



Solar Energy Resources

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Contact

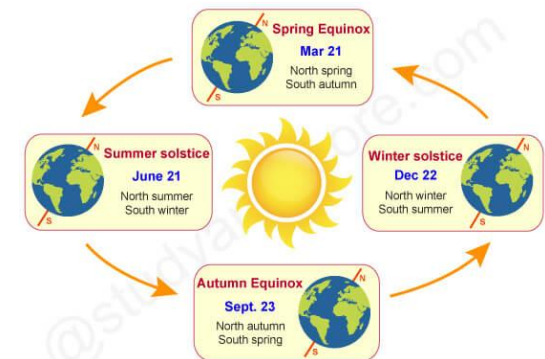
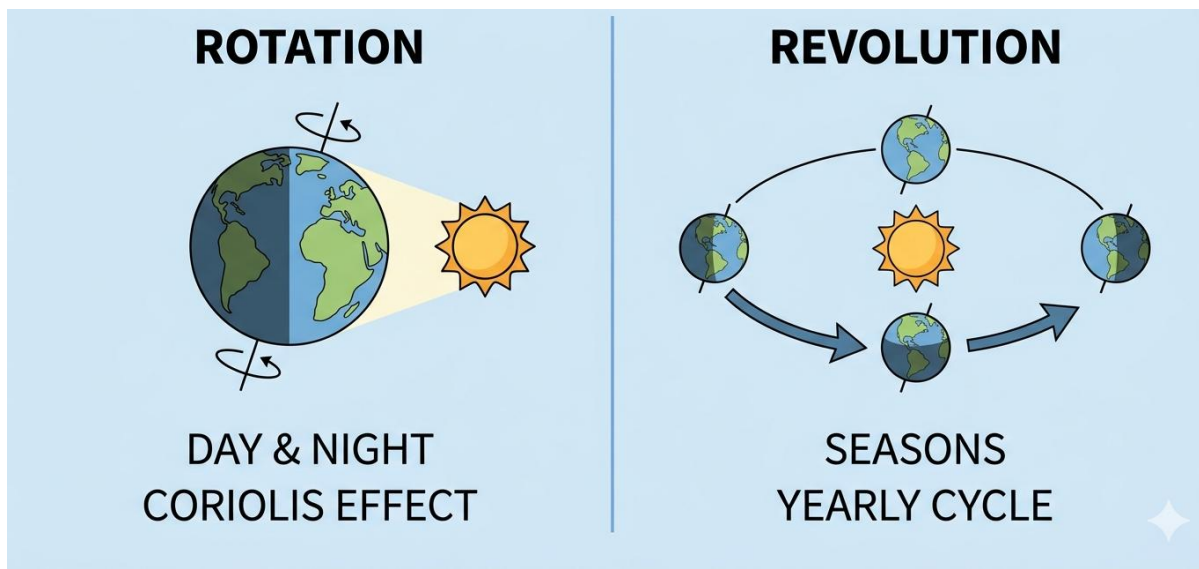
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- ☐ Distribution of solar radiation
- ☐ Solar collector tilt angle
- ☐ Solar tracking systems
- ☐ Shading of solar collector
- ☐ Types of solar radiation
- ☐ Sources of solar radiation data
- ☐ Solar energy potential



- ❑ The revolution of the Earth around the Sun, as well as the tilt of the Earth's spin axis, causes seasonal variations in solar radiation.
- ❑ The rotation of the Earth about its axis once every approximately 24 hours causes hourly variations in solar radiation.



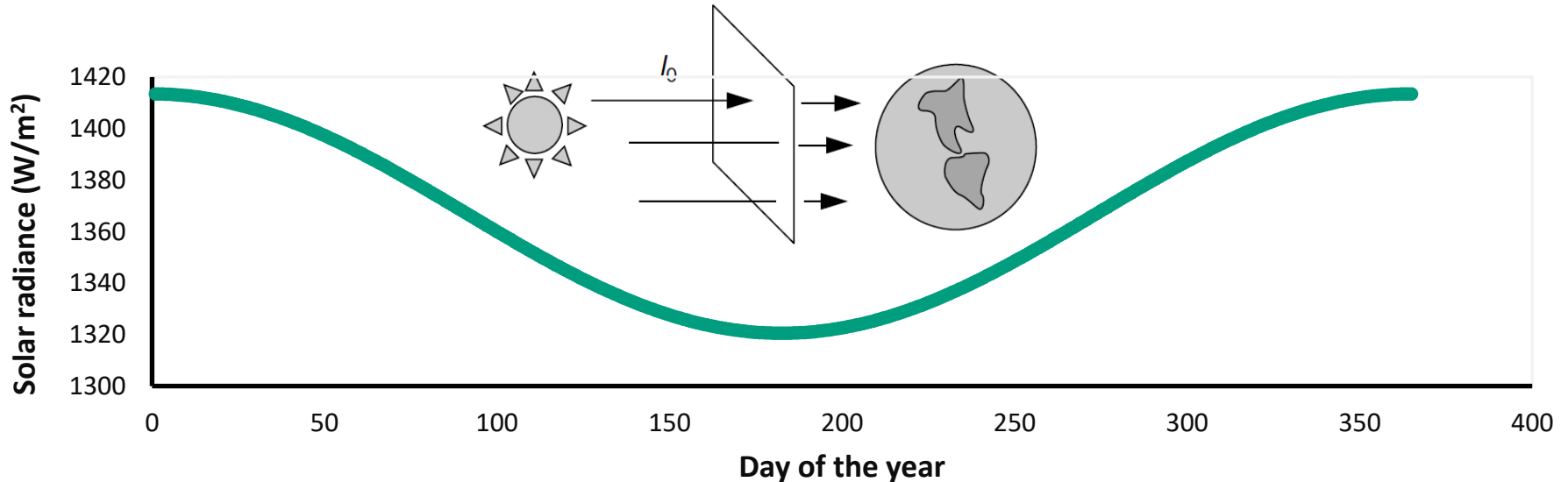
Distribution of solar radiation



Extraterrestrial solar radiance is given as:

$$I_o = I_{SC} \left[1 + 0.034 \cos \left(\frac{360 \cdot N}{365} \right) \right] \quad W/m^2 \quad (1)$$

where $I_{SC} = 1367 \text{ W/m}^2$, and N = is the day of year (1 to 365)



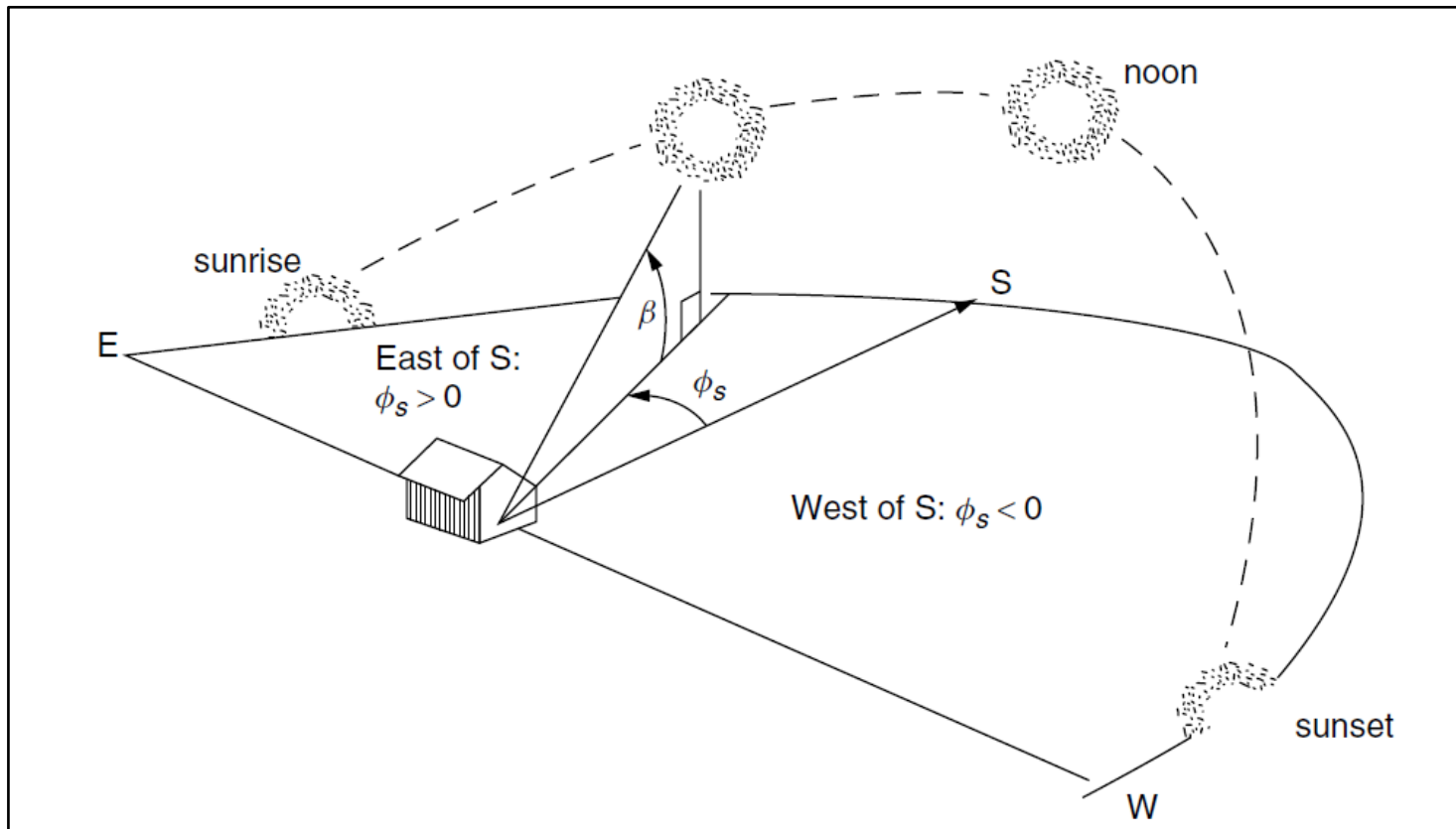
Distribution of solar radiation



- ❑ The irradiance fluctuates between 1325 W/m^2 and 1420 W/m^2 over a year on a surface perpendicular to the sun.
 - *The yearly average is called solar constant = **1367 W/m^2***

- ❑ The Earth's atmosphere reduces solar radiation through reflection, absorption, and scattering.
 - *A clear, sunny noon, irradiance can reach **1000 W/m^2** on the Earth's surface*

- The position of the sun at anytime of the day is a function of its altitude angle (β) and its azimuth angle (ϕ_s).



