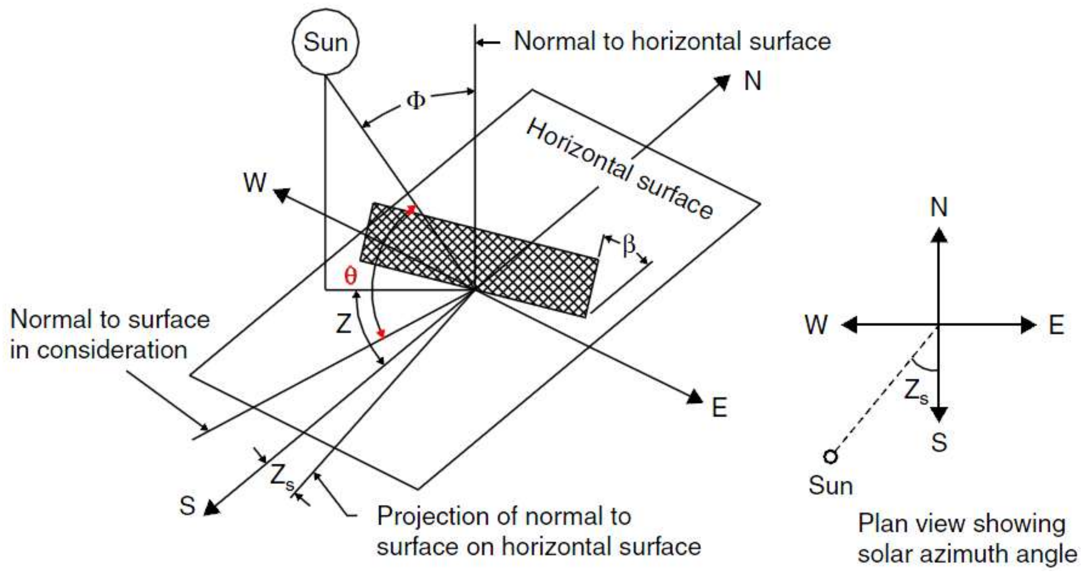
Amirkabir University of Technology
Department of Electrical Engineering

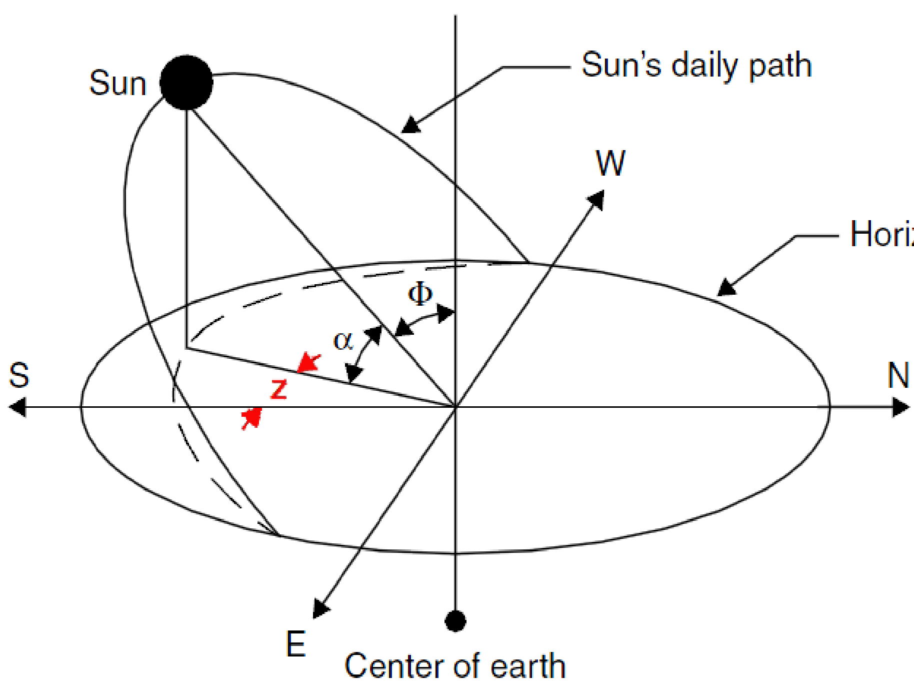
Renewable Energy II

Solar Radiation Formulation

1. Introduction

In this study, the general rules of a collector are examined four location of a city. To do this, a program is prepared using MATLAB m-file. The figures are plotted and the results are compared with the general rules of a collector. The results show the accuracy of program and the general rules of a collector are examined properly.





