The sun as the source of solar radiation is a sphere of intensely hot gas with a diameter of 1.39×10^9 m and is - on the average - 1.5×10^{11} m from the earth. The sun is a continuous fusion reactor; Figure 1. Several fusion reactions supply solar radiation as a form of energy conversion. The most important fusion reaction is a process in which hydrogen (protons) are fused into helium. The mass of the helium nucleus is less than that of the four protons of the hydrogen nucleus, mass having been lost in the reaction and converted into energy in the form of electromagnetic waves.

Solar energy is essentially blackbody radiation corresponding to a temperature of about 6000 K and is therefore of high thermodynamic quality. For example, solar energy (direct radiation) can be concentrated by mirrors or lenses in order to achieve higher energy densities. Indeed, temperatures of about 3000 K have been reached in solar furnaces. Compared to "conventional" energy technologies, such as thermal or nuclear power plants, solar energy – absorbed at the surface of the earth - has a low density.

2. Solar radiation

Solar radiation at normal incidence received at the surface of the earth is subject to two significant phenomena:

- atmospheric scattering by air molecules, water and dust and
- atmospheric absorption by O₃, H₂O and CO₂.

Solar radiation and its spectral distribution includes the ultraviolet ($\lambda < 0.38 \mu\text{m}$), the visible ($0.38 \mu\text{m} < \lambda < 0.78 \mu\text{m}$), and the infrared ($\lambda > 0.78 \mu\text{m}$) portions of the spectrum. The intensity of solar radiation outside the earth's atmosphere - the *solar constant* - is about 1367 W/m² on a surface normal to solar incidence with seasonal variations of about 3.5%.

The radiation parameters on the earth are divided into two groups according to their origin: solar (extraterrestrial) radiation and terrestrial radiation. Terrestrial radiation is the "thermal radiation" emitted by the earth's surface and by the gases, aerosol and clouds of the atmosphere, and is partly absorbed within the atmosphere. For a temperature of 300 K, the spectrum of terrestrial radiation reaches from 4.8 to 7.6 μm .

The ratio of the available global radiation on horizontal surface and the extraterrestrial radiation for the location is called "clearness index", which hardly exceeds 0.75 on very clear days.

The *global (total) radiation* on the surface of the earth comprises the *direct (beam) radiation* from the sun's disk and the *diffuse radiation*, which is received from the sun after its direction has been changed by scattering in the atmosphere; Figure 2. The proportion of direct to diffuse radiation depends on cloud cover, moisture, and dust particle content in the atmosphere and on other environmental parameters.

The radiation quantities are measured by their *irradiance* and by *irradiation or radiant exposure*. The irradiance is the rate at which radiant energy is incident on a surface, per unit area of surface: W/m^2 . The irradiation or radiant exposure is the incident energy per unit area on a surface, found by integration of irradiance over a specified time, usually one hour or a day or a year: $\text{kWh}/(\text{m}^2 \cdot \text{h})$ or $\text{kWh}/(\text{m}^2 \cdot \text{day})$ or $\text{kWh}/(\text{m}^2 \cdot \text{year})$. The values of irradiation are briefly called "hourly sum" or "daily sum" or "annual sum". The isolation is a term applying specially to solar energy irradiation.

3. Solar radiation on the earth's surface

Usually global, direct, and diffuse radiation are measured on a horizontal surface. Table 1 shows a rough indication of the relation between weather condition, global radiation and the percentage of diffuse radiation. In Central and Northern Europe, the diffuse radiation plays an important role for solar energy conversion. In these areas the diffuse part of the global radiation energy amounts to between 40% (summer) and 80% (winter).

The annually available radiant energy depends on the geographical location and meteorological conditions: the values are between 2500 (Sahara) to 775 $\text{kWh}/(\text{m}^2 \cdot \text{a})$ (Lerwick, UK); Table 2 and Figure 2 to Figure 7. The solar radiation on the earth's surface has seasonal variations, which can be 1:2 in the tropic zones and up to 1:10 in the higher latitudes. The seasonal changes of solar radiation have a larger effect on the available radiation at higher latitudes. In Central and Northern countries with higher latitudes, is highly exposed to the sun mainly during summer, otherwise the entire African continent, as an example for low latitudes, is highly exposed to the sun during the whole year.

The annual and monthly solar radiation in Europe is shown in Figure 8 and Figure 9.

4. Solar radiation on titled surfaces

The distribution of the annual incident energy on a tilted surface as a function of slope and azimuth has to be considered within the installation as well as integration of solar thermal collectors in building envelope.

The intensity of the solar radiation on a flat surface is higher when it is titled towards the sun; Figure 10 and Figure 11. The maximum intensity occurs when the flat surface is perpendicular to the sun's rays. Two-axis tracking of absorbers may thus maximize the energy gain at the expense of technical complexity. For fixed absorber surfaces, the energy gain is a function of the slope angle ($0^\circ = \text{horizontal}$, $90^\circ = \text{vertical}$) and the azimuth angle ($0^\circ = \text{South}$, $-90^\circ = \text{East}$, $+90^\circ = \text{West}$ and $180^\circ = \text{North}$).

