# RENEWABLE ENERGY TECHNOLOGY

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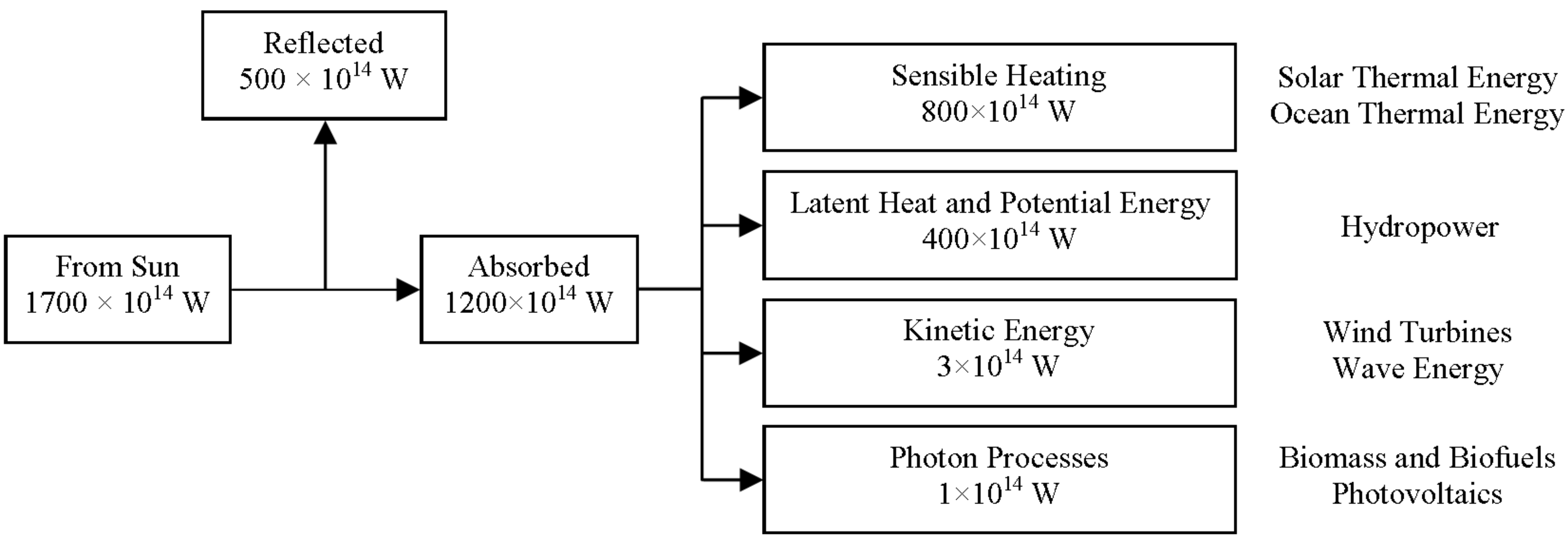
# The Sun as an Energy Source

- The Sun's energy is the driver for processes occurring at the Earth's surface and within the atmosphere
- This results in a number of energy streams which form the basis for different renewable energy supplies

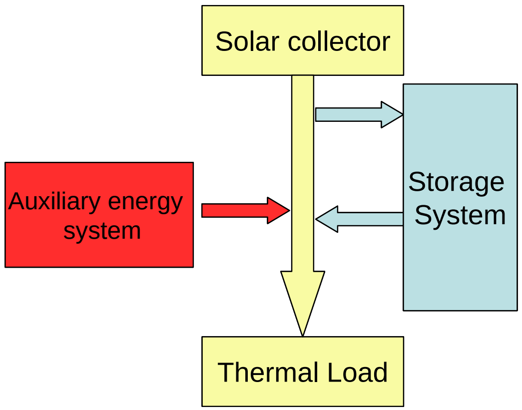



Data Source: J. Twidell & T. Weir, 2006

# Solar Thermal Power

A solar thermal system is any process which harnesses solar radiation as a power source through the conversion of the incident solar flux to ***useful heat***

- The most basic solar thermal systems use this heat directly, i.e for water heating, industrial process loads, etc.
- Through the use of energy conversion equipment (steam cycles, Stirling engines, etc.) this heat can also be converted to work



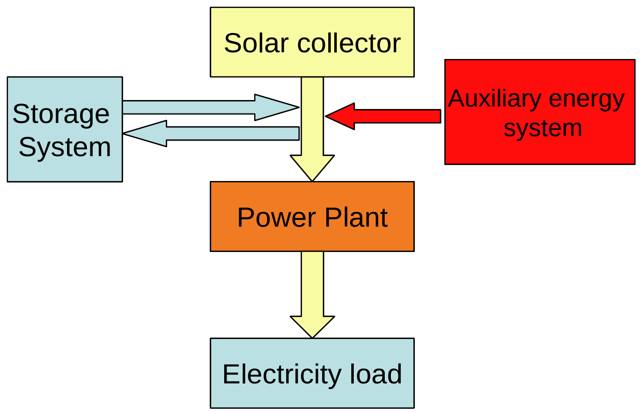
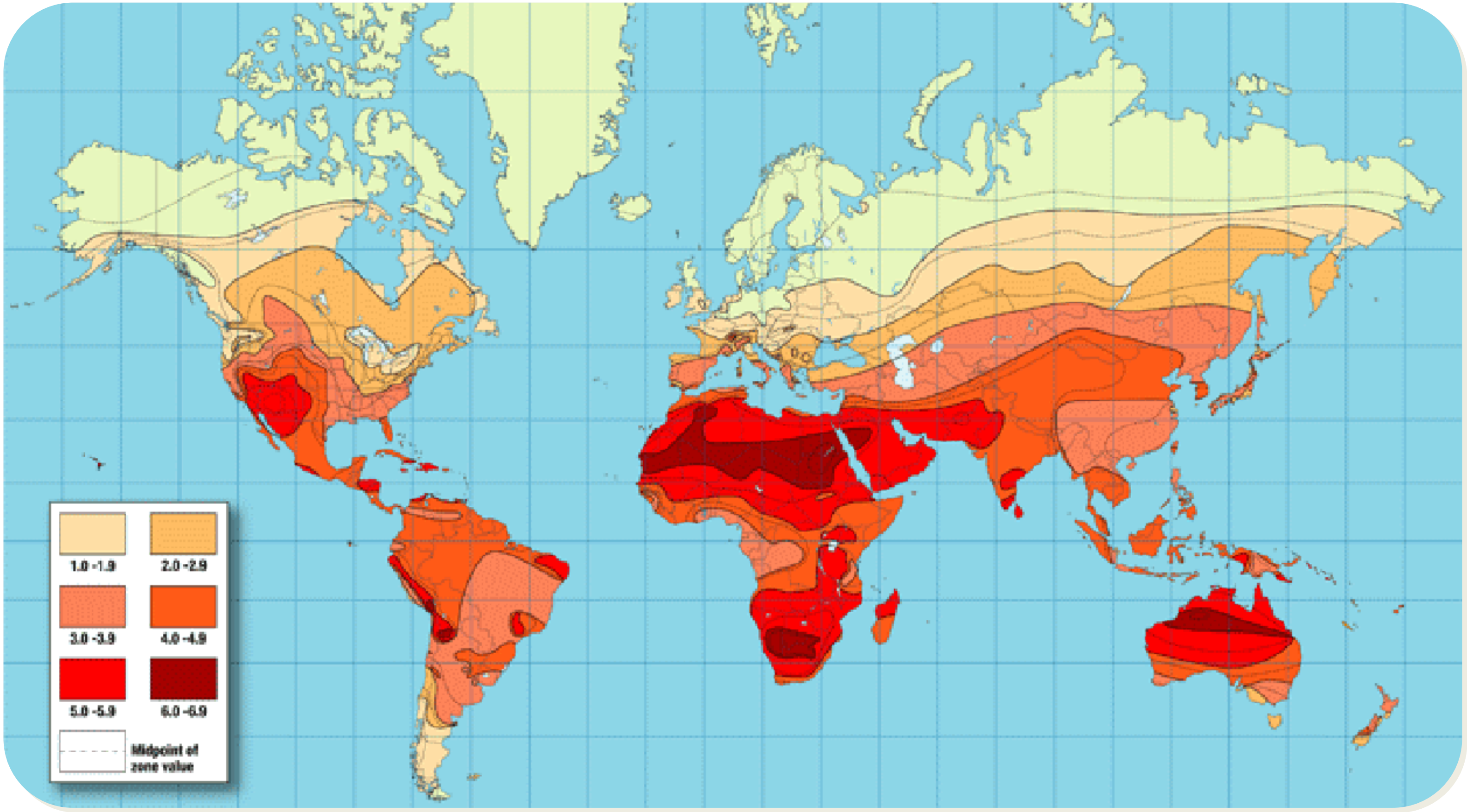




Image Source: M. Gomez, 2007

# Solar Thermal Power

- A solar thermal system is any process which harnesses solar radiation as a power source through the conversion of the incident solar flux to ***useful heat***
- The intensity of solar radiation is unevenly distributed across the globe, with highest availability in desert locations



# Morphology of the Sun

- The Sun is a main sequence star of spectral class G: just an average-sized star of average age
- The Sun fuses hydrogen to helium, releasing energy in the process, at a rate of around $3.85\times10^{26}$ W