2. Calculation Procedure:

1. Integrate the following data:

The number of month's day (n_{month})

Jan=31; % 10 dey- 10 bahman
Feb=28; % 10 bahman- 10 esfand
Mar=31; % 10 esfand- 10 farvardin
Apr=30; % 10 farvardin- 10 ordibehesht
May=31; % 10 ordibehesht- 10 khordad
Jun=30; % 10 khordad- 10 tir
Jul=31; % 10 tir- 10 mordad
Aug=31; % 10 mordad- 10 shahrivar
Sep=30; % 10 shahrivar- 10 mehr
Oct=31; % 10 mehr- 10 aban
Nov=30; % 10 aban- 10 azar
Dec=31; % 10 azar- 10 dey

Solar constant (G_{sc}) using Eq. (1)

$$G_{sc} = 1367 \ \frac{\text{W}}{\text{m}^2} \tag{1}$$

The latitude (ϕ) of selected location

$$\phi = 34^\circ \tag{2}$$

The surface azimuth angle (γ)

$$-180 \leq \gamma \leq 180 \tag{3}$$

Monthly average clearness index ($\overline{k_T}$) of selected location (see clearness index.pdf)

$$0.5 \leq \overline{k_T} \leq 1.0 \tag{4}$$

The ground reflectance (ρ_g) in winter and other seasons using Eqs. (5)-(6)

$$\rho_g = 0.6 \quad \text{If } n < 60 \ \text{(winter)} \tag{5}$$

$$\rho_g = 0.2 \quad \text{If } n > 59 \ \text{(other seasons)} \tag{6}$$

The surface slope (β)

$$0 \leq \beta \leq 90^\circ \tag{7}$$

2. Calculate the following constant parameters:

The daily sunshine hour for all days of a year using local information (see sunset-sunrise.pdf)

The daily sunset hour for all days of a year using local information

The number of daylight hour using the different of sunshine and sunset hour for all days of a year

The day number of the first day of a month (n)

The extraterrestrial normal radiation (G_{on}) using Eq. (8)

$$G_{on} = G_{sc}\left(1+0.033\cos\left(\frac{360n}{365}\right)\right) \tag{8}$$

The declination (δ) using Eq. (9)

$$\delta = 23.45\sin\left(360\frac{284+n}{365}\right) \tag{9}$$

The radiation view factor between sky, collector, and ground (F_{c-s}, F_{c-g}) using Eqs. (10)-(11)

$$F_{c-s} = \frac{1+\cos\beta}{2} \tag{10}$$

$$F_{c-g} = \frac{1-\cos\beta}{2} \tag{11}$$

3. For month 1 to 12:

For day number of first month's day to last month's day

For first daylight hour of a day to last daylight hour

Calculate hour angle (ω) using Eqs. (12)-(14)

$$\omega_2 = 15^{\circ}(t_2 - 12:00') \tag{12}$$

$$\omega_1 = 15^{\circ}(t_1 - 12:00') \tag{13}$$

$$\omega = \frac{\omega_2 + \omega_1}{2} \tag{14}$$

Calculate the total solar radiation incident on an extraterrestrial horizontal surface during an hour (I_o) using Eq. (15)

$$I_o = \frac{12\times 3600}{\pi} G_{on}\left(\cos\phi\cos\delta(\sin\omega_1 - \sin\omega_2) + \pi\left(\frac{\omega_1-\omega_2}{180}\right)\sin\phi\sin\delta\right) \tag{15}$$