Apparent position of the Sun



❑ The azimuth and altitude angles of the sun depend on:

- Latitude of the site L .
- Day of the year (Day number N , declination angle, δ)
- Time of the day (Hour angle, H)

❑ Altitude angle is the angle between the sun and the local horizon directly beneath the sun. It is expressed as:

$$\sin(\beta) = \cos(L)\cos(\delta)\cos(H) + \sin(L)\sin(\delta) \quad (2)$$

❑ Azimuth angle is the compass direction from which the sunlight is coming. It is expressed as follows:

$$\sin(\varphi_s) = \frac{\cos(\delta) \sin(H)}{\cos(\beta)} \quad (3)$$



- ❑ The hour angle is the number of degrees that the Earth must rotate before the sun will be directly over a local meridian (line of longitude) or local solar noon (12.00).

$$H_{ANG} = 15^{\circ} * (12 - ST) \quad (4)$$

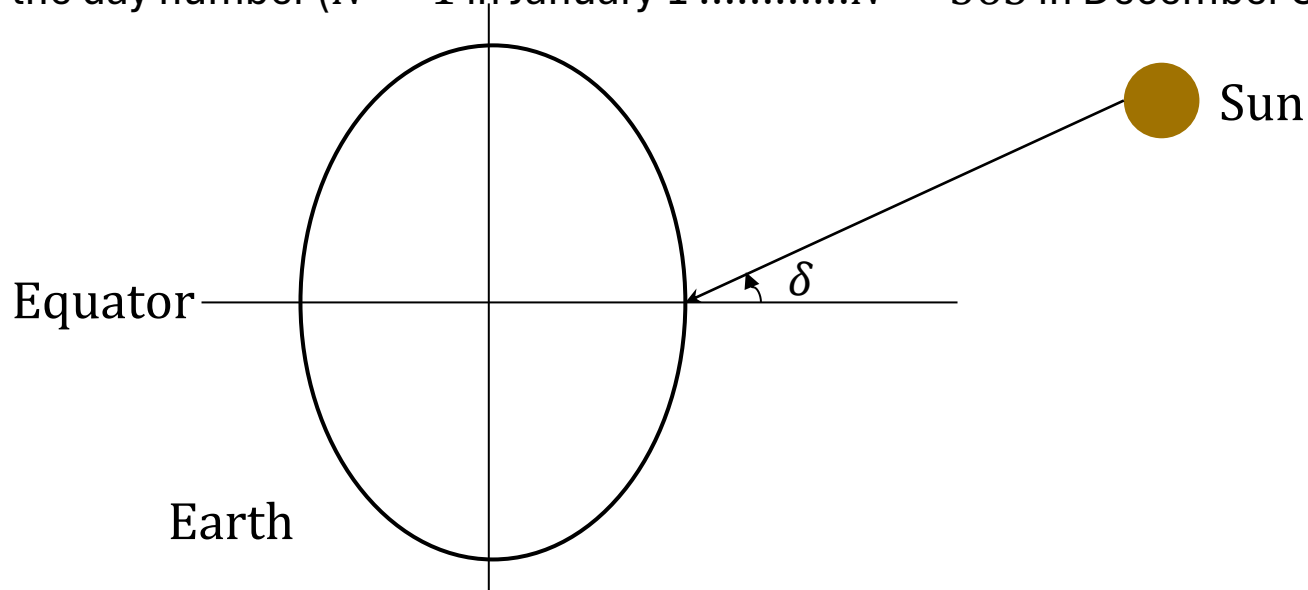
H_{ANG} is positive in the morning (before solar noon) and negative in the afternoon (after solar noon).



- ❑ Declination angle is the angle formed between the plane of the equator and a line drawn from the centre of the Sun to the centre of the Earth.

$$\delta = 23.45 * \sin \left(\frac{360}{365} (284 + N) \right) \quad (5)$$

where N is the day number ($N = 1$ in January 1 $N = 365$ in December 31).



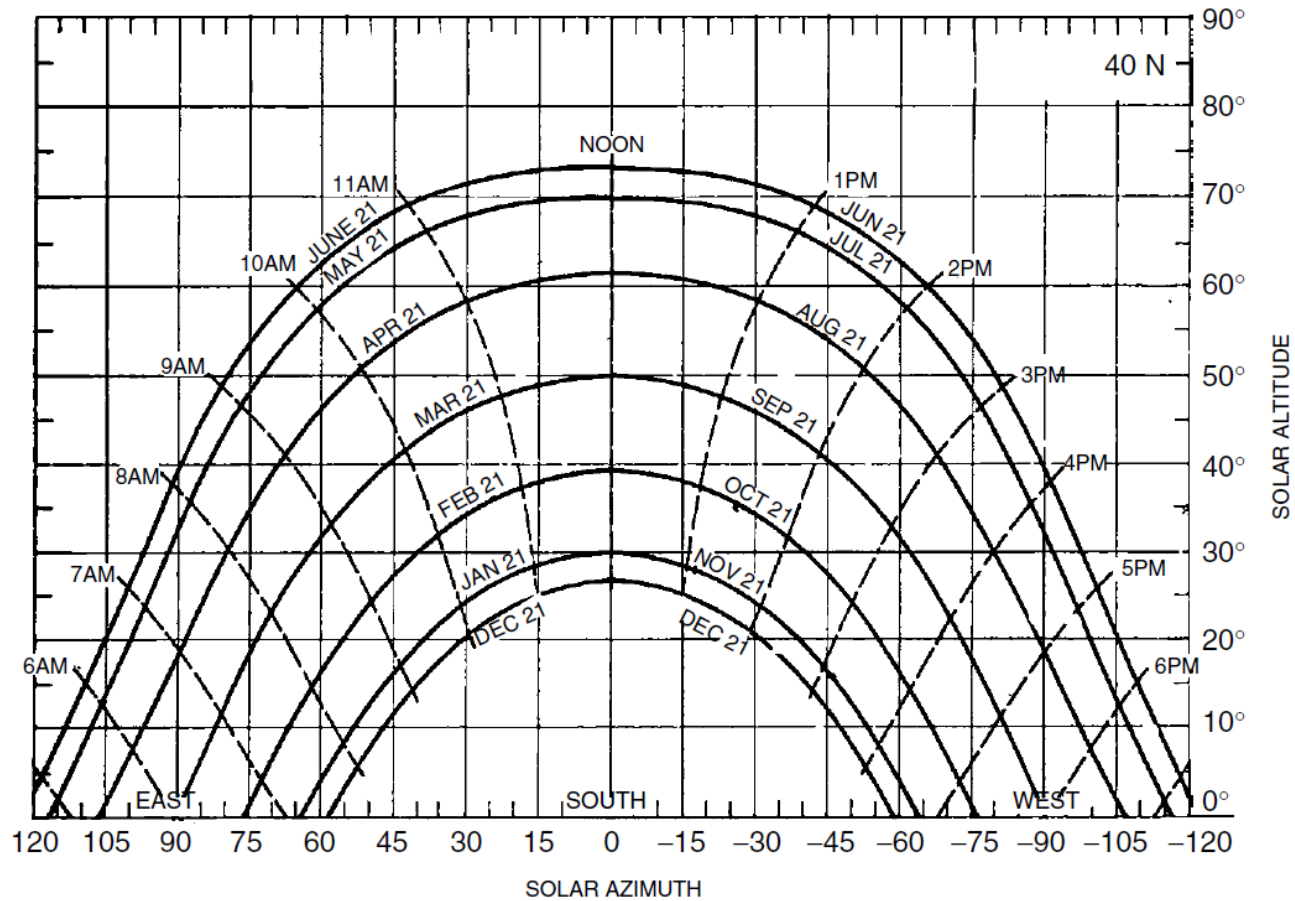


❑ Date-to-day number (N) conversion

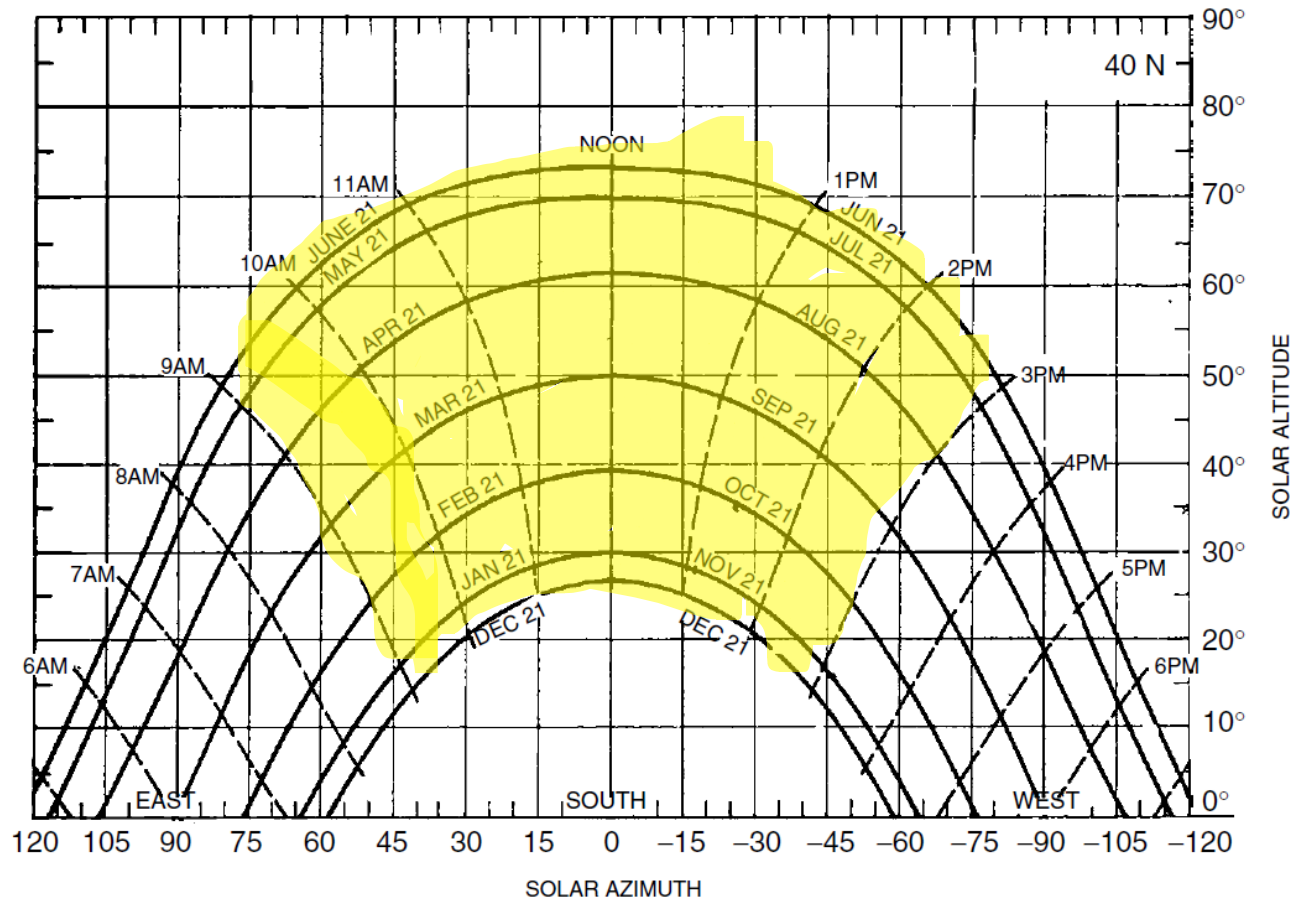
Month	N
January	n
February	$n + 31$
March	$n + 59$
April	$n + 90$
May	$n + 120$
June	$n + 151$

Month	N
July	$n + 181$
August	$n + 212$
September	$n + 243$
October	$n + 273$
November	$n + 304$
December	$n + 334$

n is date of the month.



