SOLAR RADIATION

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objectives

- to review the properties of solar radiation on Earth
- to know the theoretical upper limit of solar radiation available at the earth's surface

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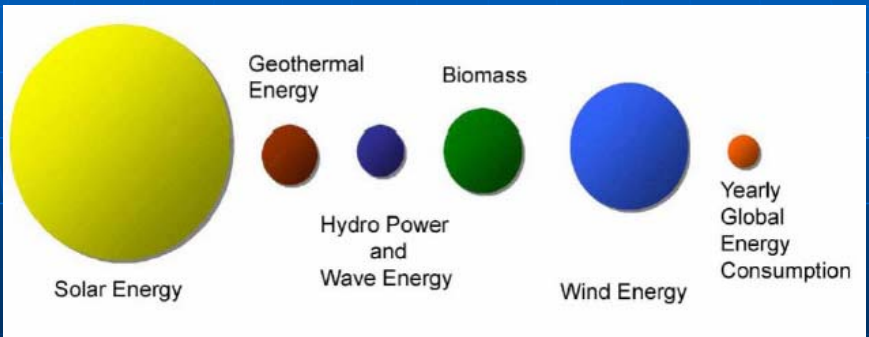
ON WORLD SCALE THE POTENTIAL OF RENEWABLE ENERGY



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The Sun

- A perennial, silent, free and nonpolluting source of energy
- Responsible for all life-forms on the planet
- For Energy generation can be either *directly* or *indirectly*
- ***Indirectly:*** wind, hydropower, photosynthesis, sea tidal energy, and to the microbiological conversion of organic matter into liquid fuels
- ***Directly:*** thermal (domestic, industrial or commercial) and electrical thermal generation
- Photovoltaic

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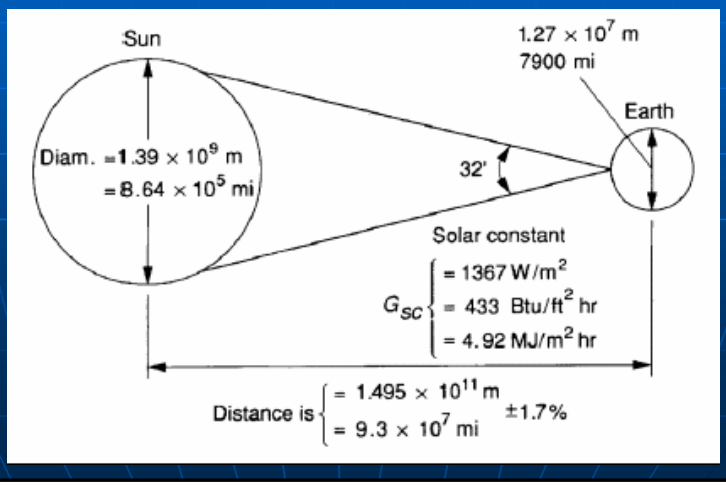
Sun – Earth Relationship

- The Sun is a large sphere of very hot gases, the heat is being generated by various fusion reactions



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Sun – Earth Relationship

- Note that it subtends an angle of 32 minutes at the earth's surface
- The small angle is due to the long distance between the earth and the Sun
- Thus, the Beam radiation from the Sun to the earth is almost parallel
- The intensity of the sun varies from it centre to its edge
- For theoretical calculations, it is assumed that the brightness allover the solar disc is uniform

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Solar Constant, G_{SC}

- Measurements indicate that the energy flux received from the Sun outside the earth's atmosphere is essentially constant.
- The ***Solar constant, G_{SC}*** is the rate at which energy received from the sun, per unit area perpendicular to the direction of propagation of the radiation, at mean earth-sun distance, outside of the atmosphere.
- The value of ***G_{SC}*** has been subjected to many experimental investigations, the standard value is ***1353 W/m²*** (based on the measurement in 970)
- According to subsequent measurements he value currently used is ***1367 W/m²***.

