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General Polynomial for Optimizing the Tilt Angle of Flat Solar Energy Harvesters Based on ASHRAE Clear Sky Model in Mid and High Latitudes

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Abstract The aim of this study was to identify the opportunity of optimising the collection of solar energy as far as it is available in order to increase its utilisation. The second aim of this study was to enhance the performance of solar energy harvesters that depend on it through the appropriate determination of optimum solar collector tilt angles. In this study, ASHRAE clear sky model is applied to calculate the solar radiation; and the fundamental solar energy equations were programmed to determine optimum tilt angles in any location on the earth. The optimum tilt angle was presented in a polynomial form to enable the most convenient use of the function of latitude angle on a Julian day in a monthly, seasonal and an annual manner. According to the comparison between the obtained results with those of the local measured authoritative data and those of NASA published data, it can be safely recommended that these polynomials be used especially in mid and high latitudes (> 20°) in the two hemispheres. The presented study could serve as a reference for the domestic solar electrical and thermal applications.

Keywords Optimum tilt angle, Solar energy

1. Introduction

Power supply affects a lot a country's economic activity. Currently, fossil fuel is the most important part of power supply in the world; however, for the consideration of the issue of environment pollution, renewable energy -including solar energy, wind energy, and biomass energy-is being paid more and more attention. Solar energy is the best choice for most of the areas all over the world [1] as it can be utilized through solar collector or photovoltaic (PV) cell. Many researchers have been dealing with this subject, but they almost were able to determine the optimum angle for limited locations only [1-14]. In addition, a comprehensive research like this current study is not dealt with in the related literature; In fact; this was the motive to carry out this research which extends comprehensively to present formula for the optimum tilt angle of flat solar harvesters for any location and any time.

To maximize the collected energy, proper installing of the collector is really needed. One way is to install the solar collectors in the correct tilt and orientation angle, in which they would obtain the maximum insolation over a specific period of time. The tilt angle depends mainly on the position of the sun and, therefore, is different from one location to another all over the world; in regard to the best orientation angle, it is advised to be directed towards the equator. There are already plenty of investigations dealing with this subject to optimize solar power systems according to the correct tilt angle or orientation. Many authors have provided empirical models to calculate the optimum tilt angle $\left(s_{opt}\right)$ by searching for the maximum total solar radiation on the collector surface. In reference to a specific period of time and purpose, daily, monthly, seasonally or yearly values have been calculated [15-17]. Elsayed in [18] also presented an analytical model based on long-term averaging of solar data. He outlined values of optimum tilt angles given in different literature and conducted that value of tilt angle that can be recommended.

In fact there is a wide range of tilt (±20) which is dependent on the applied model and the location. Some authors noted the existence of a correlation between the optimum tilt angle and the latitude. Frequently, it is recommended to apply the rule of thumb, in which the yearly optimum tilt angle is about $\left(s_{opt} = L \pm 15°\right)$ (L: latitude) and a difference of tilt with about $10°$ would hardly affect the performance. Authors of [19] determined monthly optimum tilt angles for Izmir, Turkey; they found the optimum tilt angle $\left(s_{opt}\right)$ to be equal to U throughout the year, while for summer $\left(s_{opt} = L - 15°\right)$ and for winter

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$(s_{opt} = L + 15°)$ was suggested, these values were suggested also by [20]. They advised to mount the solar collector at the monthly average tilt angle. During the last decade there have also been investigations by using simulation software. This software which was developed in order to simulate an entire solar power plant, takes the most influential parameters into account. The soft ware usually possesses a database of monthly mean global radiation data and different empirical models: for example authors of [21] applied the simulation software TRNSYS to calculate the optimum tilt angle for Cairo, Egypt. What they did was calculating the monthly mean of solar radiation data and compared it with the output power of solar cells. They stated the yearly optimum tilt angle to be $(L \rightarrow L + 15°)$.

2. Modelling of Solar Radiation on Tilt Surface

The moment the solar radiation, which is coming from the direction of the sun, reaches the earth's surface without being significantly scattered is called direct normal irradiance (or beam irradiance). Some of the scattered sunlight is scattered back into space and some of it also reaches the surface of the earth. The scattered radiation reaching the earth's surface is called diffuse radiation. Some radiation is also scattered off the earth's surface and then re-scattered by the atmosphere to the observer. This is also part of the diffuse radiation which the observer can see. This amount can be significant in areas in which the ground is covered with snow or reflectors. The total solar radiation on a horizontal surface is called global irradiance and it is the sum of incident diffuse radiation plus the direct normal irradiance projected onto the horizontal surface. If the surface under study is tilted with respect to the horizontal, the total irradiance is the incident diffuse radiation plus the direct normal irradiance projected onto the tilted surface plus ground reflected irradiance that is incident on the tilted surface.

As recommended by ASHRAE (1985) and presented in all text books of solar energy [22, 23], hourly global radiation (H_t), hourly beam radiation (H_b), hourly diffuse radiation (H_d) and hourly reflect radiation (H_r) on the inclined surface on a clear day are calculated using the following expression:

$$H_t = R_b H_b + R_d H_d + \rho_g R_r H_r \quad (1)$$

$$H_b = H_{bn} cos\theta_Z \quad (2)$$

$$H_d = CH_{bn} \quad (3)$$

$$H_{bn} = Aexp(-B/cos\theta_Z) \quad (4)$$

Where: H_{bn} is the beam normal radiation $[W/m^2]$, A is the apparent solar-radiation constant in $[W/m^2]$, B is the atmospheric extinction coefficient, and C is the diffuse sky factor and there values are tabulated in table 1 for a widely range of latitudes $0° \leq L \leq 64°$.

