2. Solar Energy Reaching The Earth's Surface

The solar Constant

- At the surface of the Sun, the intensity of the solar radiation is about 6.33×10^7 W/m^2.
- Sun rays reach the edge of the Earth's atmosphere are considered to be parallel.

The solar Constant

- The eccentricity of the earth's orbit is such that the distance between the sun and the earth changes as 1.7%.
- The Solar Constant, G_{sc}, is the energy from the sun, per unit time, received on a unit area of surface perpendicular to the direction of propagation of the radiation at the mean earth-sun distance, outside of the atmosphere.
- The World Radiation Center (WRC) has adapted a value of: 1367 W/m^2 for Solar Constant:
- $G_{sc} = 1367\ W/m^2$

Spectral distribution of extraterrestrial radiation

- Extraterrestrial Radiation: The radiation that would be received in the absence of atmosphere.
- The fraction $f_{0-\lambda}$ of the total energy between 0 to λ is given in the table 1.3.1.
- Spectral distribution of extraterrestrial radiation:

Wavelength range	$\lambda<0.38$ (Ultraviolet)	$0.38<\lambda<0.78$ (Visible)	$0.78<\lambda$ (Infrared)
Fraction in range	6.4%	48%	45.6%
Energy in range	87	656	623

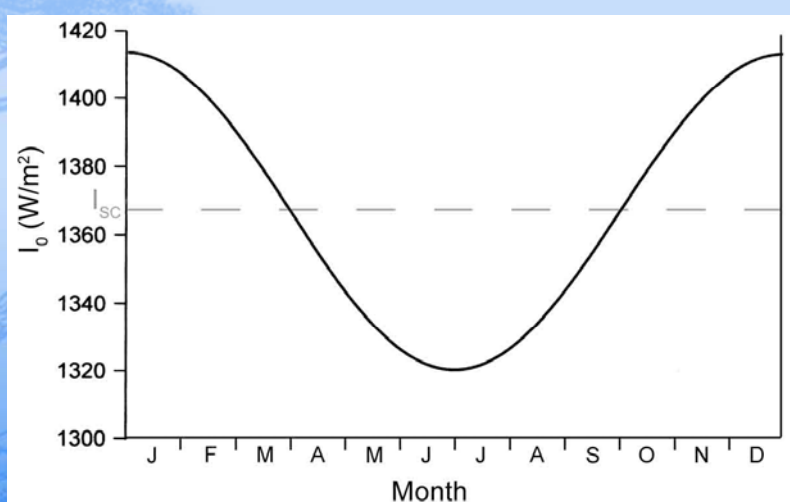
Variation of Extraterrestrial radiation

- Two sources of variation in Extraterrestrial radiation:
  - Variation in radiation emitted by the sun,
  - Variation of earth-sun distance which is described as follows (G_{sc}=1367 W/m^2):

$$G_{on} = G_{sc}(1 + 0.033\mathrm{Cos}\frac{360n}{365})$$

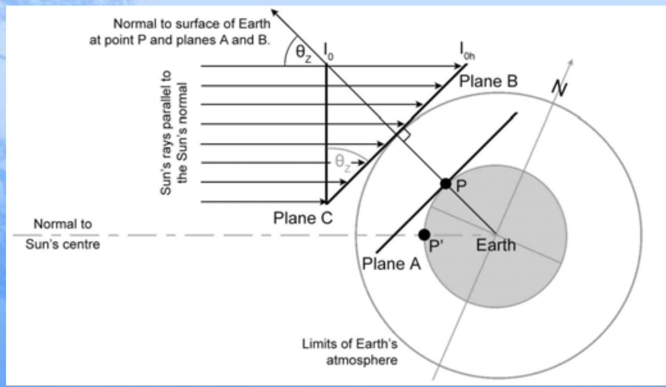
  - Where G_{on} is the extraterrestrial radiation, measured on the plane normal to the radiation on the n*th* day of the year: n=1 for 1st of January

Variation of Extraterrestrial radiation over a year



The cosine effect

- Not all points on the Earth's surface are perpendicular to the Sun's rays.
- $G_o = G_{on} \cos\theta_z$



Daily Extraterrestrial radiation on a plane perpendicular to Sun's ray

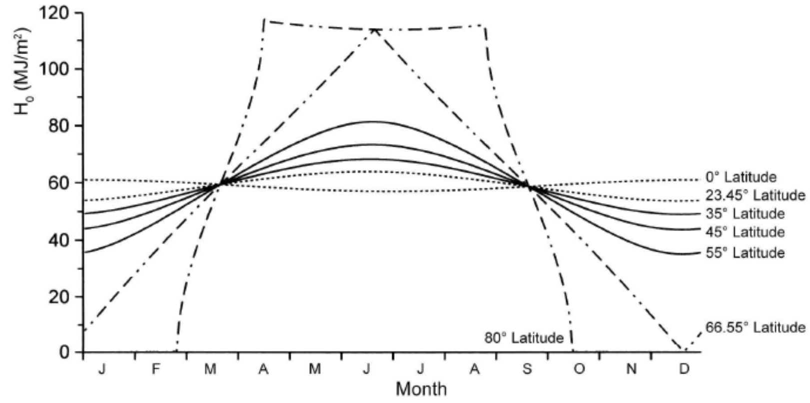


Figure 2.3: The total daily amount of extraterrestrial irradiation on a plane perpendicular to the Sun's rays (H_0) for different latitudes.