Calculate the total radiation for an hour on a horizontal surface (I) using Eq. (16)

$$I = \overline{K_T} I_o \tag{16}$$

Calculate $\cos\theta$ and $\cos\theta_z$ using Eqs. (17)-(18)

$$\cos\theta = \sin\phi\sin\delta\cos\beta + \cos\omega\cos\delta\cos\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma$$
$$+\cos\gamma\cos\omega\cos\delta\sin\phi\sin\beta + \cos\delta\sin\beta\sin\gamma\sin\omega \quad (17)$$

$$\cos\theta_z = \cos\omega\cos\delta\cos\phi + \sin\phi\sin\delta \quad (18)$$

Calculate geometric factor (R_b) using Eq. (19)

$$R_b = \frac{\cos\theta}{\cos\theta_z} \quad (19)$$

Calculate the total diffuse radiation for an hour on a horizontal surface (I_d) using Eq. (20)-(22)

$$I_d = I(1 - 0.09\overline{K_T}) \qquad \overline{K_T} \le 0.22 \quad (20)$$

$$I_d = I\left(0.95 - 0.16\overline{K_T} + 4.3(\overline{K_T})^2 - 16.6(\overline{K_T})^3 + 12.3(\overline{K_T})^4\right) \qquad 0.22 \le \overline{K_T} < 0.8 \quad (21)$$

$$I_d = 0.165I \qquad \overline{K_T} \ge 0.8 \quad (22)$$

Calculate the total beam radiation for an hour on a horizontal surface (I_b) using Eq. (23)

$$I_b = (1 - \frac{I_d}{I})I \quad (23)$$

Calculate the total radiation for an hour on a tilted surface (I_T) using Eq. (24)

$$I_T = I_b R_b + I_d F_{c-s} + I\rho_g F_{c-g} \quad (24)$$

Calculate the total radiation on a tilted surface during a day (H_T) using Eq. (25)

$$H_T = \sum_N I_T \quad (25)$$

Calculate the monthly average daily radiation on a tilted surface ($\overline{H_T}$) using Eq. (26)

$$\overline{H_T} = \frac{\sum_{n_{month}} H_T}{n_{month}} \quad (26)$$

4. Perform the above procedure for different surface slopes
5. Perform the above procedure for different surface azimuth angles
6. Plot $\overline{H_T}$ versus month number for different surface slopes
7. Calculate total annual, winter, and summer radiation using Eqs. (27)-(29)

$$E = \sum_{m} \sum_{n_{month}} \sum_{N} \{ I_T \} \tag{27}$$

$$E_w = \sum_{n_{month}} \sum_{N} \{ I_T \} \text{ for Jan. and Feb.} \tag{28}$$

$$E_s = \sum_{n_{month}} \sum_{N} \{ I_T \} \text{ for Jul., Aug., and Sep.} \tag{29}$$

8. Plot E, E_w, E_s versus month number for different surface slopes

9. Plot E versus month number for different surface azimuth angles

Fig. 1 shows the flowchart to calculate $\overline{H_T}$ and E.