R_b ; R_d and R_r are coefficients and ρ_g is ground Albedo and was assumed to be 0.5. is the ratio between global solar energy on a horizontal surface and global solar energy on a tilt surface. Meanwhile, R_d is the view factor between the sky and the tilt surface and R_r is the view factor between the ground and the surface that tilted at angle (s) from the horizontal. These coefficients evaluated from:

$$R_b = \frac{cos\,(\theta_i)}{cos\,(\theta_z)} \quad (5)$$

for isotropic diffuse:

$$R_d = \frac{1+cos\,(s)}{2} \quad (6)$$

$$R_r = \frac{1-cos\,(s)}{2} \quad (7)$$

where: θ_i is the solar incident angle and it is given by:

$$cos(\theta_i) = sin(\delta)sin(L)cos(s) - sin(\delta)cos(L)sin(s)cos(\varphi) + cos(\delta)cos(L)cos(s)cos(h) + cos(\delta)sin(L)sin(s)cos(\varphi)cos(h) + cos(\delta)sin(s)sin(\varphi)sin(h) \quad (8)$$

where: L is latitude, the angular location north or south of the equator, north positive;

$$-90° \leq L \leq 90°;$$

s, is slope of the surface; φ is the surface azimuth angle, with zero due south, east negative, west positive, $-180° \leq \varphi \leq 180°$; h is the hour angle, $h = 15 * (time - 12.0)$, morning negative, zero at noon and afternoon positive; and δ is solar declination angle, it can be found from:

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

where: n is the Julian day. Meanwhile, θ_z is the solar zenith angle, which equal to:

$$cos(\theta_z) = cos(\delta)cos(L)cos(h) + sin(\delta)sin(L) \quad (10)$$

Table 1. ASHRAE values of clear sky model parameters A, B and C [23]

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A	1230	1214	1185	1135	1103	1088	1085	1107	1151	1192	1220	1233
B	0.142	0.144	0.156	0.18	0.196	0.205	0.207	0.201	0.177	0.16	0.149	0.142
C	0.058	0.06	0.071	0.097	0.121	0.134	0.136	0.122	0.092	0.073	0.063	0.057

Table 2. The definition of the coefficients P_{00} ...P_{05} and the independent variables x, y for the offered polynomial

	P_{00}	P_{10}	P_{01}	P_{20}	P_{11}	P_{02}	P_{30}	P_{21}	P_{12}
Daily	24.58	0.6836	1.238	-2.04×10^{-2}	-1.3×10^{-3}	-1.252×10^{-2}	1.241×10^{-4}	9.717×10^{-6}	1.733×10^{-4}
Monthly	29.0	0.155	1.011	-1.162×10^{-2}	3.4×10^{-3}	-4.87×10^{-3}	6.45×10^{-5}	-1.3×10^{-5}	3.8×10^{-5}
Seasonal	33.89	0.1616	1.035	-1.148×10^{-2}	3.059×10^{-3}	-5.567×10^{-3}	6.406×10^{-5}	-1.281×10^{-5}	4.633×10^{-5}
Annual	1.50	0	1.35	0	0	1.069×10^{-2}	0	0	0
	P_{03}	P_{40}	P_{31}	P_{22}	P_{13}	P_{04}	P_{50}	P_{41}	
Daily	8.573×10^{-5}	-2.688×10^{-7}	-2.558×10^{-8}	-6.578×10^{-7}	0	-5.034×10^{-7}	1.879×10^{-10}	1.691×10^{-11}	
Monthly	0	-9.31×10^{-8}	1.15×10^{-8}	-1.11×10^{-7}	0	0	0	0	
Seasonal	0	-9.326×10^{-8}	1.162×10^{-8}	-1.252×10^{-7}	0	0	0	0	
Annual	0	0	0	0	0	0	0	0	
	P_{32}	P_{23}	P_{14}	P_{05}	x	y	R^2	$RMSE$	
Daily	5.226×10^{-10}	2.756×10^{-9}	-8.043×10^{-10}	2.759×10^{-9}	n	L	0.9407	11.19	
Monthly	0	0	0	0	n	L	0.9975	1.667	
Seasonal	0	0	0	0	n	L	0.9994	1.087	
Annual	0	0	0	0	–	L	0.9999		

3. Results and Discussions

A comprehensive computer program in FORTRAN has been created in order to calculate the hourly solar radiation incident on a surface when the tilt angle is changed by interval of $0.1°$ from $0° \leq s \leq 90°$. The surface azimuth (φ) is either $0°$ for south facing or $\pm 180°$ for north facing. In regard to the daily optimization, the basis is the daily total hourly radiation, for the monthly optimization the basis is the monthly total daily and for annual optimization the basis is the annual total monthly.

