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Brief Note

Derivation of the effective beam radiation incidence angle equations for diffuse and reflected solar radiation using a two dimensional approach

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Abstract

When calculating the performance of a flat plate solar collector, it is important to determine the amount of solar radiation that is transmitted through the cover to the absorber plate. The solar radiation transmitted to the absorber plate can be thought of as the fuel for the collector. Using the isotropic diffuse concept, solar radiation can be broken into three components: diffuse radiation, reflected radiation, and beam radiation. The diffuse and reflected radiation does not approach the collector from a single direction or at a specific angle. Rather, the diffuse and reflected radiation comes from many directions at several different angles. By using an effective beam radiation incidence angle, the transmittance of the diffuse and reflected radiation may be equated for a single angle rather than integrated over the entire range of incidence angles. The effective beam radiation incidence angles may be thought of as the initial angles at which the diffuse and reflected radiation is assumed to approach the collector cover.

The effective beam radiation incidence angle equations for the diffuse and reflected radiation have been previously derived using a three dimensional approach. The work presented offers effective beam radiation incidence angle equations that were derived using a two dimensional approach. The two dimensional approach is consistent with the equations one typically uses to calculate the transmittance for a collector cover. Therefore, the equations derived in this work are consistent with the methodology one normally uses to calculate the transmittance of solar radiation through a collector cover.

Keywords: Collector; Diffuse; Radiation; Transmittance

1. Existing equations for the effective beam radiation incidence angle for diffuse and reflected radiation

Using the isotropic diffuse concept, solar radiation can be broken into three components: diffuse radiation, reflected radiation, and beam radiation. Diffuse radiation refers to the isotropic solar radiation from the sky. Reflected radiation refers to the isotropic solar radiation from the sky that reflects off of the ground prior to impinging the collector. Beam radiation refers to the direct solar radiation from the sun to the collector. Since the beam radiation is dependent on the location of the sun, it is appropriate to use a three dimensional approach to calculate the angle at which the beam radiation approaches the collector. Unlike beam radiation, the diffuse and reflected

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Nomenclature

Latin Symbols

Crit	Critical angle
dx	length of glass traveled by the solar radiation
I	radiant power
$I_{i,s}$	amplitude of the parallel component of the beam
$I_{i,p}$	amplitude of the perpendicular component of the beam
I_o	radiant power entering the glass
I_L	radiation power leaving the glass
$I_{r,p}$	altitude of the perpendicular component of the reflected beam
$I_{r,s}$	altitude of the parallel component of the reflected beam
K	extinction coefficient
L	length solar energy travels in the glass
n_1	index of refraction for substance 1
n_2	index of refraction for substance 2
n	index of refraction for cover material
$r_{p,g1}$	perpendicular component of reflectance for the first cover layer
$r_{s,g1}$	parallel component of reflectance for the first cover layer
$r_{p,g2}$	perpendicular component of reflectance for the second cover layer
$r_{s,g2}$	parallel component of reflectance for the second cover layer
t	thickness of the glass
t_1	cover layer thickness (single glazed) or inner cover layer thickness (double glazed)
t_2	outside cover layer thickness (double glazed)

Greek Symbols

α_a	absorptance of the absorber plate
α_c	total cover absorptance
$\alpha_{p,g1}$	perpendicular component of absorptance for the first cover layer
$\alpha_{p,g2}$	perpendicular component of absorptance for the second cover layer
$\alpha_{s,g1}$	parallel component of absorptance for the first cover layer
$\alpha_{s,g2}$	parallel component of absorptance for the second cover layer
β	collector slope
θ_1	incidence angle of a ray approaching a surface
θ_2	refracted angle of a ray
$\theta_{1,\mathrm{g1}}$	effective beam radiation incidence angle for solar radiation in reference to the collector cover surface
$\theta_{1,\mathrm{g2}}$	effective beam radiation incidence angle of solar radiation on the second cover layer
$\theta_{2,\mathrm{g1}}$	refracted solar angle of solar radiation in the glass
$\theta_{2,\mathrm{g1\_Out}}$	effective beam radiation incidence angle of solar radiation on the second cover layer
$\theta_{2,\mathrm{g2}}$	refracted angle in the second cover layer
$\theta_{e,d}$	equivalent beam radiation incidence angle for diffuse radiation
$\theta_{e,g}$	equivalent beam radiation incidence angle for reflected radiation
ρ_c	total cover reflectance
ρ_g	ground reflectance
ρ_{pc}	perpendicular component of total reflectance for a two layer cover
$\rho_{p,g1}$	perpendicular component of reflectance for the first cover layer
$\rho_{p,g2}$	perpendicular component of reflectance for the second cover layer
ρ_{sc}	parallel component of total reflectance for a two layer cover
$\rho_{s,g1}$	parallel component of reflectance for the first cover layer
$\rho_{s,g2}$	parallel component of reflectance for the second cover layer
$\tau_{a,g1}$	transmittance due to absorptance for the first cover layer
$\tau_{a,g2}$	transmittance due to absorptance for the second cover layer
τ_b	beam component of the cover transmittance
τ_c	total cover transmittance
τ_d	diffuse component of the cover transmittance
τ_{pc}	perpendicular component of total transmittance for a two layer cover
$\tau_{p,g1}$	perpendicular component of transmittance for the first cover layer
$\tau_{p,g2}$	perpendicular component of transmittance for the second cover layer
τ_r	reflected component of the cover transmittance
τ_{sc}	parallel component of total transmittance for a two layer cover
$\tau_{s,g1}$	parallel component of transmittance for the first cover layer
$\tau_{s,g2}$	parallel component of transmittance for the second cover layer
$\tau\alpha$	transmittance-absorptance factor
$\tau\alpha_{\mathrm{diffuse}}$	$\tau\alpha$ product for diffuse radiation
$\tau\alpha_{\mathrm{reflected}}$	$\tau\alpha$ product for reflected radiation

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