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Extraterrestrial Radiation, G_{ON}

- The earth revolves around the sun in an elliptical orbit having a very small eccentricity, and the with the sun at one of the foci.
- The distance between the sun and the earth varies a little through the year
- Thus the extraterrestrial radiation also varies
- The value on any day can be calculated as:

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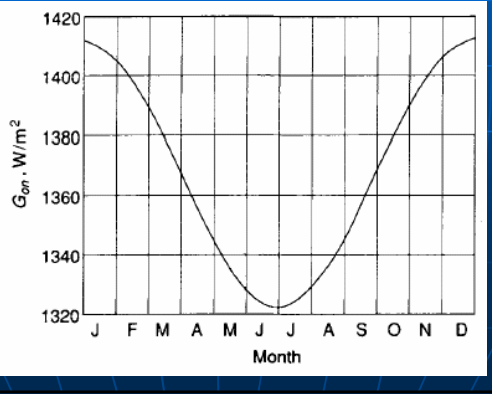
Variation of Extraterrestrial Radiation

$$G_{on} = G_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right)$$

- Where G_{on} is the radiation measured on the plane normal to the radiation on the n^{th} day of the year.



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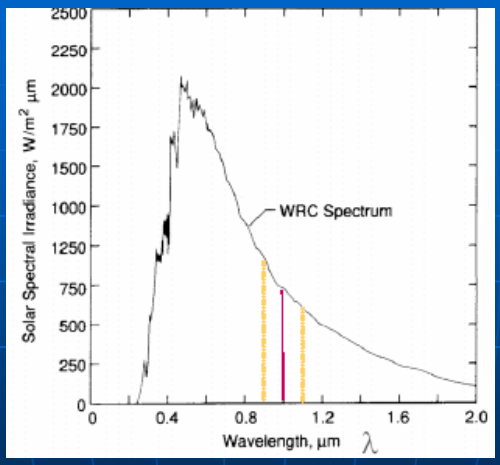
Spectral Distribution …



$G_{SC,\lambda}$: The average energy over small bandwidths cantered at wavelength $F_{0-\lambda}$: The fraction of the total energy in the spectrum that is between wavelengths 0 and λ

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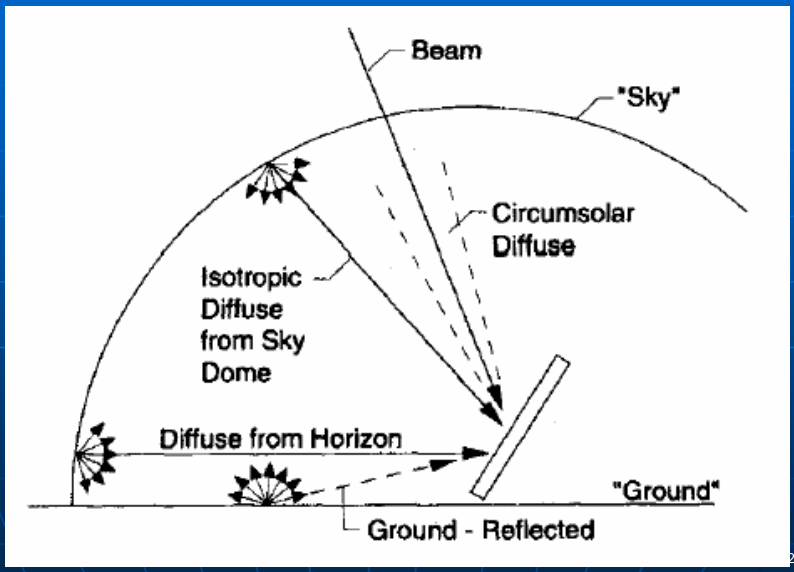
Solar Radiation in the Atmosphere



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Solar Radiation in the Atmosphere

- *Solar radiation received at the earth's surface is a attenuated*
- *Subjected to: absorption and scattering as passes through the earth's atmosphere*
- *Absorption occurs as a result of:*
  - *Ozone and water vapour*
  - *Gasses (CO_2, NO_2, CO, O_2 and CH_4)*
  - *Particulates matter (aerosols)*