It is well known that a unique surface tilt angle which exists for each time, and which corresponds to each latitude angle (L) for a particular day (n) through which the solar radiation is at peak value. Accordingly, this study enhances these two parameters as independent variables for the daily, monthly, seasonal and annual optimum angle prediction.

The seasonal average tilt angle was calculated by finding the average value of the tilt angle for each season, but the implementation of this condition requires the collector tilt to be changed four times a year. The process of adjusting the tilt angle to its monthly optimum values throughout the year does not seem to be practical, and at the same time rises the consideration of changing the tilt angle once seasonal.

The obtained results from the FORTRAN program treated by MATLAB in order to get out polynomials those fitted the daily, monthly, seasonal and annual optimum angles.

The general form of the polynomial that prescribed the optimum tilt angle is expressed in fifth order three dimension as:

$$S_{opt} = P_{00} + P_{10}x + P_{01}y + P_{20}x^2 + P_{11}xy + P_{02}y^2 + P_{30}x^3 + P_{21}x^2y + P_{12}xy^2 + P_{03}y^3 + P_{40}x^4 + P_{31}x^3y + P_{22}x^2y^2 + P_{13}xy^3 + P_{04}y^4 + P_{50}x^5 + P_{41}x^4y + P_{32}x^3y^2 + P_{23}x^2y^3 + P_{14}xy^4 + P_{05}y^5 \quad (11)$$

The coefficients P_{00}, . . . , and P_{05} and the variables x and y are defined below in table 2.

The obtained results were plotted and tabulated for comparison with other measurements and data recommended by NASA.

Figure 1 presents the Daily optimum angles for various latitudes $0°$ to $40°$ N for a complete calendar year. The abscissa presents the Julian day (n). The markets present the calculated results and the dash lines present the daily polynomial. Obviously, depending on figure 1, it can be stated that the polynomial is well fitted to the calculated data. The positive value depicted means that the surface was inclined towards the equator, where as the negative value means that the surface was inclined towards the North Pole. The slopes were within the range of $-38° < S_{opt} < 90°$ for any location on the northern hemisphere.

With the adoption of the long-term solar radiation data, the optimum tilt angle of a surface by using the monthly total daily solar irradiation on diversely latitudes was simulated for 12 months. Figures 2 presents the optimum angles for monthly tracking from January to December. From figure 2, the step-like lines present the calculated results, and the dash curves illustrate the polynomial equation that fitted the calculated data. Results were tabulated in table 4, for many cities from other references beside NASA data available on the internet to ease the comparison. Table 3 shows a considerably agreement in results obtained by the offered polynomial with the local measurements specially for mid and high latitudes ($L > 20°$) even in some times better than NASA's data. Unfortunately, for low latitudes ($L < 20°$) the model needs to more arrangements.

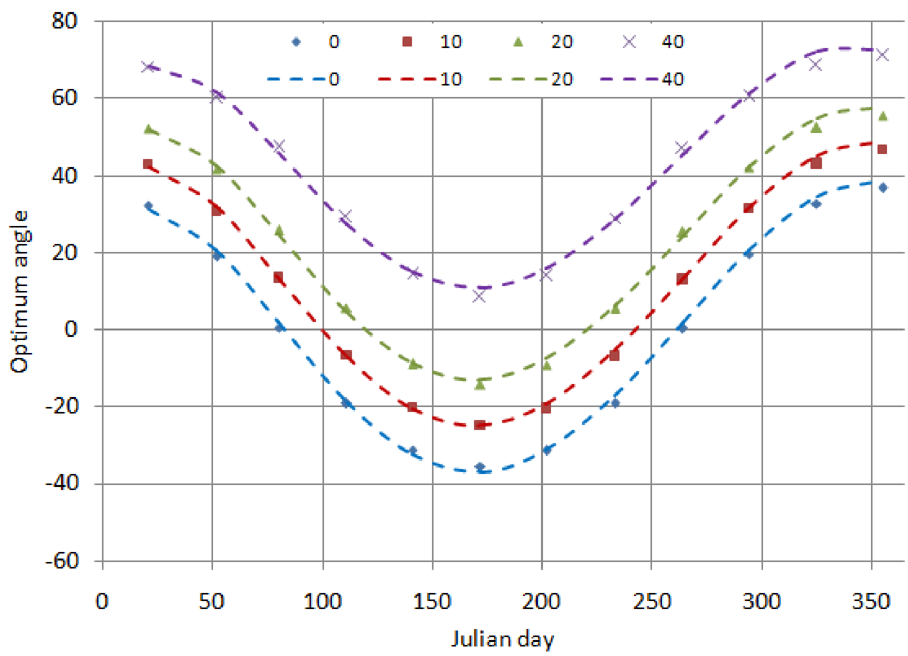

Figure 1. Daily optimum angle as a function of the Julian day n and the latitude angle L. The marks refer to the calculated results and the dash lines refer to the polynomial $s_{opt} = f(n, L)$