Typical Sun Path Diagram



☐ Solar collector should be planned

- If possible, to avoid shadows within this 'window' view.
- To avoid shadows at noon every day of the year

Typical Sun Path Diagram – 'Solar Window'



**Fixed tilt
angle systems**

**Type of
installations**

**Tracking
systems**

Solar Collector Tilt Angle



Source: <https://www.saurenergy.com/solar-energy-blog/unveiling-the-solar-water-heating-system-technology>



Source: <https://www.pvgreencard.co.za/customers/process-to-install-pv-on-your-roof/>

Fixed Tilt Angle Systems



- ❑ On average, facing a collector toward the equator and tilting it up at an angle equal to the local latitude (L) is a good rule-of-thumb for annual performance.
- ❑ For a south-oriented solar collector, the optimum fixed tilt is given as:

$$\theta_{noon} = L - \delta \quad (6)$$

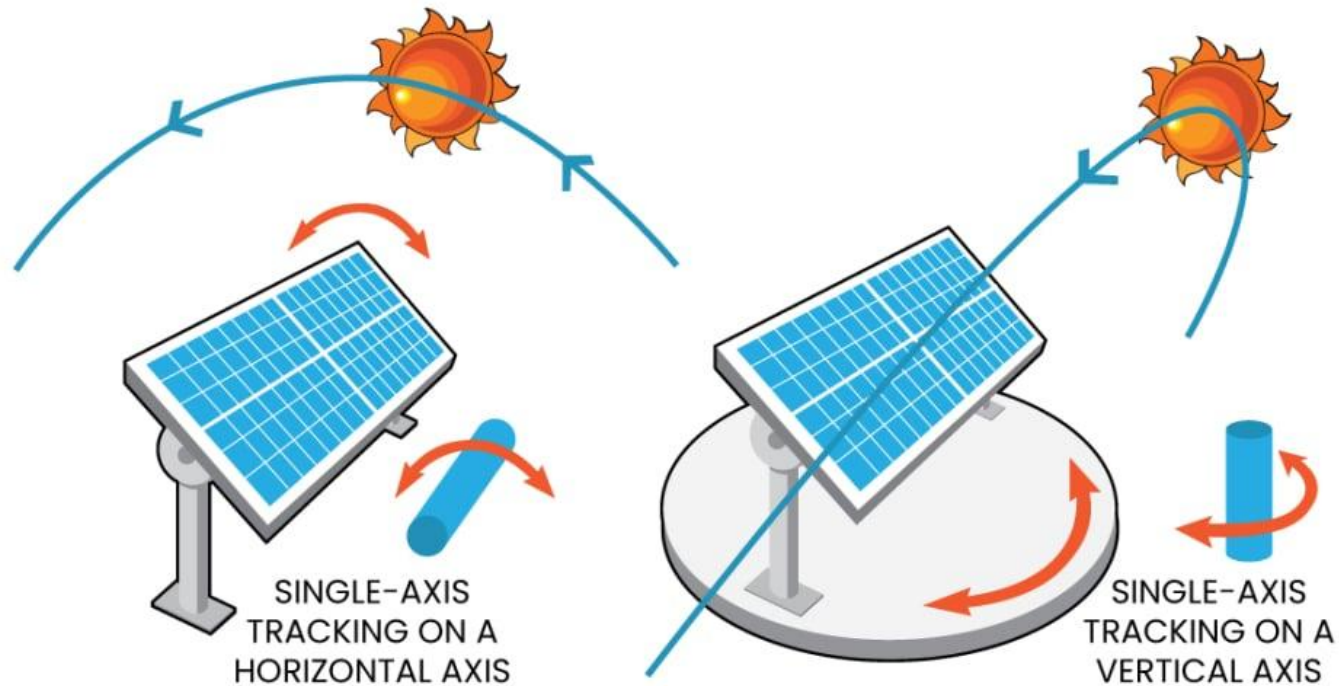


- ❑ It may not always be *possible or appropriate* to orientate the solar collector toward the equator.
 - Building orientation - fixed for existing buildings
 - Avoid shading – may be due to existing structures that cannot be moved.
 - Time of peak energy demand
 - *In the case of grid-connected - for increasing self-consumption and reduce tariffs (especially if based on peak demand), to maximise cost savings*
 - *Should be considered for a stand-alone energy system – to follow the load profile*

The solar collector should be oriented so that the main goal of the installation would be achieved optimally.

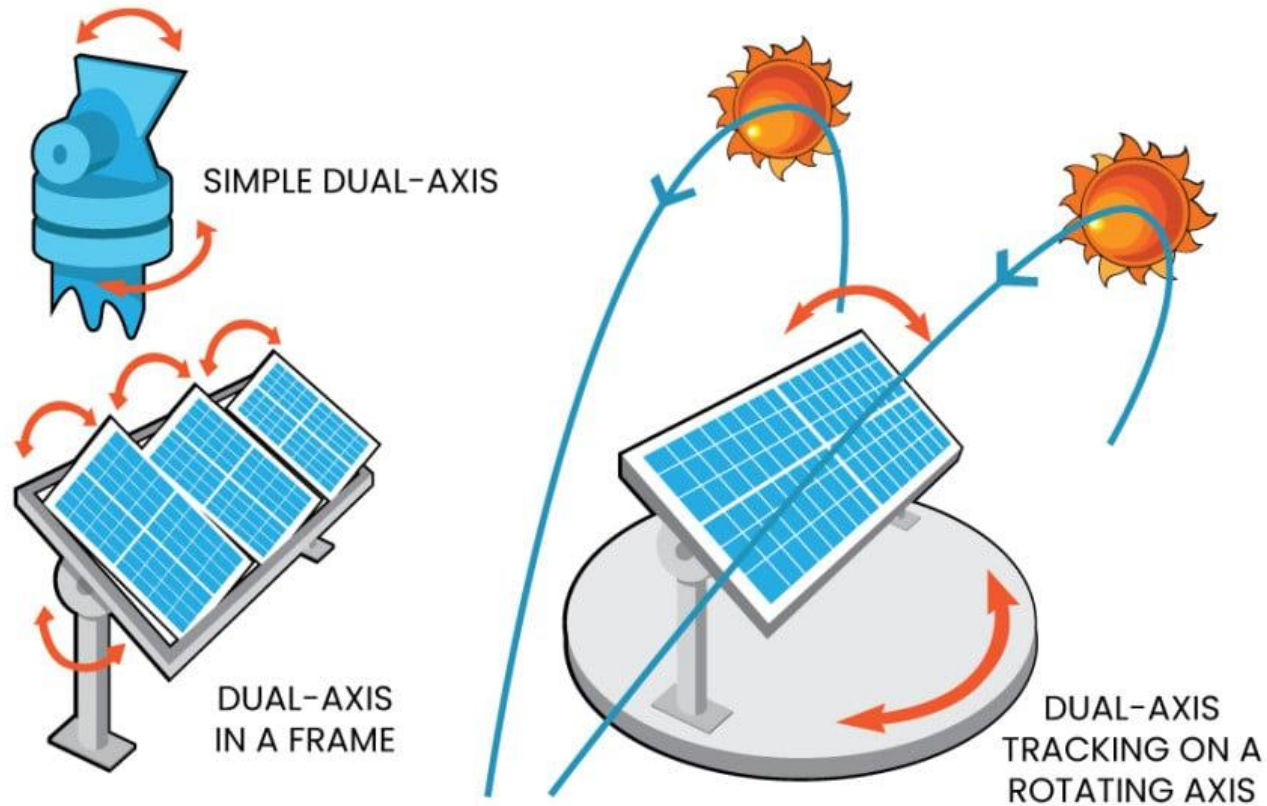


- ❑ To maximize solar radiation on a surface, tracking systems, which keep the surface facing the sun all day throughout the year, can be used.
- ❑ Energy output is higher for tracked systems than for fixed-angle systems