Nevertheless, the distribution of the annual incident energy on a tilted surface gives some freedom on choosing acceptable surfaces for collection of solar energy.

The global radiation for inclined surfaces can be calculated by the values of direct and diffuse radiation on the horizontal surface by using the *geometric factor R*. This factor is a function

of the time period considered as well as the inclination, orientation and sea level of the absorbing surface.

5. Meteorological data and simulation tool

For the simulation of solar energy systems, meteorological data from all parts of the world are needed. For many regions, measured data may only be applied within a radius of 50 km from weather stations. This makes it necessary to interpolate parameters between stations.

METEONORM – published by Meteotest, Fabrikstrasse 14, CH-3012 Bern, and supported by the Swiss Federal Office of Energy – is a global meteorological database for solar energy and applied climatology. The method enables the data to be interpolated and monthly values to be obtained for almost all points of the globe.

Through the database in METEONORM it is possible to simulate solar energy systems in all parts of the world on a consistent basis. The interpolation errors are within the variations of climate from one year to the next.

6. Solar radiation and solar applications

The influence of available solar radiation – cold, temperate and mild climates - on the heat output of solar thermal systems for hot water preparation in housing – calculated with METEONORM is illustrated in Figure 12a and b.

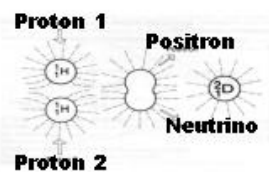
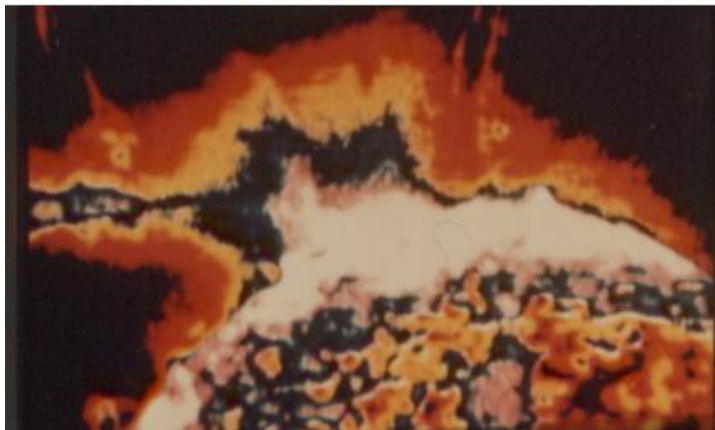
Table 1: Irradiance at different weather conditions			
Solar radiation	Cloudless blue sky	Misty, cloudy, sun visible as yellowish disc	Cloudy sky
Global radiation	600 – 1000 W/m ²	200 - 400 W/m ²	50 - 150 W/m ²
Diffuse radiation	10% - 20%	20% - 80%	80% - 100%

Table 2: Annual incident solar energy at several locations on a horizontal surface		
Location	Latitude	Annual incident energy (kWh/m²)
Sahara	25°N	2500
Israel	33°N	2000
Trapani, Italy	38°N	1800
Freiburg, Germany	48°N	1100
Helsinki, Finland	60°N	950
Lerwick, United Kingdom	60°N	775

More information:

METEONORM – published by Meteotest, Fabrikstrasse 14, CH-3012 Bern

Solar resource and radiation



High energetic radiation
 $3.7 \cdot 10^{26} \text{ W}$

Reduced solar radiation
 $< 1.37 \cdot 10^3 \text{ W/m}^2$

Fig. 1: Solar resource and radiation

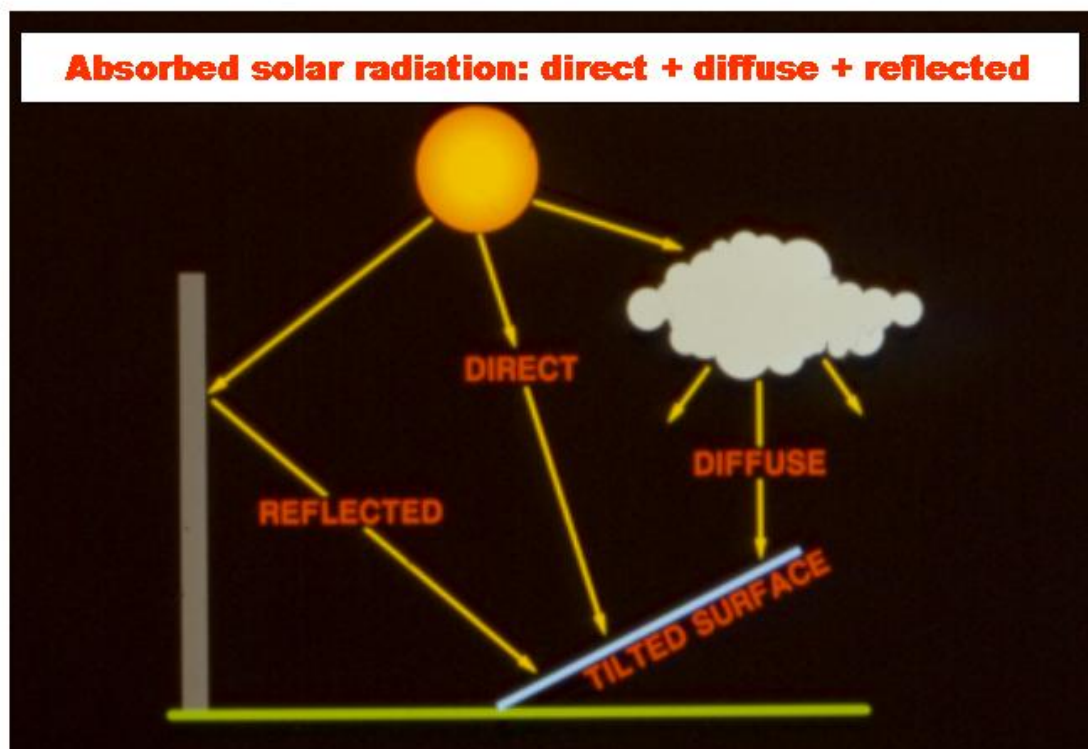


Fig. 2: Global solar radiation

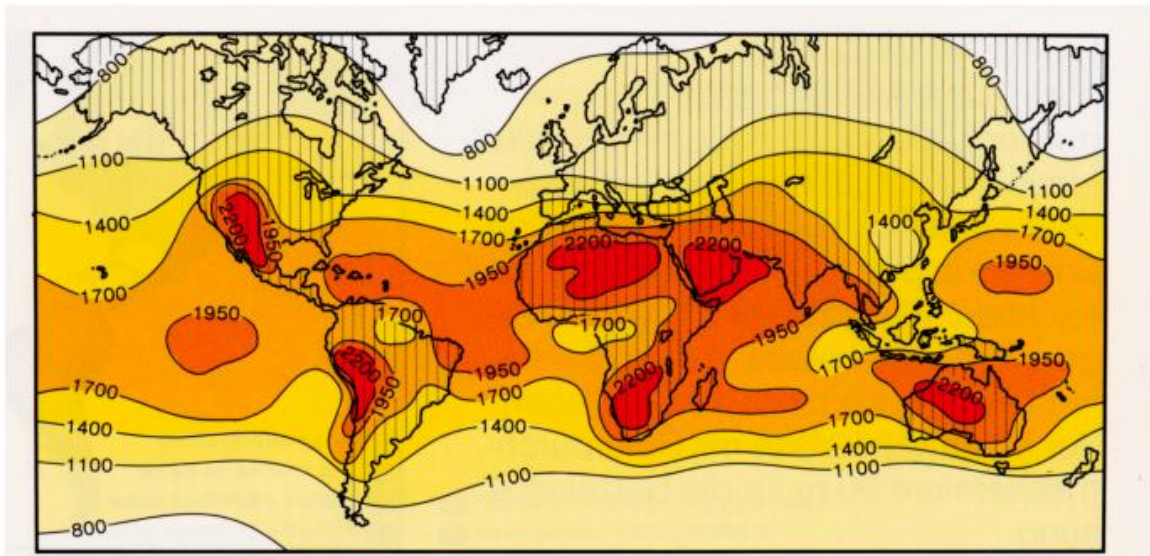


Fig. 3: Annual solar radiation, kWh/(m², year)

