

**EVALUATION OF HOURLY SOLAR RADIATION
MODELS TO ESTIMATE RADIATION ON INCLINED
SURFACES IN DRY ZONE OF SRI LANKA**

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Degree of Master of Engineering

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Sri Lanka

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DECLARATION

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Prof. R.A Attalage

ABSTRACT

An analysis of global, beam and diffuse solar radiation on horizontal and 7° tilt about east west axis and facing due south orientation at Hambanthota was carried out to assess the solar resource potential in dry zone of Sri Lanka. The calculated monthly averaged daily insolation for dry zone was found to be varying between $16.30 \text{ MJ/m}^2/\text{day}$ to $22.75 \text{ MJ/m}^2/\text{day}$ with the annually averaged daily insolation of $20.07 \text{ MJ/m}^2/\text{day}$. Calculated annually averaged beam horizontal radiation was $10.87 \text{ MJ/m}^2/\text{day}$ and diffuse horizontal radiation was found to be $9.19 \text{ MJ/m}^2/\text{day}$ while 0.56 was the annual average clearness index indicating that partly cloudy sky throughout the year. Horizon brightness coefficients of Perez et al (1990) was modified using diffuse radiation data of Hambanthota. Modified model was used for the estimation of titled radiation on due south faced surfaces. Diffuse tilted daily insolation and global tilted insolation for -45° to $+45^\circ$ inclined surfaces with 1° increments was estimated and monthly and annual optimum tilt angles were derived. The calculated monthly optimum tilt angle varied between -26° to $+27^\circ$ while having annual optimum tilt angle of -2° . Hence, tilting towards due south by same angle as latitude is not the recommended optimum tilt for fixed axis systems. Optimum tilt angle for beam radiation was derived and it was found that annual optimum tilt angle for beam radiation is 6° facing towards the due south. The derived maximum solar resource potential was 2068 kWh/m^2 per annum for fixed system at -2° tilt angle and 2169 kWh/m^2 per annum for monthly tracking system which is 5% higher than the horizontal potential. It is proposed to assess the solar resource potential for tilted surfaces with different surface azimuth angles by using modified Perez et al (1990) model in future. It is also possible to modify the coefficients of circumsolar brightness components of Perez et al (1990) model for better results.

Key Words: Diffuse Solar Radiation, Isotropic Models, Anisotropic Models, Optimum Tilt angle, Hambanthota.

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LIST OF NOMENCLATURE

Roman Letters

A	=	Apparent solar irradiation at zero air mass, Anisotropy index, Altitude of the location in kilometres, Apparent solar irradiation at zero air mass
B	=	Atmospheric extinction coefficient
C	=	Diffuse radiation factor
c_{ω}	=	Cloud cover index
$\overline{c_{\omega}}$	=	Monthly averaged daily cloud cover index
F_1	=	circumsolar brightness factor
F_2	=	horizon brightness factor
F'	=	Klucher's modified clearness index
G	=	Total scattered intensity, Total horizontal radiation
G_0	=	Incident intensity
G_b	=	Beam radiation on horizontal surface
G_{bn}	=	Beam normal radiation
G_{bt}	=	Beam radiation on tilted surface
G_d	=	Diffuse radiation on horizontal surface
G_{dt}	=	Diffuse radiation on tilted surface
G_g	=	Ground reflected radiation on horizontal surface
G_{gt}	=	Ground reflected radiation on tilted surface
G_o	=	Extra-terrestrial radiation on horizontal surface
G_{on}	=	Extra-terrestrial normal radiation
G_{sc}	=	Solar Constant
G_t	=	Total radiation on tilted surface
$G_{\lambda,0}$	=	Monochromatic intensity at $x=0$
H	=	Daily total horizontal radiation
H_b	=	Daily beam radiation on horizontal surface
H_{bn}	=	Daily beam normal radiation
H_{bt}	=	Daily Beam radiation on tilted surface
H_d	=	Daily diffuse radiation on horizontal surface
H_{dt}	=	Daily diffuse radiation on tilted surface