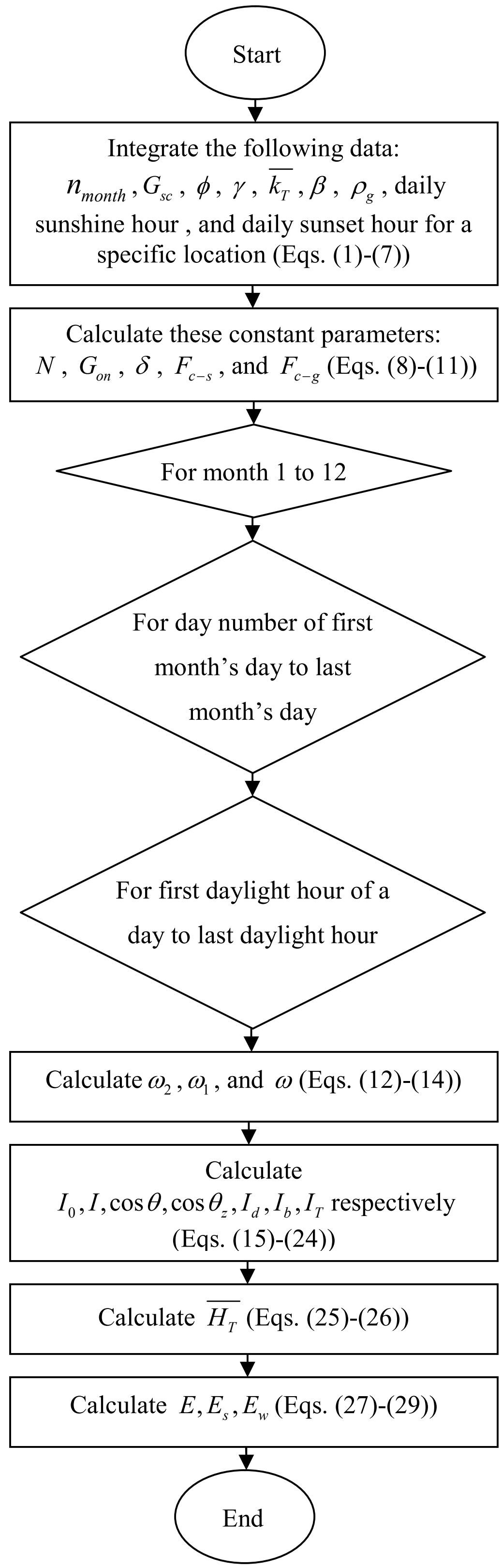


Figure. 1 The flowchart to calculate $\overline{H_T}$ and E

3. Results

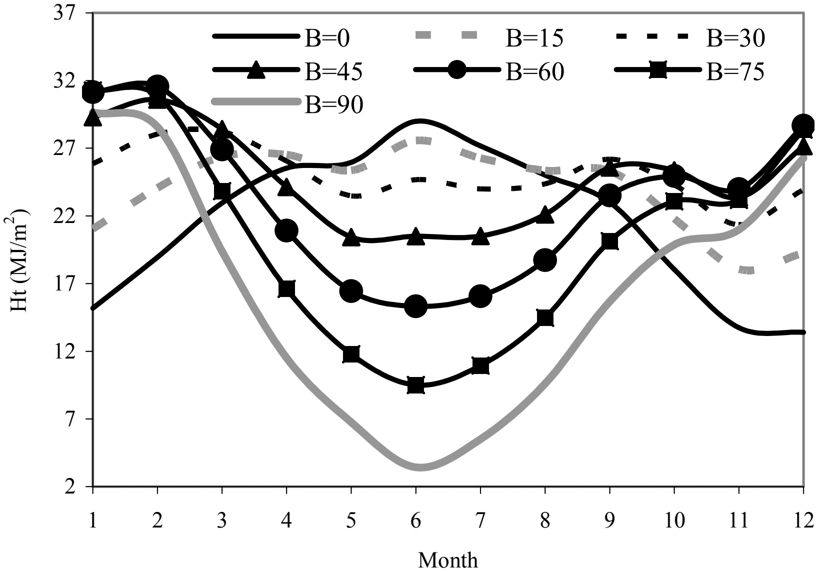


Figure 2. $\overline{H_T}$ versus month number for different surface slopes $(\gamma = 0, k_T \cong 0.7)$