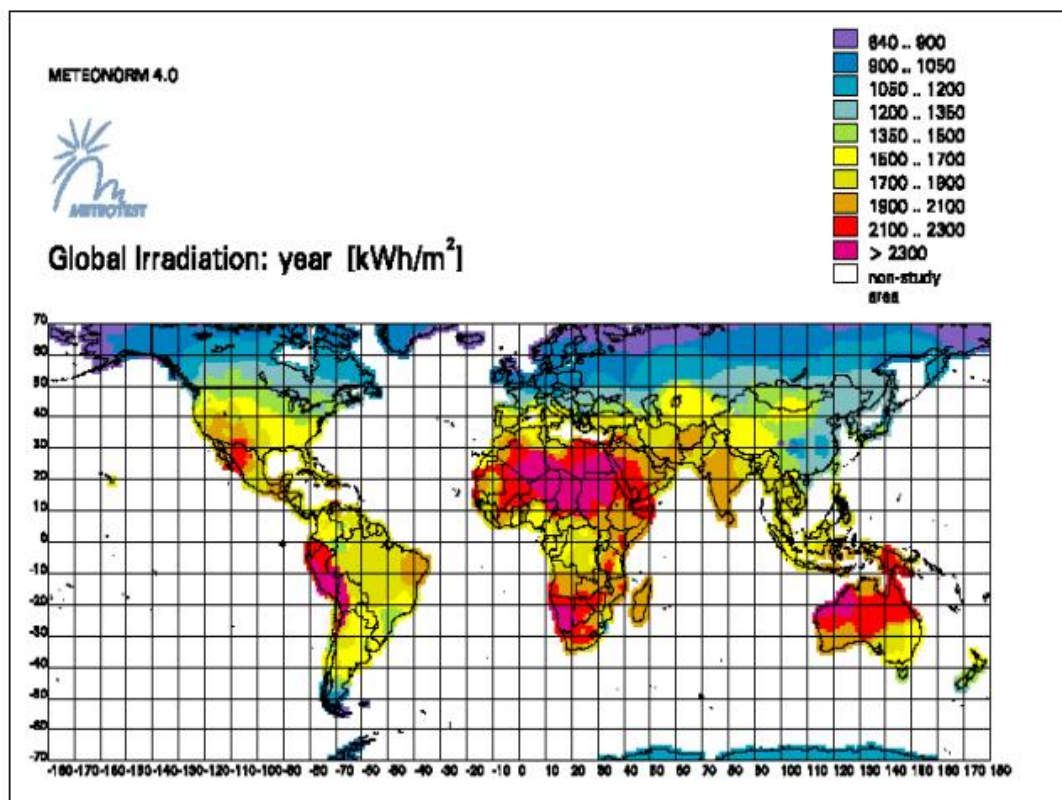


Fig. 4: Annual global solar radiation, kWh/(m², year)

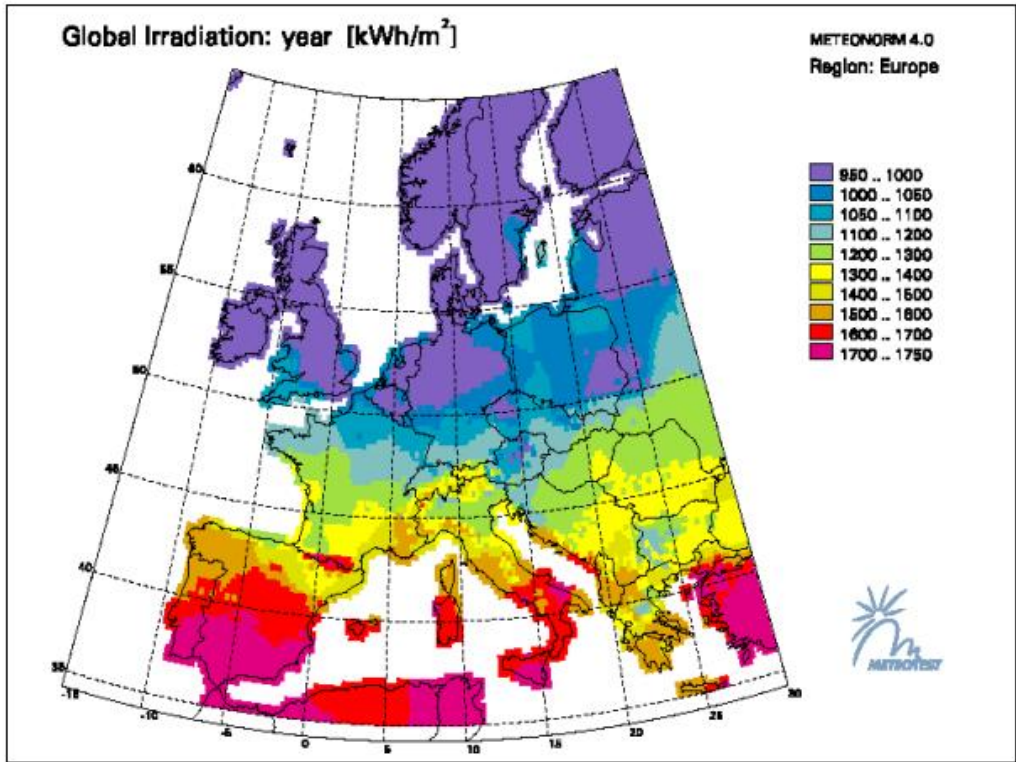


Fig. 5: Annual solar radiation in Europe, kWh/(m², year)