Daily Extraterrestrial radiation on a horizontal plane

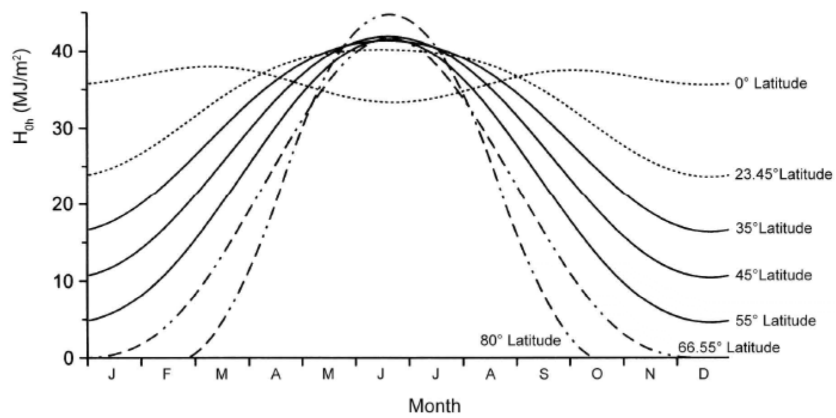


Figure 2.4: The total daily amount of extraterrestrial irradiation on a plane horizontal to the Earth's surface(H_{0h}) for different latitudes.

The atmosphere and air mass

- The atmosphere scatters and absorbs some of the Sun's energy that is incident on the Earth's surface.
- Rayleigh scattering is Scattering of radiation by gaseous molecules like CO_2 , O_2 and H_2O.
- Roughly half of the radiation that is scattered is lost to outer space.
- The remaining half is directed towards the Earth's surface from all directions as *diffuse radiation.*

The atmosphere and air mass

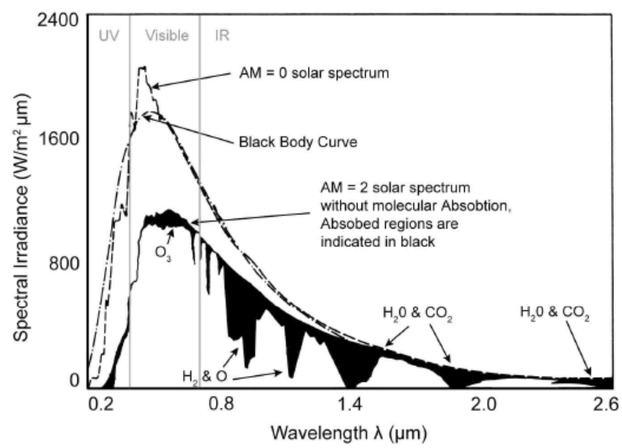


Figure 2.5: The extraterrestrial solar spectrum (AM = 0), the theoretical black body curve and the solar spectrum at the Earth's surface for AM = 2 and the absorbed regions shown in black.

The atmosphere and air mass

- Clouds reflect a lot of radiation and also absorbed a little, the rest is transmitted through. Globally, clouds reflect a lot of radiation and help regulate the surface temperature.
- The fraction of the total solar radiant energy reflected back to space from clouds, scattering and reflection from the Earth's surface is called the albedo of the Earth-atmosphere system and is roughly 0.3 for the Earth as a whole.

The atmosphere and air mass

- A plane on the Earth's surface receives:
  - Beam (or direct) radiation – coming straight through the atmosphere to hit the plane (very directional);
  - Diffused radiation – scattered in all direction in the atmosphere and then some arrives at the plane on the Earth's surface (not directional);
  - Reflected radiation – beam and diffused radiation that hits the Earth's surface and is reflected onto the plane.

Solar Radiation on the Earth

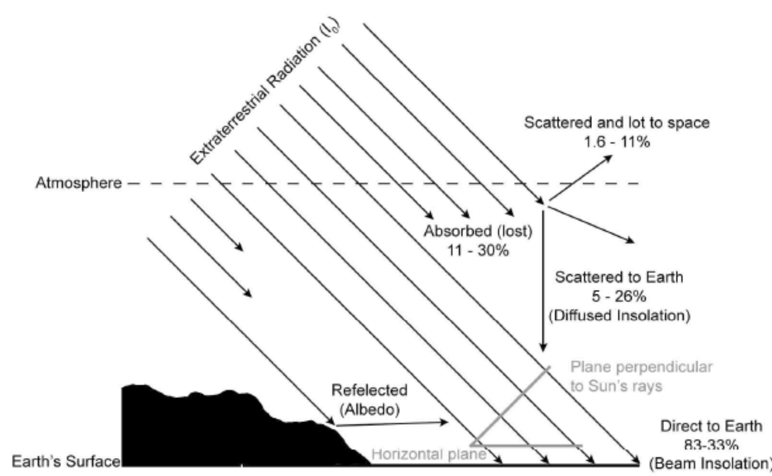


Figure 2.6: The effect of the atmosphere on the solar radiation reaching the Earth's Surface.