Table 3. Values of monthly optimum angles from many sources

Country City	Lat.	Long.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	month
			16	45	74	105	135	166	196	227	258	288	319	350	n / Ref.
Malaysia Bangi	2.92	101.78	22	16	5	-8	-18	-22	-21	-11	0	11	19	24	[24]
			28	19	6	-7	-16	-20	-18	-11	0	14	25	30	NASA
			31	21	3	-15	-30	-37	-34	-23	-5	14	29	32	*
Malaysia Alor Setar	6.12	100.37	32	22	8	0	0	0	0	0	2	15	26	31	[2]
			32	23	9	-5	-14	-17	-15	-8	3	16	27	34	NASA
			35	24	7	-12	-26	-33	-30	-19	-2	17	33	35	*
Ghana WA	10.06	-2.51	45	35	15	0	0	0	0	0	10	30	40	45	[6]
			38	27	13	0	-12	-15	-13	-6	6	22	35	40	NASA
			39	29	12	-7	-21	-28	-26	-14	3	23	38	40	*
Taiwan Taichung	24.15	120.67	50	41	26	10	-3	-8	-6	5	20	36	48	52	[1]
			47	n/a	n/a	9	0	0	0	6	20	35	44	n/a	NASA
			51	43	27	9	-4	-11	-9	2	19	37	51	52	*
India New Delhi	28.61	77.21	56	45	32	14	0	0	0	6	25	40	53	58	[7]
			55	47	33	16	1	0	0	8	24	42	52	57	NASA
			56	47	32	14	0	-6	-3	7	24	42	55	56	*
Jordan Amman	31.96	35.95	60	60	30	30	10	10	10	10	30	30	60	60	[35]
			55	47	35	18	4	0	1	11	29	43	53	58	NASA
			59	51	35	18	5	-2	0	10	28	45	58	59	*
Libya Tripoli	32.89	13.19	57	49	35	19	4	0	1	12	29	44	55	59	[37]
			56	49	35	19	5	0	2	13	29	44	53	59	NASA
			59	51	36	19	5	-1	1	12	29	46	57	58	*
Morocco Fez	34.02	-5.01	62	53	40	19	7	-1	1	16	30	47	59	59	[5]
			59	50	38	20	6	0	3	14	31	47	57	62	NASA
			60	53	38	20	7	0	2	14	30	47	60	60	*
China Beijing	39.90	116.41	65	55	41	22	5	0	1	16	34	51	62	67	[32]
			66	57	43	25	11	6	8	18	35	52	63	68	NASA
			65	58	43	26	13	7	9	19	35	53	65	65	*
Macedonia Ohrid,	41.12	20.80	60	50	40	20	20	20	20	20	20	40	60	60	[29]
			66	65	43	25	12	3	9	20	37	54	62	67	NASA
			65	59	44	27	15	9	11	21	36	54	66	66	*
Slovenia Krederica	46.38	13.85	n/a	n/a	51	n/a	n/a	16	n/a	n/a	40	n/a	n/a	75	[35]
			65	57	44	29	16	8	10	23	39	n/a	n/a	66.0	NASA
			70	65	51	35	23	16	18	29	44	60	71	72	*

* referes to the present study.

For the southern hemisphere another arrangement must be taken to estimate the monthly optimum angles; one can use the same polynomial with the same latitude but the months will be reversed. That means December in the northern hemisphere will be June in the southern hemisphere. The months must be shifted every 6 months after the ordinary calendar. Table 4 described the Julian day ($n_{southern}$) for both hemispheres for monthly tilt angle optimization, and the optimum tilt angle for southern hemisphere is negative sing of the optimum tilt angle for northern hemisphere for the same latitude.

$$s_{opt,southern} = -s_{opt,nour}\,(n_{southern}, L) \qquad (12)$$

Sometimes the cause of the difference in some values for some sites is a result of the large step of tilt angle 10°, or because the researchers had not included angles greater than 60° or less than 10°. Anyhow, it can be obviously stated from table 3 the agreement in values obtained from the mathematical model proposed in this study compared with the those results presented in other previous studies.

The study of seasonal optimum tilt angle for maximising energy collection by the absorber has been carried out. In literatures, there are two classifications for seasons: Heating and cooling group interesting with two seasons heating season and cooling season. Another classification may be adopted for solar energy group dependent on the position of the sun in the sky, they classified seasons to four seasons in 12 months. This study adopted the second classification. Each season consists of 91 days, therefore, winter (6th November to 4th February), spring (5th February to 5th May), summer (6th May to 5th August), and autumn (6th August to 5th November).

Table 4. Description of Julian day for northern and southern hemispheres that used in polynomial (11)

Month	Jan.	Feb.	Mar.	Apr.	May	Jun	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
n for northern h.	16	45	74	105	135	166	196	227	258	288	319	350
$n_{southern}$ for southern h.	196	227	258	288	319	350	16	45	74	105	135	166