H_g	=	Daily ground reflected radiation on horizontal surface
H_{gt}	=	Daily ground reflected radiation on tilted surface
H_o	=	Daily extra-terrestrial radiation on horizontal surface
H_{on}	=	Daily Extra-terrestrial normal radiation
H_t	=	Daily Total radiation on tilted surface
\bar{H}	=	Monthly averaged daily total horizontal radiation
\bar{H}_b	=	Monthly averaged daily beam radiation on horizontal surface
\bar{H}_c	=	Monthly averaged clear day radiation on horizontal surface
\bar{H}_{bn}	=	Monthly averaged daily beam normal radiation
\bar{H}_{bt}	=	Monthly averaged daily Beam radiation on tilted surface
\bar{H}_d	=	Monthly averaged daily diffuse radiation on horizontal surface
\bar{H}_{dt}	=	Monthly averaged daily diffuse radiation on tilted surface
\bar{H}_g	=	Monthly averaged daily ground reflected radiation on horizontal surface
\bar{H}_{gt}	=	Monthly averaged daily ground reflected radiation on tilted surface
\bar{H}_o	=	Monthly averaged daily extra-terrestrial radiation on horizontal surface
\bar{H}_{on}	=	Monthly averaged daily Extra-terrestrial normal radiation
\bar{H}_t	=	Monthly averaged daily Total radiation on tilted surface
I	=	Hourly total horizontal radiation
I_b	=	Hourly beam radiation on horizontal surface
I_{bn}	=	Hourly beam normal radiation
I_{bt}	=	Hourly Beam radiation on tilted surface
I_d	=	Hourly diffuse radiation on horizontal surface
I_{dt}	=	Hourly diffuse radiation on tilted surface
I_g	=	Hourly ground reflected radiation on horizontal surface
I_{gt}	=	Hourly ground reflected radiation on tilted surface
I_o	=	Hourly extra-terrestrial radiation on horizontal surface
I_{on}	=	Hourly Extra-terrestrial normal radiation
I_t	=	Hourly Total radiation on tilted surface
k_T	=	Hourly clearness index
K_T	=	Daily clearness index

$\overline{K_T}$	=	Monthly average daily cleanness index
K_λ	=	Monochromatic extinction co-efficient
L	=	Latitude angle
m_h	=	Air mass
n	=	Julian day of the year
r	=	Radius of the particle
r_b	=	Hourly beam radiation tilt factor
r_d	=	Diffuse radiation tilt factor
r_t	=	Daily global irradiance to hourly global irradiance conversion ratio
R	=	Distance between the molecule and the point of observation
R_b	=	Daily beam radiation tilt factor
R_h	=	Relative humidity
$\overline{R_b}$	=	Monthly averaged daily beam radiation tilt factor
$\overline{R_h}$	=	Monthly averaged daily relative humidity
S	=	Averaged hours of sunshine
S_0	=	Averaged maximum possible hours of sunshine
\overline{S}	=	Monthly averaged daily hours of sunshine
$\overline{S_0}$	=	Monthly averaged daily maximum possible hours of sunshine
t	=	Midpoint of the hour
T	=	Temperature
T_{\max}	=	Daily maximum temperature
T_{\min}	=	Daily minimum temperature
\overline{T}	=	Monthly averaged daily temperature
$\overline{T_{\max}}$	=	Monthly averaged daily maximum temperature
$\overline{T_{\min}}$	=	Monthly averaged daily minimum temperature
x	=	Size of the scattering particle

Greek Letters

α	=	Altitude angle, Polarisability of the particle
β	=	Tilt angle
γ	=	Solar azimuth angle
γ_p	=	Surface azimuth angle

Γ	=	Day angle
δ	=	Declination angle
Δ	=	Brightness
ε	=	Sky clearness
θ	=	Incident angle
θ_z	=	Zenith angle
λ	=	Wave length
ρ_g	=	Ground albedo
τ_λ	=	Monochromatic transmittance
ω	=	Hour angle
ω_s	=	Sunshine/sunset angle
ω_{sr}	=	Sunrise angle on tilted surface
ω_{ss}	=	Sunset angle on tilted surface

LIST OF ABBREVIATIONS

Abbreviation Description

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AST	Apparent Solar Time
LST	Local Solar Time
PV	Photovoltaic
SLSEA	Sri Lanka Sustainable Energy Authority
WMO	World Metrological Organization