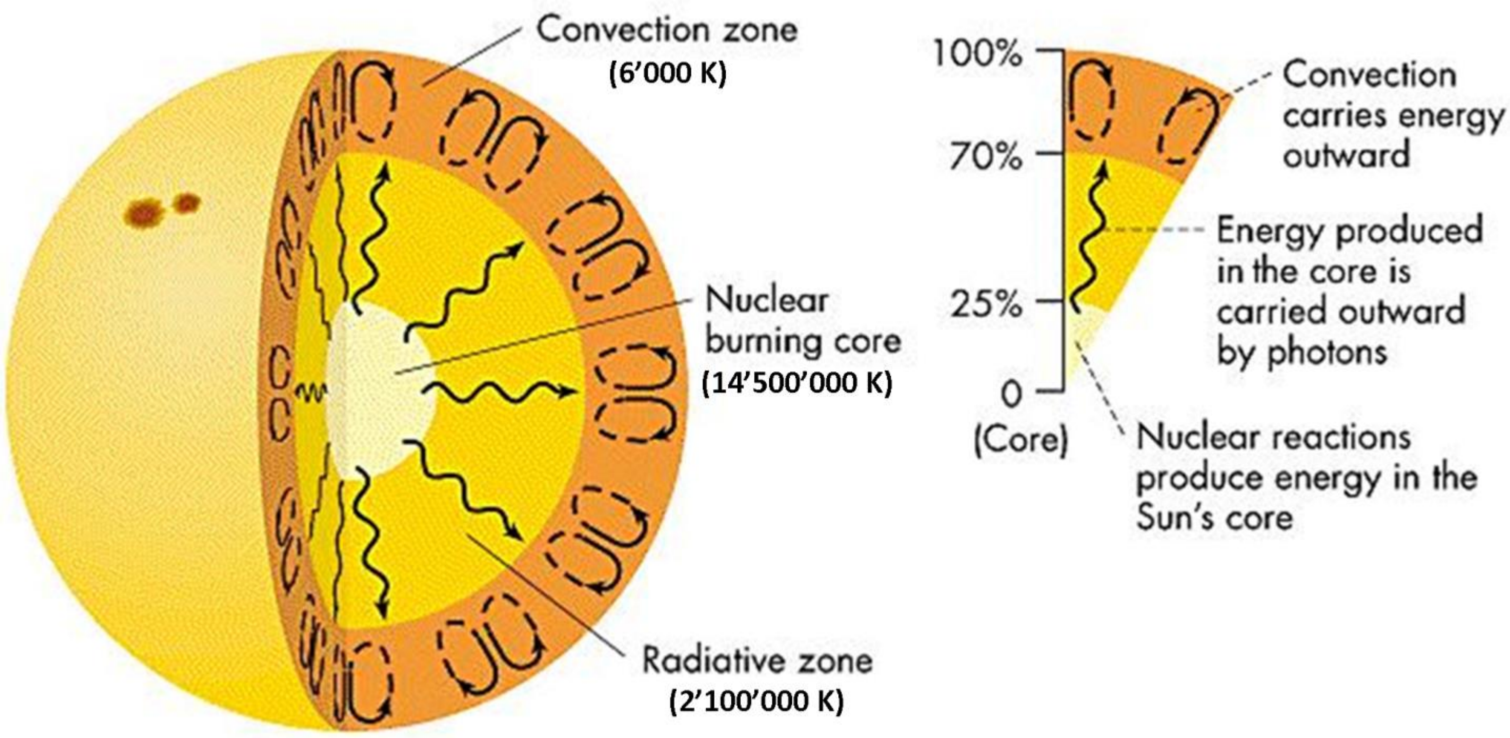



Image Source: McGraw-Hill Higher Education, 2008

# Radiant Solar Flux

- The energy produced by the Sun radiates outwards into space from the photosphere, the layer of the Sun from which photons emerge
- The intensity of the radiation decrease in accordance with the inverse-square law:

$$I(r) = \frac{Q_{fusion}}{4\pi r^2}$$

Sun's surface: $6.33\times10^{7}$ W/m$^2$

At Earth's mean orbital distance: **1,367 W/m$^2$**

This value is the internationally accepted solar constant ($I_{sc}$)

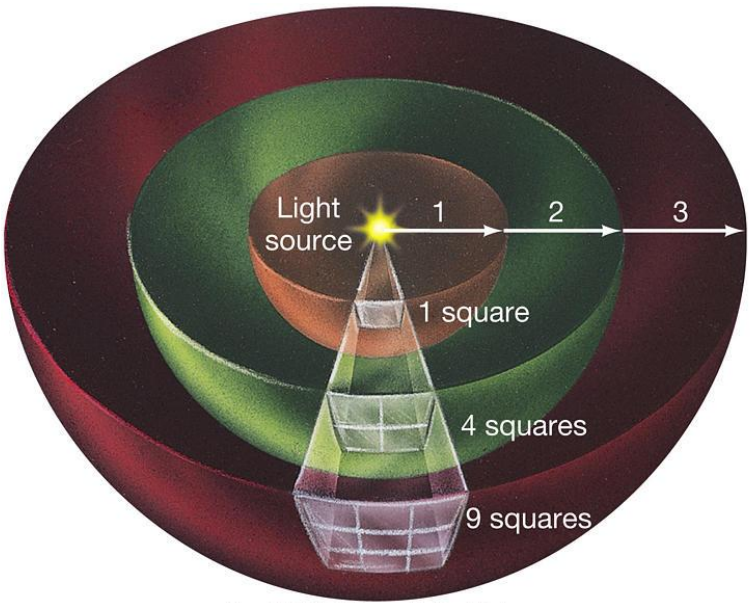



Image Source: Pearson Prentice Hall, 2005

# Extra-terrestrial Radiation

- Due the elliptical nature of the Earth's trajectory around the Sun, the incident radiant flux varies by about 3.4%
- The Earth is closest to the Sun in January (at perihelion) and furthest away in July (at aphelion)

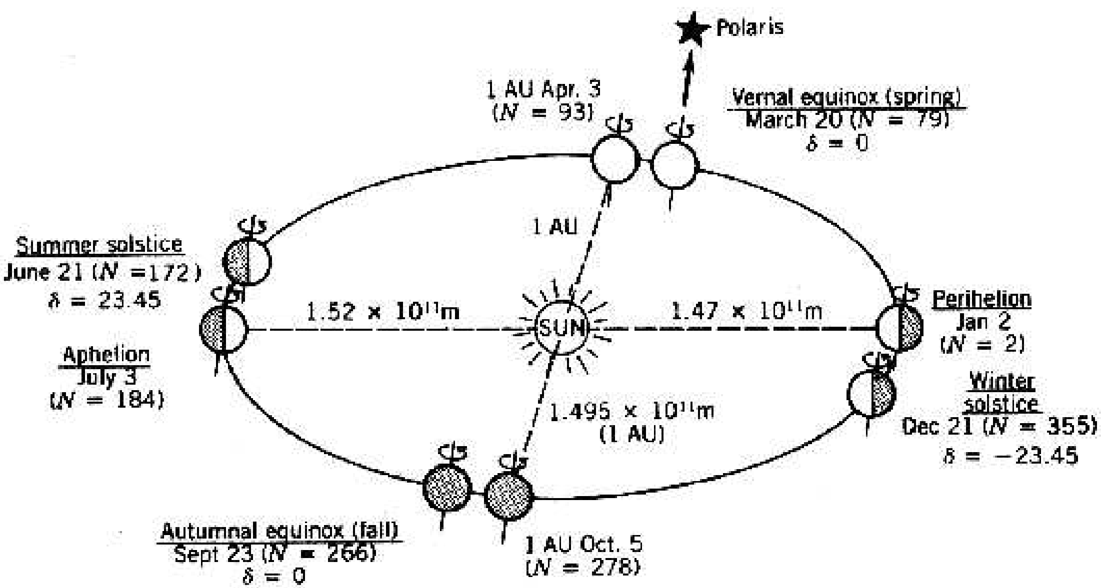



Image Source: W.B.Stine and R.W.Harrigan, 1985

- For a given day, $I_o$ can be estimated using:

$$I_o = I_{sc} \cdot \left( 1 + 0.034 \cos\left( 2\pi \frac{n-2}{365} \right) \right)$$

*n:* *calendar day* (Gregorian)

$I_o$: *incident radiation* [W/m²]

$I_{sc}$: *solar constant* [W/m²]

# Atmospheric Effects

- During passage through the Earth's atmosphere, different layers result in absorption or scattering of a fraction of the incident flux

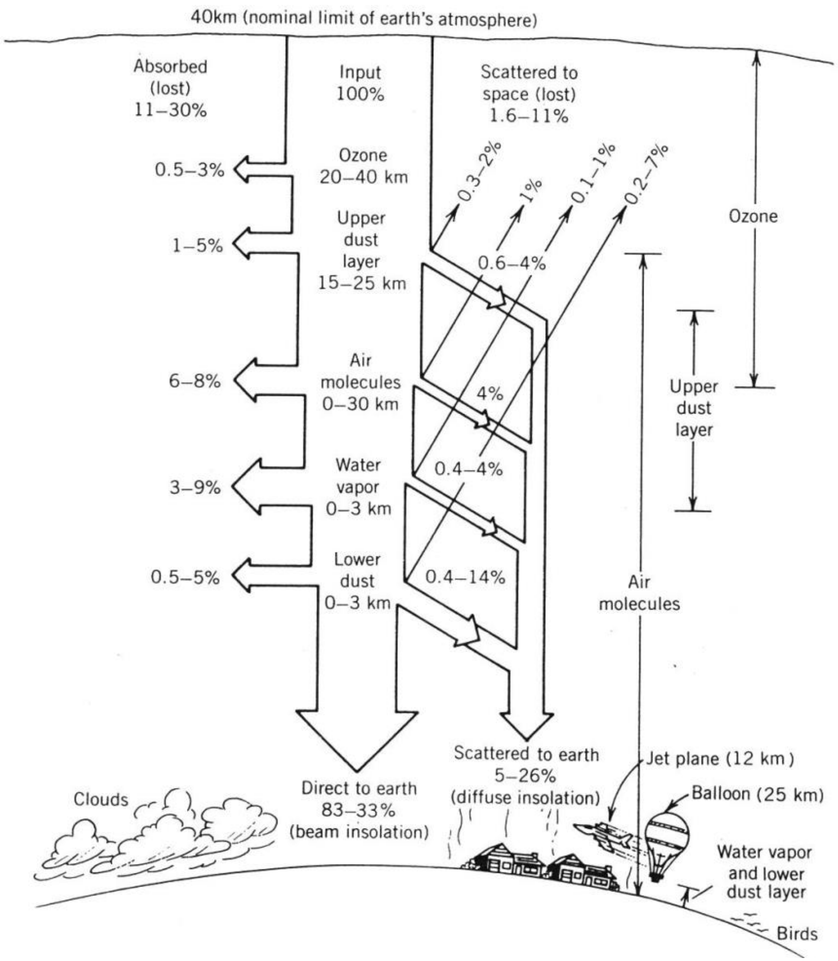



Image Source: Watt, 1978

Even on a clear day, up to 30% of the incoming radiation is absorbed:

Peak flux at Surface: **~1kW/m²**

Largest losses result from atmospheric absorption as well as reflection

# Time in Solar Calculations

- When performing solar calculations, it is important to distinguish between local clock time and local solar time:

  **Solar time** defines 12:00 as the moment when the Sun is *exactly* due South at the local position of the observer

  **Clock time** defines 12:00 as the moment when the Sun is due South for an observer on the local *standard time zone meridian*

- A number of other factors can further increase the difference:

  Daylight Saving Time imposes a 1hr difference during a ½-year

  A small correction known as the Equation of Time, due to the elliptical nature of the Earth's orbit (±15 mins)

- The combination of these factors can result in a difference of over 2hr between local clock time and solar time in some locations.

