T³ EUROPE

Teachers Teaching with Technology™

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Solar Tracker Panels – How to simulate a Sun tracker in order to optimize solar panels orientation

„Sometimes darkness can show you the light“

www.t3europe.eu

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1. Learning objectives and system aspects

a. Learning objective and curriculum

Through this real world issue, students should learn about:

- the importance of defining a frame of reference when describing a trajectory
- clockwise/anticlockwise rotation and angle measurement
- What types of components can produce green energy
- How to split a complex algorithm into smaller and simpler sub-algorithms

It aligns with the vocational school curriculum with students specialized in electro-technical and connected environments field. They practise mathematical methods where the context in mathematics or physics is as far as possible associated with ideas about environmental protection, energy efficiency or adaptation to climate change, including the economic or social dimension. In this type of activity framework, the student explores, tests, validates andf takes the risk of making mistakes. They learns to profit from their mistakes, thanks to the teacher (or their group) who helps them identify, analyze and overcome them. This work on errors supports their learning and the development of their self-confidence.

b. Science background

This activity is fully STEM compatible, in fact STEM is at the heart of the activity.

It's about finding a way to optimize the position of a rectangular solar panel in order to follow the Sun's path during the day, assuming the panel is supported on the ground.

The fact that photovoltaic cells can produce electricity from light, suggests measuring the light level and since this light is provided by the Sun, one has to know about Sun's path in relation to the Earth: welcome to Science room!

A planet's orbit can be defined by a time function and the light level can be defined by a distance function to the source. To locate the Sun in the sky during the day, we realise that angles are very convenient: welcome to Mathematics room!

To make a solar panel rotate, a servomotor can be useful and to measure the light level, a brightness sensor is needed. Now it's time to make these two elements communicate with a suitable coding language: welcome to the twin rooms, Engineering and Technology!

Now we need to assemble these rooms to build a house for hosting solutions to the problem.

c. Connection with Sustainability Development Goals

There are two main connections with Sustainability Development Goals.

Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all: How to deal with brightness.

Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation: How to connect the multiple elements and make them work together through Python coding, using physical quantities to drive the technological structure.

2. The actual activity

We need reliable power supplies to power our daily equipment but the presence of a functioning electrical network is not always assured. If no grid is available, a generator would be the logical choice to generate electricity. However, generators are noisy and very polluting. In addition, European and national guidelines strongly encourage the creation of local n units using renewable energy. Solar is one of those energies considered inexhaustible, effectively non-polluting and available in large measure all over the Earth. Solar being a sector that remains expensive, it is important to improve the efficiency of solar installations, to make the best use of resources. This could be done in two ways: the first would be to improve the photovoltaic cell;

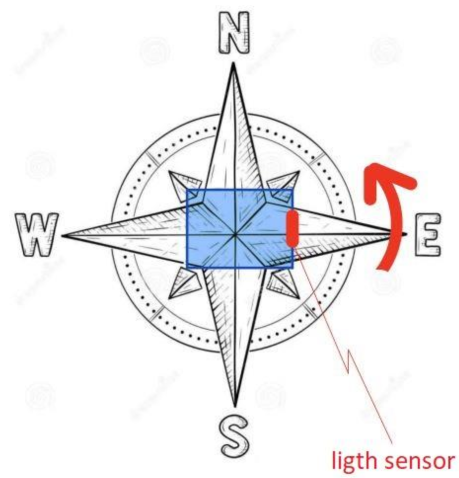
the second consists in optimizing the illumination angle of the panel according to the position of the sun.

Main issue: How to effectively angle photovoltaic solar panels in order to increase daily electricity generation?

a. Part one : Average Brightness

We have a light sensor and we want to measure the average brightness in the four directions: North, West, South and East.

• Write an algorithm that calculates an average from 4 measured values:



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• Now translate the previous algorithm into a Python script

b. Part two : Moving the Light Sensor

The light sensor is placed on a servomotor capable of rotating in15 ° steps (clockwise or counterclockwise).

• What is the type of movement of the light sensor when the servomotor is working?

