Spectral effects and determining the solar spectral distribution for Mugla and Ankara

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Article Info

ABSTRACT

Not only is the theoretical calculation of the amount of solar radiation but also the characteristics of the light so significant in deciding the spectral sensitivity of the PV modules. The amount of radiation reaching on the earth depends on many atmospheric parameters such as wavelength and air mass. Spectral 2 is a model that calculates the amount of radiation for any region depending on the wavelength and atmospheric parameters. There are no theoretical and experimental studies on this subject in Turkey until now. In this study, the amounts of radiation coming to the surface having horizontal and different tilt angles were calculated for Mugla and Ankara. Due to the different climatic characteristics of Mugla and Ankara, the amount of radiation varies. According to the results, in winter and autumn, the amount of radiation which comes to Ankara and Mugla, is different each other. Due to the different climatical and geographical characteristics of Mugla and Ankara, the amount of radiation varies. The model, which is used in this study, due to atmospheric effects that have, is more comprehensive than any other empirical models made in Turkey.

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1. INTRODUCTION

The sun is the world's largest source of energy. Calculating the amount of radiation from the sun is very important in photovoltaic applications. Sunlight is a form of electromagnetic radiation. Electromagnetic radiation from sun ranging from 0.25 µm to 4.5 µm in wavelength and has three different regions. These regions are named as ultraviolet rays (UV), visible, and infrared (IR). Sun's radiant power is the solar irradiance power in per unit area in W/m^2 or kW/m^2 [1]. Solar radiation is reduced because of atmospheric conditions like scattering, reflection, and absorption. Particles which are in the atmosphere cause scattering. Also, water vapour, in the atmosphere, causes absorption [2, 3]. Clouds are the main effect of diffused irradiance. Reflection occurs as a result of solar radiation hitting a reflective surface. Latitude of the location, day (time in the year) is the other parameters which affect the incident solar radiation. The amount of solar radiation come to the surface can be calculated using different models. But the effect of the wavelength variation on the output is not analysed or calculated in detail. Only small-scale solar cells are used with different materials. In our study, we used SPCTRL 2 calculating program which allows calculating spectral irradiance depending to wavelength for desired location will be discussed. The amount of beam, scattered, and global radiation coming to a horizontal and inclined surface in Mugla and Ankara was calculated using

the SPCTRL 2 model. Here, the factors affecting the amount of radiation incident on the surface were investigated.

2.   RESEARCH METHOD

2.1. Basic terms of solar irradiance

The amount of radiation coming to the outer surface of the atmosphere varies throughout the year due to the change in the distance between the earth and the sun [4]. Solar radiation reaching the surface; It depends on parameters such as location, atmospheric conditions, aerosol, state of the ozone layer, time of day, distance from the earth/sun. And also, it varies with wavelength which is so called spectra. The amount of radiation that reaches the surface varies depending on the wavelength. Studying this change is very important for theoretical calculations. The most commonly used spectrum is those published by The Committee Internationale d'Eclaraige (CIE) and given in Figure 1. Solar energy is named by different names, especially density and radiation. In photovoltaic applications, the terms radiation and density are preferred [5]. The amount of energy is usually expressed in units of mW/cm^2 or W/m^2 [6].
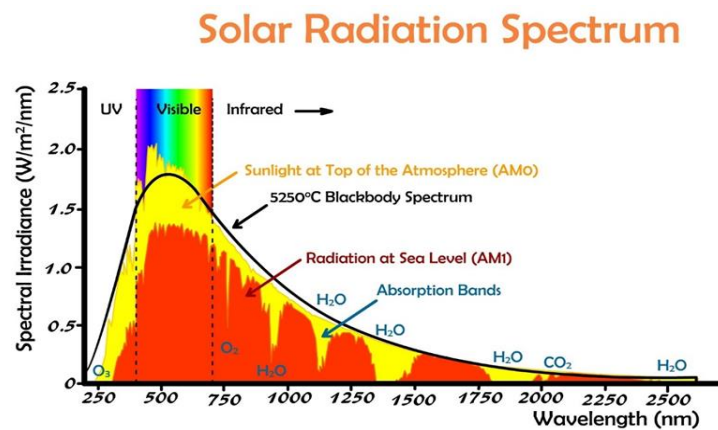