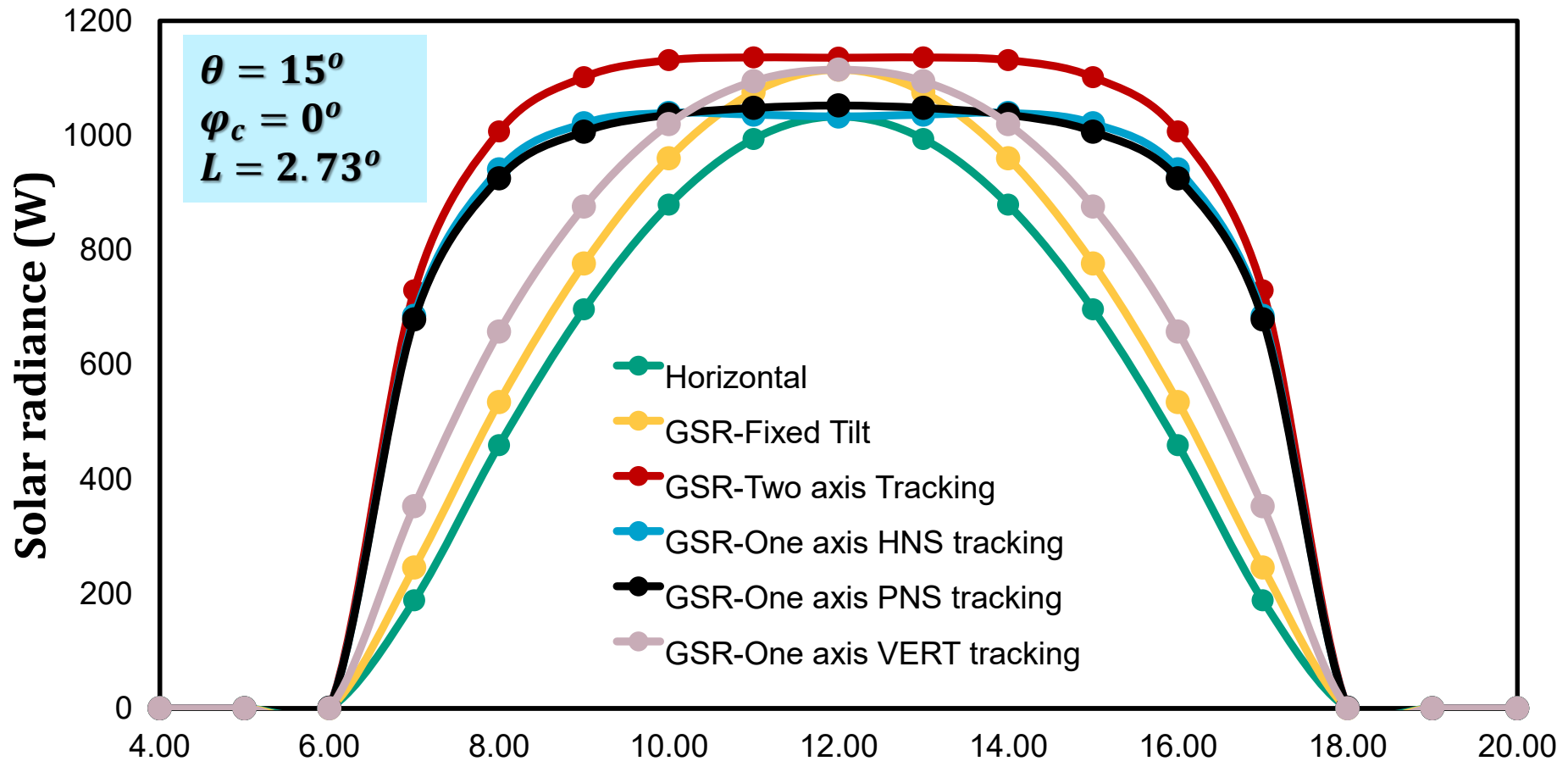
Source: <https://sinovoltaics.com/learning-center/csp/single-axis-trackers/>

Single-axis Tracking Systems

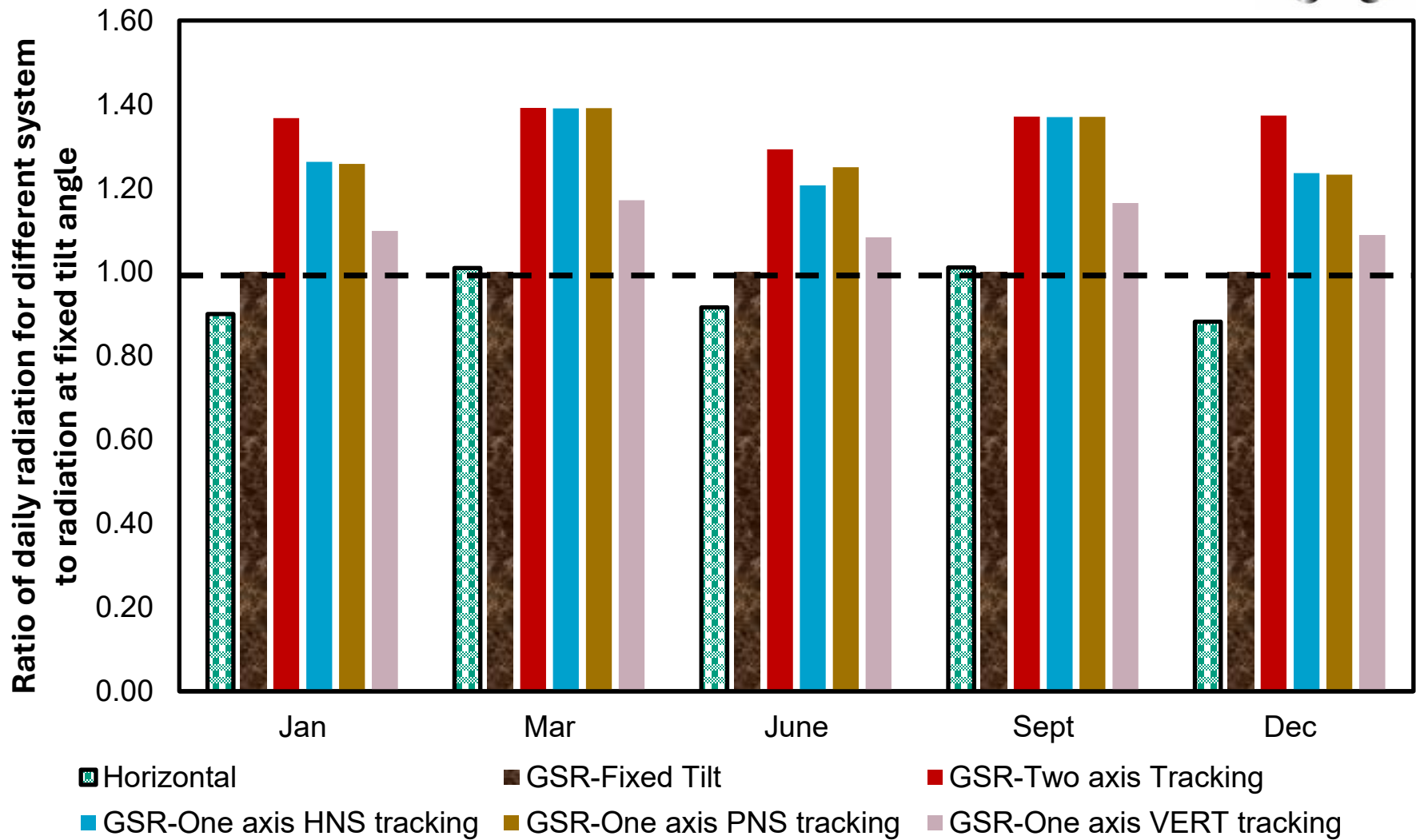


Source: <https://sinovoltaics.com/learning-center/csp/dual-axis-trackers/>

Two-axis Tracking Systems



Hourly variation of clear-sky radiation on Jan 21



Daily radiation: Jan 21 and $\theta = 15^\circ$



- ❑ Sun tracking systems are slightly more expensive
- ❑ Shading analysis for tracking systems could also be relatively more difficult.
- ❑ Tracking systems require more regular maintenance, hence, increase operation and maintenance costs.



- ❑ Peak sun hour is given as:

$$S_h = \frac{H_c, kWh/m^2/day}{1 kW/m^2} \quad (7)$$

- ❑ Hence, the average daily solar radiation (kWh/m²/day) is referred to as "peak sun hours".
- ❑ It refers to the amount of solar radiation that a particular location would receive if the sun were shining at its maximum value for a certain number of hours.



- ❑ Solar collectors, especially solar PV modules, are very sensitive to shading, and losses in the system due to shading can be significant.
- ❑ If shading cannot be eliminated or minimized, losses due to it should be estimated to help in the accurate evaluation of a solar collector's performance.
- ❑ Shading can be classified:
 - Temporary
 - Site objects
 - Trees
 - Buildings and building structures
 - Self-shading



- ❑ Temporary shading can include dust, soot, leaves, bird droppings, and other types of soiling
- ❑ Location-specific and seasonal variation
- ❑ Well-installed solar collectors can be self-cleaning, washed by rainfall
 - *Tilt angle - **tilt angle of at least 10 degrees***
 - *Higher tilt angles increase the self-cleaning ability of the system*

- ❑ In a normal location and with a specific tilt angle, the loss due to soiling could be very significant on solar collector performance
 - *If necessary, the collector should be cleaned regularly.*



Source: Kawamoto H. Electrostatic cleaning equipment for dust removal from soiled solar panels. Journal of Electrostatics 98 (2019) 11-16.



Solar module in Burkina Faso near Ghana boarder (Photo by Sam)



Solar module in Navrongo Ghana (Photo by Sam)

- ❑ Snow – mainly in the temperate regions



<https://www.facebook.com/rohitdeshmukh.72/>



<http://solarbuildermag.com/featured/snow-solar-panels/>

- ☐ Neighbouring buildings
- ☐ Trees
- ☐ Overhead cables
- ☐ Building structures, e.g., chimneys, antennae, satellite dishes