• Write an algorithm allowing the servomotor to make a full revolution

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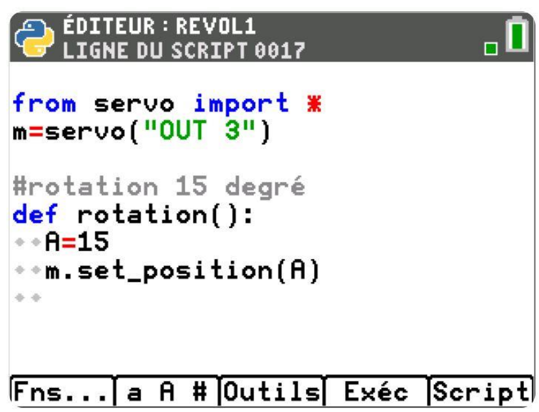
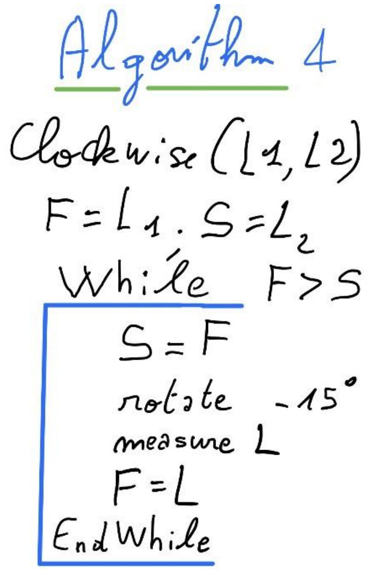
The Python script below allows the servomotor to turn by 15 °. Looking at this script, use the previous algorithm to write Python code allowing the servomotor to make a full revolution:



c. Part three : Conditional Servomotor Rotation

• Observe algorithm 4 opposite. Explain in a few sentences what this algorithm does.



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• Translate algorithm 4 into a Python script:

d. Part four : Implementation of a Suntracker

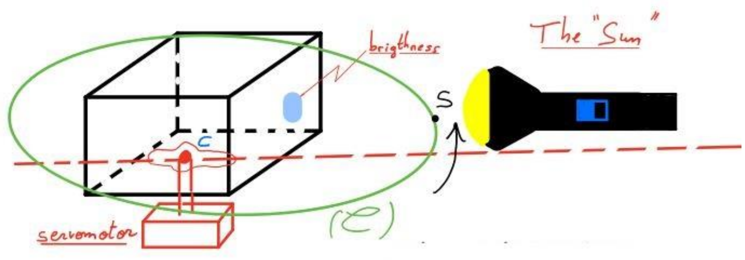
List of equipment

Servomotor

Ti-innovator Hub

External battery

Ti-83 Python

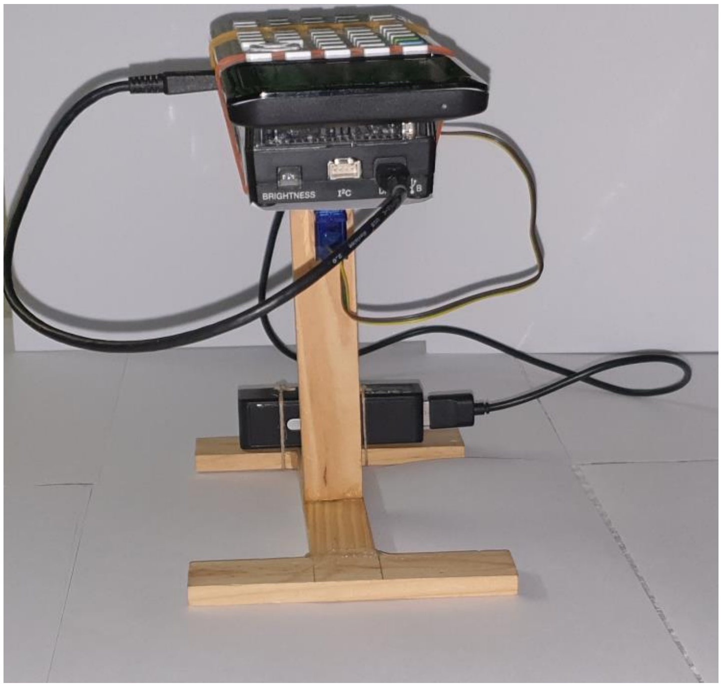


• Study the script below and comment on each of the parts indicated by a bracket:

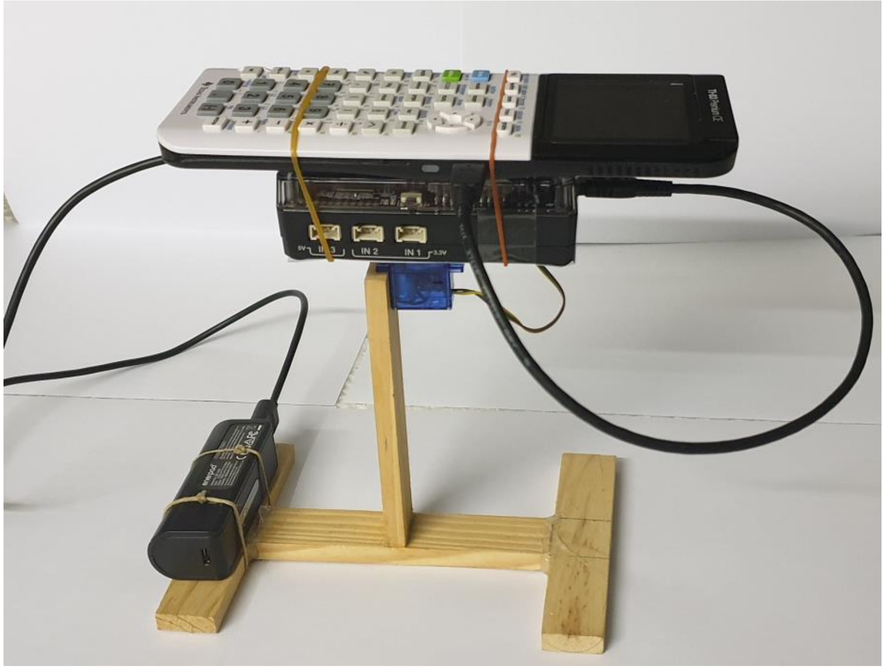
```
ÉDITEUR : REVOL1
LIGNE DU SCRIPT 0001
# Hub Project
from math import *
from ti_system import *
from time import *

import brightns
from servo import *
m=servo("OUT 3")
#sens initial
L1=brightns.measurement()
print("L1=",L1)
wait(2)
m.set_position(15)
L2=brightns.measurement()
print("L2=",L2)
wait(2)
if L2<L1:
  aclockw(L1,L2)
else:
  clockw(L2,L1)
Fns... a A # Outils Exéc Script
```

3. APPENDIX



Front view



Side view

4. Further project ideas

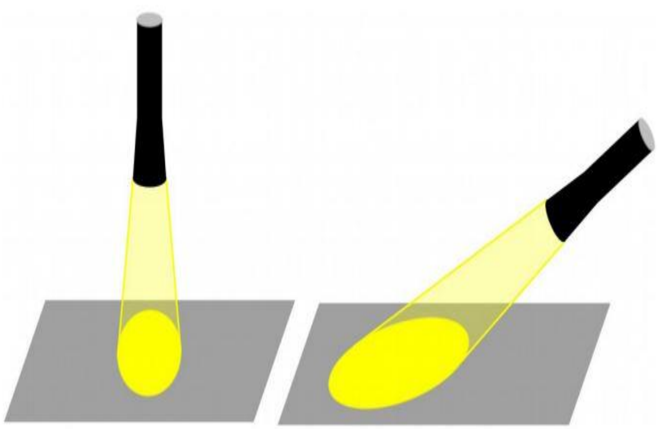
It is possible to go further by refining the Sun trajectory according to the Earth's latitude: one can imagine inclining the brightness sensor with another servomotor. There would be stress on the M of STEM as calculus is a bit more difficult to link the servomotor angle with the latitude.