Figure. 1. Atmospheric effects on global irradiance

In addition to knowing the graph of the incident radiation depending on the wavelength, the amount of energy for each wavelength must also be known. Thus, a better understanding of the spectral sensitivity of the solar cell in photovoltaic applications is provided. So, there are many studies all over the world reports the performance of different types of solar cells depend on their technologies [7, 8]. The relative spectral responsivity for several technologies is plotted in Figure 2 where the spectral responsivity is the sensitivity of the device or solar cell to optical radiation of different wavelengths.
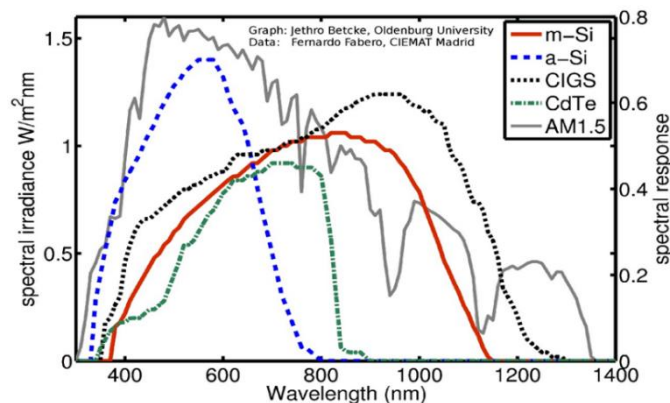

Figure. 2. Relative spectral responsivity of seven PV technologies [9]

Solar constant is the solar radiation on per unit surface (in m²) at the earth's outer atmosphere, oriented normal to the sun's rays and its value is 1.367 W/m². Air mass is an indication of the distribution of sunlight within the atmosphere and is calculated as,

$$Air\ Mass\ (AM) = \frac{1}{\cos(\theta)} \tag{1}$$

where θ is the incidence angle of sun rays. The amount of solar radiation in the atmosphere varies due to different atmospheric effects [10].

2.2. Simple spectral model on global irradiance

In this model, the variation of the amount of total solar radiation into the atmosphere depending on the wavelength is modelled by atmospheric effects. Researchers may obtain the capability to produce accurate terrestrial spectra using only a computer [11]. For wavelength λ and at ground level direct normal irradiance (DNI) on a surface normal to the direction of the sun as

$$II_{d\lambda} = H_{0\lambda}.D.T_{r\lambda}.T_{a\lambda}.T_{w\lambda}.T_{o\lambda}.T_{u\lambda} \tag{2}$$

$H_{0\lambda}$ is the extra-terrestrial irradiance depending on wavelength λ; D is the effect of the earth-sun distance; and $T_{r\lambda}$, $T_{a\lambda}$, $T_{w\lambda}$, $T_{o\lambda}$ and $T_{u\lambda}$ are the transmittance functions of the atmosphere depending on wavelength. $T_{r\lambda}$ Rayleigh scattering, $T_{a\lambda}$ aerosol attenuation [12], $T_{w\lambda}$ water vapour absorption [13], $T_{o\lambda}$ ozone absorption [14], and $T_{u\lambda}$ uniformly mixed gas absorption, respectively. Here D is given as [15]:

$$D = 1,00011 + 0,034221.\cos(\varphi) + 0,00128.\sin(\varphi) + 0,000719.\cos(2\varphi) + 0,000077.\sin(2\varphi) \tag{3}$$

The day angle φ is given;

$$\varphi = 2\pi\frac{d-1}{365} \tag{4}$$

where d is the day number of a year. Rayleigh scattering parameter ($T_{r\lambda}$) is given,

$$T_{r\lambda} = \exp\left\{\frac{-M'}{\lambda^4.(115,6406 - \frac{1,335}{\lambda^2})}\right\} \tag{5}$$

M' is the pressure-corrected air mass. Relative air mass as given by;

$$M = [\cos(Z) + 0,15(93,885 - Z)^{-1,253}]^{-1} \tag{6}$$

Z is apparent solar zenith angle.

$$M' = \frac{M.P}{P_0} \tag{7}$$

P_0 =1013 mb and P is measured surface pressure. Aerosol scattering and absorption ($T_{a\lambda}$) is;

$$T_{a\lambda} = \exp\{-\beta_n\lambda^{-a_n}M\} \tag{8}$$

$\alpha_1 = 1,2074\ for\ \lambda < 0,5\mu m$
$\alpha_2 = 1,2060\ for\ \lambda > 0,5\mu m$