<http://www.solarpanelbuyersguide.co.uk/shading/>



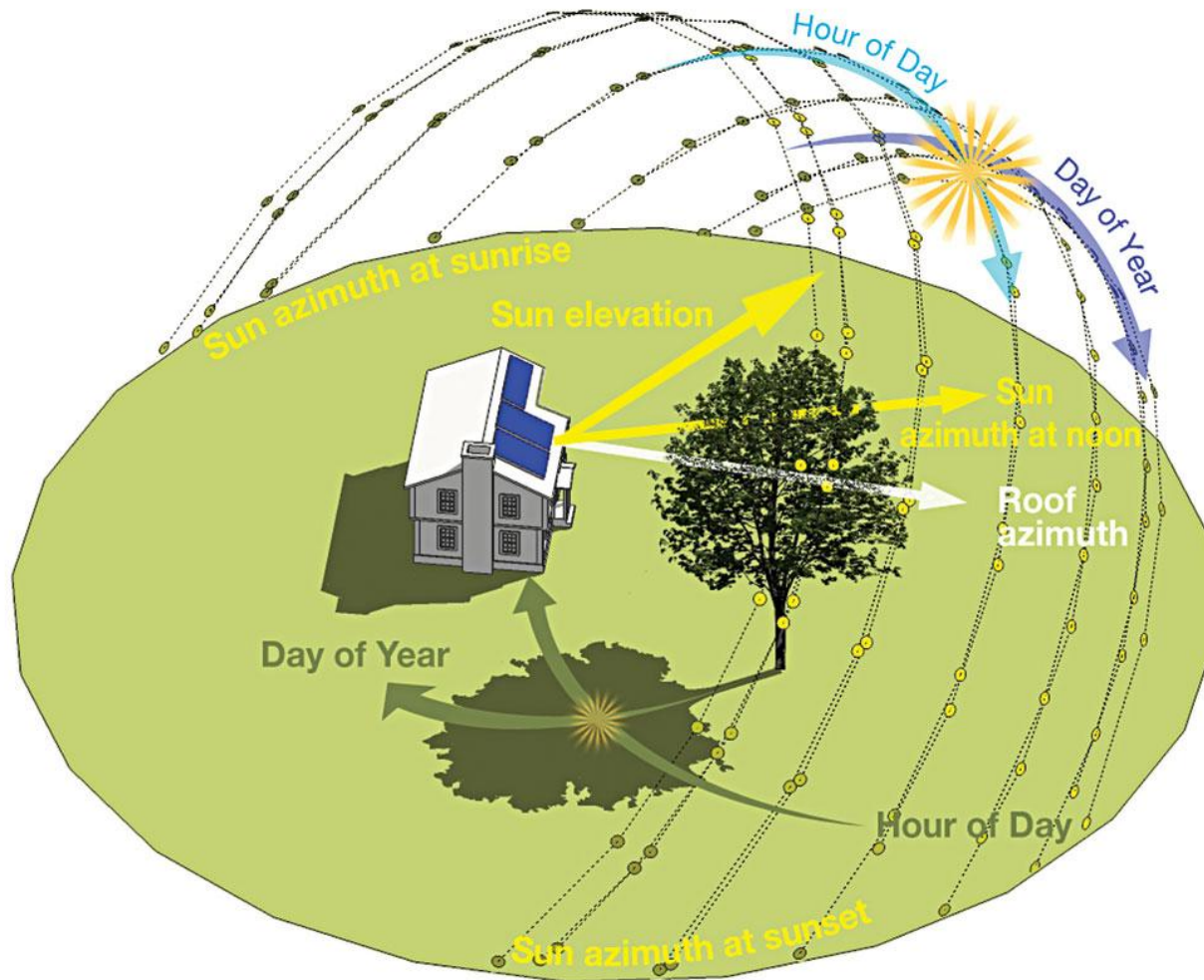
<http://www2.le.ac.uk/departments/engineering/research/electrical-power>

Semi-permanent shading



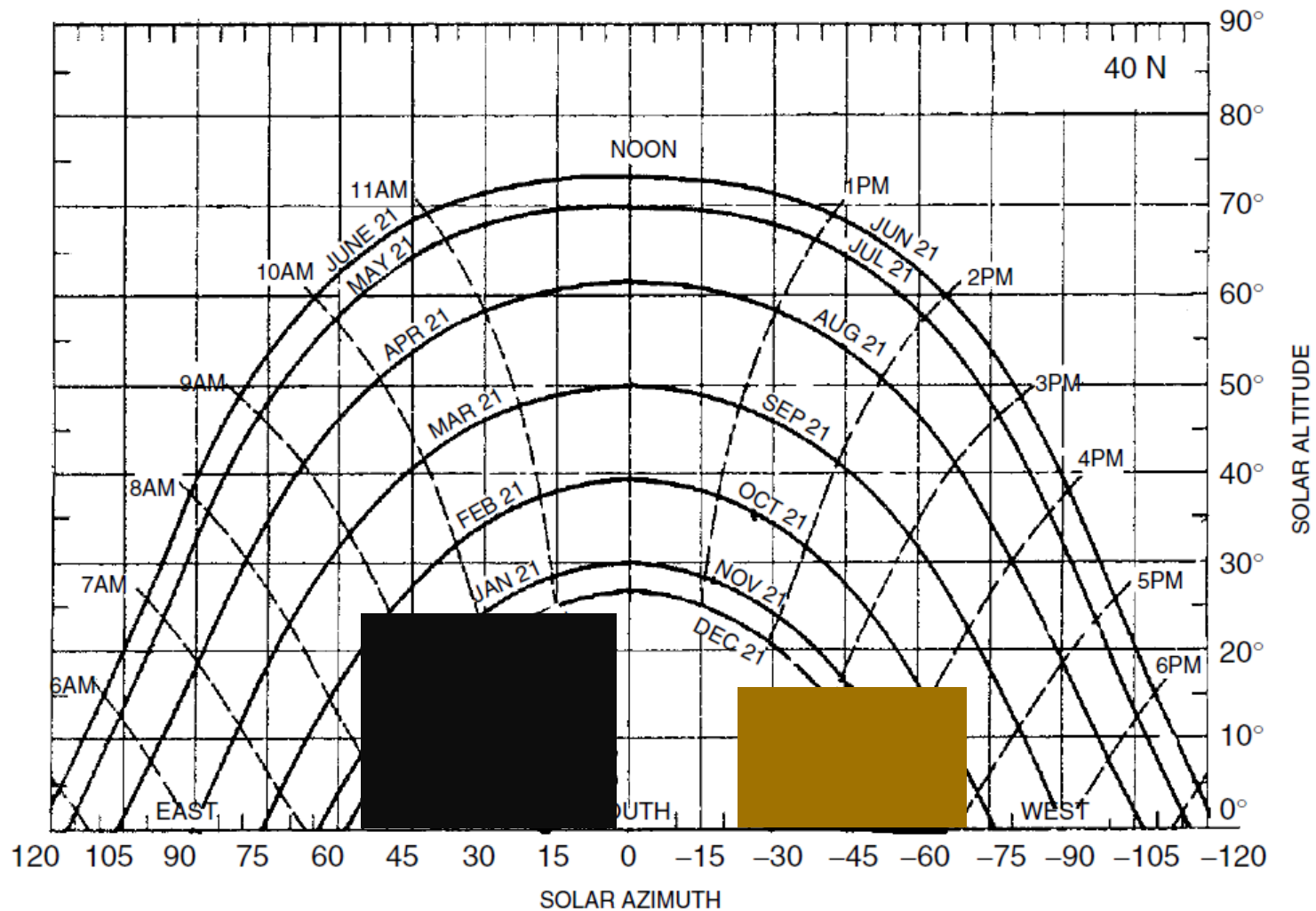
Poorly located solar PV installations under trees ????

Semi-permanent shading



Source: <https://www.homepower.com/>

Structure (Object) Shading Analysis

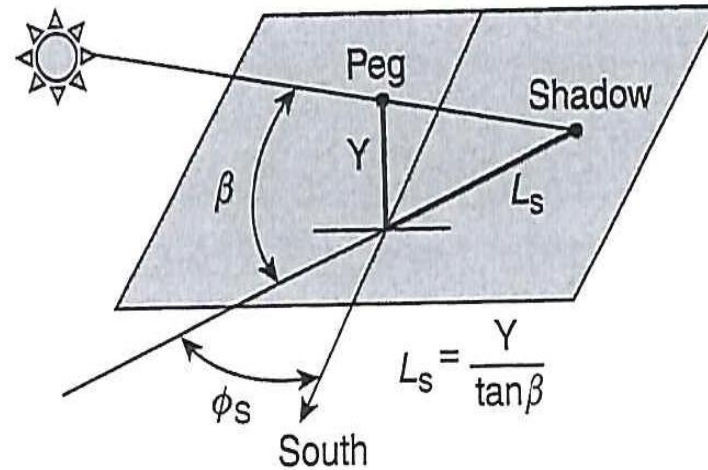


Procedures – Shading by structures

- ❑ It is common to install PV modules on flat roofs or open spaces (ground-mounted installations).
- ❑ In these situations, PV modules are arranged in rows.
- ❑ This can lead to self-shading at the lower cell rows of the modules (especially during the morning and evening hours).



http://solarprofessional.com/articles/design-installation/pv-array-electrical-aggregation-strategies?v=disable_pagination



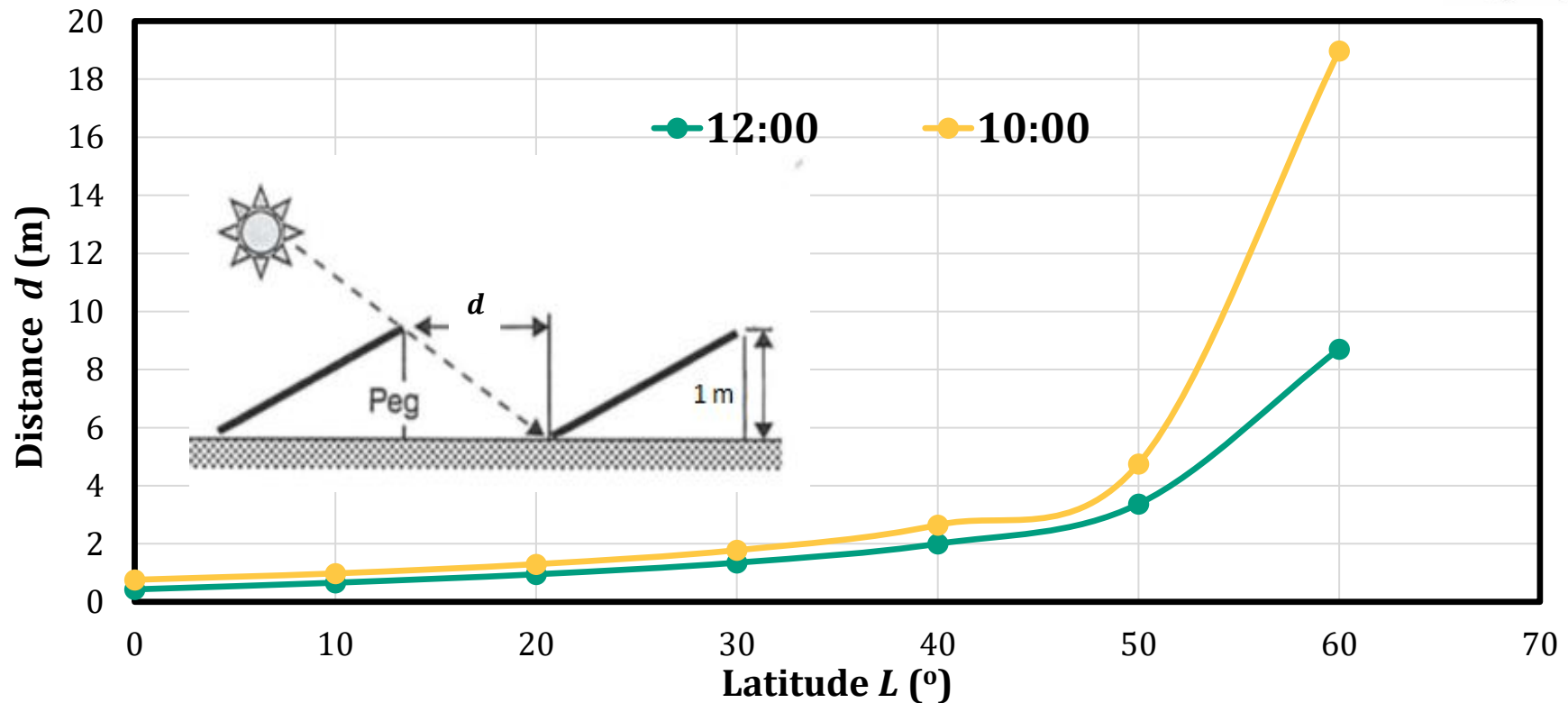
http://solarprofessional.com/articles/design-installation/pv-array-electrical-aggregation-strategies?v=disable_pagination