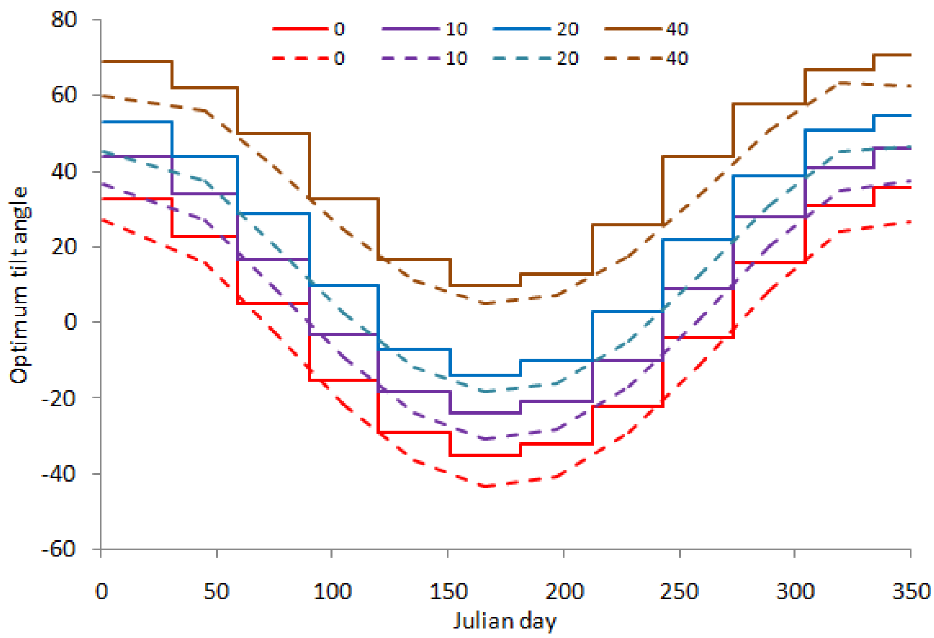

Figure 2. Monthly optimum angle as a function of the Julian day n and the latitude angle L. The solid lines refer to the calculated results and the dash lines refer to the polynomial $s_{opt} = f(n, L)$

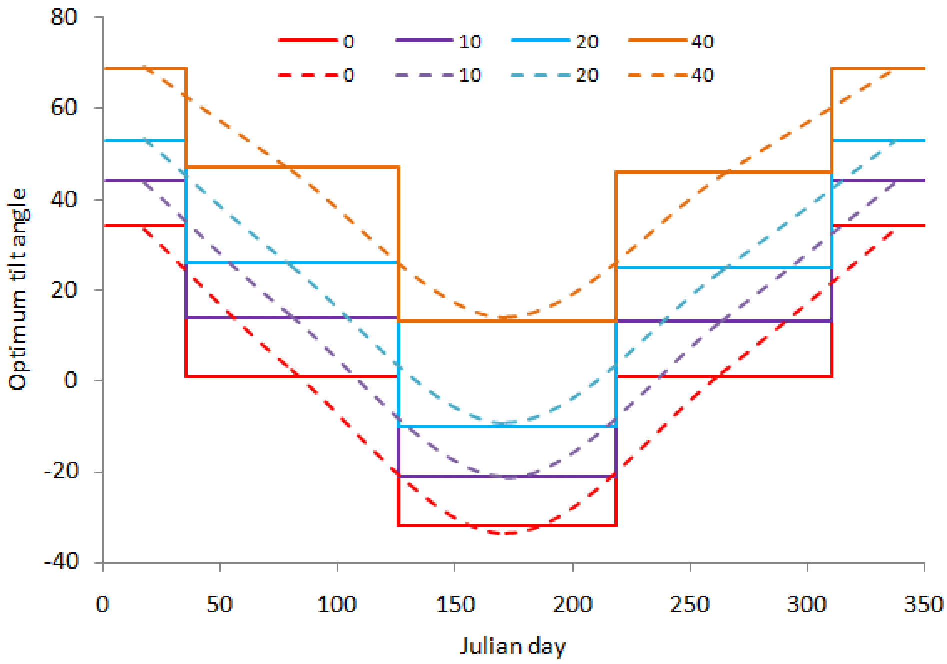

Figure 3. Seasonal optimum angle as a function of the Julian day n and the latitude angle L. The solid lines refer to the calculated results and the dash lines refer to the polynomial $s_{opt} = f(n, L)$

These seasonal is valid for northern hemisphere. In the southern hemisphere the situation is reverse the summer season (6th November to 4th February), autumn (5th February to 5th May), winter (6th May to 5th August), and spring (6th August to 5th November). Figure 3 shows the optimum seasonal tilt angle based on the total daily solar radiation reaching on a tilt surface. The step-like lines present the calculated optimum tilt angle for seasonal optimization. The simulated results have agreed to the local available measurements with similar pattern to reflect the trend at the site. From the figure, one polynomial equation were proposed to depict the trend of seasonal optimum as functions of the latitude and the day. The equation shows a good fit to the output as it obvious from the figure 4, in where the dash curves present the polynomial. A comparative results are tabulated in table 5. Unfortunately, there are no enough results to include in the table; moreover, some researches classified the season into only two seasons cold and hot seasons for heating and cooling of buildings purposed.

The annual optimum tilt angle has been computed based on the estimated annual total monthly solar radiation. The results illustrated graphically in figure 4 and tabulated in table 6 for comparative purpose. Results showed that the optimum values were almost positive for the northern hemisphere and ranged $2° \leq S_{opt} \leq 80°$ facing to the south (equator). The value was similar and agreed with the optimum slope presented by other researchers and for those of NASA, specially for high latitudes ($L > 20°$) even in some times better than NASA's data. Additionally, the computed results were fairly consistent with the general rule that the yearly optimal tilt angle was about the latitude of the location facing to the equator, specially for middle latitudes. For the southern hemisphere the optimum tilt angle ($s_{opt,sout}$) will be negative sign of the northern hemisphere ($-s_{opt,nour}$) at the same latitude.