Water vapour absorption ($T_{w\lambda}$) is;

$$T_{w\lambda} = \exp\left\{\frac{-0,2385.a_{w\lambda}.W.M}{(1+20,07.a_{w\lambda}.W.M)^{0,45}}\right\} \tag{9}$$

here $\alpha_{W\lambda}$ is the water vapour absorption coefficient as a wavelength λ and W is the precipitable water vapour (cm) in a vertical path [16]. It is difficult to calculate the amount of indirect radiation with a mathematical model for any surface. In this model, different simple formulations are used for producing spectra on inclined surfaces [17]. For a horizontal surface, there are three components of indirect radiation. First is the Rayleigh

scattering component $I_{r\lambda}$, second is the aerosol scattering component $I_{a\lambda}$, last one is the component that accounts for multiple reflection of irradiance between the ground and the air $I_{g\lambda}$ [18]. The total scattered irradiance, $I_{s\lambda}$, is then given as,

$$I_{s\lambda} = I_{r\lambda} + I_{a\lambda} + I_{g\lambda} \tag{10}$$

These components can be calculated independent of each other. The spectral global irradiance on an inclined surface is represented as [19, 20]:

$$I_{T\lambda}(t) = I_{d\lambda}.\cos(\theta) + I_{s\lambda}\left[\left(\frac{I_{d\lambda}.\cos(\theta)}{H_{0\lambda}.D.\cos(Z)}\right) + 0,5.(1 + \cos(t)).\left(\frac{1 - I_{d\lambda}}{H_{0\lambda}.D}\right)\right]$$

$$+0,5.I_{T\lambda}.r_{g\lambda}.(1 - \cos(t)) \tag{11}$$

where θ is the tilted surface incidence angle of the direct beam and tilt angle of the inclined surface is t. The tilt angle is zero for a horizontal surface and 90° for a vertical surface. The spectral global irradiance on a horizontal surface is represented as [21-28]:

$$I_{T\lambda} = I_{d\lambda}.\cos(Z) + I_{S\lambda} \tag{12}$$

Spectral irradiance is calculated for horizontal and 30° tilt angle with SPECTRAL2. Calculations were made for the Muğla and Ankara province and one month was chosen to represent every season. Due to its different geographical characteristics, the variation of the amount of radiation coming to Muğla and Ankara has been investigated depending on wavelength. Ankara is the capital and 2nd big city of Turkey with over 5.5 million populations. The annual solar irradiation per square meter is calculated as 1500 kWh/m²-year and the location in Turkey is given in Figure 3. Muğla is located at the south west corner of Turkey. It is one of the important cities of the country in tourism with over 1650 kWh/m²-year annual solar insolation and this is also given in Figure 3 in colour range with its location. Although the area under spectral irradiance-wavelength curve gives the total solar irradiance solar output of photovoltaic modules varies with their materials as defined in Figure 2. Some atmospheric parameters for Muğla and Ankara are given in Table 1.
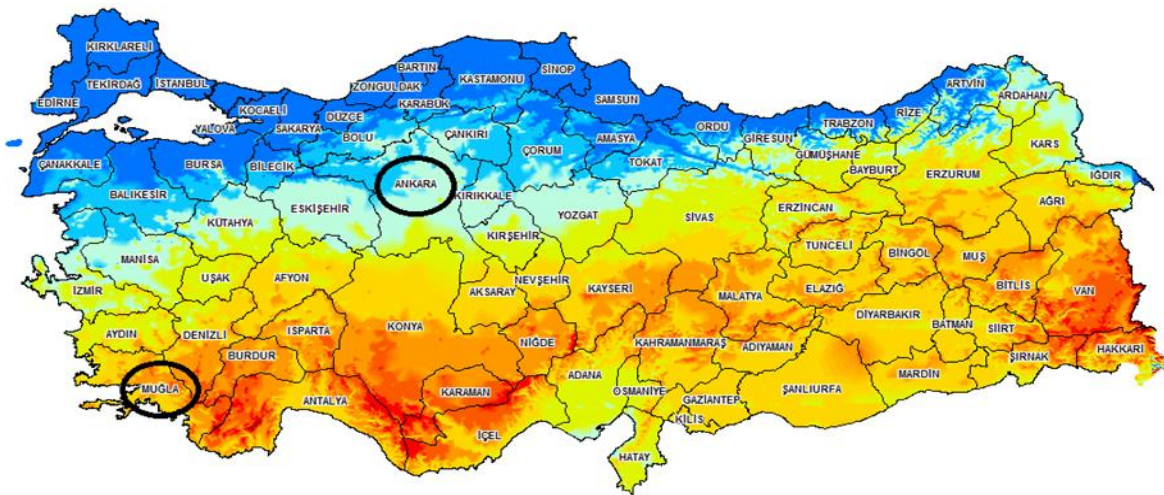

