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COMPARATIVE APPROACH FOR THE OPTIMIZATION OF TILT ANGLE TO RECEIVE MAXIMUM RADIATION

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ABSTRACT

India is both densely populated and has high solar insolation, providing an ideal combination for solar power in India. As the angle between the sun and a fixed surface is continually changing, the power density on a fixed PV module is less than that of the incident sunlight. Since the flat plate solar collectors are placed at an angle to the horizontal, it is necessary to calculate the optimum tilt angle which maximizes the amount of collected energy. The best way to collect the maximum solar energy is by using solar tracking systems, and thus to maximize the collected beam radiation. In this paper a mathematical model was used for estimating the total (global) solar radiation on a tilted surface, and to determine the optimum tilt angle and orientation (surface azimuth angle) for the solar collector in India at four different locations on a monthly basis, as well as for a specific period. The results reveal that changing the tilt angle 12 times in a year (i.e. using the monthly-averaged optimum tilt angle) maintains approximately the total amount of solar radiation near the maximum value that is found by changing the tilt angle daily to its optimum value. This achieves a yearly gain in solar radiation of 4.56% more than the case of a solar collector fixed on a horizontal surface.

Keywords: solar collector, optimum tilt angle, clearness index, solar radiation.

1. INTRODUCTION

The natural energy flows through the Earth's ecosystem are immense, and the theoretical potential of what they can produce for human needs exceeds current energy consumption by many times. For example, solar power plants on one percent of the world's desert area would generate the world's entire electricity demand today [1]. In recent centuries the types and magnitudes of the energy requirements have increased in an unprecedented manner and mankind seeks for additional energy sources.

Energy sources are vital and essential ingredients for all human transactions and without them human activity of all kinds and aspects cannot be progressive. Population growth at the present average rate of 2% also exerts extra pressure on limited energy sources Renewable energy supplies 19 percent of global final energy consumption, counting traditional biomass, large hydropower, and renewable (small hydro, modern biomass, wind, solar, geothermal, and bio fuels). Of this 19 percent, traditional biomass, used primarily for cooking and heating, accounts for approximately 13 percent and is growing slowly or even declining in some regions as biomass is used more efficiently or is replaced by more modern energy forms. Hydropower represents 3.2 percent and is growing modestly but from a large base. Other renewable account for 2.6 percent and are growing very rapidly in developed countries and in some developing countries. The amount of solar energy received by the surface of the earth per minute is greater than the energy utilization by the entire population in one year. Solar energy is referred to as renewable and/or sustainable energy because it will be available as long as the sun continues to shine. Estimates for the life of the main stage of the sun are another 4 – 5 billion years. The energy from the sunshine, electromagnetic radiation, is referred to as insulation.

The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9m. In effect the sun is a continuous fusion reactor in which hydrogen is turned into helium. The sun's total energy output is $3.8 \times 10^{20} MW$ which is equal to $63 MW/m^2$ of the sun's surface. This energy radiates outwards in all directions.

Only a tiny fraction, $1.7\times10^{14}kw$ of the total radiation emitted is intercepted by the earth **[1].**

The performance of a solar collector is highly influenced by its angle of tilt with the horizontal. This is due to the facts that tilt angle change the solar radiation reaching the surface of the collector, the tilt angle, defined as the angle of collectors with respect to horizontal, is a dominant parameter affecting the collectible radiation of a fixed collector. In general, the optimal tilt angle of a fixed collector is related to the local climatic condition, geographic latitude and the period of its use. Hence, different places will have different optimal tilt angles for a yearly-used solar collector.

2. 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 requirements. **Ahmad M. Jamil and Tiwari G.N. [2]** 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 [3].** The orientation and tilt of the panels directly relates to the annual energy yield of the panels **Mehleri E.D. et. al. [4]** 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 [5]** 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.

KorayUlgen [5] found that the optimum tilt angle changes between 0◦ (June) and 61◦ (December) throughout the year. In winter (December, January, and February) the tilt should be 55.7◦, in spring (March, April, and May) 18.3◦, in summer (June, July, and August) 4.3◦, and in autumn (September, October, and November) 43◦. **Sakonidou E.P. et. al. [6]** developed a mathematical model. The model starts by calculating the hourly solar irradiation components (direct, diffuse, ground-reflected) absorbed by the solar chimney of varying tilt and height for a given time (day of the year, hour) and place (latitude). **Moghadam Hamid et. al. [7]** estimated solar global radiation on a horizontal surface using a mathematical model and the results were compared.