Shadow length of a pole
(peg)

$$L_s = \frac{Y}{\tan \beta} \quad (8)$$

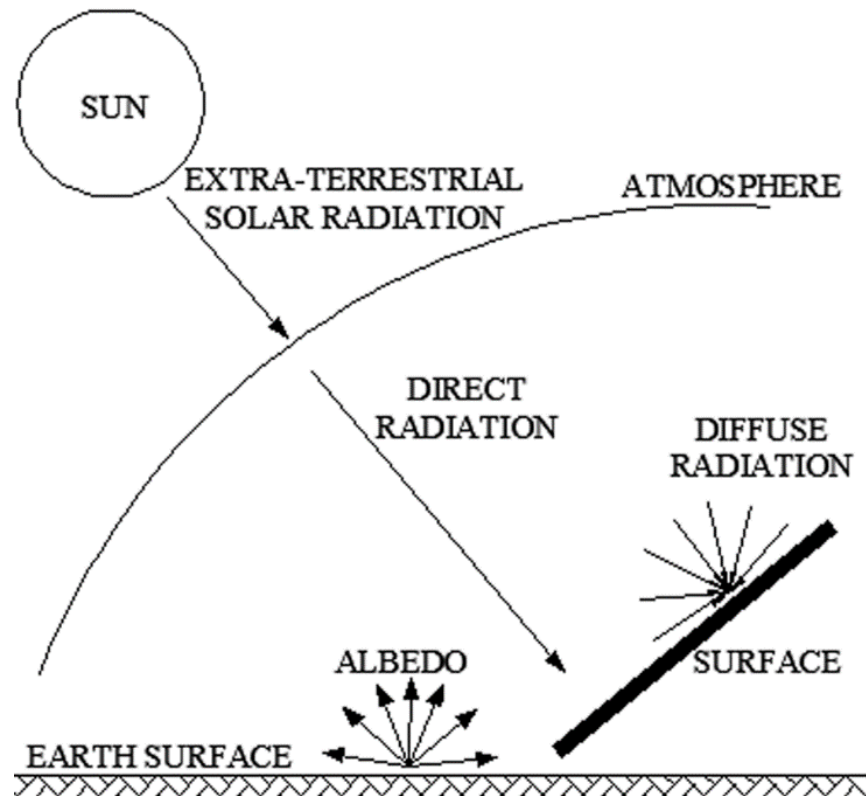
Distance between rows of
solar collectors

$$d = L_s * \cos \varphi_s \quad (9)$$



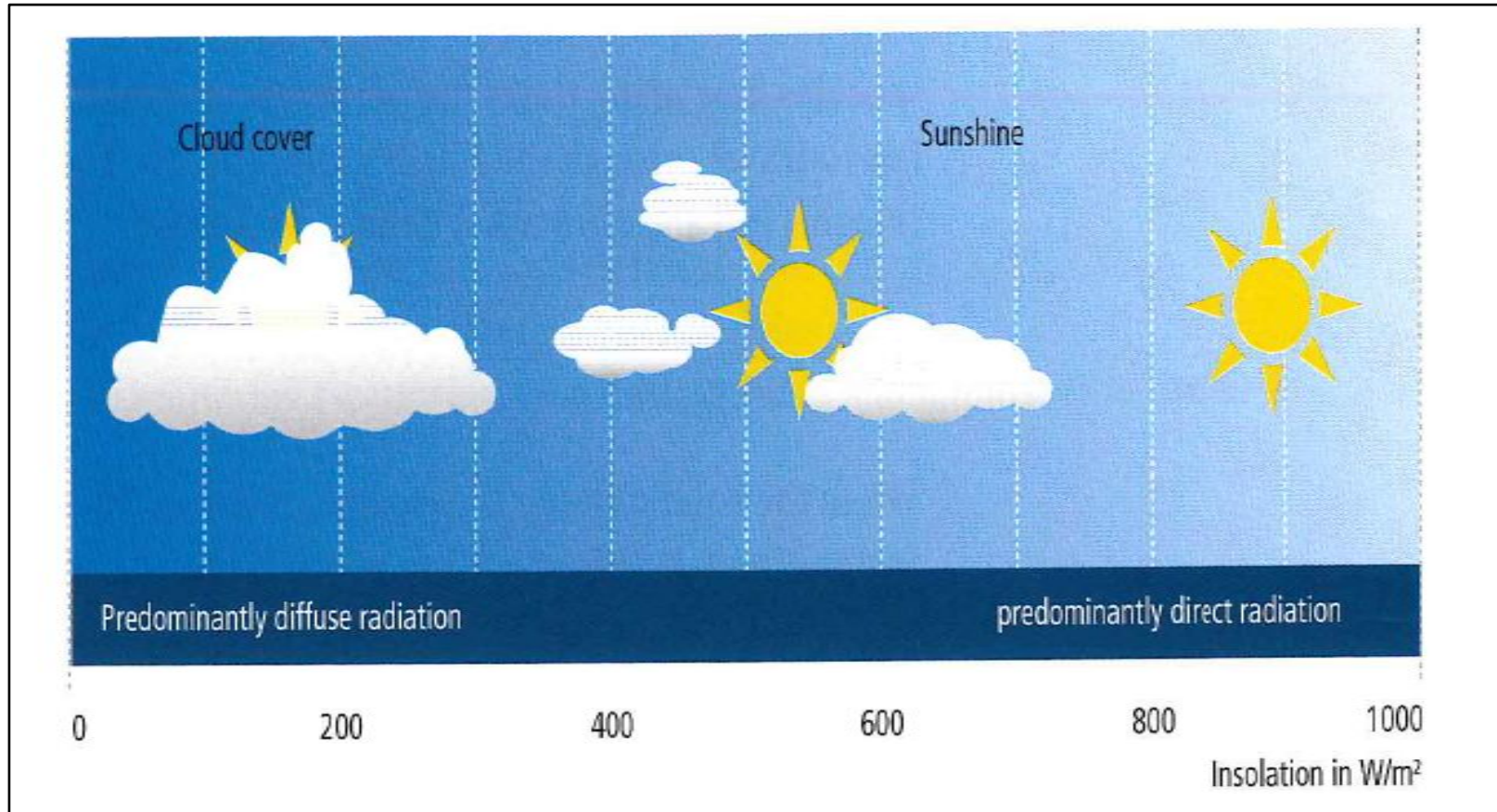
- The area required for the solar collector field increases rapidly with increasing latitude.
- The actual area required is likely to be larger
 - Additional space is needed for access routes, electrical installations, and services.

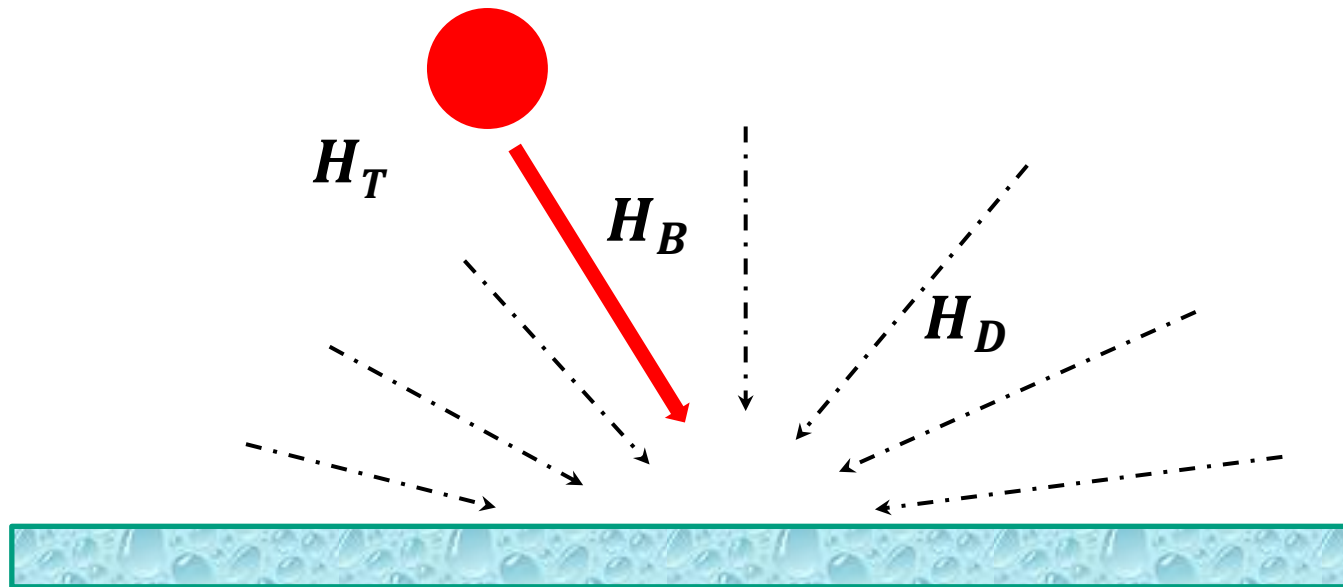
The value of d latitude on 21 Dec



- ❑ Direct radiation – from the direction of the sun and cast strong shadows of objects
- ❑ Diffuse radiation – scattered from the dome of the sky and has no defined direction.
- ❑ Reflected radiation – bounced off the ground or other surfaces in front of the solar collector.