Figure. 3. Map of selected cities with insolation colours

Table 1. Some simulation inputs for defining locations

Parameters	Muğla	Ankara
Hour and minute	12.00	12.00
Pressure	930 mbar	870 mbar
Azimuth angle	0	0
Longitude	28,36 E	32,85 E
Latitude	37,21 N	32,85 N

Seasonal variation of spectral irradiance-wavelength for the selected 2 cities on horizontal surfaces are given in Figures 4 and 5. In calculations wavelength in sun is used up to 1.5 µm because 92% of total solar irradiation is under this wavelength and most solar cells spectral responses are high under this point. The amount of incoming radiation varies due to climatic differences. Four months are selected representing seasons and wavelength distribution in horizontal planes for cities with global standard spectrum at AM0 conditions are given between in Figures 6 to 9.
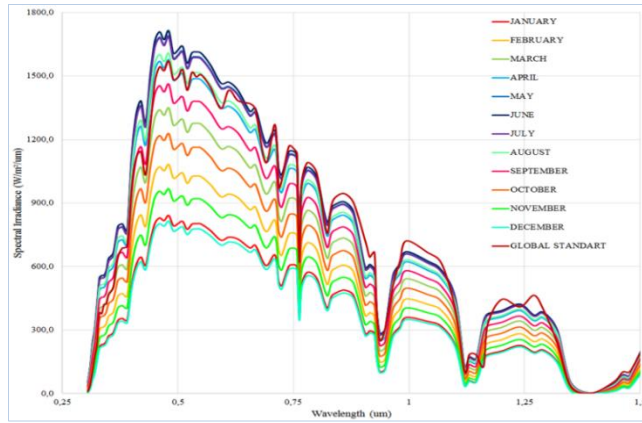

Figure 4. Horizontal surface seasonal variation of radiation for Muğla
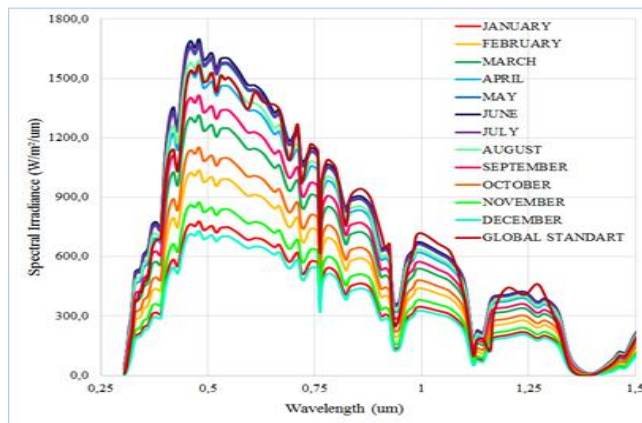

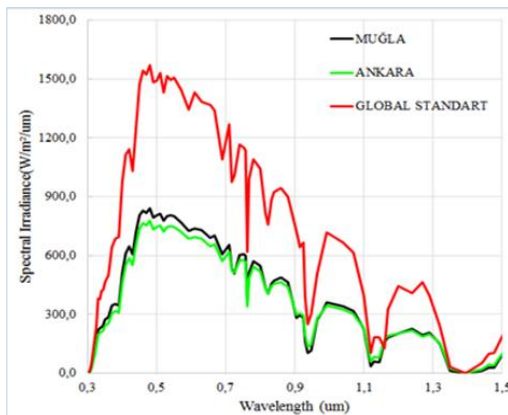Figure 5. Seasonal variation of radiation on horizontal surface for Ankara

