

3. Calculate The Declination Angle, Hour Angle, Solar Altitude Angle And Solar Zenith Angle ,azimuth

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Understanding the position of the sun in the sky is essential for various applications, including solar panel installation, designing natural lighting systems, and optimizing photovoltaic systems. Accurate calculations of the declination angle, hour angle, solar altitude angle, and solar zenith angle, along with the azimuth, provide critical insights into the sun's movement throughout the day and year. This article offers a comprehensive guide to calculating these solar parameters, their significance, and practical applications.

Introduction to Solar Angles and Their Importance

Before diving into the calculations, it's important to grasp why these angles matter:

- Declination Angle (δ): Represents the angle between the sun's rays and the plane of the Earth's equator. It varies throughout the year due to Earth's tilt and orbit.
- Hour Angle (H): Indicates the sun's position relative to solar noon, based on the time of day.
- Solar Altitude Angle (α): The angle between the sun's rays and the horizontal plane at a specific location and time.
- Solar Zenith Angle (θ_z): The angle between the sun's rays and the vertical direction (zenith) at a given location.
- Azimuth (A): The compass direction from which the sunlight is coming, relative to true north.

Accurate calculation of these angles allows for optimal positioning of solar panels, understanding daylight hours, and designing energy-efficient buildings.

Calculating the Declination Angle (δ)

What is the Declination Angle?

The declination angle varies throughout the year, oscillating between -23.45° (winter solstice) and $+23.45^\circ$ (summer solstice), reflecting Earth's axial tilt.

Formula for Declination Angle

A common approximation for the declination angle is:

$$\delta = 23.45^\circ \times \sin\left(\frac{360^\circ}{365} \times (N - 81)\right)$$

Where:

- (N) = Day of the year (1 for January 1, 365 for December 31)
- The angle is in degrees

Steps to calculate:

1. Determine the day number (N) .
2. Convert the formula to radians if necessary, depending on calculator or software.
3. Compute the sine component.
4. Multiply by 23.45° .

Example:

For June 21 ($N=172$):

$$\delta = 23.45^\circ \times \sin\left(\frac{360^\circ}{365} \times (172 - 81)\right)$$

$$= 23.45^\circ \times \sin\left(\frac{360^\circ}{365} \times 91\right)$$

Calculate the inner angle and then apply the sine.

Calculating the Hour Angle (H)

What is the Hour Angle?

The hour angle indicates the sun's position relative to solar noon, where:

$$H = 0^\circ$$

at solar noon, negative in the morning, and positive in the afternoon.

Formula for Hour Angle

$$H = 15^\circ \times (LST - 12)$$

\]

Where:

- (LST) = Local Solar Time in hours
- 15° per hour reflects Earth's rotation ($360^\circ/24$ hours)

Calculating Local Solar Time:

LST adjusts local clock time for longitude and the equation of time (EoT). The general formula:

\[

$$LST = LST_{\text{standard}} + \text{Correction for longitude} + \text{Equation of Time}$$

\]

Where:

- (LST_{standard}) is based on the local time zone
- Longitude correction accounts for the local longitude relative to the standard meridian
- Equation of Time (EoT) corrects for Earth's elliptical orbit and axial tilt

Step-by-step:

1. Determine the local standard time (e.g., 12:00 pm).
2. Adjust for longitude:

\[

$$\text{Longitude correction} = \frac{\text{Difference in degrees from standard meridian}}{15}$$

\]

3. Calculate or look up the EoT for the specific day.
4. Sum these to find LST.
5. Calculate (H) using the formula.

Calculating the Solar Altitude Angle (α)

What is the Solar Altitude Angle?

The solar altitude angle is the angle between the sun's rays and the horizontal plane at a specific location and time. It indicates how high the sun is in the sky.

Formula for Solar Altitude Angle

\[

$$\sin \alpha = \sin \phi \times \sin \delta + \cos \phi \times \cos \delta \times \cos H$$

\]

Where:

- (ϕ) = Latitude of the location

- (δ) = Declination angle

- (H) = Hour angle

To find (α) :

$$\alpha = \arcsin \left(\sin \phi \sin \delta + \cos \phi \cos \delta \cos H \right)$$

Interpretation:

- (α) ranges from 0° (sun on the horizon) to 90° (sun directly overhead).