a. Simplified model

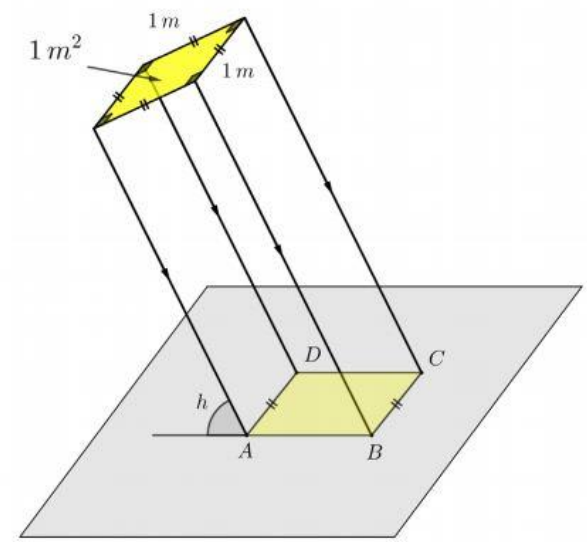
(source : https://eduscol.education.fr/cid143130/enseignement-scientifique-bac-2021.html)

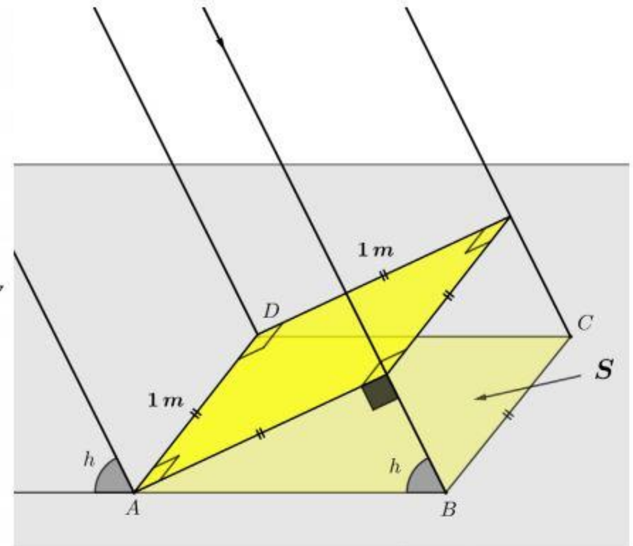
Role of the inclination of the rays on the illuminated surface.

The experiment consists of moving a flashlight illuminating a sheet of paper placed on a table. This makes it possible to visualize the variation of the surface area of the illuminated sheet according to the orientation of the lamp. This area, which is minimal for lighting perpendicular to the plane of the sheet, increases as the lighting becomes more and more inclined.



By considering a 1m^2 cross section beam we can use trigonometry to quantify the change in illuminated area with angle of inclination. Since the Earth-Sun distance can be considered infinitely large compared to all the lengths measured on the surface of the Earth, it is assumed that the solar rays arriving at the surface of the Earth are all parallel to each other. At a point M on the Earth's surface, the inclination of the solar rays is then characterized by an angle, called the solar height and noted. This is the acute angle between the direction of the solar rays and the horizontal plane passing through M. More precisely, it is the complement of the angle between the direction of the solar rays and the vertical at point M (the straight line connecting point M to the center of the Earth). In what follows, we calculate the area of the surface illuminated by a solar beam as a function of the inclination of the beam with respect to the surface.





The area, in m², of the ground surface illuminated by the beam is equal to :

$$AB \times BC = AB \times 1 = AB$$

$$\text{Now } \sin h = \frac{1}{AB}$$

So the area of the illuminated surface, equal to $\frac{1}{\sin h}$, is smaller the higher the Sun is. Its minimum value is reached for h=90° when the Sun is vertical to the place. This shows that the radiative power received from the sun per unit area increases with angle of inclination.