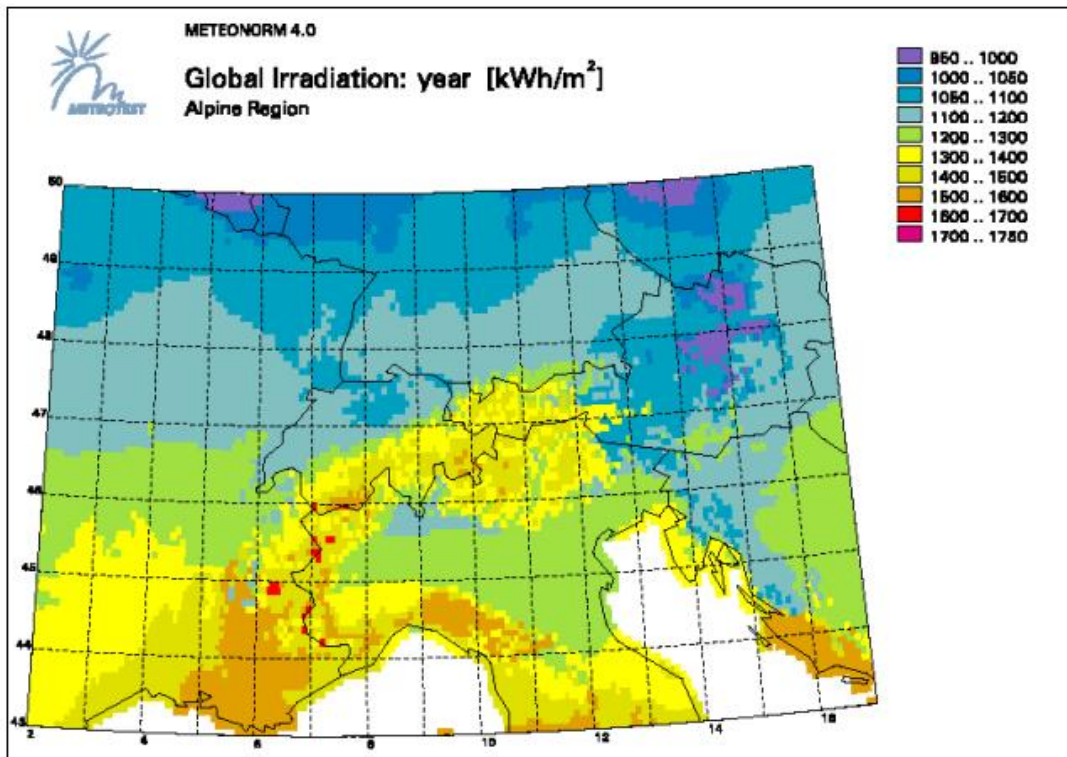
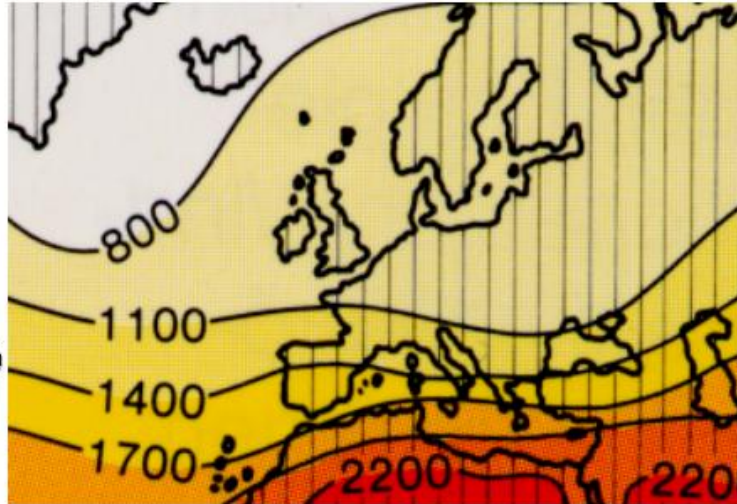


Fig. 6: Annual solar radiation in Middle-Europe, kWh/(m², year)

kWh/(m², year)



	Helsinki	Vienna	Athens	
Latitude	60.3	48.3	38.0	Deg
Total radiation	1017	1106	1636	kWh/m ²
Diffuse radiation	43	51	36	%
Ambient temperature	5.0	9.7	17.8	C-deg