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  - **Clock time** defines 12:00 as the moment when the Sun is due South for an observer on the local *standard time zone meridian*

$$t_s = t_{clk} + \frac{\psi_{std} - \psi_{loc}}{15°} + \frac{\Delta t_{EOT}}{60} + \Delta t_{DST}$$

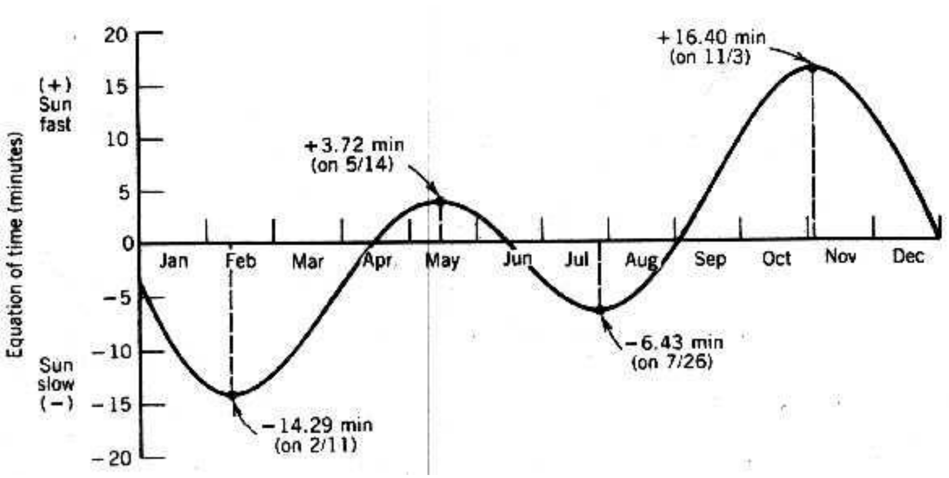



Image Source: W.B.Stine and R.W.Harrigan, 1985

$t_s$: *solar time* [hrs]

$t_{clk}$: *clock time* [hrs]

$\Psi_{std}$: *time zone meridian longitude* [°W]

$\Psi_{loc}$: *local longitude* [°W]

$\Delta t_{EOT}$: *equation of time correction* [min]

$\Delta t_{DST}$: *daylight saving time correction* [hrs]

# Mathematical Problem: Solar Time

Q.1. What is the local solar time when it is 10h00 on the clock in Liverpool (53°N, 3°W) on the 14th February? Liverpool uses Greenwich Mean Time with the standard time zone meridian at 0°W. Daylight saving time is not in effect in winter. **(Answer: 9 hrs 56 min)**

**Required Formula:**

$$t_s = t_{clk} + \frac{\psi_{std} - \psi_{loc}}{15^\circ} + \frac{\Delta t_{EOT}}{60} + \Delta t_{DST} \quad (1)$$

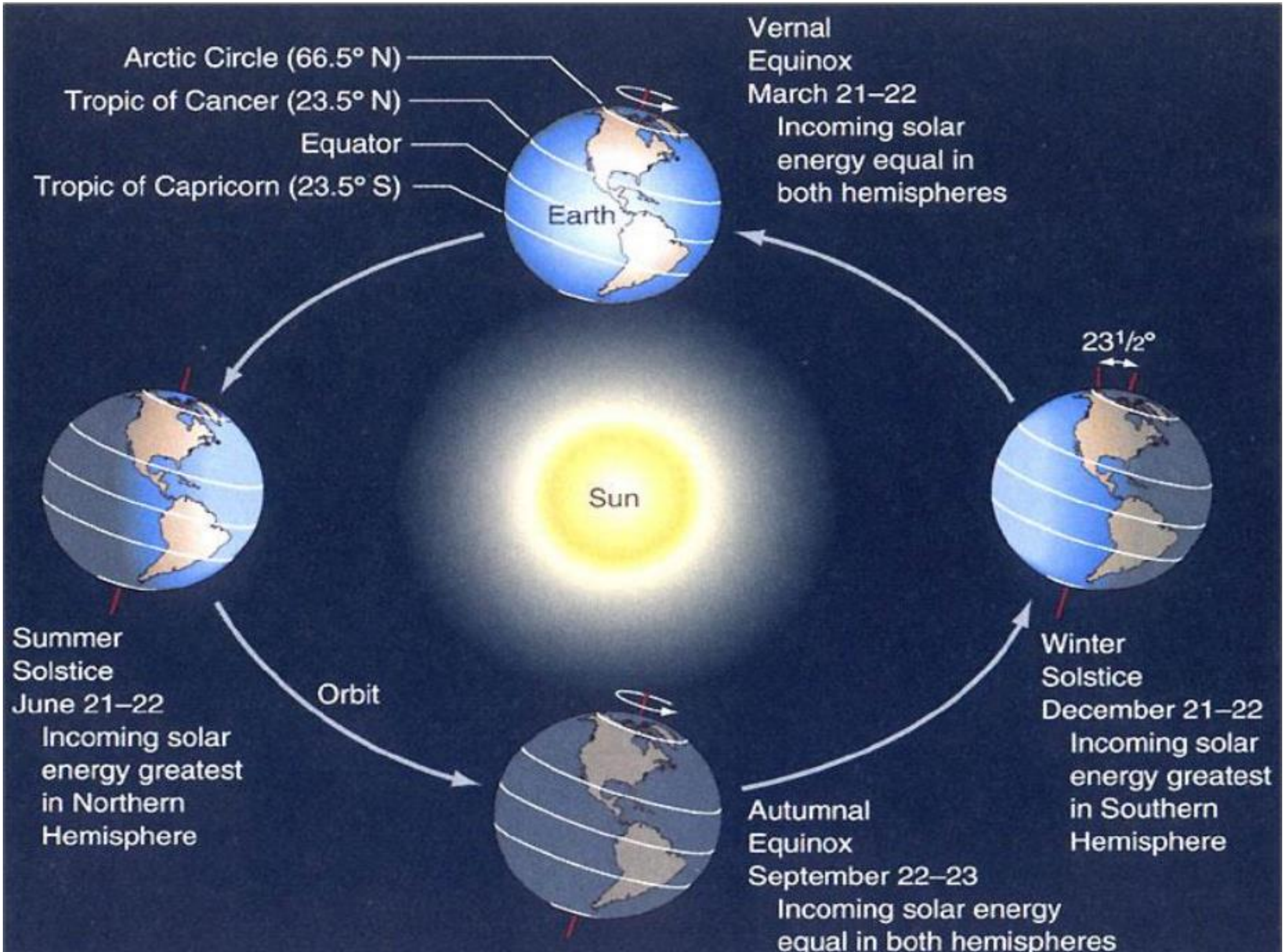
$$\Delta t_{EOT} = A\cos\left(2\pi\frac{n-1}{365}\right) + B\sin\left(2\pi\frac{n-1}{365}\right) + C\cos\left(4\pi\frac{n-1}{365}\right) + D\sin\left(4\pi\frac{n-1}{365}\right) \quad (2)$$

| | | |
|---|---|---|
| $t_s$ | Solar Time | [hrs] |
| $t_{clk}$ | Local Clock Time | [hrs] |
| $\Psi_{std}$ | Time Zone Meridian | [°W] |
| $\Psi_{loc}$ | Local Longitude | [°W] |
| $\Delta t_{EOT}$ | Equation of Time | [min] |
| $\Delta t_{DST}$ | Daylight Saving Time | [hrs] |
| $n$ | Gregorian Calendar Day | [#] |

Coefficients of the EOT

| | |
|---|---|
| A | 0.258 |
| B | -7.416 |
| C | -3.648 |
| D | -9.228 |

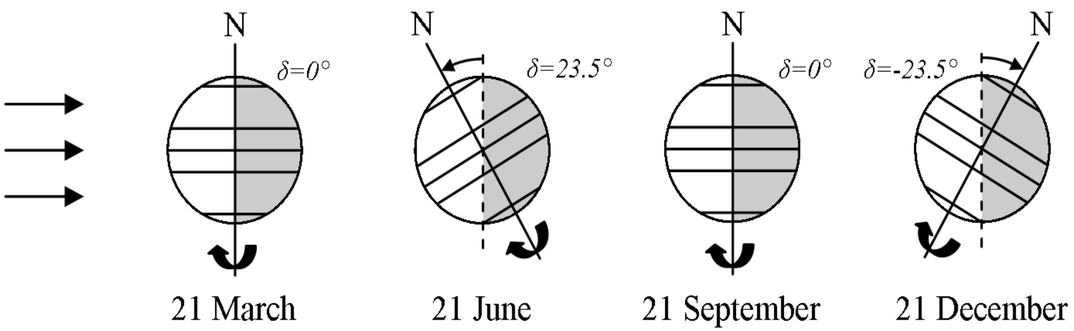
Q.2. What time is indicated on the clocks when the Sun passes due south on the 21st November in A Coruña (43°N 8°W)? A Coruña uses Central European Time, with the standard time zone meridian at 15°E. Daylight saving time is not in effect in winter. **(Answer: 13 hrs 9 min)**



Arctic Circle (66.5° N)
Tropic of Cancer (23.5° N)
Equator
Tropic of Capricorn (23.5° S)
Earth
Vernal
Equinox
March 21–22
Incoming solar
energy equal in
both hemispheres
23½°
Sun
Summer
Solstice
June 21–22
Incoming solar
energy greatest
in Northern
Hemisphere
Orbit
Winter
Solstice
December 21–22
Incoming solar
energy greatest
in Southern
Hemisphere
Autumnal
Equinox
September 22–23
Incoming solar energy
equal in both hemispheres