b. Role of seasons and latitude on solar height

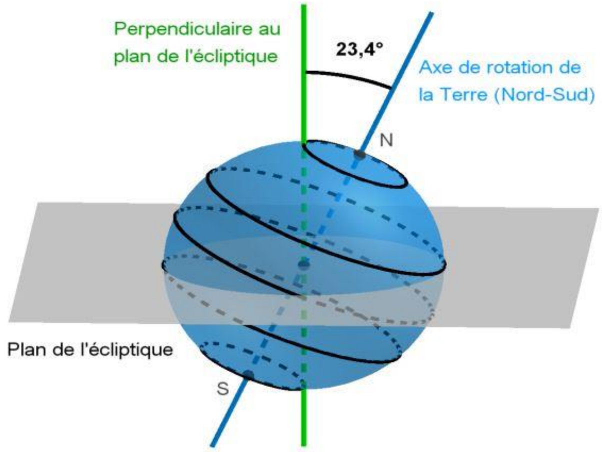
This part studies the evolution of the Sun's height as a function of latitude and seasons to understand both seasonal temperature variations and climate zonation. While it r on itself once a day, the Earth also takes a year to complete its orbit around the Sun (from which it is located at an average distance of 150 million kilometers), following an elliptical path very close to a circle. The plane of this elliptical path is called the plane of the ecliptic. If the axis of rotation of the Earth was perpendicular to the plane of the ecliptic, the duration of the day would be equal to that of the night all year round at any point on the surface of the Earth. But the Earth's axis is tilted about 23 degrees from the perpendicular to the ecliptic plane (this angle is called the obliquity). With very small variations, this inclination of the Earth's axis can be considered constant during the Earth's orbit around the Sun. Since the Earth's axis of rotation maintains a fixed direction, the length of the day depends on the location of the Earth in its orbit (seasonal phenomenon). Thus, from March to September, the northern part of the globe sees the Sun higher in the sky at noon than the southern part. The Sun rises earlier, sets later, and the days are actually longer in the northern hemisphere than in the southern hemisphere where the Sun's rays, which are more inclined, illuminate a larger area, thus distributing less heat per unit area.

These effects are all the more pronounced the greater the latitude of the observer. At the equator, the effect is weak, and the duration of day and night hardly varies. At the poles, the effect is extreme, so that day and night there last six months each. From an astronomical point of view, four dates play a special role:

- When the north side of the Earth's axis "tilts" to the Sun, the angle between the sun's rays and the plane of the equator reaches its maximum value (+23° 26' 13 " ≈ 23.4°). It is the solstice of June, the longest day for the Northern Hemisphere, whose date varies between June 20 and 22. The Sun at noon is at the zenith of the Tropic of Cancer, which has latitude of 23° 26' 13 " North. It is the longest day of the year for the northern hemisphere and the shortest day of the year for the southern hemisphere; - when the southern side of the Earth's axis "tilts" to the maximum towards the Sun, the angle between the sun's rays and the plane of the equator reaches its minimum value (-23° 26' 13 "). It is the solstice of December, the shortest day for the northern hemisphere, whose date varies between December 20 and 22. The Sun at noon is at the zenith of the Tropic of Capricorn, which has latitude of 23° 26' 13" south. It is the longest day of the year for the southern hemisphere and the shortest day of the year for the northern hemisphere.

- The two other dates correspond to the spring (March 19-21) and fall (September 21-24) equinoxes. The axis is then tilted at 90° to the direction of the sun's rays; the duration of the day is now equal to that of the night at any point on the Earth. At any point on the equator, the Sun is at its zenith at solar noon. The equinoxes are the only two dates when the solar rays are parallel to the equatorial plane. In addition to the Equator and the Tropics, two other parallel circles play a special role:
    - the Arctic Polar circle and
    - the Antarctic Polar circle.

The Arctic Circle is the northern latitude beyond which there is at least one day without night and one day without daylight during the year. The days concerned are around the summer solstice and the winter solstice. At the June solstice, the Sun's rays arrive tangentially to the Earth's surface at just one point on the Arctic Circle. That point is where the perpendicular to the ecliptic through the centre of the Earth cuts the Earth's surface, at 66° 53' North .The Arctic Circle is the parallel of latitude 66° 53' North. Everywhere inside that circle will experience at least one 24 hour period of daylight and one 24 hour period. The Antarctic Circle is similarly defined.