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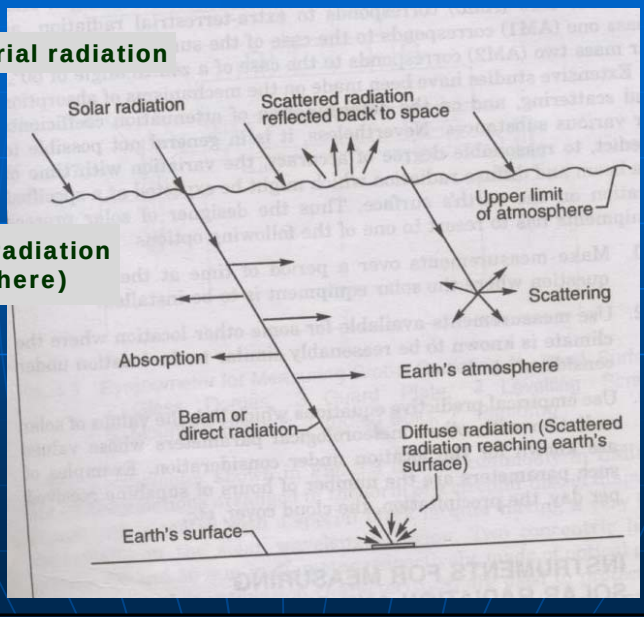
Solar Radiation in the Atmosphere

Extraterrestrial radiation

Terrestrial radiation (atmosphere)



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Irradiance & Irradiation

- Irradiance is given in W/m^2 and is represented by the symbol G. The rate at which radiant energy is incident on a surface per unit area of surface.
- Irradiation is given in Wh/m^2 and is defined as the measure of solar energy density incident per unit area on a surface - determined by integration of irradiance over a specified time, usually an hour or a day.
- Insolation is a term used to represent solar energy irradiation
- Irradiance and irradiation both apply to all components of solar energy
- The quantities depend on location, weather conditions and time of the year, also they depend whether the surface of interest is shaded or horizontal

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Other definitions

- ***Direct or Beam Radiation, G_B***: radiation received on the surface directly (not scattered or reflected)
- ***Diffuse radiation, G_D***: Scattered radiation that reaches the earth
- ***Albedo, G_R***: Radiation reaching the earth's surface after reflection
- ***Total or Global Radiation, G***: the sum the three above

$$G = G_B + G_D + G_R$$

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Solar Insolation

- Solar Insolation, H is the total solar energy radiated on a unit surface area over a certain period of time.
- The standard measure of H is given as the total solar energy on a unit area per day.
- Insolation values are given in tables as average monthly values for specific locations on the earth
- H [kWh/m^2.day]

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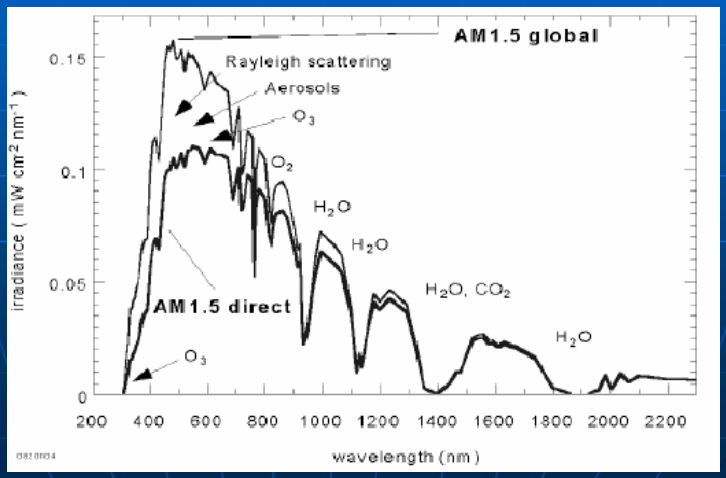
Global Radiation

- The global spectrum comprises the direct plus the diffused light.



