Tutorial 7a: Short-wave radiation

Q1. What does the term 'circumsolar activity' mean and what is its significance in the modelling of solar radiation?

Circumsolar activity defines the apparent ring around the sun from which there emanates highly directional diffuse radiation. This requires that the true direct be augmented by the circumsolar component, which is then subtracted from the measured diffuse radiation to give a truly background diffuse irradiance.

Q2. Differentiate between isotropic and anisotropic sky conditions.

An isotropic sky has uniform brightness (luminance) while an anisotropic sky has non-uniform brightness (luminance), which gives rise to complexity in the calculation of the diffuse component of solar heat gain.

Q3. Explain with the aid of a sketch how solar radiation finds its way into a building to become a cooling load.

The solar flux impinging on exposed opaque surfaces is absorbed and reflected. A portion of the absorbed component is, after a time delay, conducted to the inside surface where it is convected to the room air and transmitted to other room surfaces by longwave radiation exchange. The convected flux contributes to the cooling load.

At the other surfaces a portion of the arriving longwave radiation is likewise convected to the room air.

The solar flux impinging on a window is transmitted, absorbed and reflected. The absorbed component contributes to the cooling load as above, while the transmitted component strikes internal surfaces where it is absorbed and reflected. Again a portion of this absorbed component is convected to the room air where it contributes to the cooling load.

A portion of the heat absorbed at the internal surfaces at some previous time may reappear as a convective flux transfer to the air depending on the prevailing temperature differentials.

Q4. Using the data sheets provided and the information that follows, determine the total solar irradiation of the given surface.

latitude: 50°N
ground reflectivity: 0.25
date and time: 22 August @ 15:00
surface azimuth: 180° from N
sky condition: clear
surface inclination: 15°

angle of incidence: $i_\beta = \cos^{-1}\left[\sin(a)\cos(90-\beta) + \cos(a)\cos(\omega)\sin(90-\beta)\right]$

where a is the solar altitude, β the surface inclination, $\omega = |z-s|$, z the solar azimuth and s the surface azimuth.

surface diffuse irradiance: $i_{s\beta} = I_{fh}\left[(I_{dh}/I_{eh})\cos i_\beta / \cos(90-\beta_s) + 0.5(1 + \cos(90-\beta_f))(1 - I_{dh}/I_{eh})\right]$

where $I_{s\beta}$ is the sky diffuse irradiance, I_{fh} the diffuse horizontal irradiance and I_{eh} the extraterrestrial horizontal irradiance given by 1325 sin a (all in W/m²).

From Table A2.23: solar azimuth, z = 240º; solar altitude, a = 37º (note that a=β_s)
Surface inclination, β = 15º; ω = 240 - 180 = 60º; r_g = 0.25
From Table A2.35: I_{dh} = 445 W/m²; I_{fh} = 80 W/m²; I_{eh} = 797 W/m²
i_{15} = cos^{-1} [sin 37 cos (90-15) + cos 37 cos 60 sin (90-15)] = 57.2º

Direct beam: I_{d15} = I_{dh} cos i_β / sin a = 445 cos 57.2 / sin 37 = 400.6 W/m²
Ground reflected: I_{r15} = 0.5(1-cos(90-β))(I_{dh} + I_{fh}) r_g = 0.5(1-cos(90-15))(445+80)0.25 = 48.6 W/m²
Sky diffuse: I_{s15} = I_{fh} [(I_{dh}/I_{eh})cos i_β/cos (90-a) + 0.5 (1 + cos (90 – β)) (1 – I_{dh}/I_{eh})]
                = 80 [(445/797)cos 57.2/cos (90-37) + 0.5(1+cos(90-15))(1-445/797)] = 62.6 W/m²
Total incident radiation: 511.8 W/m²

Q5. Identify the most effective shading device based on the numerical values of the contributing components. Explain your choice.

The most effective shading device would be one that blocks the direct component because this is the dominant portion of the total surface irradiance. Although usually not cost effective, this is best done by employing a device that tracks the solar position.

Q6. Based on theoretical considerations, describe how the direct component of the calculated total irradiance might be reduced without the use of a shading device. Give a specific example.

By increasing the angle of incidence of the direct beam by making appropriate adjustments to the surface azimuth and/or elevation angles, e.g. by reducing the azimuth to <180º or the elevation to <15º.

Q7. In solar irradiation calculations, which quantities are normally available as input and which are normally calculated?

Inputs (as measured):
   diffuse horizontal irradiance;
   global horizontal (or direct normal) irradiance.

Calculated (for an arbitrarily inclined surface):
   direct irradiance;
   sky diffuse irradiance;
   ground/surroundings reflected irradiance.

Q8. A photovoltaic panel is to be deployed on a building roof, which faces South-West (225° from North) and has an inclination angle of 45°. Calculate the panel power output using the data tables provided and under the following conditions: latitude: 55°N; sky condition: clear; ground reflectivity: 0.2; date and time: 22 April @ 11:00; you may assume the following equations.

$$i_\beta = \cos^{-1}\left[\sin(a)\cos(90-\beta) + \cos(a)\cos(\omega)\sin(90-\beta)\right]$$

where i_β is the angle of incidence, a the solar altitude, β the surface inclination, $\omega = |z\text{-}s|$, z the solar azimuth and s the surface azimuth; and

$$I_{s\beta} = I_{fh}\left[0.5\left(1+\cos(90-\beta)\right)\right] \times \left[1+\left(1-I_{fh}^2/I_{Th}^2\right)\sin^3(0.5\beta)\right]$$
$$\times \left[1+\left(1-I_{fh}^2/I_{Th}^2\right)\sin^3(90-a)\cos^2(i_\beta)\right]$$

where $I_{s\beta}$ is the sky diffuse irradiance, I_{fh} the diffuse horizontal irradiance and I_{Th} the total horizontal irradiance (all in W/m²). PV power output: $P = 0.13\ I_T$ where I_T is the total radiation incident on the panel.

Table A2.23 provides the solar azimuth (z) and altitude (a) angles: z = 159°, a = 45°
Table A2.35 provides the direct (I_{dh}) and diffuse (I_{fh}) horizontal radiation: I_{dh} = 600 W/m², I_{fh} = 90 W/m²
$I_{Th} = I_{dh}+I_{fh}$ = 690 W/m²

1st equation gives the radiation incidence angle: i_β=45.3°

2nd equation gives the anisotropic sky diffuse component of the radiation incident on the PV panel: $I_{s\beta}$= 95W/m²

The direct incident radiation is given by
$I_{d\beta} = I_{dh} * \cos(i_\beta) / \sin(a)$ = 600* cos(45.3)/sin(45) = 596.8 W/m²
and the ground reflected radiation by
$I_{r\beta} = 0.5 * (1\text{-}\cos(90\text{-}\beta))\ (I_{dh} + I_{fh}) * r_g$ = 0.5 * (1-cos(90-45)) * (600+90) * 0.2 = 20.2 W/m²
Hence the total radiation on the tilted surface, $I_{T\beta}$, is $I_{s\beta} + I_{r\beta} + I_{d\beta}$ = 596.8+95+20.2 = 712 W/m²
The PV power output is given by P = 0.13 * $I_{T\beta}$ = 0.13 * 712 = 92.6 W/m²