Perpendiculaire au
plan de l'écliptique
23,4°
Axe de rotation de
la Terre (Nord-Sud)
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Plan de l'écliptique
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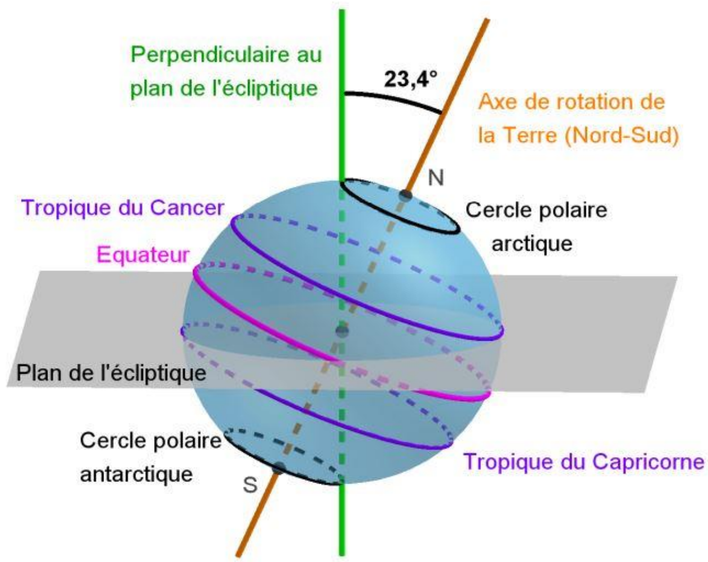
Perpendiculaire au
plan de l'écliptique
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Axe de rotation de
la Terre (Nord-Sud)
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Cercle polaire
arctique
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Cercle polaire
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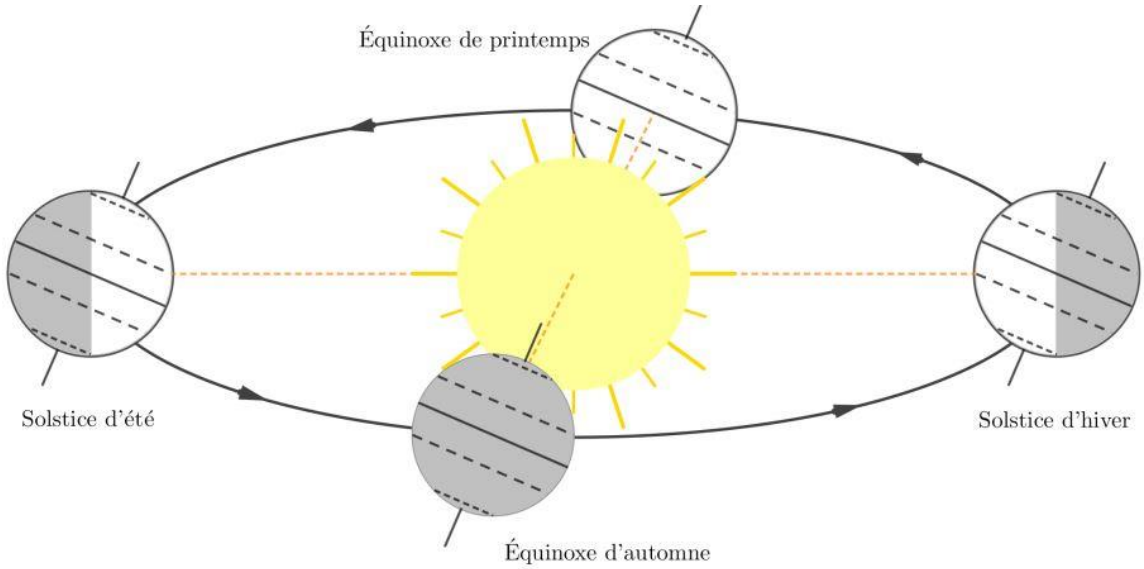
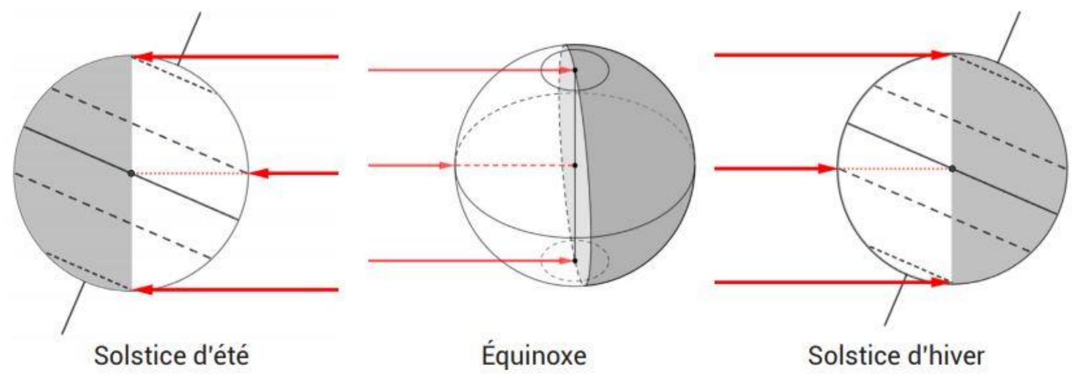