Air mass

- The amount of energy reflected, scattered and absorbed depends on the amount of atmosphere that the incident radiation travels through as well as the levels of dust particles and water vapour present.
- The latter is difficult to judge but the distance travelled through the atmosphere by incident radiation depends on the angle of the Sun.

Air mass

The distance travelled through the atmosphere by the Sun's rays incident on the Earth is accounted for by a quantity called *air mass* (AM).

$$\text{air mass} = \frac{\text{path length travelled}}{\text{verticle depth of the atmosphere}}$$

$$AM = \frac{BP}{CP} = \left[\left(\frac{R}{H}\cos\theta_Z\right)^2 + 2\frac{R}{H} + 1\right]^{1/2} - \left(\frac{R}{H}\right)\cos\theta_Z \qquad (2.3)$$

Where:
R = the radius of the Earth, taken to be 6370 km;
H = thickness of atmosphere, taken to be 7991 km (although it is considerably thicker at the equator than the poles).

See next figure

Air mass

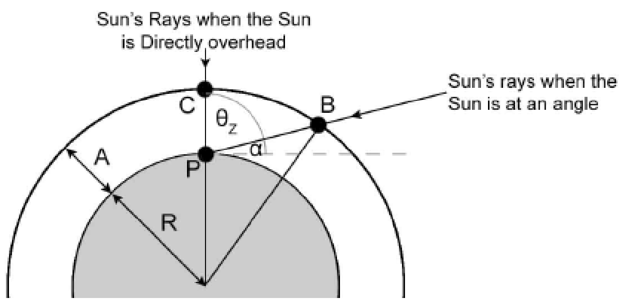


Figure 2.7: The distance travelled through the atmosphere by the Sun's rays.

Air mass

For angles of $\theta_Z < 70°$:

$$AM \approx \frac{1}{\cos\theta_Z} = \sec\theta_Z \qquad (2.4)$$

Therefore outside the Earth's atmosphere AM = 0, when the Sun is directly overhead $\theta_Z = 0$, AM = 1 and when the $\theta_Z = 60°$ AM = 2. AM is normally taken to be an average of 1.5 for a clear sunny day and this value is used for the calibration of solar cells.

Rough Estimates Of The Solar Energy Available At The Earth's Surface

The solar constant is the average extraterrestrial insolation at the edge of the atmosphere:

$$I_{SC} = 1367 \text{ W/m}^2$$

The Earth presents a disc of area πR^2 to the Sun, therefore the total amount of extraterrestrial insolation incident on the Earth is $I_{SC} \times \pi R^2$. This value is then divided by half the surface areas of the Earth, $4\pi R^2/2$, which gives 684 W/m^2, the average insolation incident on unit area of the Earth facing the Sun (figure 2.8). Note that solar panels are calibrated assuming that there is 1000 W/m^2 available.

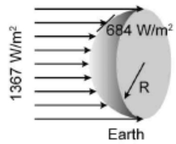


Figure 2.8

A rough estimate of the irradiation incident per unit area (H) of the Earth's surface can be made if we assume that 30% of the Sun's energy is lost in the atmosphere and that the a day is an average of 12 hours long at any location.

$$H = 0.7 \times 684 \times 12 = 5.75 \text{kWh / day}$$

Or if we assume that the Sun is only at an appreciable strength for an average 6 hours in the day (as is likely in more northerly latitudes):

$$H = 0.7 \times 684 \times 6 = 2.88 \text{kWh / day}$$

Figure 2.9 shows the yearly profile of mean solar radiation for different locations around the world. The solid grey line show the value of 5.75 kWh/day and the dashed grey line shows 2.88 kWh/day.

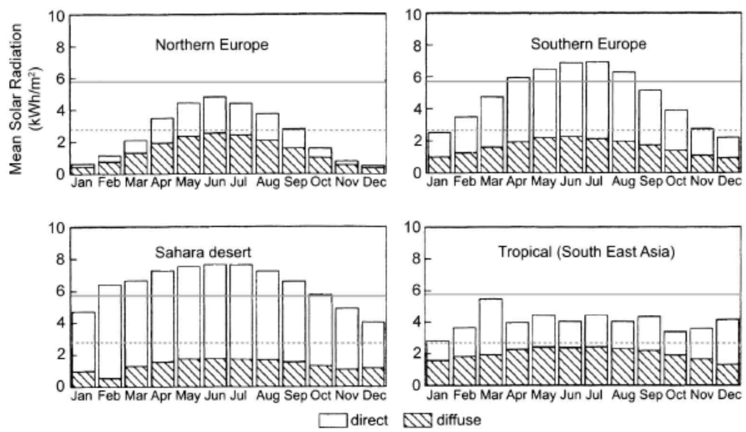


Figure 2.9: The yearly profile of mean solar radiation for different locations around the world.