Example:

Suppose $(\phi = 40^\circ \text{ N})$, $(\delta = 23.45^\circ)$, and $(H = 0^\circ)$:

$$\alpha = \arcsin \left(\sin 40^\circ \times \sin 23.45^\circ + \cos 40^\circ \times \cos 23.45^\circ \times 1 \right)$$

Calculate each component and then the inverse sine to find (α) .

Calculating the Solar Zenith Angle (θ_z)

What is the Solar Zenith Angle?

The solar zenith angle is the angle between the sun's rays and the vertical (zenith) at the location. It's complementary to the solar altitude:

$$\theta_z = 90^\circ - \alpha$$

Alternatively, it can be calculated directly:

$$\cos \theta_z = \sin \phi \sin \delta + \cos \phi \cos \delta \cos H$$

So,

$$\theta_z = \arccos \left(\sin \phi \sin \delta + \cos \phi \cos \delta \cos H \right)$$

Significance:

- A smaller (θ_z) indicates the sun is higher in the sky.
- $(\theta_z = 0^\circ)$ when the sun is at zenith.

Calculating the Solar Azimuth Angle (A)

What is the Azimuth?

The solar azimuth angle indicates the compass direction from which the sunlight is coming, relative to true north (0°). It varies throughout the day and year.

Formulas for Azimuth

The calculation depends on the time of day:

$$A = \arctan \left(\frac{\sin H}{\cos H \times \sin \phi - \tan \delta \times \cos \phi} \right)$$

However, to ensure correct quadrant placement, use the two-argument arctangent function:

$$A = \arctan2 \left(\sin H, \cos H \times \sin \phi - \tan \delta \times \cos \phi \right)$$

Adjustments:

- For solar morning (before noon): (A) is east of south.
- For afternoon (after noon): (A) is west of south.

Final step:

- Convert the azimuth to degrees from north, adjusting based on the hemisphere and time of day.

Practical Applications and Significance of Solar Angle Calculations

Understanding and calculating these angles serve multiple practical purposes:

- Solar Panel Optimization: Proper tilt and orientation depend on the sun's path to maximize energy capture.

- Daylight Harvesting: Designing windows and shading devices based on sun angles improves indoor comfort and energy efficiency.
- Climate and Environment Studies: Analyzing solar angles helps in understanding local climate patterns and solar radiation distribution.
- Agricultural Planning: Sunlight exposure influences crop planting schedules and growth patterns.

Tools and Software for Solar Angle Calculations

While manual calculations are educational, several tools simplify the process:

- Solar Position Algorithms (SPA): Developed by NREL, these provide accurate solar position data.
- Online Solar Calculators: Websites like Time and Date, PVWatts, and SunCalc.
- Mobile Apps: Sun Seeker, Solar Path, and others.
- Specialized Software: PVsyst, Helioscope, and SAM for detailed solar system design.

Conclusion

Accurately calculating the declination angle, hour angle, solar altitude angle, solar zenith angle, and azimuth is crucial for harnessing solar energy effectively and designing sustainable structures.

Frequently Asked Questions

What is the declination angle in solar geometry and how is it calculated?

The declination angle is the angle between the sun's rays and the Earth's equatorial plane, indicating the sun's position relative to the Earth's surface throughout the year. It can be calculated using the formula: $\delta = 23.45^\circ \times \sin(360^\circ/365 \times (N - 81))$, where N is the day of the year.

How do you determine the hour angle for a given location and time?

The hour angle (H) represents the sun's position relative to solar noon and is calculated as $H = 15^\circ \times (LST - 12)$, where LST is the local solar time in hours. It indicates how far the sun has moved east or west from the local meridian.

What is the solar altitude angle and how do you compute it?

The solar altitude angle (α) is the angle between the sun's rays and the horizontal plane at a specific location. It can be calculated using the formula: $\alpha = \arcsin [\sin \delta \times \sin \varphi + \cos \delta \times \cos \varphi \times \cos H]$, where δ is the declination angle, φ is the latitude, and H is the hour angle.