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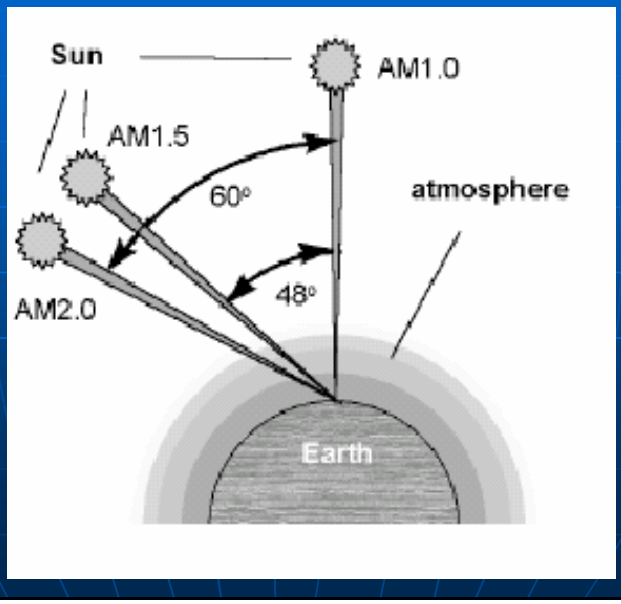
AIR MASS



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..... AIR MASS

- The path length of beam radiation through the Earth's atmosphere before it reaches a location on the earth's surface
- It is measured in units of ***Air Mass (AM)***

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..... AIR MASS

- AM = Ratio of the mass of the atmosphere through which the beam radiation passes to the mass it would pass through if the sun is directly overhead (i.e., at zenith angle, θ_Z)

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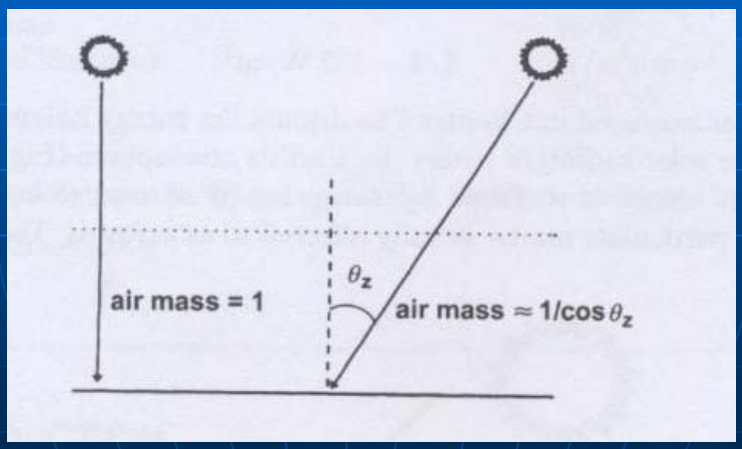
..... AIR MASS

- AM ≈ $1/\text{Cos}(\theta_Z)$



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..... AIR MASS

- The easiest way to estimate the air mass in practice is to measure the length of the shadow s cast by a vertical structure of height *h* using

$$AM = \sqrt{1 + \left(\frac{s}{h}\right)^2}$$

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..... AIR MASS

- Air Mass AM: The ratio of the mass of atmosphere through which beam radiation passes to the mass it would pass through if the sun were at zenith (directly overhead). At sea level, AM =1 when the sun is at zenith; AM= 2 for a zenith angle θ_z of 60^0. For $0 < \theta_z < 70^0$ AM= $1/\cos \theta_z$

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Electromagnetic Spectrum

- Emission results from changes in electronic, rational and vibrational states of atoms and molecules → thus distributed over a range of wavelengths
- The spectrum of electromagnetic wavelength is divided into wavelength bands

