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A BRIEF REVIEW OF COMPUTING THE PERFORMANCE OF EXISTING SOLAR DRYERS BY OPTIMAZING THE TILT ANGLES OF SOLAR COLLECTORS TO RECEIVE MAXIMUM SOLAR RADIATION

ABHINAV. D. SARDAR, SAGAR. M. CHARTHAL

Department of Mechanical Engineering [M.E Thermal], Prof. Ram Meghe Institute of Technology & Research, Badnera-Amravati, Lecturer Kirti Polytechnic, Amravati, Amravati, India

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Abstract: The tilt position of the solar collector affect the amount of solar radiation that falls on the collector surface over the course of the day and indeed the year. The choice of tilt angle for a solar panel is fundamental to its efficient operation because incorrectly positioning the solar panel leads to an unnecessary loss in potential power. In the past, much work has been done by authors to determine the optimum tilt angle by applying existing models to their locations. This approach has been successful in climates with the most favorable solar potential, where greater than 90 percent of the solar radiation arrives as direct beam radiation.

Keywords: Solar collector, optimum tilt angle, solar radiation, HOMER

Corresponding Author: MR. ABHINAV. D. SARDAR

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INTRODUCTION

Drying is an excellent way to preserve food and solar food dryers are appropriate food preservation technology for sustainable development. Drying was probably the first ever food preserving method used by man, even before cooking. It involves the removal of moisture from agricultural produce so as to provide a product that can be safely stored for longer period of time. With cultural and industrial development, artificial mechanical drying came into practice, but this process is highly energy intensive and expensive which ultimately increases product cost. Recently, efforts to improve “sun drying” have led to “solar drying”. In solar drying, solar dryers are specialized devices that control the drying process and protect agricultural produce from damage by insect pests, dust and rain. In comparison to natural “sun drying”, solar dryers generate higher temperatures, lower relative humidity, lower product moisture content and reduced spoilage during the drying process. In addition, it takes up less space, takes less time and relatively inexpensive compared to artificial mechanical drying method. Thus, solar drying is a better alternative solution to all the drawbacks of natural drying and artificial mechanical drying. The amount of solar energy incident on a solar collector in various time scales is a complex function of many factors including the local radiation climatology, the orientation and tilt of the exposed collector surface and the ground reflection properties. The performance of a solar collector is highly influenced by its angle of tilt with the horizon. This is due to the facts that tilt angle change the solar radiation reaching the surface of the collector. our main aim is optimizing the tilt angles of solar collectors to receive maximum radiation

II. LITERATURE REVIEW

There are various devices for absorbing the solar radiation. The Sun rays are to be always focused onto the absorber plate. The collector has to be rotated by tracking system, but the tracking system is very costly so we cannot use this for every system economically. Due to this reason the solar collector is fixed either monthly, seasonally or yearly pattern, based on our requirement Ahmad M. Jamil and Tiwari G.N. [1] analyzed the theoretical aspects of choosing a tilt angle for the solar flat plate collectors used at ten different stations in the world and makes recommendations on how the collected energy can be increased by varying the tilt angle. For Indian stations, the calculations are based upon the measured values of monthly mean daily global and diffuse solar radiation on a horizontal surface. As explained in Bekker et al [2]. The orientation and tilt of the panels directly relates to the annual energy yield of the panels Mehleri E.D. et. al. [3] determined optimum tilt angle and orientation for solar photovoltaic arrays in order to maximize incident solar irradiance exposed on the array, for a specific period of time. The ratio of monthly average hourly diffuse radiation to monthly average hourly global radiation was correlated by Ulgen Koray and Hepbasli Arif [4] with the monthly average hourly clearness index in the form of the polynomial relationships for the city of Izmir in the western part of Turkey. The values of the monthly average daily clearness index ranged from 0.41 to 0.66, averaged for the same period.

