SOLAR RADIATION MEASUREMENT

BY

Jirakom Padumanon
Electricity Generating Authority of Thailand (EGAT)
Thailand

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OBJECTIVE

To be familiar with the two basic solar radiation measuring instruments which are the pyranometer and the pyrheliometer, and to study the information needed in setting up the instruments properly which lead to the accurate data acquired. In addition, the measuring of total solar radiation using two standard Eppley pyranometers at various inclined plane angle will be made to attain the ratio of total radiation at inclined plane and horizontal plane compared to the calculated values.

INTRODUCTION

In solar radiation measurements two basic instruments are used. The accepted terms of these are as follow:

1. Pyrheliometer. An instrument for measuring solar radiation from the sun and from a small portion of the sky around the sun at normal incidence, or the direct component of solar radiation. In this particular purpose some mean of tracking is needed to follow the sun's path through the hemisphere.

2. Pyranometer. An instrument for measuring total hemisphere solar radiation consisting of direct component and diffuse radiation usually on a horizontal surface, or the total radiation. In addition, pyranometer is able to be applied for measuring direct component and diffuse radiation by using two pyranometers, one with and another without a shading object to block the direct component of the sun. The pyranometer with a shading object reads the diffuse radiation and the other reads the total radiation. The difference in two readings is the direct component of solar radiation.

In setting up the solar radiation measuring instruments, it is necessary to know the fundamental characteristics of the sun and some meteorological data. On the other hand, the information and measured data are essential in all design and solar systems. In order to achieve the said information some calculations
have to be made including the ratio of total radiation at titled surface and horizontal surface which is one of the objectives in this measurement.

THEORY

The terms of information and relationship in calculating the data will be introduced as follows:

1. The location of the sun at any particular time which is of great importance in measuring the direct component of solar radiation and the sun tracking design considerations. The factor that indicates sun location are the solar altitude, $\beta$, above the horizontal line, and the solar azimuth, $\phi$, measured from the south.

2. The local latitude, $L$.

3. The solar declination, $\delta$, at solar noon, which is the function of the date.

4. The apparent solar time, expressed as the hour angle, $H$.

5. The standard time zones, the local standard time at any particular area.

Fig. 1. Standard Time Zones of the United States.
6. The sun charts, the plot of the sun's location at different times throughout the day from sunrise to sunset.

![Sun Chart Diagram]

Fig. 2. The complete sun chart at any month of the year.

7. The magnetic declination, the variation of magnetic compass from true north/south. Since all solar calculations are based on true south, it is necessary to adjust the compass reading by a few degrees east or west to obtain true north/south. The amount of variation depends upon the location. Using the Isogonic chart in Fig. 3 to compensate the magnetic compass variations.
Fig. 3. The Isogonic chart for magnetic compass compensation.

8. The angle of incidence, $\theta$, for any surface which is the angle between the incoming solar rays and the line normal to that surface.

9. The surface solar azimuth, $\phi$.

10. The surface azimuth, $\psi$.

11. The surface tilt angle, $\beta$.

Fig. 4. The solar angles for any titled surface.
12. The ratio of total radiation on the tilted surface to that on a horizontal surface at any time, \( R \), which is the important value to estimate the solar radiation for hours and days on a tilted surface from the most commonly available solar radiation data measured on a horizontal surface, either total or beam and diffuse.

METHODOLOGY

1. Simultaneous readings from two pyranometers with one on a horizontal plane and the other on the various tilted angle plane faced to the true south.

2. Record the local times at any reading along with the value of solar radiation from two pyranometers for further calculations.