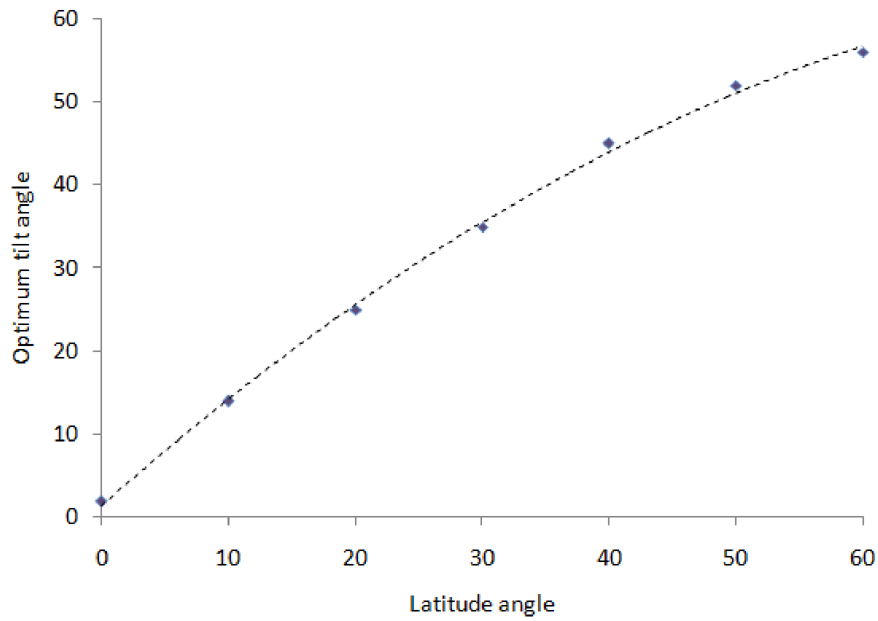

Figure 4. Annual optimum angle as a function of the latitude angle L. The marks refer to the calculated results and the dash lines refer to the polynomial $s_{opt} = f(L)$

Table 5. Values of seasonal optimum angles from many sources

Country	City	Lat.	Season I	Season II	Season III	Season IV	Ref.
Malaysia	AlorSetar	6.11	23	0	-	-	[2]
			24.4	-2.6	-	-	*
India	New Delhi	28	56	30	0	34	[7]
			60.0	33.9	0.14	32.8	*
Morocco	Fez	33.93	55	12	-	-	[5]
			52.4	7.9	-	-	*
Macedonia.	Ohrid	41.12	50	20	-	-	[29]
			47.3	15.3	-	-	*

* referes to the present study.

Table 6. Values of annual optimum fixed angles from many sources and NASA

Country	City	Latitude	Longitude	Reference	S_{opt} offered by references	S_{opt} offered by NASA [37]	S_{opt} offered by this study
Malaysia	Bangi	2.92	101.78	[24]	1.4	16.1	5.4
Nigeria	Enugu	6.46	7.55	[28]	6.0	17.0	9.5
Taiwan	Taichung	24.15	120.67	[1]	21.5	n/a	27.9
Egypt	Luxor	25.69	32.64	[24]	28.1	25.4	29.1
Egypt	Sharm Sheikkh	27.91	34.33	[24]	30.1	27.5	30.8
India	New Delhi	28.61	77.21	[7]	30.0	27.8	30.8
Jordan	Aqaba	29.53	35.01	[29]	25.0	28.2	32.3
Morocco	Agadir	30.43	-9.60	[24]	32.2	29.3	32.6
Iraq	Nasiriyah	31.05	46.27	[36]	31.0	28.8	33.1
Libya	Syrte	31.19	16.57	[24]	31.3	29.6	33.2
Egypt	Alexandria	31.20	29.92	[24]	31.3	29.7	33.2
Palestine	Gaza	31.50	34.47	[24]	32.2	29.5	33.3
Jordon	Amman	31.96	35.95	[29]	32.0	29.4	33.7
Morocco	Smara	32.15	-8.25	[24]	28.3	30.3	29.9
Libya	Tripoli	32.89	13.19	[24]	34.1	30.2	34.3
Iraq	Baghdad	33.31	44.36	[36]	33.0	31.2	34.6
Syria	Damascus	33.51	36.28	[24]	33.1	30.7	34.7
Algeria	Mecheria	33.54	-0.28	[24]	35.3	31.4	34.7
Lebanon	Beirut	33.89	35.50	[24]	31.9	31.7	34.9
Morocco	Fez	34.02	-5.01	[5]	34.0	32.1	34.9
Morocco	Larache	35.17	-6.15	[24]	34.9	33.3	35.7
Cyprus	Nicosia	35.19	33.38	[27]	35.0	32.5	35.7
Cyprus	Nicosia	35.19	33.38	[24]	34.1	32.5	35.7
Greece	Heraklion	35.34	25.14	[24]	32.5	32.7	35.8
Iraq	Kirkuk	35.47	44.38	[36]	35.0	32.9	35.9
Syria	Latakia	35.54	35.80	[24]	35.1	33.3	35.9
Malta	Valetta	35.90	14.51	[24]	35.6	33.5	36.1
Tunisia	Tunis	36.80	10.18	[24]	37.2	33.4	35.8
Tunisia	Bizerte	37.27	9.86	[24]	37.0	34.4	36.9
Spain	Seville	37.39	-5.98	[24]	36.5	35.3	37.0
Turkey	Isparta	37.76	30.55	[24]	36.9	34.9	37.2
Italy	Marsala	37.80	12.44	[24]	37.4	35.4	37.2
Greece	Athens	37.98	23.73	[24]	35.7	35.0	37.3
China	Beijing	39.90	116.41	[32]	36.0	37.5	37.6
Turkey	Bursa	40.19	29.06	[24]	36.0	n/a	38.4
Spain	Madrid	40.42	-3.70	[24]	39.2	37.9	38.5
Albania	Vlorë	40.47	19.49	[24]	38.1	n/a	38.6
Greece	Thessaloniki	40.64	22.94	[24]	37.7	n/a	38.7
Chine	Shenyang	41.81	123.3	[26]	40.0	39.0	39.2
Italy	Naples	40.85	14.27	[24]	38.5	38.0	38.7
Montenegro	Podgorica	42.43	19.26	[24]	39.5	n/a	39.5
Bosnia	Sarajevo	43.86	18.43	[24]	41.8	n/a	40.0
Monaco	Monaco	43.74	7.42	[24]	43.9	40.5	40.0
Italy	Florence	43.77	11.26	[24]	40.5	39.9	40.1
Italy	Milan	45.47	9.19	[24]	43.0	n/a	40.7
France	Lyon	45.76	4.84	[24]	43.7	n/a	40.8
Croatia	Zagreb	45.82	15.98	[24]	39.1	n/a	40.9
Slovenia	Ljubljana	46.06	14.51	[24]	42.1	n/a	40.9
Slovenia	Kredarica	46.38	13.85	[33]	42.0	n/a	40.8
Ireland	Galway	53.27	-9.06	[34]	44.0	n/a	43.0