III. PROBLEM IDENTIFICATION

Based on the literature survey it is seen that the incident solar radiations on a collector surface are greatest for an optimal tilt angle of the collector at a particular region which is also not constant throughout the year. To obtain maximum power output from the solar collector system it is desirable to tilt the collector to that tilt angle at which the incident solar radiations are maximum. If not monthly, the tilt angles of the collector surfaces can be changed four times in a year to their seasonal optimum tilt angles at which slightly less power is obtained than monthly optimal angles but large compared to yearly optimal tilt angle.

IV. OBJECTIVE OF THE STUDY

The following general objectives for tilt angle study:

i. Daily and monthly Optimum tilt angles.

ii. Seasonal Optimum tilt angles.

iii. Yearly optimum tilt angle.

iv. To compare the different model.

From above objectives we have discuss daily and monthly Optimum tilt angles, yearly optimum tilt angle.

A .SOLAR RADIATION

Solar radiation can best be approximated to the radiation of a black body with a temperature of 5780 K in both intensity and spectrum. Taking this into consideration, the extraterrestrial solar radiation falling on a surface normal to the sun's rays at the mean sun earth distance, which is also called the solar constant, can be calculated using equation 1:

$$G_{SC} = \sigma T^4 . \frac{r_s^2}{r_{se}^2} \quad (1)$$

The solar constant is approximately equal to 1367 W/m2; this value is an approximation based on the distance between the earth and the sun, which is equal to 1AU. And since the earth's orbit around the sun is elliptical, then the Gsc value may change slightly (about +3.3%) due to the change in the distance between the earth and the sun. This value was verified experimentally and the World Meteorological Organization (WMO) chose the average value 1367 W/m2 as the solar constant.

B. DIFFUSION OF SOLAR RADIATION

The solar radiation is subjected to several radiation attenuating effects when it travels across the atmosphere. There are two general cases of attenuating effects: absorption and scattering (reflection is a special case of scattering). The radiation that is neither scattered nor absorbed and reaches the surface directly from the sun disk is called direct radiation, while the scattered radiation that reaches the ground is called diffused radiation. The radiation extinction depends on different factors, such as: humidity, cloud coverage, other residual particles; those factors can only be determined by measurements, while others can be calculated (such as the path length of the solar beam from the top of the atmosphere to a given location on the earth's surface, which is called the air mass), and it is a function of the geographic altitude of a certain location and the solar zenith angle *Θz* at that location, but it can be simplified using Eq. 2:

$$AM = \frac{1}{COS\theta_Z} \tag{2}$$

C. SOLAR RADIATION ON TILTED SURFACES AND RADIANCE DISTRIBUTION OVER THE SKY

In order to determine the incident radiation on a tilted surface, the measured value of radiation on a horizontal surface can be used in addition to the direction of the beam and the diffused radiation component. The distribution of the solar diffused radiance over the sky is shown in Figure 1. It consists of three components: isotropic dome, where the diffused radiation is uniform over the sky dome, circumsolar brightening [5], which is concentrated at the center of the sun, and horizon brightening, which is assumed to be a line source concentrated at the horizon; the latter results from radiation reflected from the ground, thus the horizontal brightening is a function of ground reflection (albedo). Clear sky diffused radiation is maximized at the horizon and decreases when moving away from the horizon and the radiance increases away from the horizon at the overcast skies, specific solar angles on tilted surfaces are shown in Figure 2.

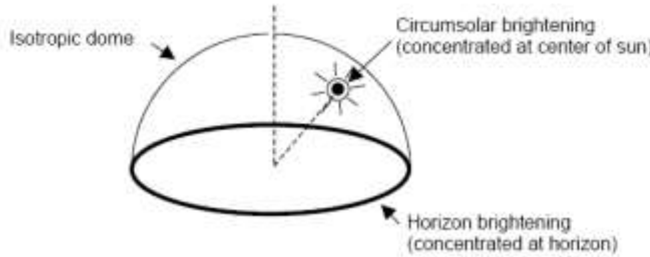


Figure 1. Distribution of diffused radiance

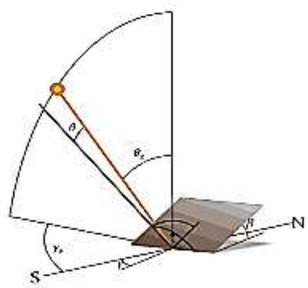


Figure 2. Solar radiation angles

The isotropic model, which assumes that the diffused radiation is uniform over the sky dome, can describe the overcast or cloudy sky, while the anisotropic model, which includes diffused sky radiation in the circumsolar and horizon brightening components of the solar radiation, is more accurate in describing clear sky. Isotropic diffused solar radiation can be obtained by the following equations:

$$G_T = G_{T,b} + G_{T,d} + G_{T,ref} \quad (3)$$

$$G_{T,b} = G_d\left(\frac{1+\cos\beta}{2}\right) \quad (4)$$

$$G_{T,ref} = G_{ref}\left(\frac{1-\cos\beta}{2}\right) \quad (5)$$

$$G_{T,b} = G_b.R_b \quad (6)$$

$$R_b = \frac{\cos(\varphi-\beta)\cos\delta\sin\omega_s + \left(\frac{\pi}{180}\right)\omega_s\sin(\varphi-\beta)\sin\delta}{\cos(\varphi)\cos\delta\sin\omega_s + \left(\frac{\pi}{180}\right)\omega_s\sin(\varphi)\sin\delta} \quad (7)$$

$$\omega_s = \cos^{-1}\left(-\tan(\varphi-\beta).\tan\delta\right) \quad (8)$$

The previous equations are based on Liu and Jordan model which is one of the simplest and earliest models. Anisotropic models should take into consideration two more components, as the following equation shows:

$$G_T = G_{T,b} + G_{T,d,iso} + G_{T,d,os} + G_{T,d,hc} + G_{T,ref} \quad (9)$$

where,

GT is the global radiation

GT,b is the beam radiation

GT,d,iso is the isotropic component

GT,d,cs is the circumsolar component

GT,d,hz is the Horizontal brightening component

GT,d,ref is the reflected radiation component

Researchers have introduced a variety of isotropic and anisotropic models, suggesting relations to determine the ratio of the average daily diffused radiation incident on an inclined surface to that on a horizontal surface (*Rd*). A. K. Yadav and S. S. Chandel conducted a review of the solar radiation models, where each model had its own limitations and conditions [6]. Nooriana *et al.* made an evaluation in which 12 models where investigated to estimate the hourly diffused radiation on inclined surfaces and compared the results to actual measured data [7]. If one of those models can be validated for a certain place and atmospheric conditions, an optimum tilting angle can be reached by varying tilt angle (β) from 0 to 90 until the solar radiation on the tilted surface is maximized.

V- CALCULATION OF GLOBAL SOLAR RADIATION WITH THE HELP OF HOMER SOFTWARE

(Hybrid Optimization of Multiple Energy Resources)

The time of day affects the location of the sun in the sky, which we can describe by an hour angle. HOMER (Hybrid Optimization of Multiple Energy Resources) uses the convention whereby the hour angle is zero at solar noon (the time of day at which the sun is at its highest point in the sky), negative before solar noon, and positive after solar noon. HOMER is the global standard in microgrid software, based on decades of listening to the needs of users around the world with experience in designing and deploying microgrids and distributed power systems that can include a combination of renewable power sources, storage, and fossil-based generation HOMER uses the following equation to calculate the hour angle:)

$$\omega = \left(t_s - 12hr\right).15^\circ / hr \qquad (10)$$

Where:

ts is the solar time [hr]

The value of ts is 12hr at solar noon, and 13.5hr ninety minutes later. The above equation follows from the fact that the sun moves across the sky at 15 degrees per hour. HOMER (Hybrid Optimization of Multiple Energy Resources)assumes that all time-dependent data, such as solar radiation data and electric load data, are specified not in solar time, but in civil time, also called local standard time. HOMER calculates solar time from civil time using the following equation:

$$t_s = t_c + \frac{\lambda}{15^\circ / hr} - Z_c + E \qquad (11)$$

Where:

tc is the civil time in hours corresponding to the midpoint of the time step [hr]

Λ is the longitude [°]

Zc is the time zone in hours east of GMT [hr]

E is the equation of time [hr]

Note that west longitudes are negative, and time zones west of GMT are negative as well.