# Earth-Sun Geometry

- The direction of the incident beam radiation depends upon the position of the Sun, which varies throughout the day
- The path taken by the Sun depends on the observers latitude and the day of the year (through the ***declination angle***)




$$\delta = \arcsin\left(0.39795\cos\left(2\pi\frac{n-173}{365}\right)\right)$$

*δ:* *declination angle* [rad]

*n:* *calendar day* (Gregorian)

Image Source: J. Spelling, 2009

Based on the declination angle and latitude, the length of a given day can be calculated:

$$N = \frac{24}{\pi}\arccos\left(-\tan\left(\pi\frac{\varphi}{180}\right)\tan\delta\right)$$

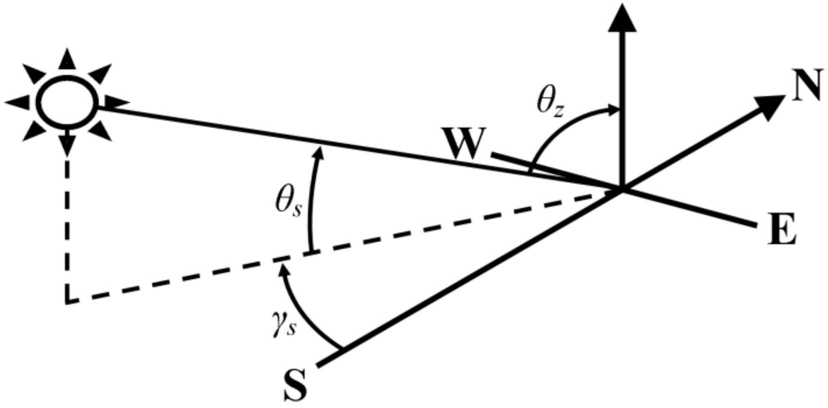
*N:* *day length* [hrs]

*φ:* *latitude* [°N]

# Earth-Sun Geometry

The design of solar power systems requires knowledge of the position of the Sun throughout the day

Solar position can be defined using a number of angle




**Hour Angle**: $\omega = \frac{\pi}{12}\left(t_s - 12\right)$

The hour angle is the angle through which the Earth has rotated since noon

**Solar Zenith Angle**: The zenith angle is the angle between the sun and the vertical.

The zenith angle is similar to the elevation angle but it is measured from the vertical rather than from the horizontal, thus making the zenith angle = **90°** - elevation

$$\theta_z = \arccos\left(\cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta\right)$$

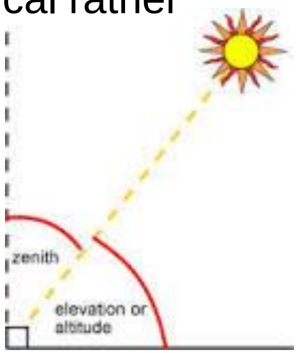
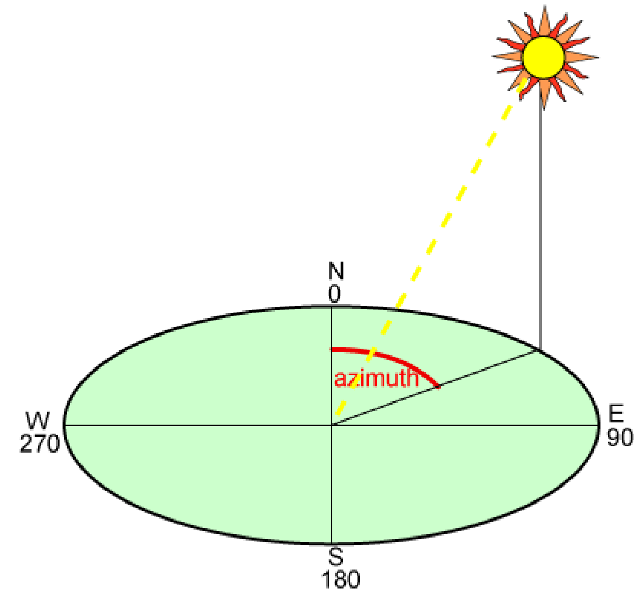



Image Source: J. Spelling, 2009

# Earth-Sun Geometry

**Solar Azimuth Angle**

- The azimuth angle is the compass direction from which the sunlight is coming.
- At solar noon, the sun is always directly south in the northern hemisphere and directly north in the southern hemisphere.
- The azimuth angle varies throughout the day as shown in the animation below.



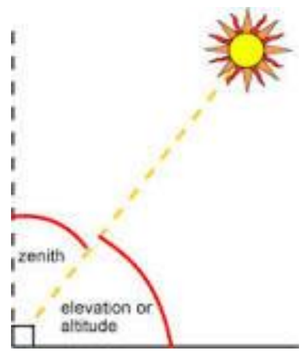

- At the equinoxes, the sun rises directly east and sets directly west regardless of the latitude, thus making the azimuth angles 90° at sunrise and 270° at sunset.
- In general however, the azimuth angle varies with the latitude and time of year and the full equations to calculate the sun's position throughout the day are given as

$$\gamma_s = \mathrm{sgn}(\omega)\left|\arccos\left(\frac{\cos\theta_z \sin\varphi - \sin\delta}{\sin\theta_z \cos\varphi}\right)\right|$$

Image Source: J. Spelling, 2009

# Earth-Sun Geometry

**Solar Altitude Angle:** $$\theta_s = \frac{\pi}{2} - \theta_z$$




The solar altitude angle is the angle between the sun's rays and a horizontal plane, as shown in Figure.

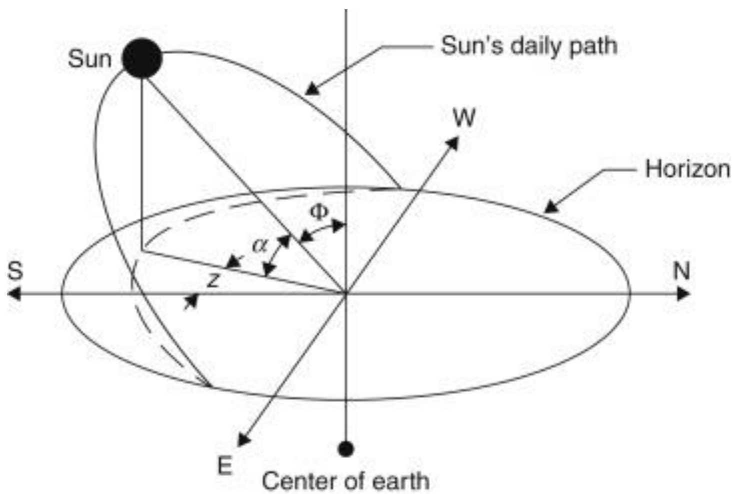



Image Source: J. Spelling, 2009

# Mathematical Problem: Solar Position Angles

Q.3. Calculate the maximum and minimum solar elevation angles for Stockholm (59°N, 18°E).

**(Answer: 54.43$^0$, 7.55$^0$)**

**Required Formula:**

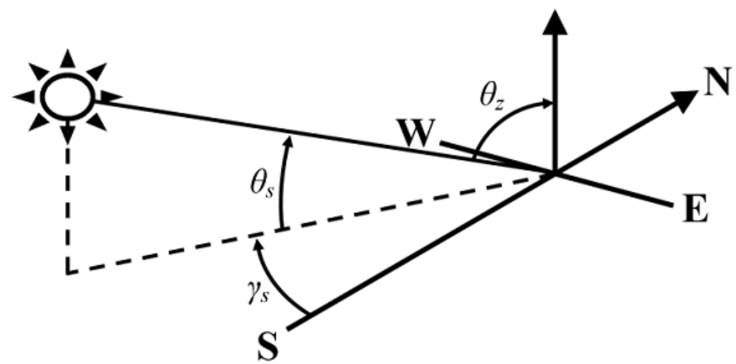
$$\omega = \frac{\pi}{12}(t_s - 12) \qquad (3)$$

$$\delta = \arcsin\left(0.39795\cos\left(2\pi\frac{n-173}{365}\right)\right) \qquad (4)$$

$$N = \frac{24}{\pi}\arccos(-\tan(\varphi)\tan\delta) \qquad (5)$$

$$\theta_z = \arccos(\cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta) \qquad (6)$$

$$\gamma_s = \mathrm{sgn}(\omega)\left|\arccos\left(\frac{\cos\theta_z\sin\varphi - \sin\delta}{\sin\theta_z\cos\varphi}\right)\right| \qquad (7)$$




$$\theta_s = \frac{\pi}{2} - \theta_z \qquad (8)$$

| | | | | | |
|---|---|---|---|---|---|
| $\delta$ | Declination Angle | [rad] | $\theta_z$ | Solar Zenith Angle | [rad] |
| $\varphi$ | Latitude | [rad] | $\theta_s$ | Solar Elevation Angle | [rad] |
| $N$ | Length of Day | [hrs] | $\gamma_s$ | Solar Azimuth Angle | [rad] |
| $\omega$ | Hour Angle | [rad] | | | |

Q.4. For how long is the Sun above the horizon on the 23rd October in Athens (38°N, 23°E)?