* referes to the present study.

4. Conclusions

We have successfully applied the ASHRAE clear sky model to create comprehensive three dimension polynomials for daily, monthly, seasonal and annual optimum tilt angle for diversely latitudes. According to the comparison between the obtained results with local measured authoritative data and NASA published data, it can safely recommended to use of these polynomials especially in mid and high latitudes in the two hemispheres.

REFERENCES

[1] Feng-Jiao Liu, Tian-Pau Chang, Optimizing the Tilt Angle of Solar Collector under Clear Sky by Particle Swarm Optimization Method, Journal of Applied Science and Engineering, Vol. 18, No. 2, 2015, pp. 167-172.

[2] T. Khatib, A. Mohamed, M. Mahmoud, K. Sopian, Optimization of the Tilt Angle of Solar Panels for Malaysia, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects , Taylor & Francis Group, LLC, 37, 2015, pp. 606–613.

[3] M. Benghanem, Optimization of tilt angle for solar panel: Case study for Madinah, Saudi Arabia, Applied Energy 88, 2011, pp. 1427–1433.

[4] Jasmina Skerlić, Jasna Radulović, Danijela Nikolić, and Milorad Bojić, Maximizing performances of variable tilt flat-plate solar collectors forBelgrade (Serbia), J. Renewable Sustainable Energy 5, 2013, doi: 10.1063/1.4819254.

[5] Belkacem Ihya, Abdellah Mechaqrane, Rachid Tadili, Mohammed Najib Bargach, Optimal tilt angles for solar collectors facing south at Fez city (Morocco), Journal of Natural Sciences Research, Vol.4, No.10, 2014, pp. 120-127.

[6] Felix A. Uba and Emmanuel A. Sarsah, Optimization of tilt angle for solar collectors in WA, Ghana, Advances in Applied Science Research, 4(4), 2013, pp. 108-114.

[7] M. Jamil Ahmad, G.N. Tiwari, Optimization of Tilt Angle for Solar Collector to Receive Maximum Radiation, The Open Renewable Energy Journal, 2, 2009, pp. 19-24.

[8] Dhrupad Sarm, Parimal Bakul Barua, Diganta Hatibaruah, Optimization of Glazing Cover Parameters of a Solar Flat Plate Collector (FPC), International Journal of Engineering Trends and Technology (IJETT) – V. 14 No 2, 2014, pp. 74-80.

[9] Ying-Pin Chang1, Der-An Wang, Optimization of Tilt Angle for Photovoltaic Modules Based on the Neural-Genetic Algorithm, Journal of Nan Kai, Vol.7, No.1, 2010, pp. 57-70.

[10] Jayashri Vajpai Navaneet Maru Model based Optimization of Tilt angle for Solar PV Panels in Jodhpur, International Journal of Computer Applications, 2014, pp. 33-39.

[11] Qais Azzam Khasawneh, Qatada Abdullah Damra, Omaymah Husni Bany Salman, Determining the Optimum Tilt Angle for Solar Applications in Northern Jordan, Jordan Journal of Mechanical and Industrial Engineering, V. 9 No. 3, 2015, pp. 187 - 193.