The equation of time accounts for the effects of obliquity (the tilt of the earth's axis of rotation relative to the plane of the ecliptic) and the eccentricity of the earth's orbit.

HOMER calculates the equation of time as follows:

$$E = 3.82\left(0.000075 + 0.001868.\cos B - 0.03277.\sin B - 0.014615.\cos 2B - 0.04089.\sin 2B\right)$$

(12)

Where *B* is given by:

$$B = 360^\circ \frac{(n-1)}{365} \qquad (13)$$

Where n is the day of the year, starting with 1 for January 1st. Now, for a surface with any orientation, we can define the angle of incidence, meaning the angle between the sun's beam radiation and the normal to the surface, using the following equation:

$$\cos\theta = \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\cos\phi\cos\beta\cos\omega + \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega$$

(14)

Where,

θ is the angle of incidence

β is the slop of the surface

γ is the azimuth of the surface

ϕ is the latitude

δ is the solar declination

ω is the hour angle

An incidence angle of particular importance, which we will need shortly, is the zenith angle, meaning the angle between a vertical line and the line to the sun. The zenith angle is zero when the sun is directly overhead and 90° when the sun is at the horizon. Because a horizontal surface has a slope of zero, we can find an equation for the zenith angle by setting $\beta = 0^\circ$ in the above equation, which yields:

$$\cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta \qquad (15)$$

Where:

θ_Z is the zenith angle.

Now we turn to the issue of the amount of solar radiation arriving at the top of the atmosphere over a particular point on the earth's surface. HOMER assumes the output of the sun is constant in time. But the amount of sunlight striking the top of the earth's atmosphere varies over the year because the distance between the sun and the earth varies over the year due to the eccentricity of earth's orbit. To calculate the extraterrestrial normal radiation, defined as the amount of solar radiation striking a surface normal (perpendicular) to the sun's rays at the top of the earth's atmosphere, HOMER uses the following equation:

$$G_{ON} = G_{SC}\left(1 + 0.033.\cos\frac{360n}{365}\right) \quad (16)$$

Where:

Gon is the extraterrestrial normal radiation [kW/m2]

Gsc is the solar constant [1.367 kW/m2]

n is the day of the year [a number between 1 and 365]

Table I Solar radiation and clearness in Chhattisgarh throughout the year is given below in table

Month	Index	Daily Radiation(kWh/m2/d)
January	0.619	4.526
February	0.644	5.123
March	0.622	5.899
April	0.618	5.969
May	0.609	6.445
June	0.579	6.109
July	0.496	4.997
August	0.439	4.336
September	0.488	4.019
October	0.559	3.879
November	0.589	4.465
December	0.601	4.989

To calculate the extraterrestrial horizontal radiation, defined as the amount of solar radiation striking a horizontal surface at the top of the atmosphere, HOMER uses the following equation

$$G_O = G_{ON} \cos\theta_Z \quad (17)$$

Where:

Go is the extraterrestrial horizontal radiation [kW/m2]

G*on* is the extraterrestrial normal radiation [kW/m2]

θ_z is the zenith angle

Since HOMER simulates on a time step by time step basis, we integrate the above equation over one time step to find the average extraterrestrial horizontal radiation over the time step

$$\overline{G_0} = \frac{12}{\pi}[\cos\phi\cos\delta(\sin\omega_2 - \sin\omega_1) + \frac{\pi(\omega_2 - \omega_1)}{180^0}\sin\phi\sin\delta] \quad (18)$$

Where:

$\overline{G_0}$ is the extraterrestrial horizontal radiation averaged over the time step [kW/m2]

G_{ON} is the extraterrestrial normal radiation [kW/m2]

ω_1 is the hour angle at the beginning of the time step.