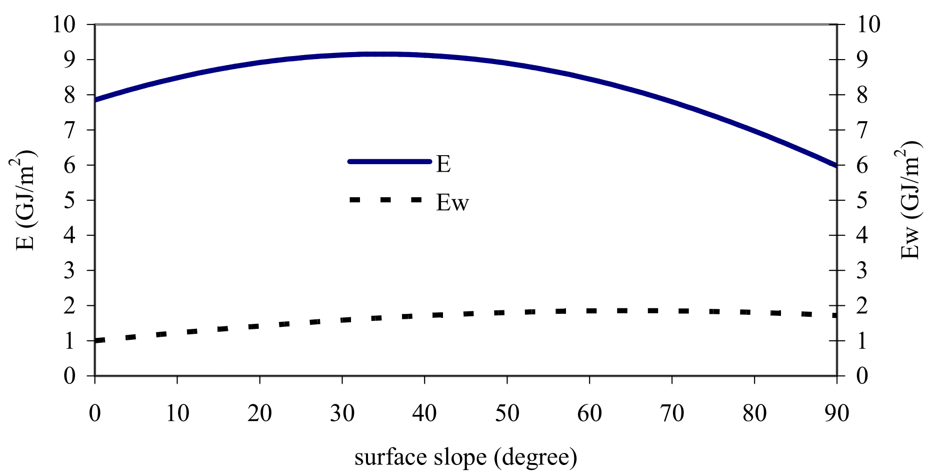


Figure 3. E, E_w versus β $(\gamma = 0, k_T \cong 0.7)$

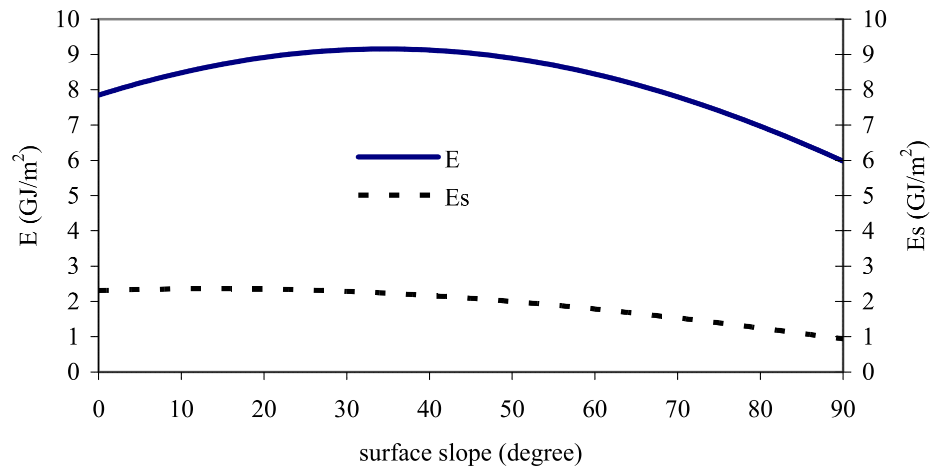


Figure 4. E, E_s versus β $(\gamma = 0, k_T \cong 0.7)$

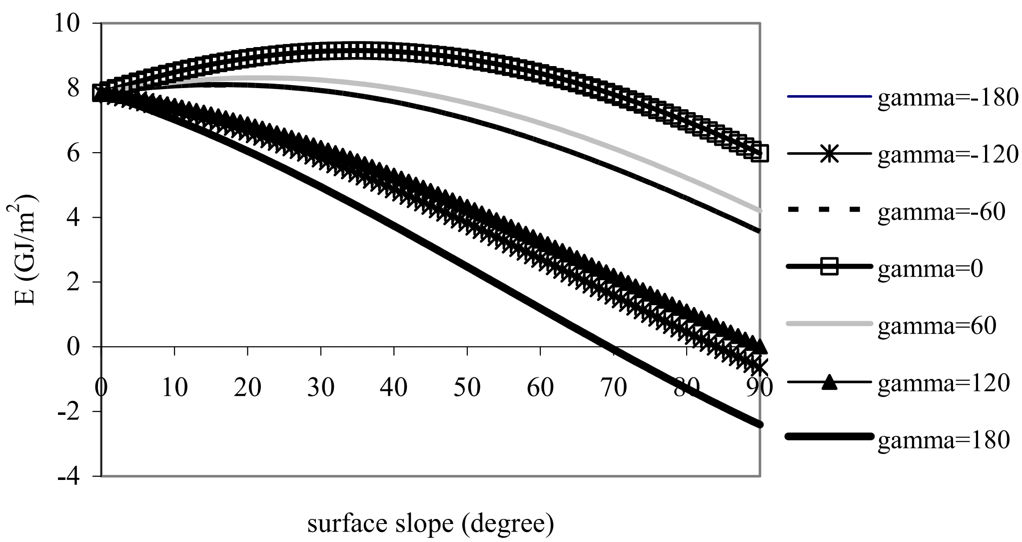


Figure 5. E versus β for different surface azimuth angles $(k_T \cong 0.7)$