[12] Arslanoglu A., Optimization of tilt angle for solar collectors: A case study for Bursa, Turkey, International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering Vol:10, No:5, 2016, pp. 517-520.

[13] Hasan M.S., Optimization of surface orientation angles to receive maximum solar radiation at Sebha city in Libya, M.SC. thesis, Sebelas Maret University, Surakarta, 2015.

[14] Nassar Y.F., Simulation of solar tracking systems, Energy & Life Journal, No 21, March 2005, pp. 81-90.

[15] EL-Kassa by, M.M., Monthly and daily optimum tilt angle for south facing solar collectors; theoretical model, experimental and empirical correlations. Solar & Wind Technology 5, 1988, pp. 589–596.

[16] Soulayman, S.S., On the optimum tilt of solar absorber plates. Renewable Energy 1, 1991, pp. 551–554.

[17] Ibrahim, D., Optimum tilt angle for solar collectors used in Cyprus. Renewable Energy 6, 1995, pp. 813–819.

[18] Elsayed, M.M., Optimum orientation of absorber plates. Solar Energy 42, 1998, pp. 89–102.

[19] Gunerhan, H., Hepbasli, A., Determination of the optimum tilt angle of solar collectors for building applications. Building and Environment 42, 2007, pp. 779–783.

[20] H. P. Garg, Treatise on solar Energy, vol. 1, Fundamentals of solar energy, New York, Willy, 1983.

[21] Hussein, H.E.-G.H.M.S., Ahmad, G.E., Performance evaluation of photovoltaic modules at different tilt angles and orientations. Energy Conversation and Management 45, 2004, pp. 2441–2452.

[22] Duffie J. A. and Beckman W. A., Solar Engineering of Thermal Processes, 3ed., John Wiley & Sons, Inc., 2006.

[23] Nassar Y. F., Solar energy engineering active applications, Sebha University, Libya, 2006. "Arabic language".

[24] Hassane Darhmaoui, Driss Lahjouji, Latitude Based Model for Tilt Angle Optimization for Solar Collectors in the Mediterranean Region, Science Direct, Energy Procedia 42, 2013, pp. 426 – 435.

[25] Khai Mun Ng, Nor Mariah Adam, Othman Inayatullah, Mohd Zainal Abidin Ab. Kadir, Assessment of solar radiation on diversely oriented surfaces and optimum tilts for solar absorbers in Malaysian tropical latitude, Int. J. Energy Environ. Eng., 2014, 5:75.

[26] Yueren Wang, Chenfei Bi, Wen Lou, Yueren Wang, Chenfei Bi, Wen Lou, Collector solar hot water installation angle optimization in severe cold area, International Conference on Applied Science and Engineering Innovation (ASEI 2015).

[27] Ioannis M. Michaelides, Computer simulation and optimisation of solar heating systems for Cyprus, PhD thesis, Faculty of Engineering and Science, Westminster Research http://www.westminster.ac.uk /west minster research, 1993.

[28] Y. N. Udoakah1, N. I. Okpura, Determination of optimal tilt angle for maximum solar insolation for pv systems in Enugu-southern Nigeria, Nigerian journal of technology, vol. 34 no. 4, 2015, pp. 838 – 843.

[29] Igor Shesho, Done Tashevski, Developing simulation application using graphical programming language for optimization of solar collector position, Mechanical Engineering – Scientific Journal, Vol. 31, No. 1–2, 2013, pp. 63-75.

[30] Z. Bouhssine1, M. Faraji1, M. Najam1 and M. El Alami, Numerical Investigations of an Integrated Phase-Change -Material Solar Collector, Tech Science Press FDMP, vol.11, no.1, 2015, pp. 63-85.

[31] Adnan Shariah, M-Ali Al-Akhras, I.A. Al-Omari, Optimizing the tilt angle of solar collectors, Renewable Energy 26, 2002, pp. 587–598.

[32] Shaoning Wang, Bo Hong, Optimum Design of Tilt Angle and Horizontal Direction of Solar Collectors under Obstacle's Shadow for Building Applications, Journal of Building Construction and Planning Research, 3, 2015, pp. 60-67.

[33] Jože Rakovec, Klemen Zakšek, Kristijan Brecl, Orientation and Tilt Dependence of a Fixed PV Array Energy Yield Based on Measurements of Solar Energy and Ground Albedo – a Case Study of Slovenia, Energy Management Systems, 2011, pp.145-160. www.intechopen.com.

[34] S. Armstrong, W.G. Hurley, A new methodology to optimise solar energy extraction under cloudy conditions, Renewable Energy 35, 2010, pp. 780–787.

[35] Ahmad Qasaimeh, Solar Energy Optimization through Seasons: Case Study in Jordan, Smart Grid and Renewable Energy, 3, 2012, pp. 275-281. www.SciRP.org/journal/sgre.

[36] Fawaz Sultan, Firas Aziz Ali, Tariq Khalid A. Razaq, Tilt Angle Optimization of Solar Collectors for Maximum Radiation in Three Iraqi cities, International Journal of Engineering and Industries (IJEI),Volume3, no 4, December 2012, pp. 99-107.

[37] NASA surface meteorology and solar energy - available tables. https://eosweb.larc.nasa.gov/cgi-bin/see/grid.cgi?