ω_2 is the hour angle at the end of the time step.

The above equation gives the average amount of solar radiation striking a horizontal surface at the top of the atmosphere in any time step.The solar resource data give the average amount of solar radiation striking a horizontal surface at the bottom of the atmosphere (the surface of the earth) in every time step. The ratio of the surface radiation to the extraterrestrial radiation is called the clearness index. The following equation defines the clearness index:

$$K_T = \frac{\overline{G}}{\overline{G_0}} \quad (19)$$

Where:

$\overline{G}$ is the global horizontal radiation on the earth's surface averaged over the time step [kW/m2].

$\overline{G_0}$ is the extraterrestrial horizontal radiation averaged over the time step [kW/m2]

Now let us look more closely at the solar radiation on the earth's surface. Some of that radiation is beam radiation, defined as solar radiation that travels from the sun to the earth's surface without any scattering by the atmosphere. Beam radiation (sometimes called direct radiation) casts a shadow. The rest of the radiation is diffuse radiation, defined as solar radiation whose direction has been changed by the earth's atmosphere. Diffuse radiation comes from all parts of the sky and does not cast shadow. The sum of beam and diffuse radiation is called global solar radiation, a relation expressed by the following equation:

$$\overline{G} = \overline{G_b} + \overline{G}_d \qquad (20)$$

Where:

$\overline{G_b}$ is the beam radiation [kW/m2]

$\overline{G}_d$ is the diffuse radiation [kW/m2]

The distinction between beam and diffuse radiation is important when calculating the amount of radiation incident on an inclined surface. The orientation of the surface has a stronger effect on the beam radiation, which comes from only one part of the sky, than it does on the diffuse radiation, which comes from all parts of the sky.

VI. OPTIMUM TILT ANGLE CALCULATION

Failing to install PV panels at its optimum tilt angle leads to the loss of the potential solar power. The optimum tilt angle calculations are based on maximizing the solar radiation falling on a sloped surface using different optimization techniques. In [8], the authors summarized some of the relations between the latitude and the optimum tilt angle. This section shows the work of different researchers who have determined optimum tilt angles analytically or experimentally for a number of locations. Skeiker [9] used a mathematical model to estimate the daily optimum tilt angle according to equation (21), and a monthly optimum tilt angle according to equation (23) for many locations in Syria, and, in addition to that, the seasonal and annual optimum tilts angles. The annual optimum tilt angle for Daraa (on the northern border of Jordan – 32°37’N 36°6’E) was *ß* = 30.13°, monthly, and the seasonal tilt angles energy gains were 28% and 26%, respectively. A major concern regarding this model was that it took into consideration the varying tilt angle to the maximize extraterrestrial radiation but disregarded the attenuation effects that changes the properties of the solar radiation. Soulayman [10] commented on Skeiker work and set all the negative values of the tilt angles to zero, identifying some other errors in his methodology.

$$\beta_{opt,d} = \phi - \tan^{-1}\left[\frac{h_{ss}}{\sin(h_{ss})}\tan(\delta)\right] \quad (21)$$

$$\beta_{opt,m} = \phi - \tan^{-1}\frac{X}{Y} \quad (22)$$

$$X = \sum_{n=n1}^{n=n2}\frac{24}{\pi}I_0\left[1+0.034\cos\left(\frac{2\pi n}{365}\right)\right]\sin(\delta)h_{ss} \quad (23)$$

$$Y = \sum_{n=n1}^{n=n2}\frac{24}{\pi}I_0\left[1+0.034\cos\left(\frac{2\pi n}{365}\right)\right]\cos(\delta)\sin(h_{ss}) \quad (24)$$