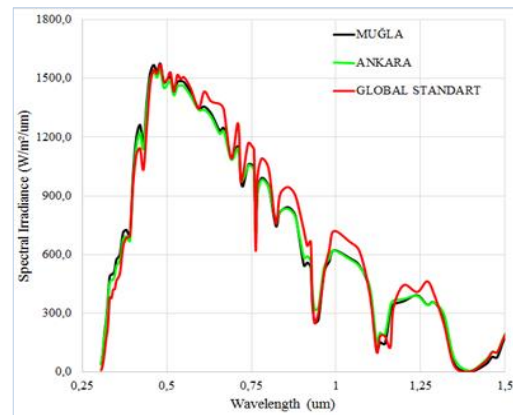Figure 6. Spectral irradiance for horizontal surface in Mugla and Ankara in January

Figure 7. Spectral irradiance for horizontal surface in Mugla and Ankara in April
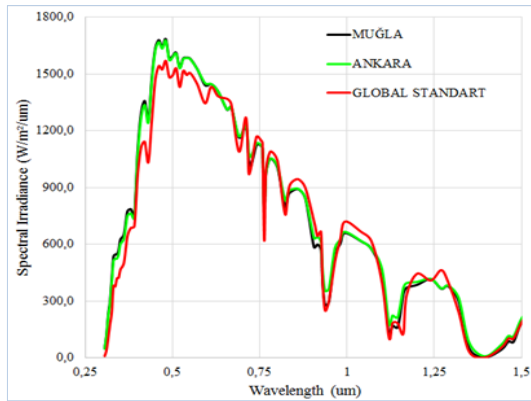
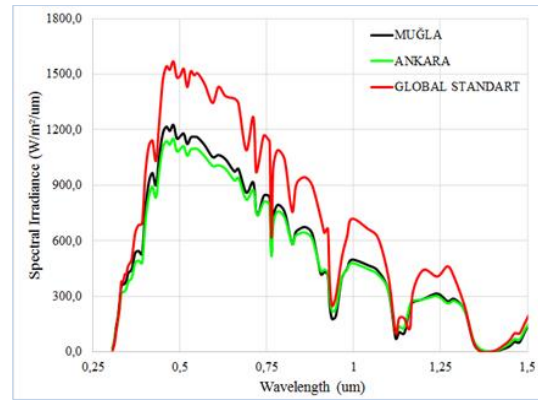Figure 8. Spectral irradiance for horizontal surface in Mugla and Ankara in July

Figure. 9. Spectral irradiance for horizontal surface in Muğla and Ankara in October

Although horizontal irradiation is important for determining the solar potential and used in measurements generally plane of irradiation (POA) is very important in solar application. In photovoltaic applications PV planes are installed mostly with latitude tilts or obeying the roof slopes. In Turkey generally 30^0 tilt roof are constructed so in the present study spectral distribution is also calculated for 30^0 tilt surfaces and the results in seasons are given between Figures 10 to 13.
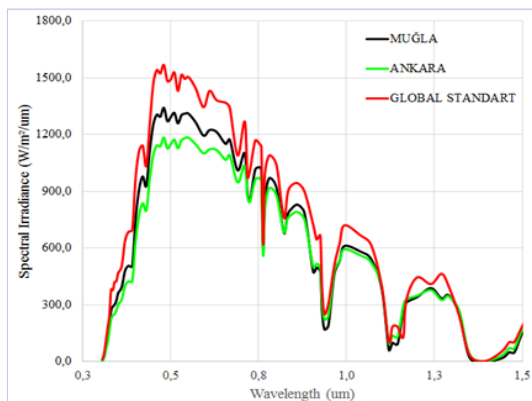

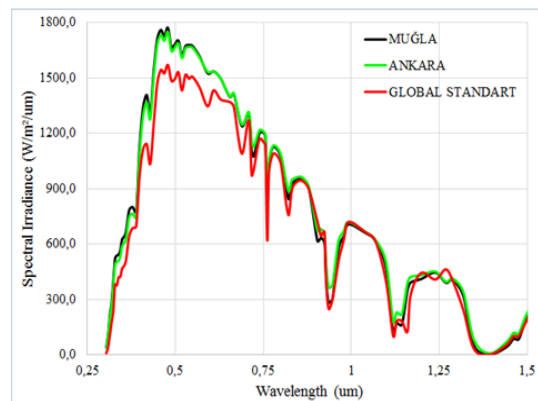Figure 10. Spectral irradiance for 30° inclined surface in Mugla and Ankara in January