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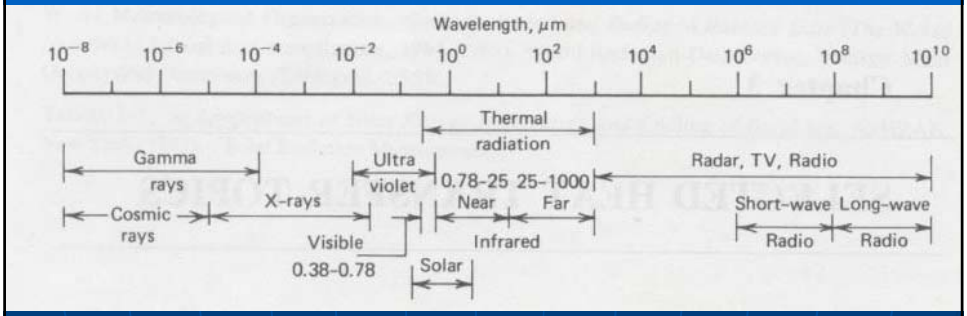
The Spectrum of Electromagnetic Radiation



- The wavelength of importance in solar energy and its applications are in the ***ultraviolet*** and ***near-infrared*** range

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Photon Radiation

- Solar radiation is made up of particles known as photons, which are energy units with zero mass
- Energy of a photon is given as: $E = h\nu$
  - $h = 6.6256 \times 10^{-34}$ Js (Planck's Constant)
  - $\nu = C/\lambda$ [Hz] frequency, C = speed of light and λ [m] is the wavelength

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Photon Radiation …

- The dependence of photo energy on spectral wavelength is significant where a minimum photon energy is needed to bring about required change
- Like in Photovoltaics during the creation of electron-hole pair
- There is a limit where this occur

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Black body radiation (*perfect absorber and emitter*)

- Radiation from the sun ←→ Blackbody radiation
- Thus Planck's law give a distribution as:

$$E_{\lambda b} = \frac{2\pi h C_o^2}{\lambda^5 [\exp(hC_o/\lambda kT) - 1]}$$

- Equating Planck's distribution to zero ←→ Wein's displacement law: $\lambda_{max}.T = 2.8978\ nmK$
- From Stefan – Boltzmann law the temperature of the surface of the sun is approximated to be 5770 K (at Solar Constant, 1367 W/m^2) ←→ 6000 K

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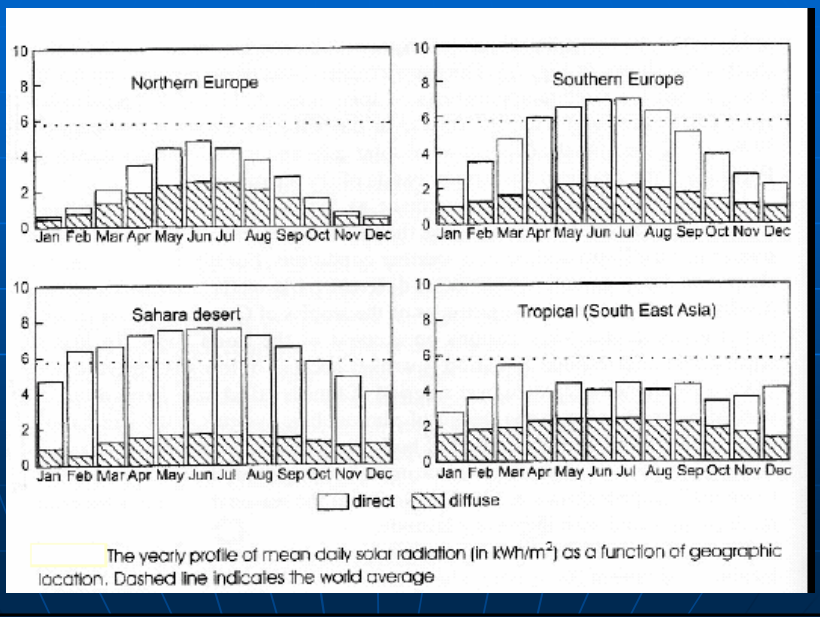
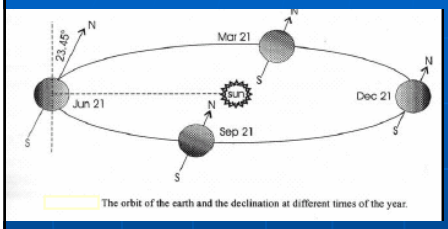
Examples of Mean Daily Solar Radiation