**(Answer: 14 hrs 4 min)**

# Mathematical Problem: Solar Position Angles

Q.5. Calculate the position (azimuth, elevation) of the Sun 1h before local solar noon on the 4th July in Los Angeles (34°N,118°W). **(Answer: Azimuth= 55.18$^0$, Elevation=73.16$^0$)**

**Required Formula:**

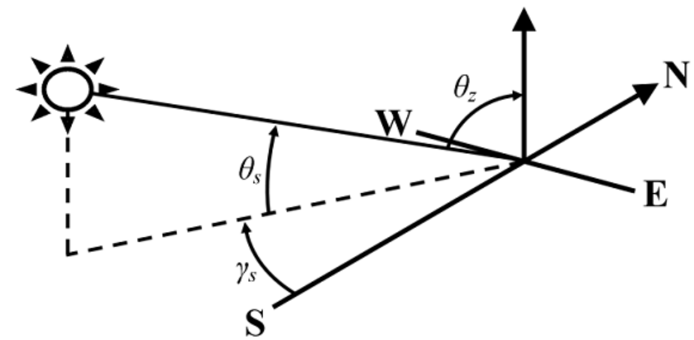
$$\omega = \frac{\pi}{12}(t_s - 12) \quad (3)$$

$$\delta = \arcsin\left(0.39795 \cos\left(2\pi \frac{n-173}{365}\right)\right) \quad (4)$$

$$N = \frac{24}{\pi} \arccos(-\tan(\varphi)\tan\delta) \quad (5)$$

$$\theta_z = \arccos(\cos\varphi \cos\delta \cos\omega + \sin\varphi \sin\delta) \quad (6)$$

$$\gamma_s = \mathrm{sgn}(\omega)\left|\arccos\left(\frac{\cos\theta_z \sin\varphi - \sin\delta}{\sin\theta_z \cos\varphi}\right)\right| \quad (7)$$




$$\theta_s = \frac{\pi}{2} - \theta_z \quad (8)$$

| | | | | | |
|---|---|---|---|---|---|
| $\delta$ | Declination Angle | [rad] | $\theta_z$ | Solar Zenith Angle | [rad] |
| $\varphi$ | Latitude | [rad] | $\theta_s$ | Solar Elevation Angle | [rad] |
| $N$ | Length of Day | [hrs] | $\gamma_s$ | Solar Azimuth Angle | [rad] |
| $\omega$ | Hour Angle | [rad] | | | |

Q.6. Calculate the position (azimuth, elevation) of the Sun at 15h30 on the clock in Istanbul (41°N,28°E) on the 6th August. Istanbul uses Eastern European Time, with the standard time zone meridian at 30°E. Daylight saving time is in effect (summer time is one hour ahead of winter time).

Q5.

We know,

$$\delta = \sin^{-1}\left(0.39795 \cos\left(2 \times 180 \times \frac{185-173}{365}\right)\right)$$

$$= 22.923$$

$$\theta_z = \cos^{-1}\{\cos 34 \cos(22.923) \cos(-15) + \sin(34) \sin(22.923)\}$$

$$= 17.186$$

$$\gamma_s = \sin^{-1}(\omega)\left[\cos^{-1}\left(\frac{\cos\theta_z \sin\phi - \sin\delta}{\sin\theta_z \cos\phi}\right)\right]$$

$$= \sin^{-1}(-15)\left[\cos^{-1}\left(\frac{\cos(17.186)\sin(34) - \sin(22.923)}{\sin(17.186)\cos(34)}\right)\right]$$

$$= -58.788$$

$$\theta_s = 90^\circ - \theta_z = 90^\circ - 17.186 = 72.814$$

$+30+4$

$= 185$

$t_s = 11h$

$$\omega = \frac{180}{12}(11-12)$$

$$= -15$$

$\phi = 34$

$sgn(12) = 1$

$sgn(-2.1) = -1$

$sgn(0) = 0$

# Components of Solar Radiation

- Beneath the Earth's atmosphere the Solar flux can be divided into two distinct components:
  - **Beam Radiation** ($I_b$), which is incident from the direction of the Sun's disk, i.e has not been scattered by the atmosphere
  - **Diffuse Radiation** ($I_d$), which is received from the Sun after it has been scattered by the atmosphere
- Even on a clear day, diffuse radiation accounts for 10% of the incident flux, increasing to 100% for overcast days
- **Global Irradiation** ($I_t$) is the sum of the beam and diffuse radiation for ***a given surface***

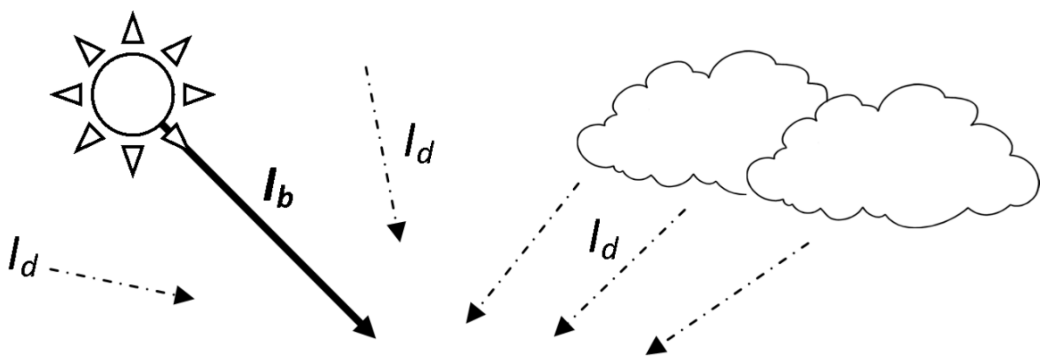



Image Source: Spelling, 2011

# Components of Solar Radiation

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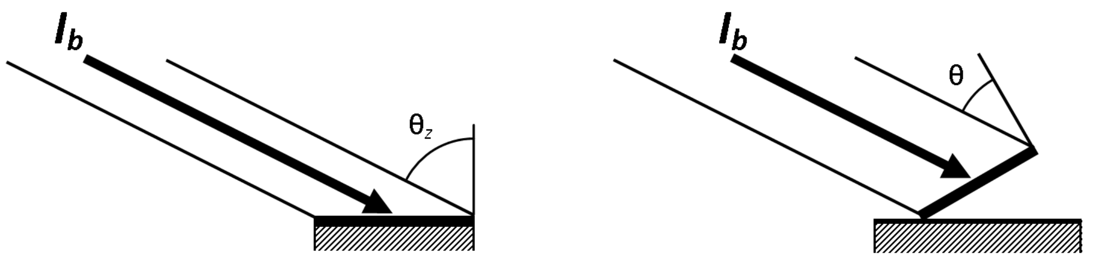
  - **Beam Radiation** ($I_b$), which is incident from the direction of the Sun's disk, i.e has not been scattered by the atmosphere
  - **Diffuse Radiation** ($I_d$), which is received from the Sun after it has been scattered by the atmosphere
- The intensity of the beam radiation is strong dependant upon the orientation of the surface which intercepts it.

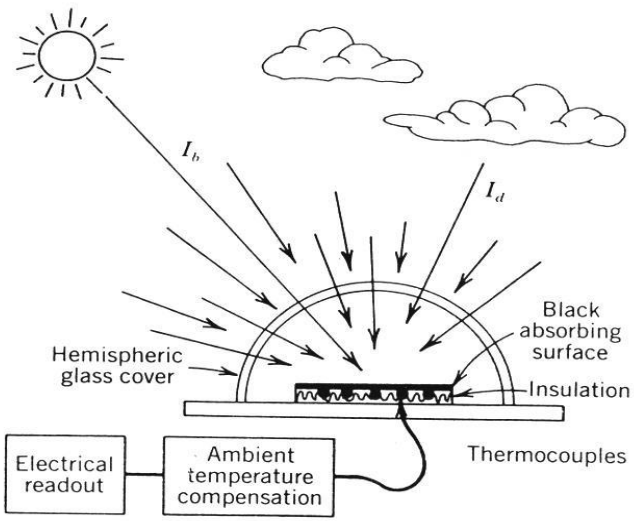



$$I_{bh} = I_b \cdot \cos(\theta_z) \qquad I_{bc} = I_b \cdot \cos(\theta)$$

Image Source: Spelling, 2011

# Measuring Solar Radiation

- The incident solar radiation at a site can be measured using a **pyranometer**, which measures the ***global*** solar irradiation




- A thin absorbing surface is shielded from heat losses and connected to thermocouples
- The surface temperature reached is proportional to the incident flux

- Pyranometers are usually placed flat, where they measure *horizontal global irradiance*:

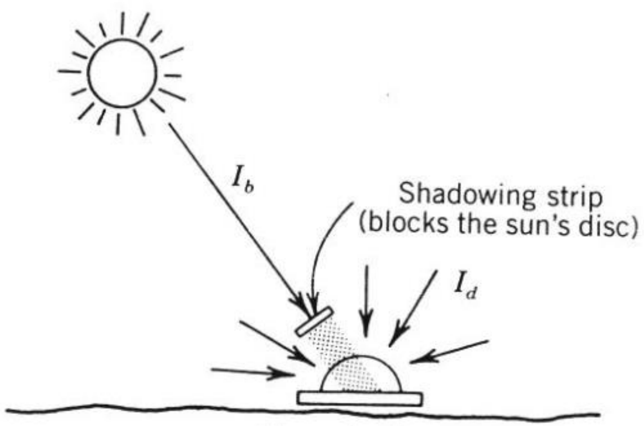
$$I_{t,h} = I_b \cos\theta_z + I_{d,h}$$

# Measuring Solar Radiation

- In order to obtain a measure of the diffuse radiation at a site, a **shadow-band pyranometer** can be used, which blocks the Sun's beam to measure only diffuse radiation.