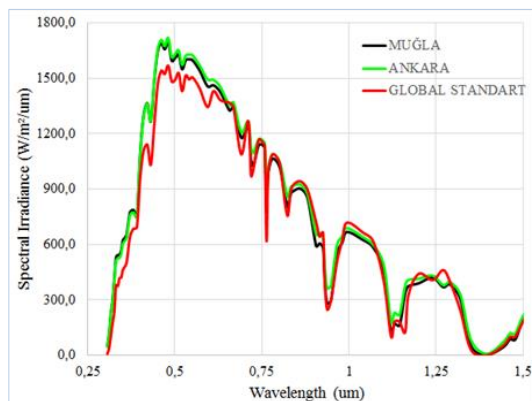Figure 11. Spectral irradiance for 30° inclined surface in Mugla and Ankara in April

Figure 12. Spectral irradiance for 30° tilt surface in Muğla and Ankara in July
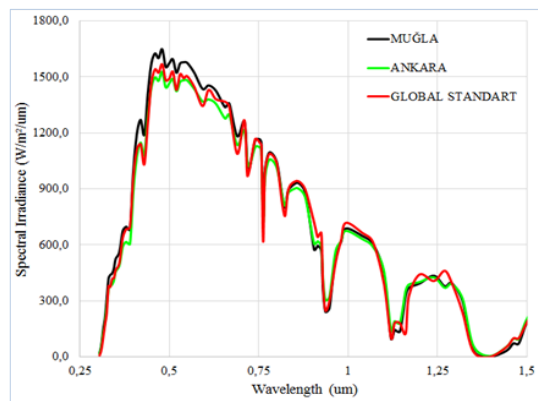

Figure 13. Spectral irradiance for 30° inclined surface in Mugla and Ankara in October

3. RESULTS AND DISCUSSION

Due to the different climatic and geographical characteristics of Muğla and Ankara, the amount of incoming radiation varies. Besides, the amount of incoming radiation shows differences seasonally. In particular, the amount of radiation differs due to differences in temperature, humidity and evaporation levels between seasons. The amount of radiation coming to the horizontal surface is less then compared to other seasons in winter and autumn. But in the same seasons the amount of radiation coming to the sloping surfaces are more than the amount of radiation coming to the horizontal surface. In this case, more radiation falls on the sloped surface of the module in winter and autumn. According to this result, slope can be a factor that increasing efficiency of PV modules in these seasons. The amount of radiation coming to these regions was calculated with the SPCTRL 2 program. In the SPCTRL 2 model used in calculation, it has more atmospheric effects than other models. This ensures that the results obtained are more reliable. The amount of radiation coming to the horizontal surface is less in winter and autumn than in other seasons.

4. CONCLUSION

The amount of solar radiation in the atmosphere can be calculated for any moment of the day with SPCTRL 2. The spectrum of the solar radiation can be seen easily calculated and PV system efficiency values for different time intervals can be understood with presented models. Most of the incident solar radiation is in the range of 0.2-1.1 µm wavelength so wavelength up to 1.5 µm is calculated in the present study. As the wavelength increases, the amount of radiation to the surface decreases. It is seen from the graphs that there is more radiation in spring and summer seasons than in other seasons. Moreover, it is observed that in winter and in autumn, more radiation is emitted to the inclined surface than the horizontal surface. The greatest amount of incoming radiation is in the range of 0.2-1.1 µm wavelength. In this wavelength range, sudden decreases occur due to atmospheric and climatic reasons. Water vapour and gasses present in the atmosphere cause absorption and scattering at certain wavelengths of incoming radiation. This causes a sudden decrease in the amount of radiation. Ankara is a crowded city and the annual total solar radiation per square meter is 10% lower than Muğla so it is expected that PV modules output installed at Muğla will produce directly proportional to irradiation. But calculations show that (not described and given in detail at this work) decrease in some types of solar cells is not linearly changes with the decrease in incident solar radiation. But this study shows that the amount of radiation to a horizontal or inclined surface for a given day with SPCTRL 2 can be calculated based on atmospheric conditions.

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