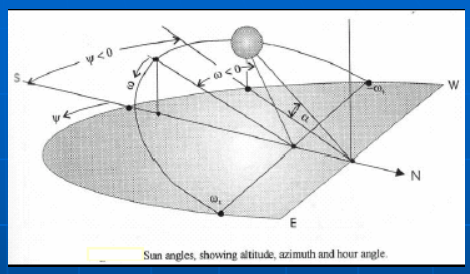


The yearly profile of mean daily solar radiation (in kWh/m^2) as a function of geographic location. Dashed line indicates the world average

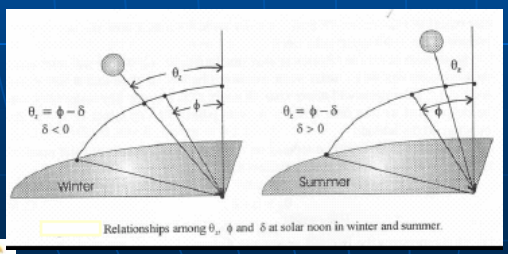
Solar Radiation on an Inclined Surface



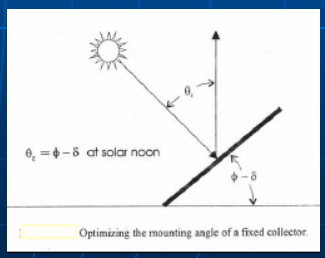
The orbit of the earth and the declination at different times of the year.



Sun angles, showing altitude, azimuth and hour angle.



Relationships among θ_z, ϕ and δ at solar noon in winter and summer.



Optimizing the mounting angle of a fixed collector.

Measurement of Solar Radiation

- Note: Calculations & approximations of solar radiation on any surface at a give angle in a given time at all places in the world do not yield the same value.
- Use in PV: The data used in design of PV is based on long term data averaged over a long time.
- Required measurements: The irradiance data is measured and accumulated for a specified period of time
- Desired: To measure global, beam, diffuse or albedo components of irradiance
- Instruments: Pyranometer, pyrheliometer and the PV Cell (limited range of spectrum)

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Pyranometer

- Designed to measure global radiation
- Mounted horizontally to collect data for global radiation on a horizontal surface
- Mounted in the plane of the PV panel
- Pyranometer designed to respond to all wavelength of the spectrum
- Can be shaded to measure diffuse radiation
- To study the performance of a Solar PV system it necessary to install it with a complete measuring system on which a logger is incorporated

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Conversion of Solar Radiation

- There are two ways in which solar radiation [absorbed at earth surface] can be converted to other forms of energy. The first, known as **"solar thermal applications,"** involve using the energy of the sun to directly heat air or a liquid.
- The second, known as **"photoelectric applications,"** [Solar-PV] involve the use of photovoltaic cells to convert solar energy directly to electricity.
- **"Passive solar applications"** make use of both light and heat from solar radiation, for example natural heating and lighting of buildings using sunshine. Day-lighting/heating is simply the use of natural sunlight to brighten/heat up a building's interior.

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Solar Energy in Uganda

- Solar Energy in Uganda like the rest of the world, is utilized in two forms, that is, Solar-Thermal and Solar-Photovoltaic.
- Solar Photovoltaics have the biggest share of the market, though no independent study has been carried out to establish the number of systems sold and the total installed watt-peak in the country.
- Solar thermal is in limited application, specifically heating water and drying foods. However country-wide data for installed capacity is not available.

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