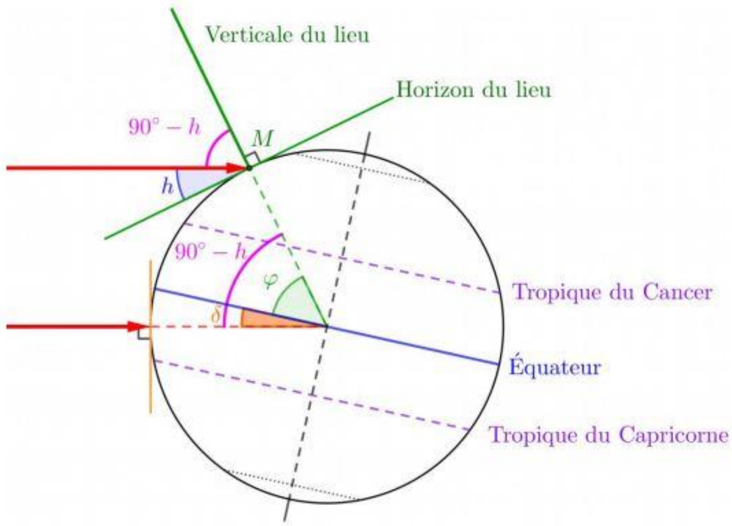
The diagram above is obviously not to scale.



Seen from the Earth, the Sun seems to describe a semicircle: it rises in the East and sets in the West. In a given place, solar noon is the time of day when the Sun seems to be the highest in the sky. On any given date, solar declination is the angle between the plane of the equator and the sun's rays. Its value depends on the inclination of the sun's rays relative to the inclination of the Earth's axis, and therefore on the seasons. At equinoxes, the Sun's rays are parallel to the equatorial plane. The declination is then equal to zero.

The maximum value of the declination is +23.45°. It corresponds to the position of the Sun at solar noon on the June solstice at any point in the Tropic of Cancer (the Sun is then at the zenith).

The minimum value of the declination is -23.45°. It corresponds to the position of the Sun at solar noon on the December solstice at any point of the Tropic of Capricorn (the Sun is then at the zenith). The height h of the Sun at a point on the surface of the Earth is defined as the acute angle formed by the solar rays with the plane of the horizon at solar noon. The drawing below corresponds to a negative declination and a point M located in the Northern Hemisphere.

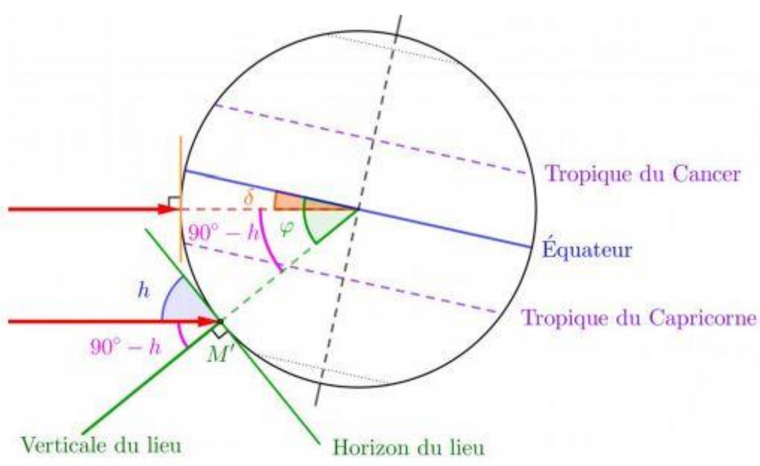


Analysing the angles shows that at point M of a Northern latitude,the height h_M of the Sun is given by :

$$\varphi = 90° - h_M - |\delta|$$

Therefore $h_M = 90° - \varphi - |\delta|$

A similar calculation shows that at point M' of the Southern Hemisphere, having for Southern latitude and at the same time $\varphi = 90° - h_{M'} + |\delta|$ .Therefore $h_{M'} = 90° - \varphi + |\delta|$.|. It shows that the Sun is higher in the sky in M' than in M.