Types of Solar Radiation





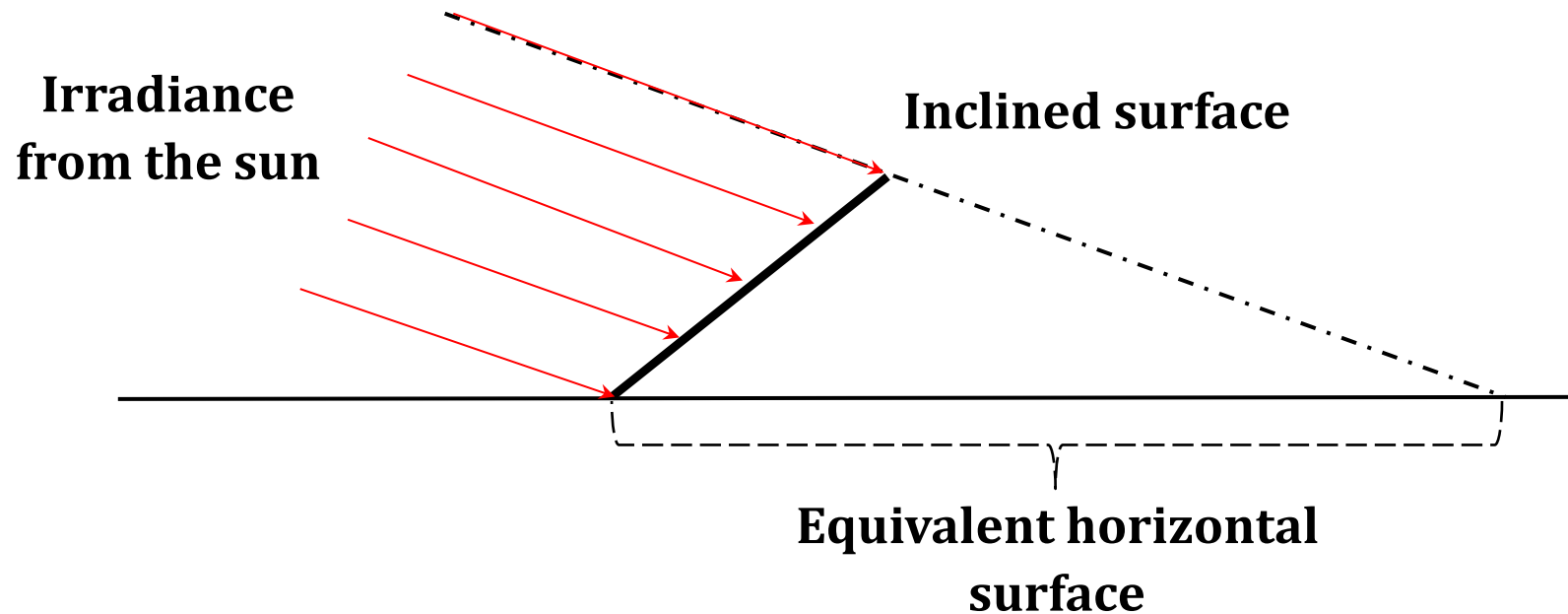
$$H_T = H_B + H_D \quad (\text{kWh}/\text{m}^2/\text{day}) \quad (10)$$

Where H_T is the total global radiation; H_B is the direct beam radiation and H_D is diffuse radiation

In most weather/meteorological stations, H_B and H_D are normally measured.



- ❑ Tilted solar collectors collect more radiation than placing them on a horizontal or vertical plane.





- ❑ Total in-plane radiation (H_C) on inclined surface is given as:

$$H_C = R_B * (H_T - H_D) + H_D * \left(\frac{1 + \cos(\theta)}{2} \right) + \rho * H_T * \left(\frac{1 - \cos(\theta)}{2} \right) \quad (11)$$

Where R_B = direct beam factor; ρ = albedo (depend surface reflectance); H_T = global radiation on horizontal surface; H_D = diffuse radiation on horizontal surface

- ❑ For a surface in the northern hemisphere, tilted toward the equator at noon, the value of R_B can be determined from:

$$R_B = \frac{\cos|L - \delta - \theta|}{\cos|L - \delta|} \quad (12)$$



Type of surface	Reflection factor/albedo
Asphalt	0.10 – 0.15
Green forest	0.10 – 0.20
Wet ground	0.10 – 0.20
Dry ground	0.15 – 0.30
Grass-covered ground	0.20 – 0.30
Concrete	0.20 – 0.35
Desert sand	0.30 – 0.40
Old snow	0.50 – 0.75
Newly fallen snow	0.75 – 0.90

Source: Häberlin H (2012). Photovoltaics- system design and practice. John Wiley and Sons, Ltd, 1st Edition

Typical values of albedo for selected surfaces



A solar collector system, which consists of single-row solar collectors, is located in Gulu, Uganda (Latitude of 2.78°N), is the oriented towards south direction at fixed tilt angle, $\theta = 15^{\circ}$. Assuming that the average daily global solar radiation and diffuse radiation on a horizontal surface, as well as the monthly average albedo in this location, are shown in the Table below. Use the direct solar radiation factor at noon to determine the monthly plane-of-array radiation on the solar collectors.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H_T	5.38	5.57	5.56	5.46	5.17	4.58	4.22	3.92	4.03	4.71	5.08	5.05
H_D	1.73	1.94	2.16	2.24	2.15	2.14	2.17	2.23	2.27	2.14	1.86	1.73
ρ	0.19	0.19	0.21	0.22	0.22	0.23	0.25	0.25	0.26	0.24	0.24	0.21
n	17	16	16	15	15	11	17	16	15	15	14	10
H_C												



☐ Solar map

- Gives a physical feel for the variation of solar radiation
- Quick identification of 'good' sites.
- Based on numerical simulation/modelling

☐ Simulated weather data

- For example: <https://climate.onebuilding.org/#gsc.tab=0>

☐ Ground measurement data

- More accurate than satellite data
- Meteorological stations

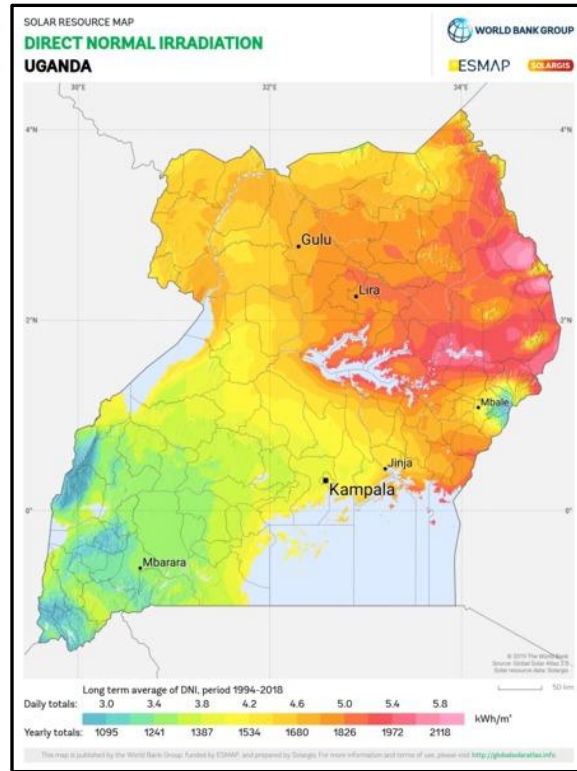
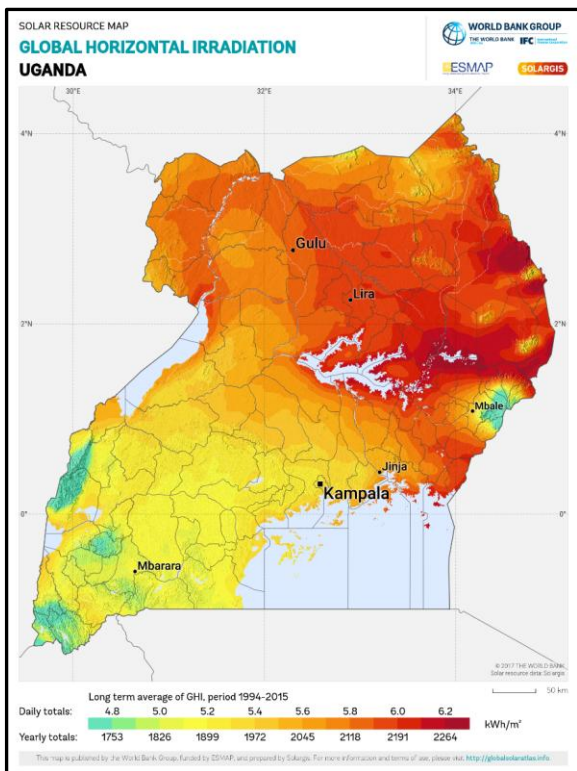
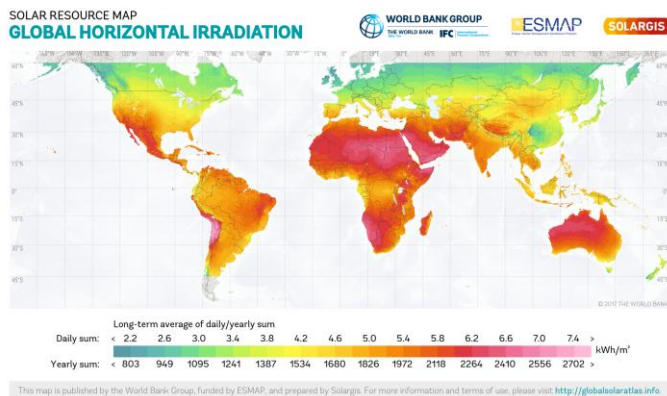