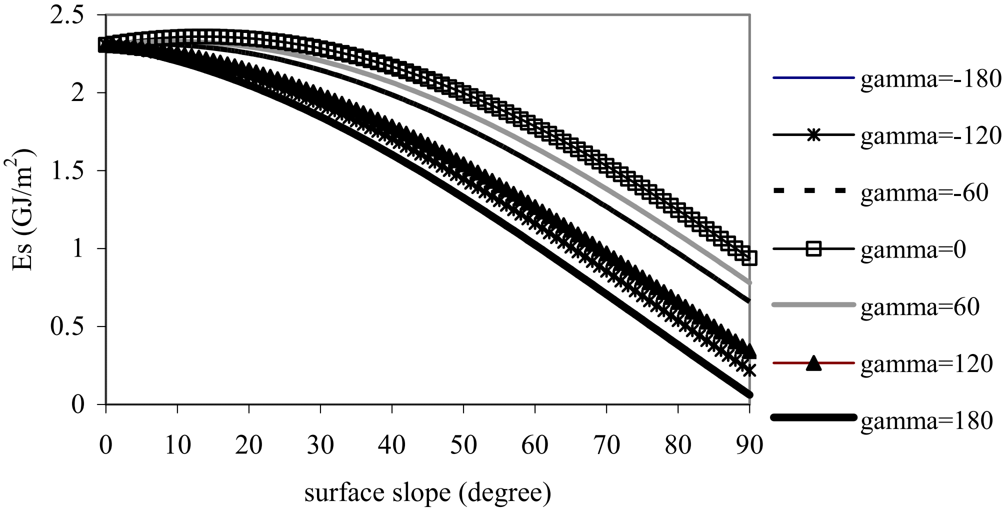


Figure 6. E_s versus β for different surface azimuth angles ($k_T \cong 0.7$)

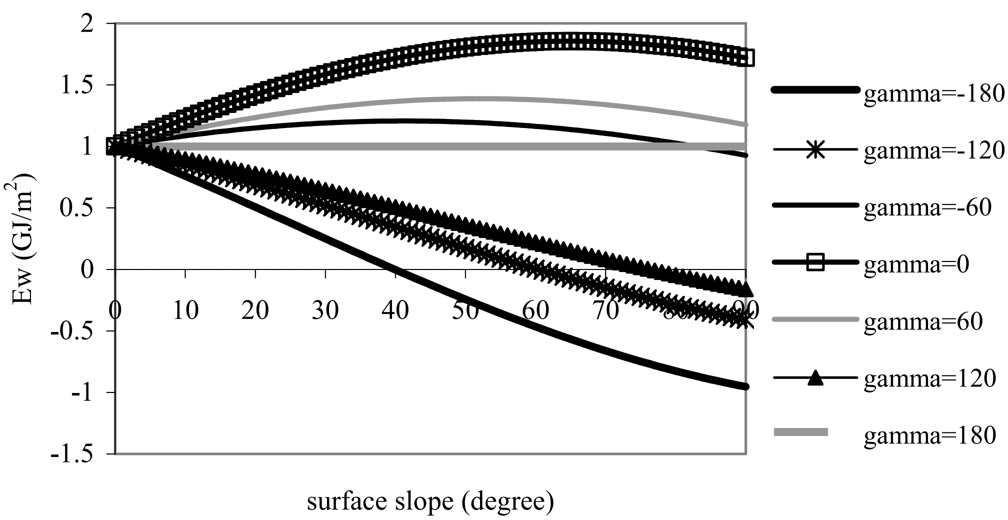


Figure 7. E_w versus β for different surface azimuth angles ($k_T \cong 0.7$)