How is the solar zenith angle related to the solar altitude angle, and how is it calculated?

The solar zenith angle (θ_z) is the angle between the sun's rays and the vertical (zenith) direction, and it is complementary to the solar altitude angle: $\theta_z = 90^\circ - \alpha$. Alternatively, it can be calculated directly using: $\theta_z = \arccos [\sin \delta \times \sin \varphi + \cos \delta \times \cos \varphi \times \cos H]$.

What is the azimuth angle in solar position calculations, and how do you determine it?

The azimuth angle indicates the compass direction of the sun from a specific location, usually measured from north. It can be computed using the formula: $\text{Azimuth} = \arccos [(\sin \delta \times \cos \varphi - \cos \delta \times \sin \varphi \times \cos H) / \cos \alpha]$. Adjustments are made based on the sun's position in the sky (morning or afternoon).

Why are the declination, hour angle, solar altitude, and zenith angles important in solar energy applications?

These angles are crucial for accurately modeling the sun's position, optimizing the orientation and tilt of solar panels, predicting solar radiation, and improving the efficiency of solar energy systems by understanding how the sun's position varies throughout the day and year.

Additional Resources

Calculate The Declination Angle, Hour Angle, Solar Altitude Angle, Solar Zenith Angle, and Azimuth: A Comprehensive Guide

Understanding the position of the sun in the sky is fundamental for various applications, including solar panel installation, architectural design, agriculture, and climate studies. To accurately determine the sun's position, you must analyze several key angles: the declination angle, hour angle, solar altitude angle, solar zenith angle, and azimuth. This comprehensive guide delves into each of these parameters, explaining their significance, how to calculate them, and their practical applications.

1. Solar Declination Angle

What is the Declination Angle?

The solar declination angle (δ) represents the angle between the sun's rays and the Earth's equatorial plane. It varies throughout the year due to the tilt of Earth's axis ($\sim 23.45^\circ$) and Earth's orbit around the sun. The declination determines the sun's apparent position north or south of the Earth's equator, influencing the intensity and duration of sunlight received at different latitudes.

Significance of Declination

- Indicates the sun's position relative to the equator.
- Affects the solar altitude and azimuth angles.
- Critical for calculating solar radiation incident on surfaces.
- Vital for designing solar energy systems, especially for tracking systems.

How to Calculate Declination Angle

The declination angle can be approximated using empirical formulas based on the day of the year. One popular formula is:

$$\delta = -23.45^\circ \times \cos \left(\frac{360^\circ}{365} \times (N + 10) \right)$$

Where:

- (N) = Day number of the year (1 for January 1, 365 for December 31).
- The angle is in degrees.

Alternative (More Accurate) Formula:

$$\delta = 23.45^\circ \times \sin \left(\frac{360^\circ}{365} \times (N - 81) \right)$$

Note: The choice of formula depends on the desired accuracy and the specific application.

Practical Calculation Example

Suppose you want to calculate the declination on the 172nd day (June 21, the summer solstice):

$$\delta = 23.45^\circ \times \sin \left(\frac{360^\circ}{365} \times (172 - 81) \right)$$

$$\begin{aligned} &= 23.45^\circ \times \sin \left(\frac{360^\circ}{365} \times 91 \right) \\ &= 23.45^\circ \times \sin (89.96^\circ) \approx 23.45^\circ \times 1 \approx 23.45^\circ \end{aligned}$$

This confirms that around June 21, the declination is approximately $+23.45^\circ$, aligning with the axial tilt.

2. Hour Angle (H)

Understanding the Hour Angle

The hour angle (H) indicates the sun's position relative to solar noon and is expressed in degrees. It essentially measures the Earth's rotation from solar noon, with positive values in the afternoon and negative in the morning.

Definition:

$$H = 15^\circ \times (\text{LST} - 12)$$

Where:

- (LST) = Local Solar Time (hours)
- 15° per hour because the Earth rotates 360° in 24 hours.