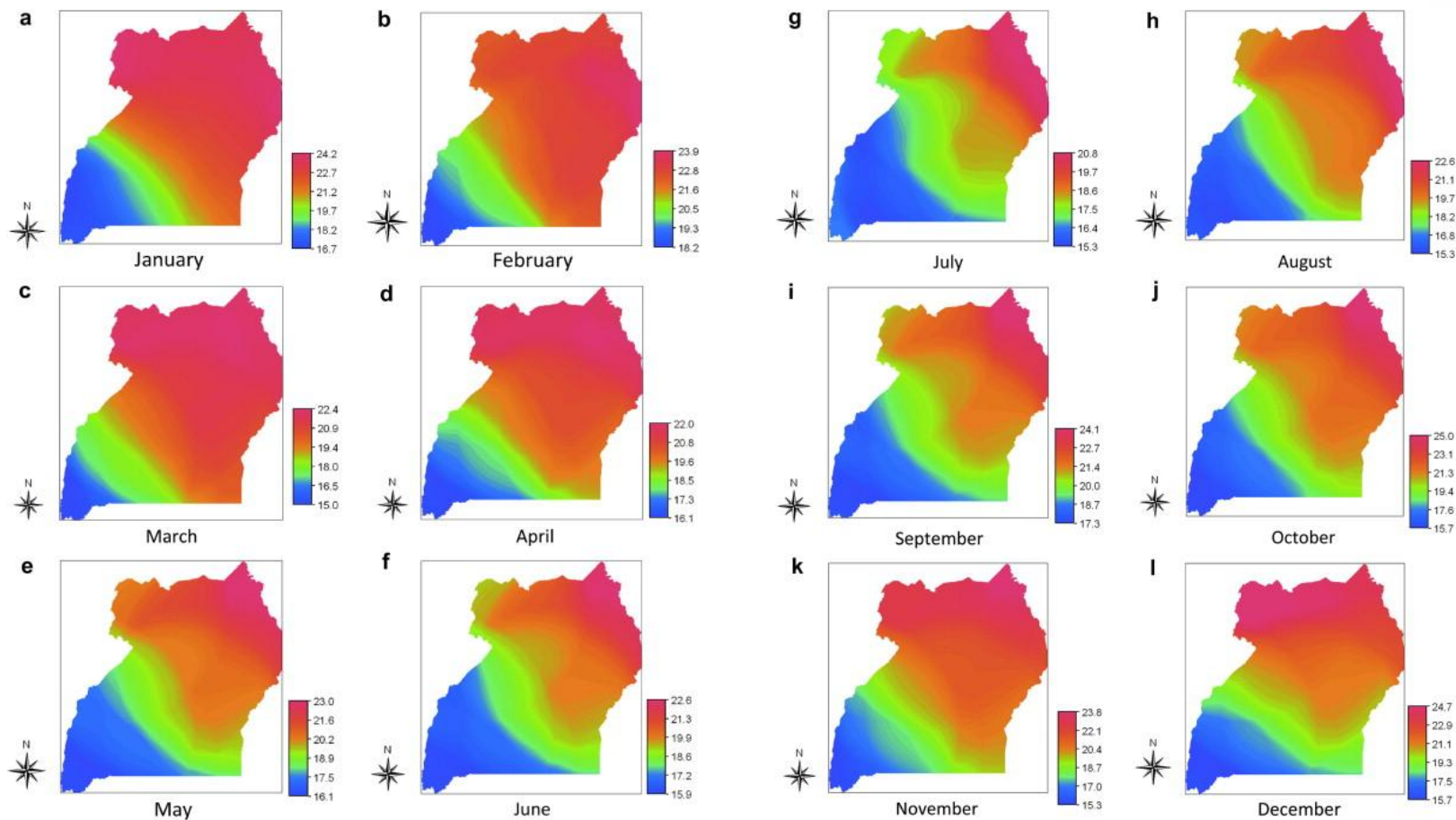
☐ Solar radiation data

- Global radiation
- Direct radiation
- Diffuse radiation
- Albedo (fraction of reflected global radiation)

☐ Ambient site' conditions

- Temperature
- Wind speed and direction
- Dust (quantity and size)
- Shadow casting objects
- Ground surface conditions
- Rain (requirement for cleaning)
- Air quality (humidity, pollution)





Monthly average daily global solar irradiation maps for Uganda: A location in the equatorial region - <https://doi.org/10.1016/j.renene.2011.11.018>



Climate.OneBuilding.Org



Eastern Africa

BDI - Burundi
ERI - Eritrea
MDG - Madagascar
MUS - Mauritius
RWA - Rwanda
SSD - South Sudan
ZMB - Zambia

COM - Comoros
ETH - Ethiopia
MOZ - Mozambique
MYT - Mayotte
SYC - Seychelles
TZA - Tanzania
ZWE - Zimbabwe

DJI - Djibouti
KEN - Kenya
MWI - Malawi
REU - Reunion
SOM - Somalia
UGA - Uganda

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UGA_EAS_Soroti.AP.636580_TMYx.2009-2023.zip	438 K				

- ❑ **Unshaded pyranometer** for measuring the **global irradiance** (radiant flux, W/m^2) on a plane surface:
 - Global solar radiation
 - Diffuse radiation
- ❑ **Shaded pyranometer** for measuring only the **diffuse irradiance** (radiant flux, W/m^2) on a plane surface



Source: <http://www.kippzonen.com/Customer-Stories/Solar-Energy>



Source: <http://www.kippzonen.com/Customer-Stories/Solar-Energy>

- ❑ Tilted unshaded pyranometer at different angles.
 - To determine the optimum angle for fixed solar panels
 - To measure global solar radiation on the plane of the solar collector



Inverter pyranometer at NMBU met station:

- Mounted 2 m above the ground

<https://www.nmbu.no/fakultet/realtek/laboratorier/fagklim/maleinstrumenter/straling#GLOB>

<http://www.kippzonen.com/Customer-Stories/Solar-Energy>



- ☐ the upfacing one measuring global solar radiation
- ☐ the downfacing one measuring reflected solar radiation

<http://www.hukseflux.com/product/sra01-albedometer>

- ☐ Set to measure albedo



<http://www.directindustry.com/prod/hukseflux-thermal-sensors-bv/product-88003-826371.html>



<http://www.kippzonen.com/News/443/Reporting-back-from-the-NREL-Pyrheliometer-Comparison-2013#.WL6qOnkzV9A>

- ❑ Measure **direct beam solar irradiance**
- ❑ Mounted on an automatic tracking system to point precisely at the centre of the sun.

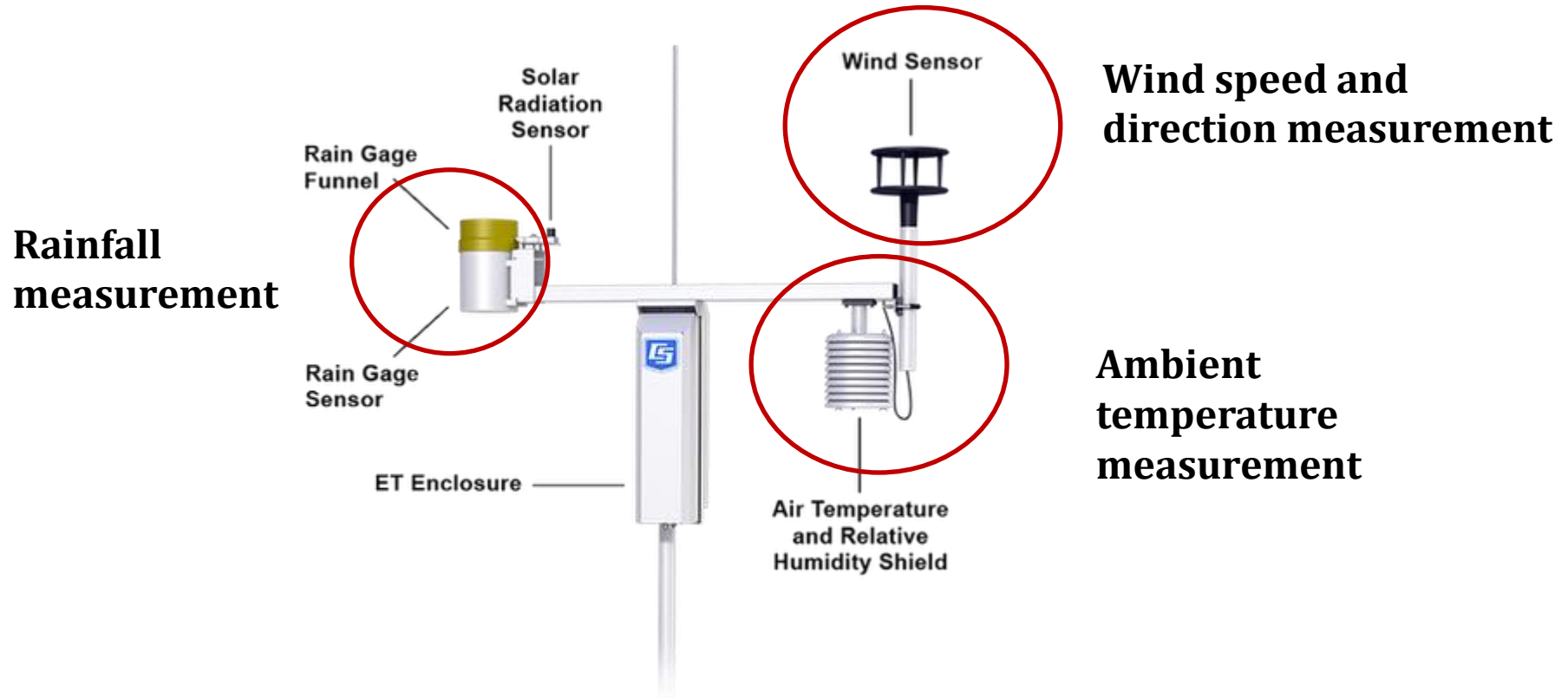


CSD sunshine meter

- ☐ Sunshine duration during a given period (e.g. within one day) is defined as the sum of the time for which the direct solar irradiance exceeds 120 W/m^2

Source:

http://www.hko.gov.hk/education/edu01met/wxobs/ele_solardurationinst_e.htm



Source: <https://www.campbellsci.com/blog/et-station-components-to-maintain>



☐ Solar energy conversion (SEC) technology selection

- Flat PV
- Concentrated collectors
- Thermal systems

☐ Siting of SEC systems

☐ Design of SEC systems

☐ Performance of SEC systems

- Prediction
- Monitoring

☐ Cost of energy estimation

Collector	Concentration ratio	Typical working temperature range (°C)
Flat plate collector	1	≤ 70
Evacuated tube collector	1.5 - 2	60 - 120
Parabolic trough collector	10 - 50	150 - 350
Parabolic dish collector	200 - 500	250 - 700
Central receiver	500 - > 3000	500 - > 1000

A high proportion of direct radiation favours concentrated systems



- ❑ Estimate the total surface area of your site, $S_{Area} (m^2)$
- ❑ Estimate the annual solar radiation at the site, $H_a (kWh/m^2)$

$$H_a \left(\frac{kWh}{m^2} \right) = H_{daily} \left(\frac{kWh}{day \cdot m^2} \right) * 365 \text{ days} \quad (13)$$

- ❑ The annual theoretical solar energy potential is calculated from:

$$SE_{tp} = H_a \left(\frac{kWh}{m^2} \right) * S_{Area} (m^2) \quad (14)$$



- ❑ Discuss challenges of solar energy resources assessment in Uganda.
- ❑ Suggest ways to resolve these identified challenges.



Questions?