CALCULATION AND DATA

1. The location of the sun \( \beta, \phi \), can be calculated by the equations below:

\[
\sin \beta = \cos L \cos \delta \cos H + \sin L \sin \delta \\
\cos \phi = (\sin \beta \sin L - \sin \delta)/(\cos \beta \cos L)
\]

where \( \delta = 23.45 \sin \left(360 \cdot \frac{284 + n}{365}\right); n = \text{day of the year} \)

\( H = 0.25 \times (\text{Number of minutes from local solar noon}) \) the term solar noon, the time the sun crosses the meridian of the observer is not the local noon time. The solar time at any particular time and location can be calculated by the equation as follows:

\[
\text{Solar time} = \text{Standard time} + 4 \left( L_{st} - L_{loc} \right) + E
\]

where \( L_{st} \) is the standard meridian for the local time zone

\( L_{loc} \) is the longitude location in question in degree west

\( E \) is the equation of time

\( E = 9.87 \sin 2 \beta - 7.53 \cos \beta - 1.5 \sin \beta \)

where \( \beta = \frac{360 (n-81)}{364}; n = \text{day of the year} \)
From the above equations, at a present study in Gainesville, on May 12, 1983, for which a measurement has been made, we get

\[ L_{st} = 75^\circ W \text{ (Eastern Standard Time, EST)} \]

\[ L_{loc} = 82.5^\circ W; L = 29.5^\circ N \]

\[ n = 132; \beta = 50.44, E = 3.76 \]

Solar time = Standard time - 26.24 (86.24 for Eastern Daylight Time, EDT)

\[ \delta = 18.04 \]

Using the data and equations above we can calculate the location of the sun in terms of solar altitude, \( H \), and solar azimuth, \( \phi \), at the specific time as shown in Table 1 below.

<table>
<thead>
<tr>
<th>Local Time (EDT)</th>
<th>Solar Time</th>
<th>H (degree)</th>
<th>( \beta ) (degree)</th>
<th>( \phi ) (degree)</th>
</tr>
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<tr>
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<td>8.26P</td>
<td>5.00A</td>
<td>7.00P</td>
<td>105.0</td>
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<td>6.00P</td>
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<tr>
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<td>30.0</td>
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<tr>
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</tr>
<tr>
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<td>1.56P</td>
<td>11.30A</td>
<td>0.30P</td>
<td>7.5</td>
</tr>
<tr>
<td>1.26P</td>
<td>12.00 NOON</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. The sun's location at any specific time.
Fig. 5  Sun chart at Gainesville May 12, 1983
2. The angle of incidence, $\theta$, for any surface is related to $\beta, \gamma$, and $\Sigma$ by the equation:

$$\cos \theta = \cos \beta \cos \gamma \sin \Sigma + \sin \beta \cos \Sigma$$

For the horizontal plane where $\Sigma = 0$, we get

$$\cos \theta = \sin \beta$$

For the tilted surface in the measurement $\gamma = \varnothing$ (faced to the south)

so, $\cos \theta = \cos \beta \cos \varnothing \sin \Sigma + \sin \beta \cos \Sigma$

By using the sun chart and the measuring time data we can locate the positions of the sun on the sun chart and the $\beta, \varnothing$, can be obtained for any specific time. Then, the angle of incidence $\theta$ can be calculated.

3. The ratio of total radiation on a tilted surface to that on the horizontal surface, $R$, is, by definition

$$R = \frac{\text{total radiation on a tilted surface}}{\text{total radiation on a horizontal surface}}$$

$$= \frac{I_T}{I}$$

Assuming that the diffuse radiation is concentrated from the area of the sky near the sun, then the total radiation is treated as though it is all beam radiation, and we get

$$R = \frac{\cos \theta}{\cos \theta_T}$$

From the above equations and data measured we can calculate $\cos \theta$, $\cos \theta_T$ and $R$ at any particular time and tilt angle as shown in Table 2 and the plot of $R$ from measured results and calculated results $v.s.$ tilt angle as shown in Fig. 6.
Table 2. The calculated and measured results on May 12, 1983.
Fig. 6 Plot of measured and calculated $R$ vs. tilt angle.
CONCLUSION

Using the plot of the sun chart to calculate for the R at any specific time corresponded to the measuring time and the results obtained agree with the results obtained directly from the measurement.

DISCUSSION

According to the assumption made in calculating the value of R that the diffuse radiation comes from an apparent origin near the sun and comes from the direction of the sun, so the diffuse radiation that distributes over the sky is not taken into account in the calculation. Therefore, this approximation is responsible for some remarkable differences between the calculated result and direct measured result.

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REFERENCES