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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DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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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 MJ/m^2/day to 22.75 MJ/m^2/day with the annually averaged daily insolation of 20.07 MJ/m^2/day. Calculated annually averaged beam horizontal radiation was 10.87 MJ/m^2/day and diffuse horizontal radiation was found to be 9.19 MJ/m^2/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° 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° 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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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

$\overline{H_b}$ = Monthly averaged daily beam radiation on horizontal surface

$\overline{H_c}$ = Monthly averaged clear day radiation on horizontal surface

$\overline{H_{bn}}$ = Monthly averaged daily beam normal radiation

$\overline{H_{bt}}$ = Monthly averaged daily Beam radiation on tilted surface

$\overline{H_d}$ = Monthly averaged daily diffuse radiation on horizontal surface

$\overline{H_{dt}}$ = Monthly averaged daily diffuse radiation on tilted surface

$\overline{H_g}$ = Monthly averaged daily ground reflected radiation on horizontal surface

$\overline{H_{gt}}$ = Monthly averaged daily ground reflected radiation on tilted surface

$\overline{H_o}$ = Monthly averaged daily extra-terrestrial radiation on horizontal surface

$\overline{H_{on}}$ = Monthly averaged daily Extra-terrestrial normal radiation

$\overline{H_t}$ = 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 maximum temperature

$\overline{T}$ = Monthly averaged daily temperature

$\overline{T_{max}}$ = Monthly averaged daily maximum temperature

$\overline{T_{mın}}$ = Monthly averaged daily maximum 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