  This allows calculation of the beam radiation intensity:

$$I_b = \frac{I_{t,h} - I_{d,h}}{\cos\theta_z}$$



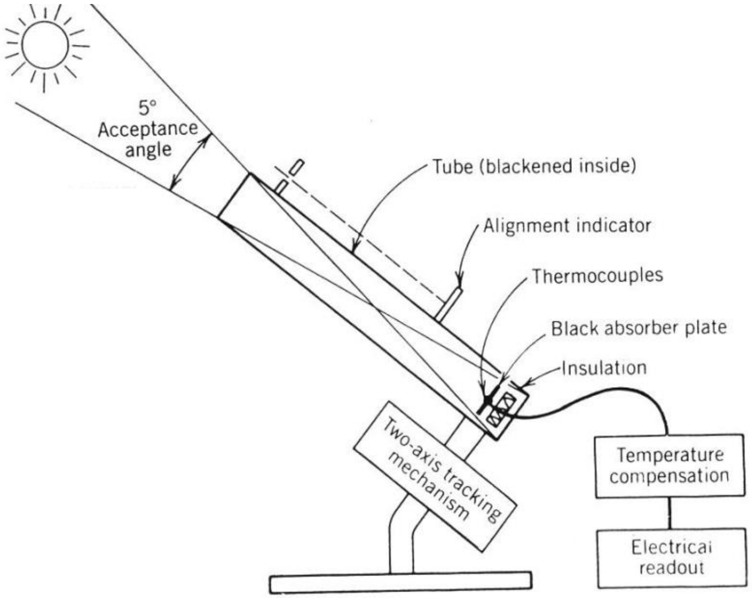

Fixed shadowband

Rotating shadowband

Image Source: W.B.Stine and R.W.Harrigan, 1985

# Measuring Solar Radiation

- Beam radiation can be measured directly using a normal-incidence **pyrheliometer** (NIP), which attempts to eliminate diffuse radiation
- The NIP must be aligned to point at the Sun
- To simplify operation of the NIP, an acceptance cone of ~5° is used for incident radiation
- The NIP will therefore tend to **overestimate** the value of $I_b$



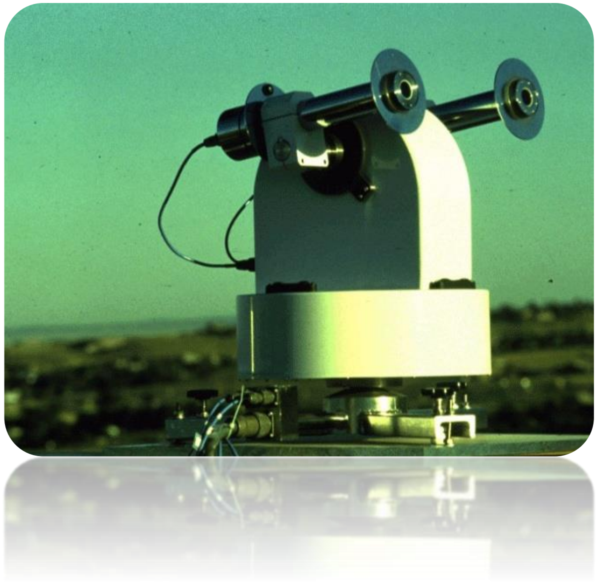



Image Source: W.B.Stine and R.W.Harrigan, 1985

# Radiation on a Surface

- The intensity of radiation that is incident on a given surface is dependant on the relative orientation of the surface and the position of the Sun
- The position of the surface (or aperture) can be defined by two angles:
- The **slope angle $\boldsymbol{\beta_c}$** defined between the normal to the aperture and the zenith
- The **surface azimuth $\boldsymbol{\gamma_c}$** defined by the surface normal clockwise from due-South
- For the determination of radiant flux on a given surface it is necessary to determine the ***incidence angle* θ**

$$\theta = \arccos\left(\cos\beta_c \cos\theta_z + \sin\beta_c \sin\theta_z \cos(\gamma_s - \gamma_c)\right)$$

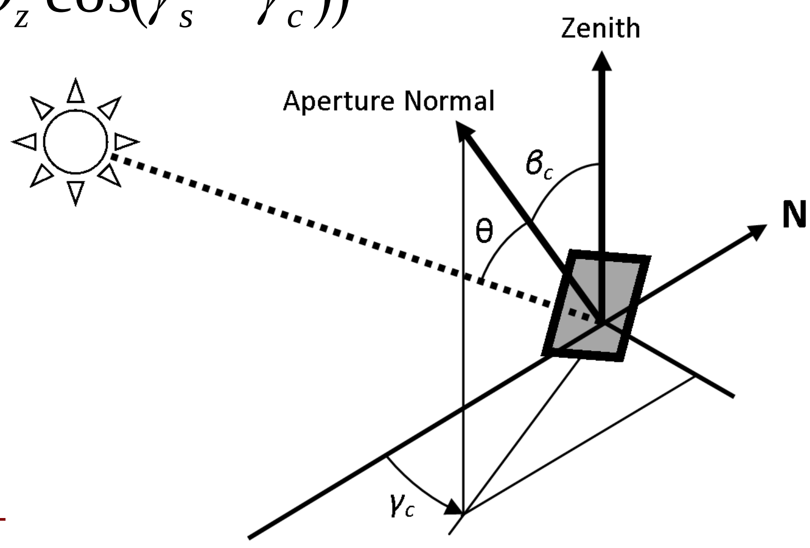



Image Source: J. Spelling, 2011

# The Cosine Effect

- The intensity of radiation that is incident on a given surface is dependant on the relative orientation of the surface and the position of the Sun
- When the incident radiation does not arrive normal to a collector, the surface intensity ($I_c$) of the radiation is reduced
- The interception area is increased by the inverse of the cosine of the incidence angle
- Conservation of energy gives: $I_b A_o = I_c A_c = I_c A_o / \cos\theta$
- The cosine effectiveness of a surface can be defined as: $\varepsilon_{\cos} = \dfrac{I_c}{I_b} = \cos\theta$

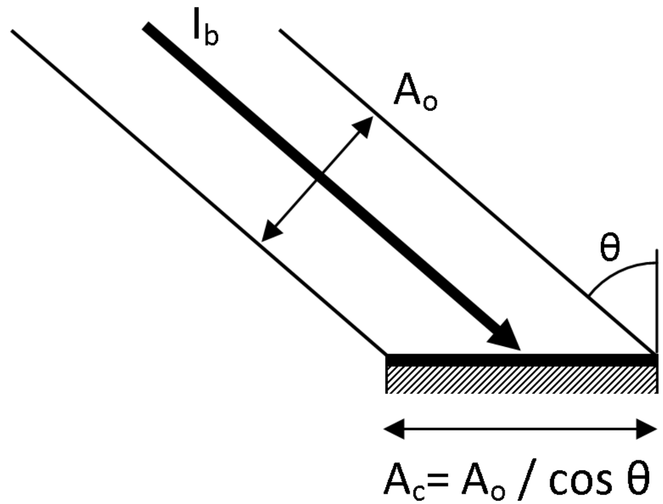
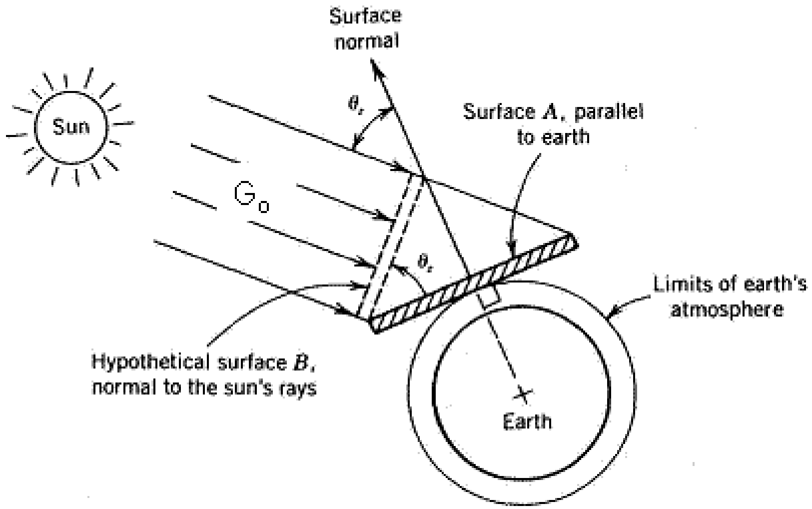



Image Source: J. Spelling, 2011

# The Cosine Effect

- Consider a flat surface just outside the earth's atmosphere and parallel to the earth's surface below. When this surface faces the sun, the solar irradiance falling on it will be Go, the maximum possible solar irradiance.  This is the case A which is illustrated in the figure.
- If the surface is not normal to the sun (case B in the figure), the solar irradiance falling on it will be reduced by the cosine of the angle between the surface normal and a central ray from the sun.
- **Reduction of radiation by the cosine of the angle between the solar radiation and a surface normal is called the cosine effect.**




http://www.energy.kth.se/

Image Source: J. Spelling, 2011

# Horizontal Surface Radiation

- Radiation incident on horizontal surfaces is an important factor in agriculture and crop drying.
- The radiation intensity is dependant directly on the zenith angle $\theta_z$

$$\varepsilon_{\cos} = \cos\theta_z = \cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta$$

  - Cosine effectiveness of horizontal surfaces is a strong function of latitude

- *δ:* *declination angle* [rad]
- *φ:* *latitude* [°N]
- *ω: Hour angle*

# Radiation on Tilted Surfaces

- The cosine effectiveness of tilted surfaces is dependent on the slope and the azimuth of the surface
- For a non-tracking (fixed orientation) surface, the most efficient azimuth angle $\gamma_c$ is **due South** (for the total energy received)
- Cosine effectiveness can then be determined as a function of the slope

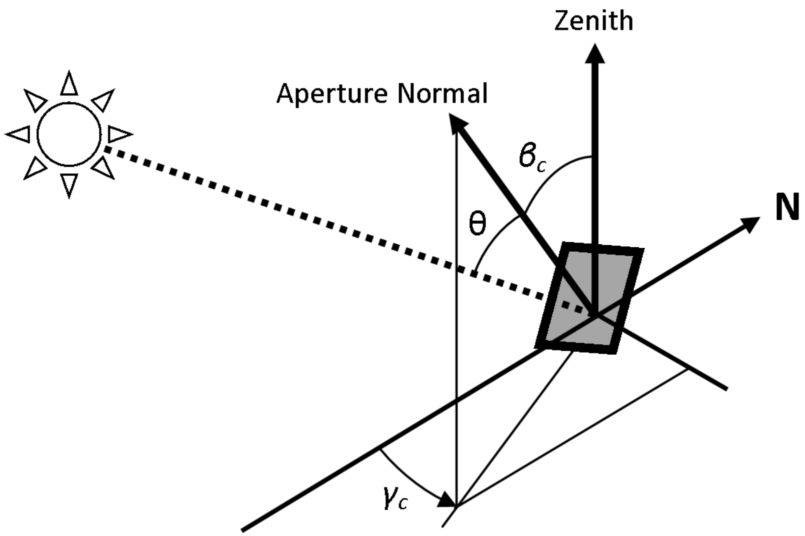



Image Source: J. Spelling, 2011

# Mathematical Problem: Solar Radiation

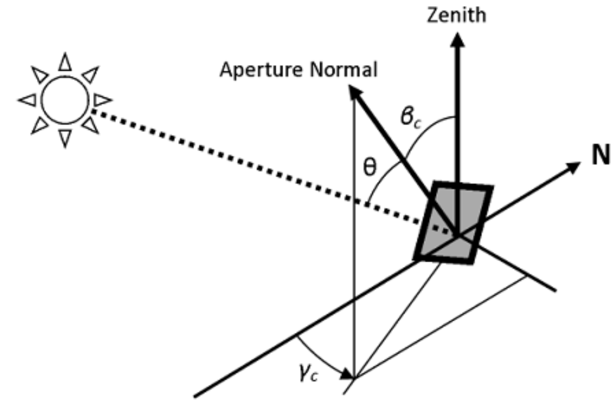
Q.7. What is the cosine effectiveness of a surface if solar radiation is incident at an angle of 25° to the aperture normal? **(Answer: 90.63%)**