Fig. 7: Meteorological data in Europe

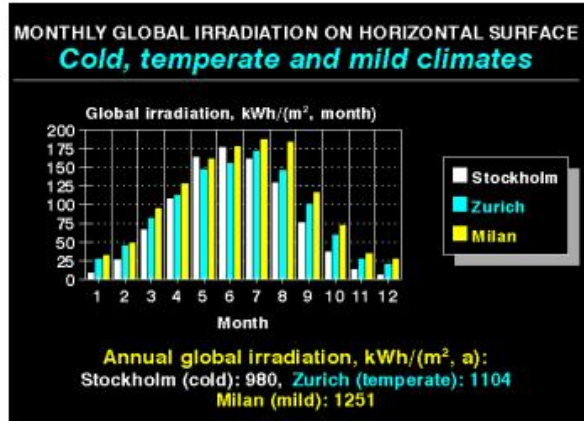
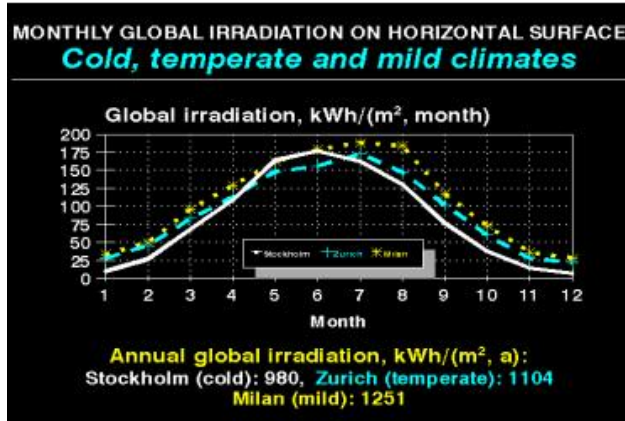
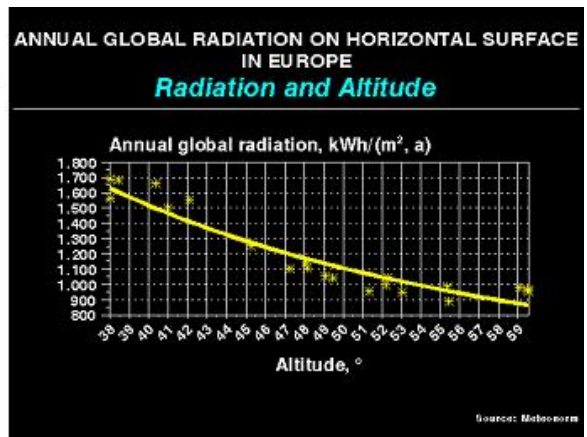
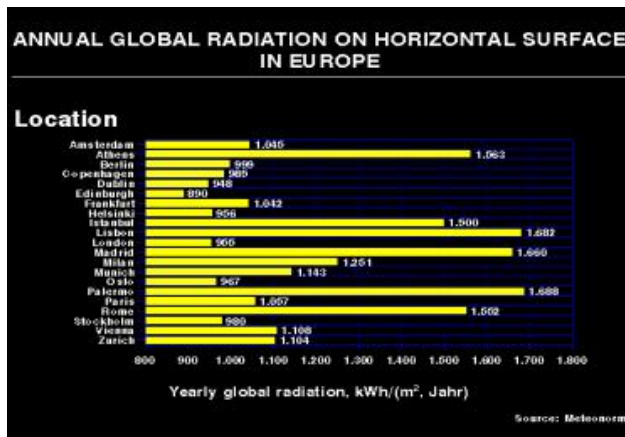


Fig. 8: Annual and monthly solar radiation in Europe, kWh/(m², year) /kWh/(m², month)

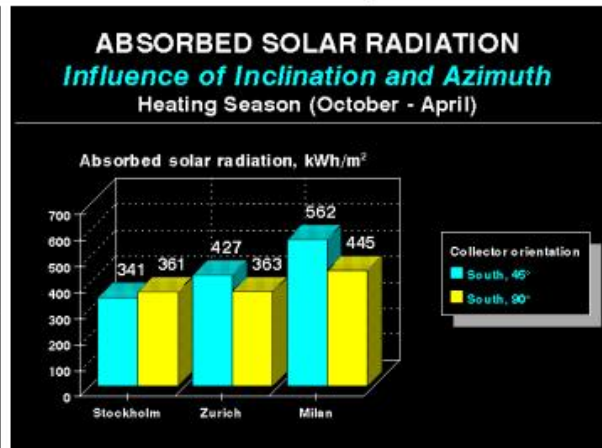
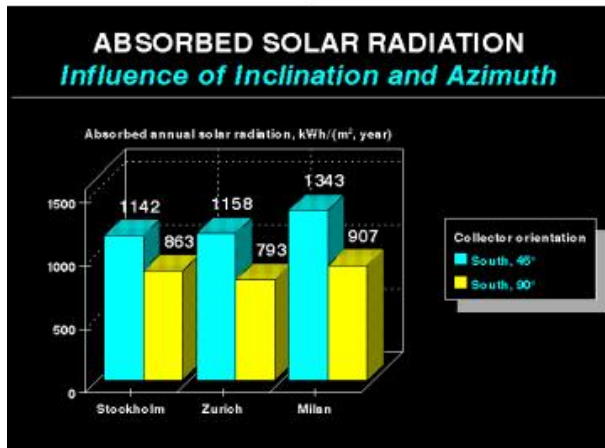
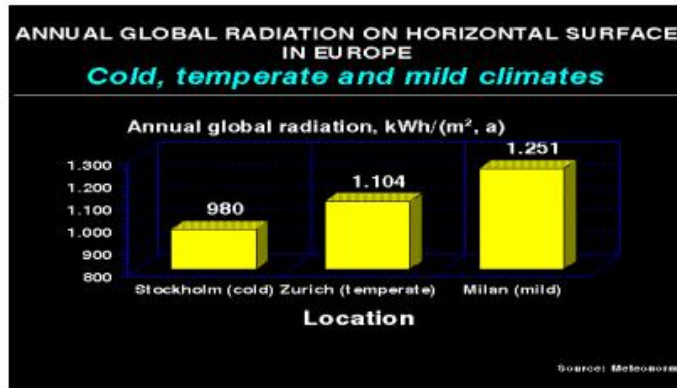