Agha and Sbita [11] conducted a study for four different locations in Libya to determine the optimum tilt angle for the solar systems using an accurate simple sizing method rather than numerical methods. The selection criterion for the optimum tilt angle was based on an optimization factor (*Fopt*) as shown in equation:

$$F_{opt}(\beta) = \frac{H_{avg}(\beta)}{S_{DEV}(\beta)} \quad (25)$$

where , *Havg* is the monthly average of the daily total of the solar irradiation (kWh/m2.day), SDEV is the standard deviation of the curve that represents the divergence between the normalized load curve and normalized solar irradiation curve at a certain angle. One of the cities, included in this study, is Tripoli, *Lat.*=32.87° which is close to that of the northern part of Jordan. The optimum tilt angle for Tripoli is about 25°. One of the assumptions of the present study is, excluding the cloudy days, even though Tripoli is a coastal city, both Tripoli and Jordan have near latitude but concerning other factors, like the weather conditions and temperature variation, solar radiation, etc., which affect the optimum tilt angle, they are different. Moghadam *et al.* [12] conducted a study to determine the optimum tilt angle of the solar collectors in Iran by making a simulation using MATLAB program. Iran is located on the sun belt of the world and has a high value of solar radiation; it is mostly sunny all year around. Moghadam *et al.* [12] calculated the monthly, seasonal, semi-annual and annual optimum tilt angles for Zahedan city (*latitude* = 29.49°). The annual optimum tilt angle for Zahedan was equal to 28°. The study also found that the tilt angle was equal to 5° in the first half of the year and 50° in the second half and if the tilt angle is adjusted two times in a year, the total annual extra received energy will be more than 8%.Talebizadeh [13] developed new correlations to calculate the monthly, seasonal, and yearly optimum slope angles for latitudes of 20° to 40° north, suggesting that the annual optimum tilt angle was $\beta_{opt} = 0.6804\phi + 7.203$ (26)

Therefore, the optimum for locations in northern Jordan equals 29.17°. The correlations were obtained according to the optimum slope angles predicted by the researcher and using the optimum slope angles achieved by other researchers at locations out of Iran but in the same range of latitudes; the results showed that the optimum azimuth angle is zero for receiving maximum solar energy. It can be noticed that the previous results are consistent with the simple and general correlations to determine the optimum tilt angle depending only on the latitude that can be used as a rule of thumb, such as Heywood [14] who came up with the following equation:

$$\beta opt = \emptyset - 10° \quad (27)$$

According to equation 27, the optimum tilt angle in the northern part of Jordan is equal to 22.29 degree. Or Lunde [15] suggested the following equation:

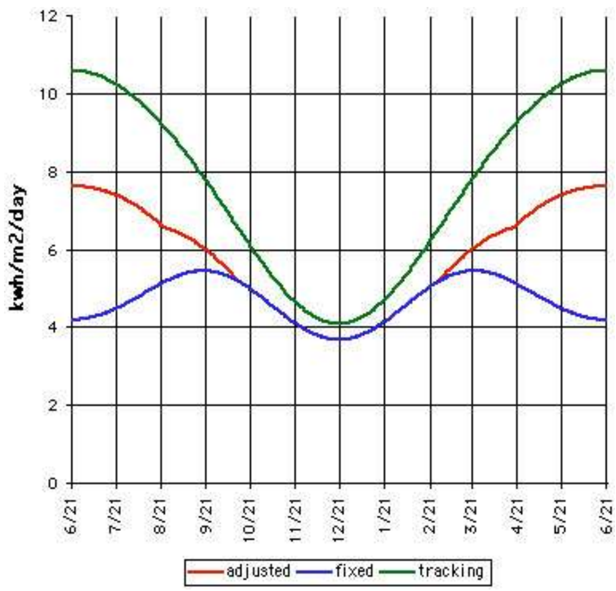
$$\beta opt = \emptyset \pm 15° \quad (28)$$

The optimum tilt angle for the northern part of Jordan, according to equation 28, is equal to 17.5 in summer, 47.5 in winter, where the plus and minus signs are used for the winter and summer seasons.

Duffie and Beckman [16] suggested that the optimum tilt is in the range of the latitude plus 10^{o}to the latitude plus 20°, and the variation of 10° either way outside of this range, so, accordingly, the optimum tilt angle (*ß*) is equal to 52.29° - 62.29^o, in winter, and from 32.29^o to 42.29^o, in summer. That was determined to insure the visibility of a thermal system recommendation but is not expected to be accurate within the view of a PV system.