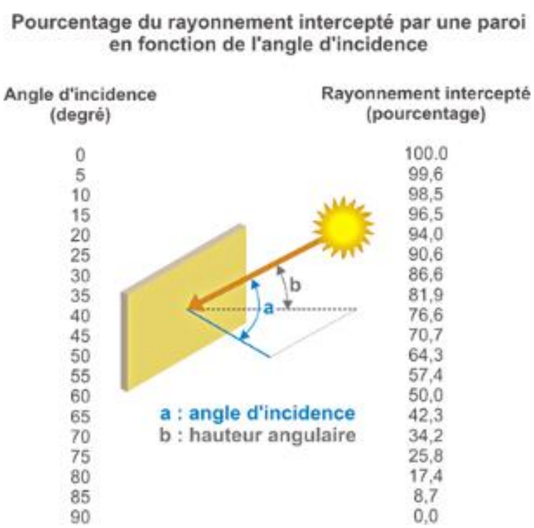


c. Illustrations

The two animations below allow you to visualize various things. The first one aims to show that a cylindrical beam of light from the Sun spreads on the surface of the Earth and that this spreading depends on the latitude (moving North-South) but also on the time of day (moving East or West). To do this, move the red dots and rotate the Earth. N.B. the solar rays are perpendicular to the surface of the globe at the equator, this situation is an equinox. The second one discretizes the real situation. This number of points per unit area gives an idea of the variation in received power per unit area according to latitude and time of day.

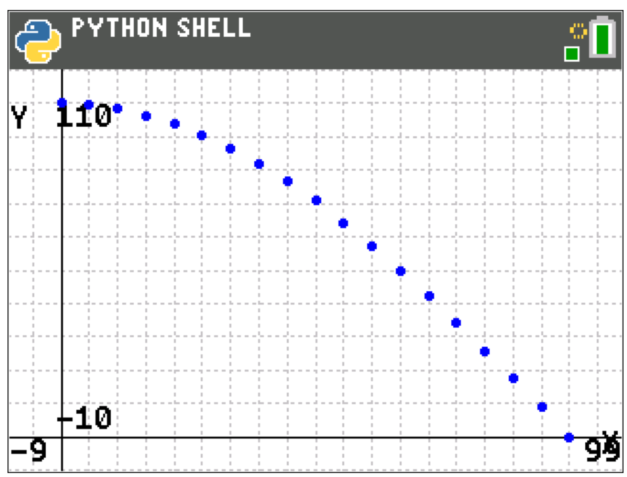
This animation is composed of several buttons:

- “Initialize" to initialize the view;
- "Rays density" to vary the number of rays per unit area;
- "Points" to make a grid of particles (one per ray) appear as photons;
- "Project" to project the grid of points on the surface of the Earth;
- "Constant area zone" to make a circle of fixed radius appear on the surface of the Earth and calculate the number of points within this zone.



Pourcentage du rayonnement intercepté par une paroi en fonction de l'angle d'incidence

Angle d'incidence (degré)	Rayonnement intercepté (pourcentage)
0	100.0
5	99,6
10	98,5
15	96,5
20	94,0
25	90,6
30	86,6
35	81,9
40	76,6
45	70,7
50	64,3
55	57,4
60	50,0
65	42,3
70	34,2
75	25,8
80	17,4
85	8,7
90	0,0



Source: https://energieplus-lesite.be/theories/climat8/ensoleillement-d8/

d. Reflection on priority locations and current lifestyles

If consumers around the world switched to energy-efficient light bulbs, the world would save $120 billion a year.

If the world's population reaches 9.6 billion people by 2050, the equivalent of nearly three planets would be needed to provide the resources to maintain current lifestyles.

Where to set up energy production units as a priority?

What are the sectors where the need is real? (necessity vs. comfort)