Fig. 9: Absorbed solar radiation

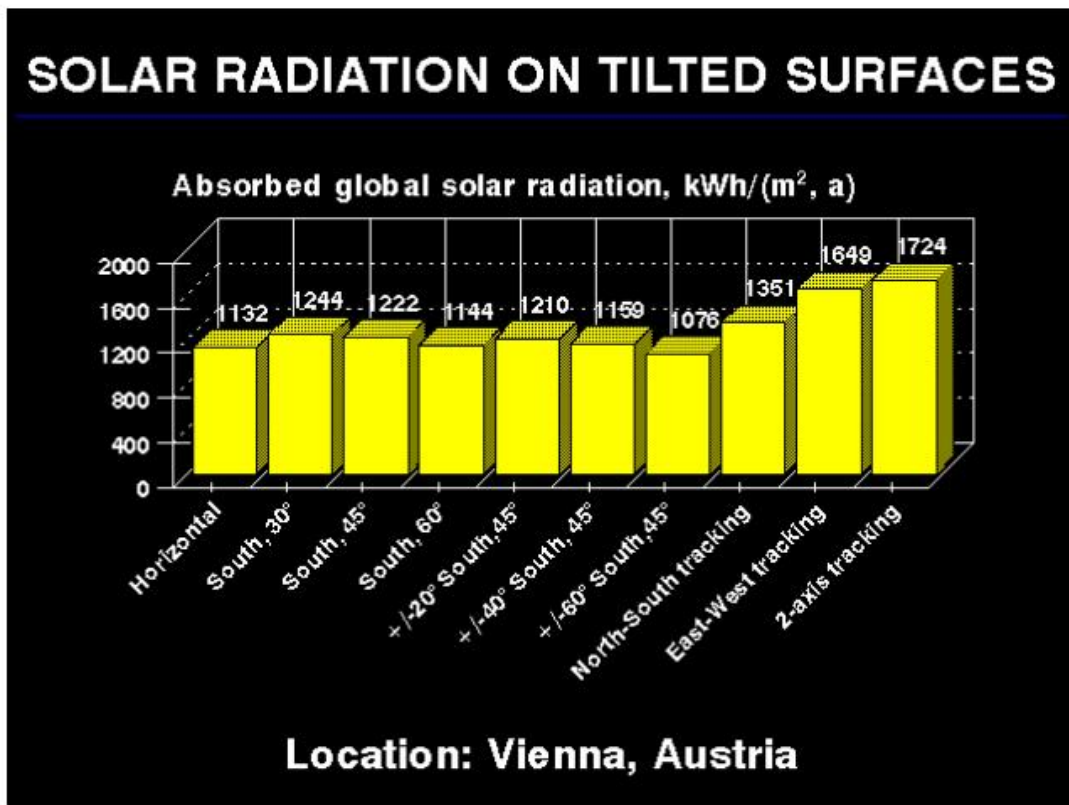


Fig. 10: Solar radiation on tilted surfaces

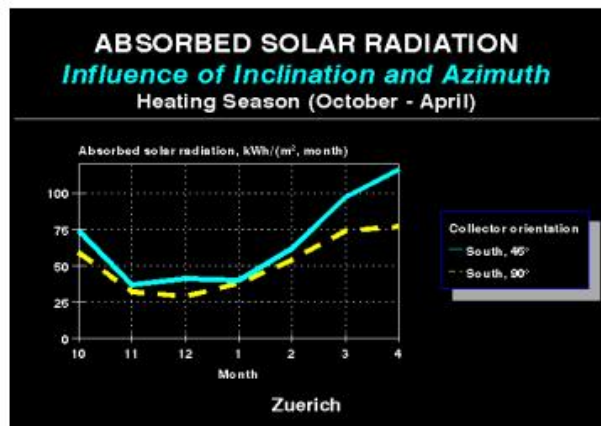
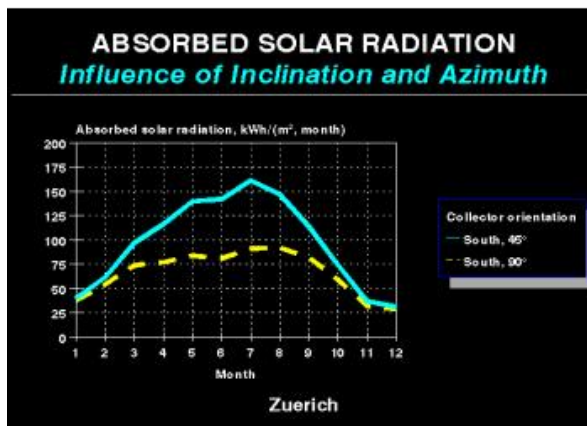
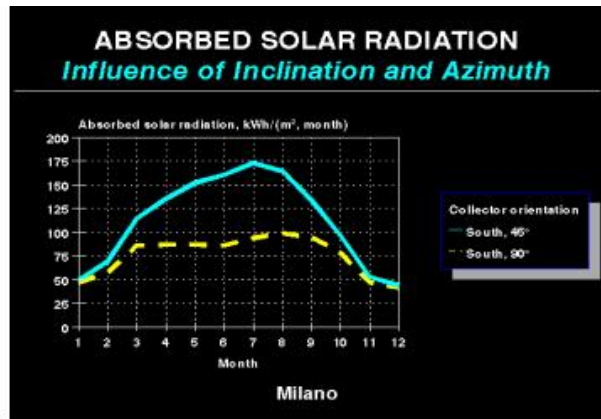
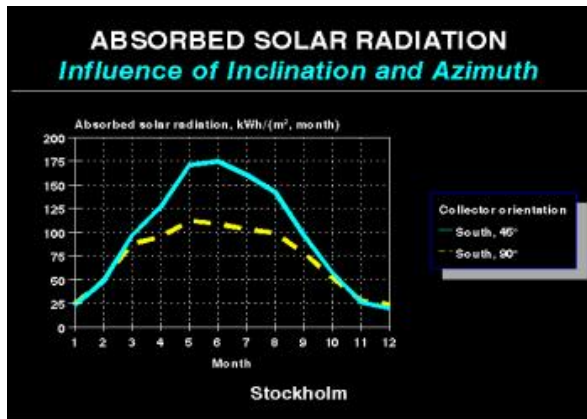
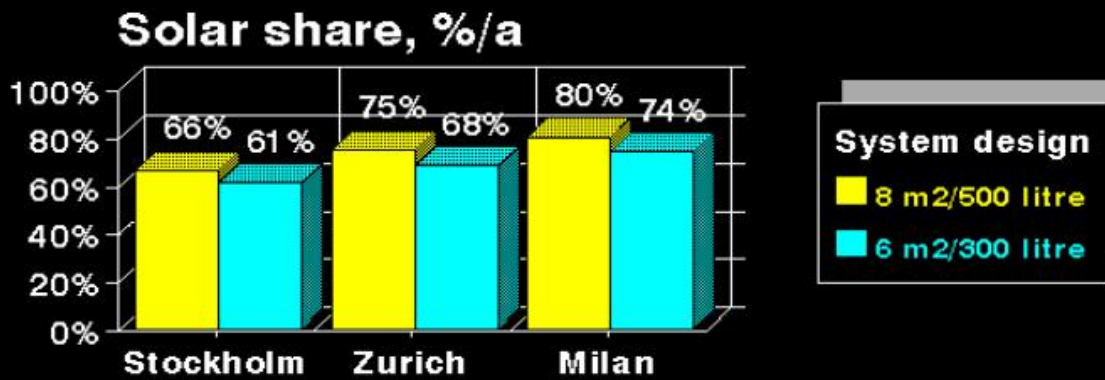


Fig. 11: Influence of inclination and azimuth on absorbed solar radiation

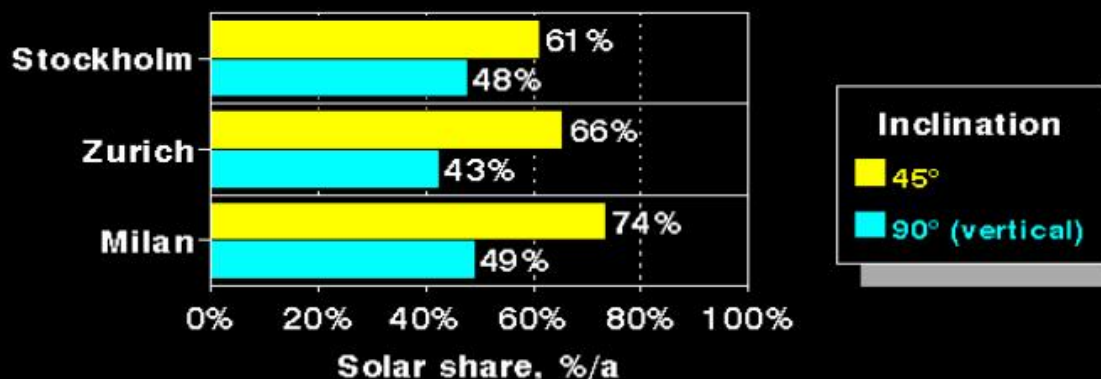
SOLAR HEATING SYSTEM FOR HOT WATER
Compact system for household
Design of collector area and storage volume



Selective coated flat plate collector
 Hot water demand: 120 litre/day (50°C)
 Azimuth: 0°(south), inclination: 45°

Fig. 12a: Design of solar hot water system

SOLAR HEATING SYSTEM FOR HOT WATER
Solar system for apartment house
Collector inclination and heat output



Selective flat plate collector, 96 m² & 6000 litre water tank
 Hot water demand: 1920 litre/day (16 flats, 50°C)
 Azimuth: 0°(south)

Fig. 12b: Design of solar hot water system