**Required Formula:**

$$I_{t,h} = I_b \cos\theta_z + I_{d,h} \quad (1)$$

$$\theta = \arccos\left(\cos\beta_c \cos\theta_z + \sin\beta_c \sin\theta_z \cos(\gamma_s - \gamma_c)\right) \quad (2)$$

$$\varepsilon_{\cos} = \frac{I_c}{I_b} = \cos\theta \quad (3)$$




| | | | | | |
|---|---|---|---|---|---|
| $I_{t,h}$ | Total Horizontal Irradiation | [W/m²] | θ | Surface Incidence Angle | [rad] |
| $I_b$ | Beam (Direct Normal) Irradiation | [W/m²] | $\gamma_c$ | Surface Azimuth Angle | [rad] |
| $I_{d,h}$ | Diffuse Horizontal Irradiation | [W/m²] | $\beta_c$ | Surface Tilt Angle | [rad] |
| $I_c$ | Surface Normal Irradiation | [W/m²] | $\varepsilon_{cos}$ | Surface Cosine Effectiveness | [ - ] |

Q.8. What is the angle of incident of solar radiation on a horizontal surface at solar noon in Addis Ababa (9°N, 39°E) on the 15th of July? **(Answer: 12.55$^0$)**

Q.9. Two pyranometers are mounted horizontally at a prospective site (36 °N, 115°W) for a solar power plant. At solar noon on June 12th, the horizontal pyranometer measures 850 W/m$^2$ while the shadow band pyranometer measures 150 W/m$^2$. What is the intensity of the direct beam radiation at this time? And what would be the cosine effectiveness of a horizontal surface? **(Answer: 791.42 W/m$^2$, 88.4%)**

# Non-Tracking Collectors

- For solar collectors that are mounted in a fixed position, the initial orientation must be carefully selected
- For maximising the total energy received over the year:
  - Azimuth $\gamma_c$ = 0° (collector faces ***due South***)
  - Slope $\beta_c = \varphi$ (collector slope equal to the ***latitude***)
  - This optimum does not take into account a number of factors:
    - Shadowing/blocking
    - Energy demand curves
    - Local microclimates
  - Each situation requires its own design!

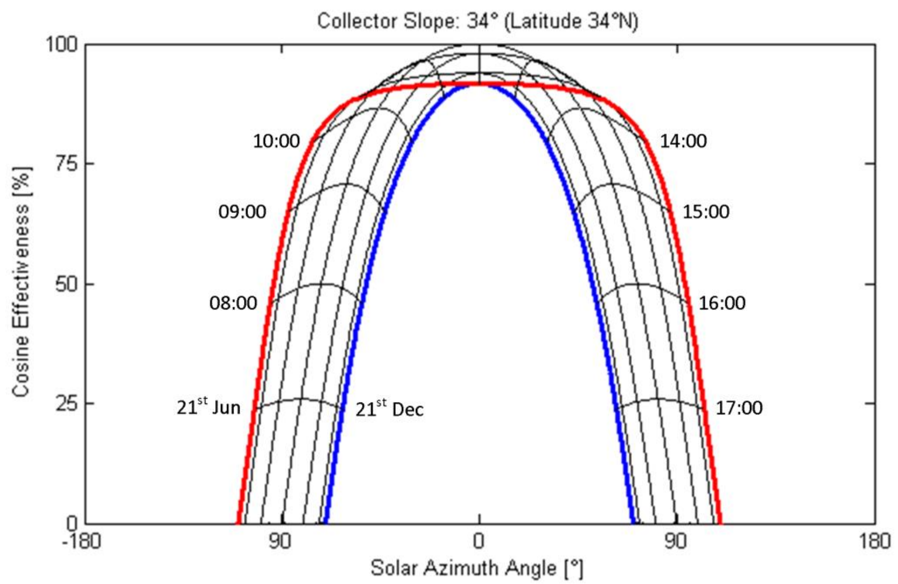



Image Source: J. Spelling, 2011

# Single Axis Tracking

- In order to increase the energy received, the solar collector can be repositioned throughout the day to track the Sun
- The cosine effectiveness of the surface can be increased by reducing the incidence angle of the incident solar flux
- The tracking system can be defined by certain quantities:
  - **Tracking Angle** (***ρ***): fixed by the tracking system and adjusted throughout the day
  - **Solar Tracking Incidence Angle** ($\boldsymbol{\theta_t}$)
  - **Tracking Axis** (***n***): vector about which the tracking system rotates to position the collector

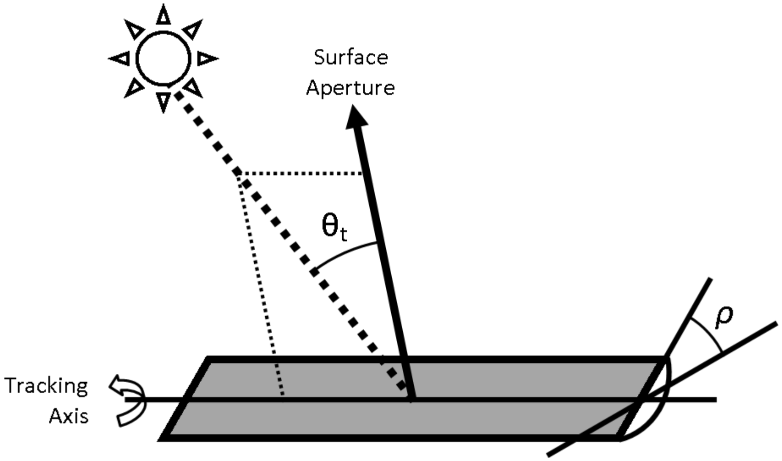


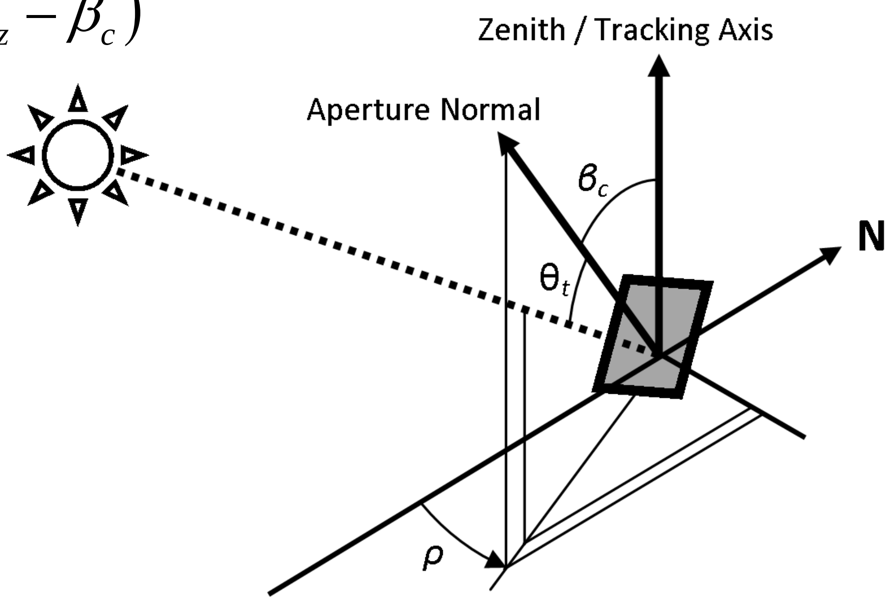

Image Source: J. Spelling, 2011

# Vertical Axis Tracking

- One possibility is to mount the tracking axis vertically, following the progress of the solar azimuth angle
- The collector tilt can either be vertical (aligned with the axis) or offset at a fixed angle (i.e. the optimum angle for the latitude)

**Tracking Angle**: $\rho = \gamma_s$

**Incidence Angle**: $\cos\theta_t = \cos(\theta_z - \beta_c)$

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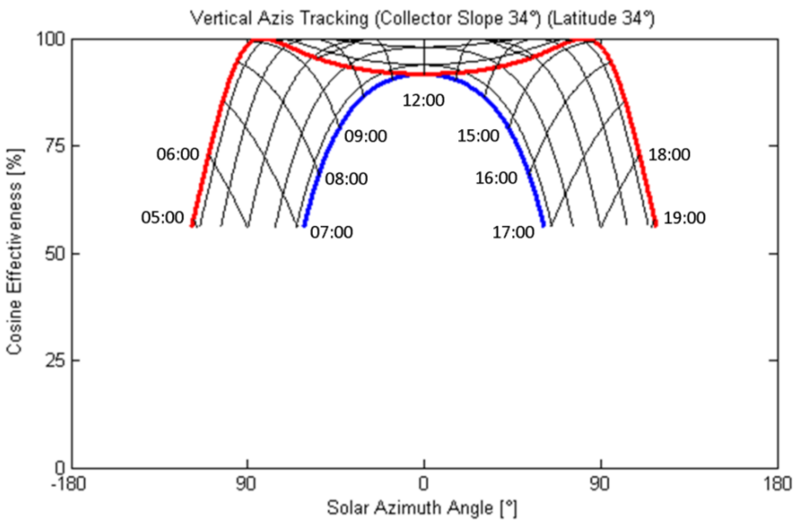
# Vertical Axis Tracking

- One possibility is to mount the tracking axis vertically, following the progress of the solar azimuth angle
- The collector tilt can either be vertical (aligned with the axis) , offset at a fixed angle (i.e the optimum angle for the latitude)
    - Strong improvement in Cosine-effectiveness observed