Table II

Solar radiation for adjusted collectors, fixed collectors, tracking collectors for single day per month



VII. CONCLUSION

The optimum tilt is different for each months of the year. The Collected solar energy will be greater if we choose the optimum panel tilt for each month. Also, we have found that the yearly average of optimum tilt is equal to the latitude of the site. The results show that the average optimum tilt angle at Chhattisgarh for the winter months is 37_ and for the summer months is 12_. So, the yearly average tilt panel is 23.5_ which nearly corresponding to the latitude of Chhattisgarh site (24.5_). This, in general, is in agreement with the results of many other researchers [15°, 16°].The loss of energy when using the yearly average fixed angle is around 8% compared with the optimum tilt for each month at Chhattisgarh. It can be concluded that a yearly average fixed tilt can be used in many general applications in order to keep the manufacturing and installation costs of collectors low. For higher efficiency, the collector should be designed such that the angle of tilt can easily be changed at least on a seasonal basis, if not monthly. Alternatively, solar tracking systems can be used in industrial installations where higher efficiency is required.

VIII.REFRENCES

1. Ahmad M. Jamil and Tiwari G.N., —Optimization of Tilt Angle for Solar Collector , The Open The Open Renewable Energy Journal, 2009; 2: 19-24

2. Renewable Energy Journal, 2009; 2: 19-24Bekker, B. (2004). Methods to extract maximum electrical energy

3. Mehleri E.D., Zervas P.L., Sarimveis H., Palyvos J.A. and Markatos N.C., —Determination of the optimal tilt angle and orientation for solar photovoltaic arrays‖, Renewable Energy, 2010; 35: 2468 – 2475

4. Ulgen Koray and Hepbasli Arif, —Prediction of Solar Radiation Parameters through Clearness Index for Izmir, Turkey‖, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2002; 24: 8, 773 - 785.

5. The methods used in calculation of solar radiation in Energy Plus http://www.designbuilder.co.uk/

6. A. K. Yadav, S.S. Chande, "Tilt angle optimization to maximize incident solar radiation: A review". Renewable and Sustainable Energy Reviews, Vol. 23 (2013), 503–513.

7. A. M. Noorian, I. Moradi, G. A. Kamali, "Evaluation of 12 models to estimate hourly diffuse irradiation on inclined surfaces". Renewable Energy, Vol. 33 (2008) No. 6, 1406–1412.

8. A. K. Yadav, S.S. Chande, "Tilt angle optimization to maximize incident solar radiation: A review". Renewable and Sustainable Energy Reviews, Vol. 23 (2013), 503–513.

9. K. Skeiker "Optimum tilt angle and orientation for solar collectors in Syria". Energy Conversion and Management, Vol. 50 (2009), 2439–2448.

10. S. Soulayman, W. Sabbagh, "Comment on 'Optimum tilt angle and orientation for solar collectors in Syria' by Skeiker". Energy Conversion and Management, Vol. 89 (2015), 1001–1002.

11. K. R. Agha, M. N. Sbita, "On the sizing parameters for stand- alone solar-energy systems". Applied Energy, Vol. 65 (2000) No. 1, 73–84.

12. H. Moghadam, F. F. Tabrizi, A. Z. Sharak, "Optimization of solar flat collector inclination". Desalination, Vol. 265 (2011) No. 1, 107–111.

13. P.Talebizadeh,M. A. Mehrabian, M. Abdolzadeh, "Determination of optimum slope angles of solar collectors based on new correlations". Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, Vol. 33 (2011) No. 17, 1567-1580.

14. H. Heywood, "Operating experience with solar water heating". JIHV, Vol. 39 (1971), 63–69.

15. Lunde PJ. Solar thermal engineering. New York: Wiley; 1980.

16. Duffie JA, Beckman WA. Solar engineering of thermal processes. New York: Wiley; 1991.