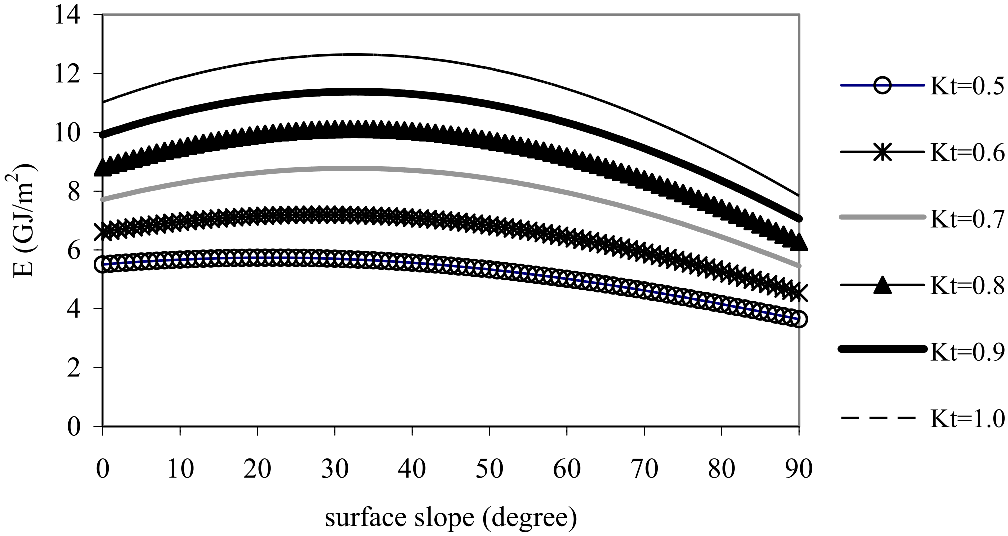


Figure 8. E versus β for different $\overline{k_t}$ $(\gamma = 0)$

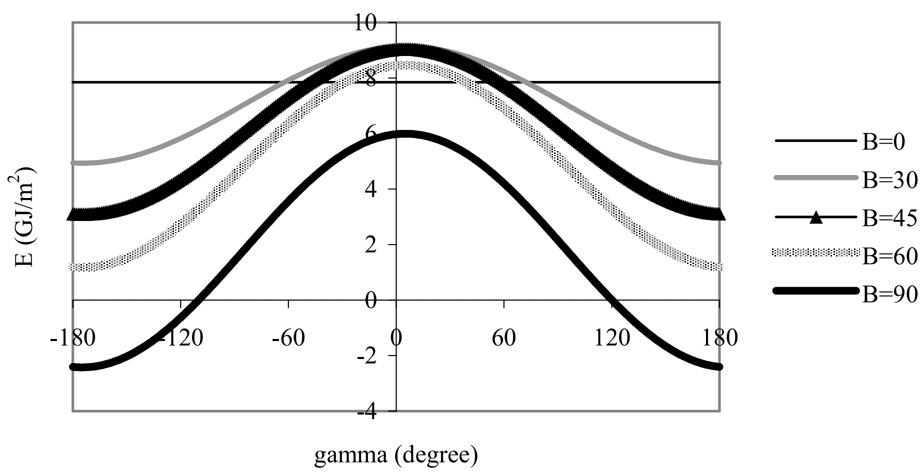


Figure 9. E versus γ for different surface slopes ($k_T \cong 0.7$)

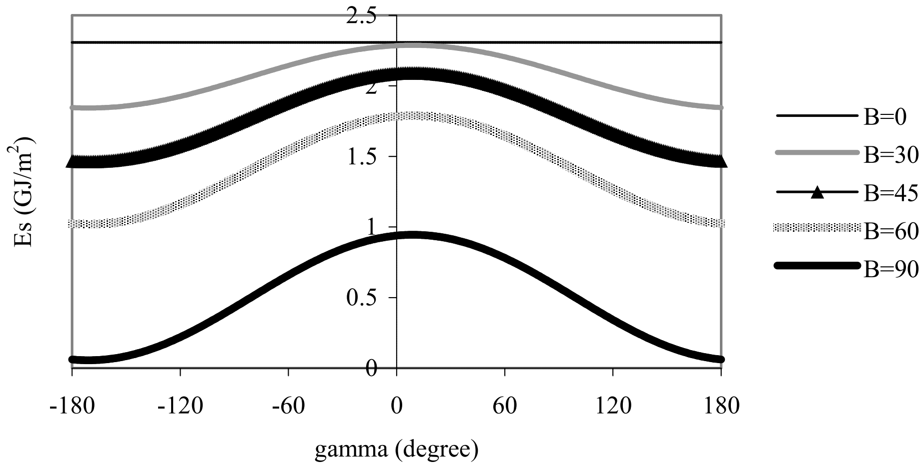


Figure 10. E_s versus γ for different surface slopes ($k_T \cong 0.7$)