<u>Tracking</u>

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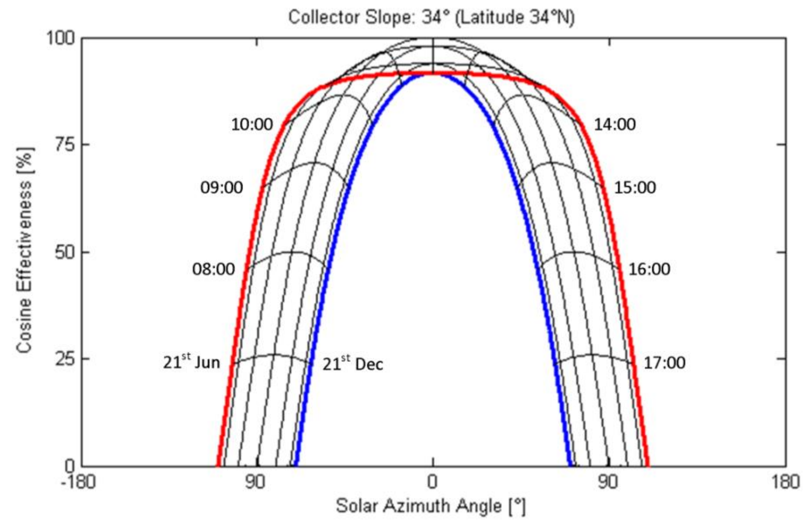
<u>Non-Tracking</u>

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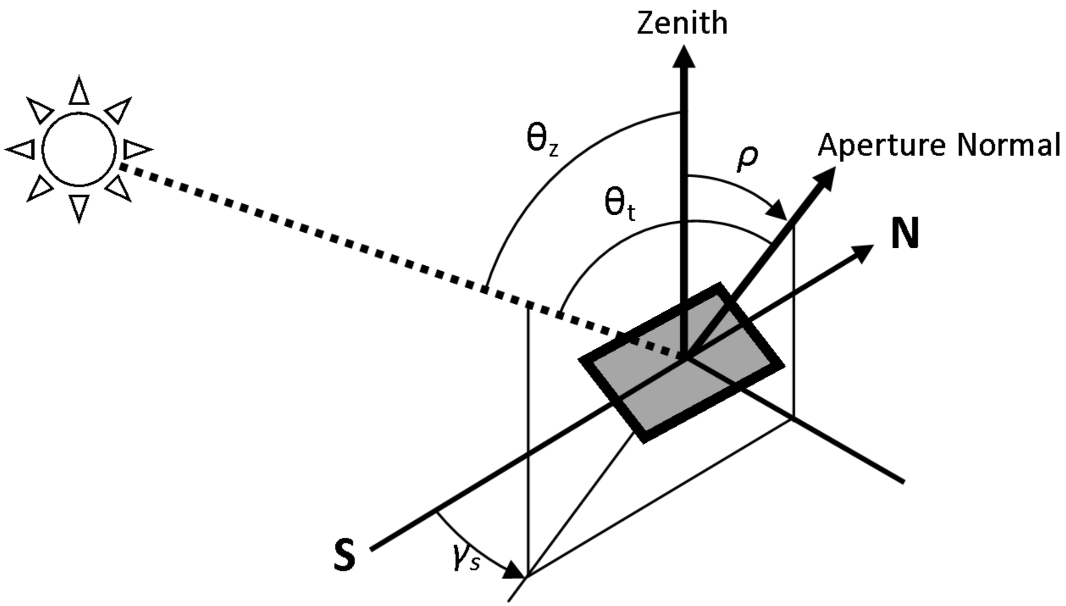
# Horizontal Axis Tracking (NS)

- If the solar collector system is very large, it may be necessary to mount the tracking axis horizontally
- If the axis is aligned ***North-South***, the tracking angles are given by:

**Tracking Angle**: $$\rho = \arctan \frac{\sin \gamma_s}{\tan \theta_s}$$

**Incidence Angle**: $$\cos\theta_t = \sqrt{1 - \cos^2 \theta_s \cos^2 \gamma_s}$$

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# Horizontal Axis Tracking (EW)

- If the solar collector system is very large, it may be necessary to mount the tracking axis horizontally
- If the axis is aligned ***East-West***, the tracking angles are given by:

**Tracking Angle**: $\rho = \arctan \dfrac{\cos \gamma_s}{\tan \theta_s}$

**Incidence Angle**: $\cos \theta_t = \sqrt{1 - \cos^2 \theta_s \sin^2 \gamma_s}$

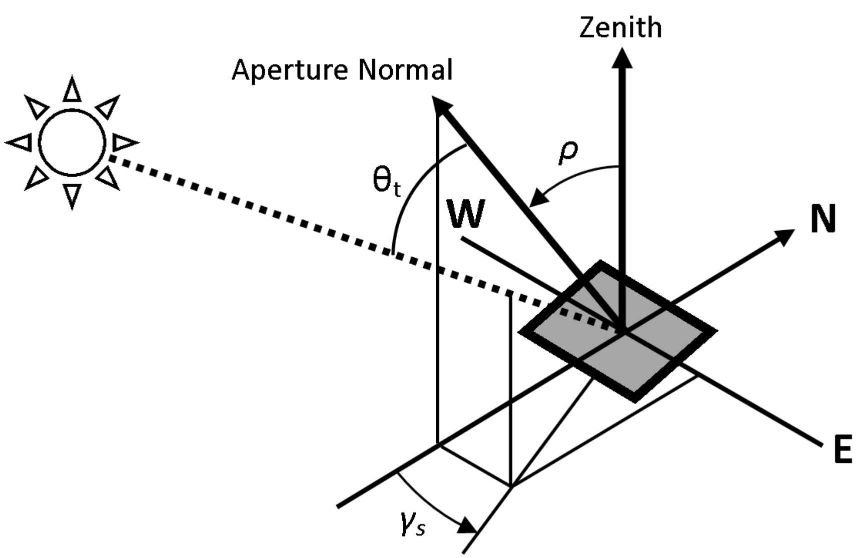



Image Source: J. Spelling, 2011

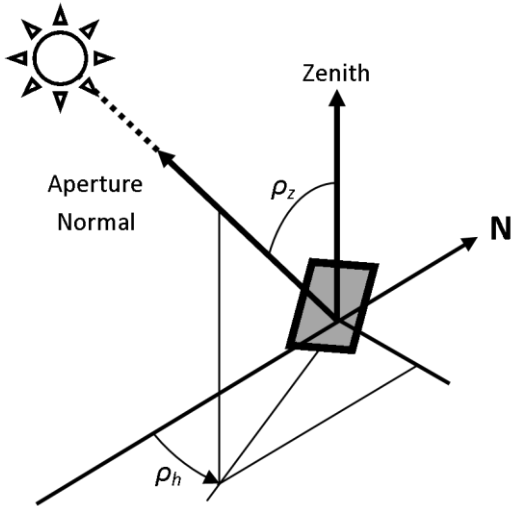
# Dual Axis Tracking

- In order to maximise the energy received, the solar collector should be position to face the Sun directly at all times
- The cosine effectiveness of the surface will therefore always be 100%
- The tracking system can be defined by certain quantities:
  - **Horizontal Tracking Angle (*$\rho_h$*)**: tracks the solar Azimuth position

$$\rho_h = \gamma_s = \mathrm{sgn}(\omega)\left|\arccos\left(\frac{\cos\theta_z \sin\varphi - \sin\delta}{\sin\theta_z \cos\varphi}\right)\right|$$

  - **Zenith Tracking Incidence Angle (*$\rho_z$*)**: tracks the solar zenith angle

$$\rho_z = \theta_z = \arccos(\cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta)$$

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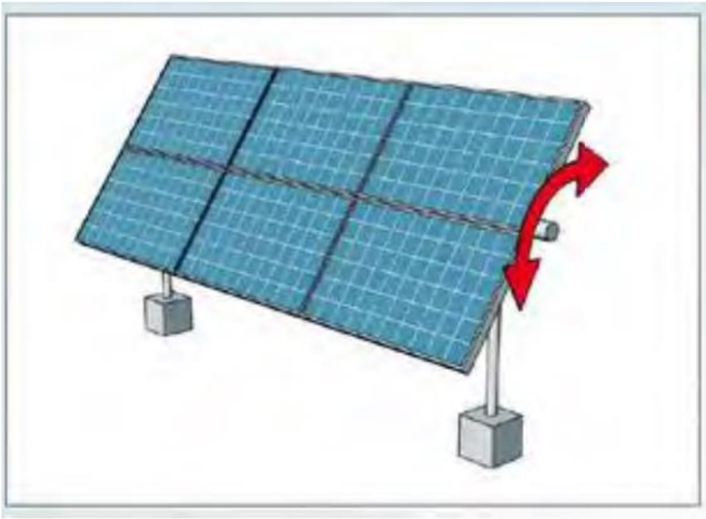
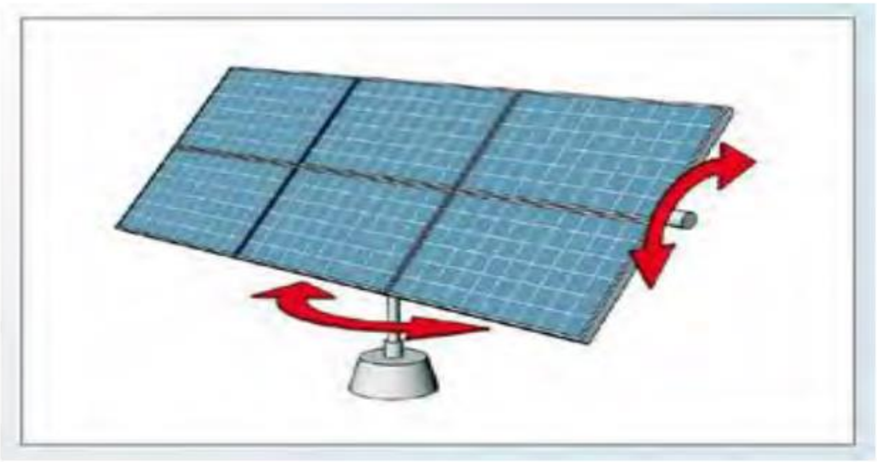


Horizontal Axis Tracker



Dual Axis Tracker

# Renewable Energy Technology

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