Alternatively, if you have the local time (t) and the longitude (λ) , you can compute (H) as:

$$H = 15^\circ \times (\text{LST} - 12)$$

where:

$$\text{LST} = \text{Standard Time} + \text{Longitude Correction}$$

Longitude Correction:

$$\text{Longitude Correction} = \frac{\lambda_{\text{standard}} - \lambda_{\text{local}}}{15}$$

Calculating the Hour Angle in Practice

Suppose it's 9:00 am local time at a location with longitude $(\lambda = 75^\circ \text{ W})$, and the standard meridian for the timezone is at (75° W) . The local solar time (LST) is then approximately 9:00 am.

$$H = 15^\circ \times (9 - 12) = -45^\circ$$

This negative value indicates the sun is in the morning hours, 45 degrees east of solar noon.

Significance of Hour Angle

- Determines the sun's position during the day.
- Used in calculating solar altitude and azimuth.
- Essential for designing solar tracking systems.

3. Solar Altitude Angle (α)

What is the Solar Altitude Angle?

The solar altitude angle (α) is the angle between the sun's rays and the horizontal plane at a specific location and time. It indicates how high the sun is in the sky.

Range:

- 0° at sunrise and sunset.
- Max at solar noon, when the sun reaches its highest point.

Formula for Solar Altitude Angle

The general formula combines the declination angle, latitude ((ϕ)), and hour angle ((H)):

$$\sin \alpha = \sin \phi \times \sin \delta + \cos \phi \times \cos \delta \times \cos H$$

Where:

- (ϕ) = Latitude of the location (degrees).
- (δ) = Declination angle (degrees).
- (H) = Hour angle (degrees).

Once $(\sin \alpha)$ is computed, the altitude angle is:

$$\alpha = \arcsin(\sin \alpha)$$

Calculating Solar Altitude: Practical Example

Suppose:

- Latitude $(\phi = 40^\circ \text{ N})$
- Declination $(\delta = 23.45^\circ)$ (June 21)
- Hour angle $(H = 0^\circ)$ (solar noon)

Calculations:

$$\begin{aligned}\sin \alpha &= \sin 40^\circ \times \sin 23.45^\circ + \cos 40^\circ \times \cos 23.45^\circ \times \cos 0^\circ \\ &= (0.6428 \times 0.3978) + (0.7660 \times 0.9175 \times 1) \\ &= 0.2559 + 0.7033 = 0.9592\end{aligned}$$

Then,

$$\alpha = \arcsin(0.9592) \approx 73.7^\circ$$

This indicates the sun is approximately 73.7° above the horizon at solar noon on June 21 at 40° N latitude.

4. Solar Zenith Angle (Z)

Defining the Solar Zenith Angle

The solar zenith angle (Z) measures the angle between the sun's rays and the vertical (zenith) directly overhead. It complements the solar altitude angle:

$Z = 90^\circ - \alpha$

$$Z = 90^\circ - \alpha$$

Implication:

- When the sun is directly overhead, $(Z = 0^\circ)$.
- At sunrise or sunset, $(Z \approx 90^\circ)$.

Calculation of Zenith Angle

Using the same parameters as for the altitude:

$$\cos Z = \sin \phi \times \sin \delta + \cos \phi \times \cos \delta \times \cos H$$

This is similar to the altitude calculation but directly yields the zenith angle:

$$Z = \arccos(\sin \phi \times \sin \delta + \cos \phi \times \cos \delta \times \cos H)$$

Practical Example

Continuing the previous example:

$$\begin{aligned} \cos Z &= 0.6428 \times 0.3978 + 0.7660 \times 0.9175 \times 1 \\ &= 0.2559 + 0.7033 = 0.9592 \end{aligned}$$

Thus,

$$Z = \arccos(0.9592) \approx 16.3^\circ$$

This confirms the sun is approximately 16.3° away from the zenith at solar noon on June 21.

5. Azimuth Angle (A)

Understanding Azimuth

The azimuth angle (A) describes the compass direction of the sun, measured clockwise from North (0°). It indicates the solar position relative to North and varies throughout the day.

Key points:

- At sunrise, the azimuth is approximately 90° (East).
- At solar noon, the azimuth is either due South in the Northern Hemisphere or due North in the Southern Hemisphere.
- At sunset, the azimuth approaches 270° (West).

Calculating the Solar Azimuth

The formula depends on the time of

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