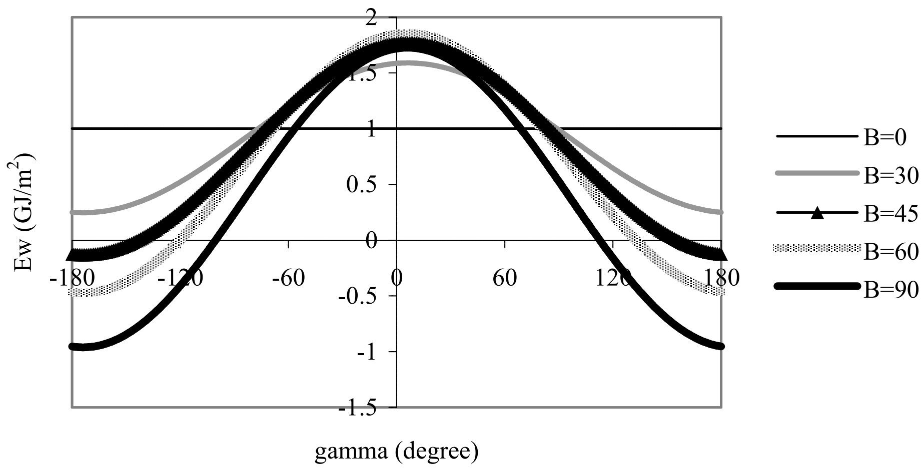


Figure 11. E_w versus γ for different surface slopes ($k_T \cong 0.7$)

Nomenclature:

E	Total annual radiation $(\frac{J}{m^2})$
E_s	Total summer radiation $(\frac{J}{m^2})$
E_w	Total winter radiation $(\frac{J}{m^2})$
F_{c-g}	Radiation view factor between ground and collector
F_{c-s}	Radiation view factor between sky and collector
G_{on}	Extraterrestrial normal radiation $(\frac{W}{m^2})$
G_{sc}	Solar constant $(\frac{W}{m^2})$
H_T	The total radiation on a tilted surface during a day $(\frac{J}{m^2})$
$\overline{H_T}$	Monthly average daily radiation on a tilted surface $(\frac{J}{m^2})$
I	Total radiation for an hour on a horizontal surface $(\frac{J}{m^2})$
I_b	Total beam radiation for an hour on a horizontal surface $(\frac{J}{m^2})$
I_d	Total diffuse radiation for an hour on a horizontal surface $(\frac{J}{m^2})$
I_o	The total solar radiation incident on an extraterrestrial horizontal surface during an hour $(\frac{J}{m^2})$
I_T	Total radiation for an hour on a tilted surface $(\frac{J}{m^2})$
$\overline{k_T}$	Monthly average clearness index
m	Number of month (=1 to 12)
N	Number of daylight hours
n	Day number of year
n_{month}	The number of month's day
R_b	Geometric factor
t_1, t_2	First and end hour of a time period (minute)
β	Surface slope (degree)
γ	Surface azimuth angle (degree)
δ	Declination (degree)
θ	Angle of incidence (degree)
θ_z	Zenith angle (degree)
ρ_g	Ground reflectance

ϕ Latitude (degree)
ω Hour angle (degree)
ω_1, ω_2 First and end hour angles of a time period (degree)

E	کل انرژی خورشیدی سالیانه
F_{c-g}	فاکتور دید بین زمین و کلکتور
F_{c-s}	فاکتور دید بین آسمان و کلکتور
G	شدت تابش خورشید
G_{on}	توان خورشیدی خارج از جو نرمال
G_{sc}	ثابت تابش خورشیدی
H_T	کل انرژی خورشیدی روزانه روی کلکتور
$\overline{H_T}$	متوسط ماهانه انرژی خورشیدی روی کلکتور
I	کل انرژی خورشیدی ساعتی روی سطح افقی
I_b	انرژی خورشیدی ساعتی اشعه روی کلکتور
I_d	انرژی خورشیدی ساعتی بازتابشی روی کلکتور
I_o	کل انرژی خورشیدی ساعتی خارج از جو
I_T	کل انرژی خورشیدی ساعتی روی کلکتور
$\overline{k_T}$	شاخص صافی هوا
n	شاخص روز
R_b	فاکتور هندسی
t	شاخص زمان

T	کل بازه مطالعه
t_2 , t_1	زمان ابتدایی و انتهایی
β	زاویه کلکتور
γ	زاویه azimuth سطح
δ	Declination
θ	زاویه برخورد
θ_z	زاویه zenith
ρ_g	بازتابش زمین
ϕ	عرض جغرافیایی
ω	زاویه ساعت
ω_2 , ω_1	زوایای زمان ابتدایی و انتهایی
A_{PV}	سطح آرایه PV