Ibrahim D. [8] examined for selection of optimum tilt angle of Cyprus. For maximum radiation the results were calculated by varying tilt angle form 0° to 90° with the increment of 10°.

Tang R. and Tong W. [9] presented a mathematical procedure to compare the optimum tilt angles of collectors through monthly diffused radiation and actual monthly diffused radiations. The best orientation for solar collectors in Izmir was south facing.

3-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.

4- OBJECTIVE OF THE STUDY

The following objectives are covered under this study:

i. Daily and monthly Optimum slope angles.
ii. Seasonal Optimum tilt angles.
iii. Yearly optimum tilt angle.
iv. To compare the different model.
v. To compare with the solar panel setup installed at Village Nandha, Bhiwani, Haryana

Joakim Widén [10] mentioned the models of solar radiation, daylight and solar cells as a chapter in his thesis. **M.S.Alam [11]** et.al. developed a mathematical model for simulation of solar radiation system by using dynamics methodology in their paper.

5- MODELING OF GLOBAL RADIATION

Angstrom's equation[20] is used to express the average radiation on a horizontal surface in terms of constants α1,α2 and the observed values of average length of solar days.

Fig.1- Solar Panel installed at MGICC-Delhi Govt., Alipur-Bakauli, New Delhi

The constants α1,α2 will be determined for this model based on actual old measurements and equating the data in the Angstrom's equation given as follows:

$$\frac{H_g}{H_c} = \alpha_1 + \alpha_2 \left(\frac{L_h}{L_m}\right)$$

Manes A, and Ianetz A. [1] presented energy radiates outwards in all directions. Only a tiny fraction, $1.7\times10^{14}\ kw$ of the total radiation emitted is intercepted by the earth. The variation of the earth-sun distance due to earth's orbit causes variable extraterrestrial radiation. The dependence of extraterrestrial radiation on time of year is indicated by **Duffie J.A. and Beckman W. A. [13]:**

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

The sunset hour angle ω for any day (n) of the year can be obtained as follows. The total daily irradiation on a horizontal plane, H, is the combination of two components: the direct (beam) irradiation and the diffuse irradiation from the sky.

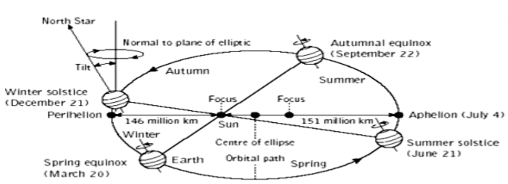

Fig.2- Earth Sun Geometry

6- EARTH-SUN GEOMETRY

The term Earth rotation refers to the spinning of our planet on its axis. At any one moment in time, one half of the Earth is in sunlight, while the other half is in darkness. The edge dividing the daylight from night is called the circle of illumination. The Earth's rotation also creates the apparent movement of the Sun across the horizon.

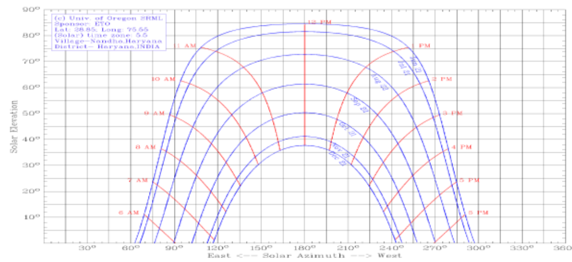

Fig.-3-Sun Path for Village Nandha, Haryana along the year

The annual change in the relative position of the Earth's axis in relationship to the Sun causes the height of the Sun or solar altitude to vary in our skies. Solar altitude is normally measured from either the southern or northern point along the horizon and begins at zero degrees. Maximum solar altitude occurs when the Sun is directly overhead and has a value of 90°.

7- MODELS FOR CALCULATION OF CLEARNESS INDEX

The monthly-average clearness index K_t is the ratio of the monthly average daily radiation on a horizontal surface (H) to the monthly average daily extraterrestrial radiation (H_o)

$$K_t = \frac{H}{H_o}$$

Chandel S.S. [12] gave a relation between mean daily sunshine duration 'n' and the mean daily global solar radiation 'h' as a function of latitude, altitude, maximum and minimum temp of a site.

$$\frac{H}{H_o} = K_t = \left[\Delta T \sin\phi\left(e^{(-0.0001184\times h)}\right)\right]^{0.5} \times 7.9 \times \phi^{-1}$$

Where, ΔT is the difference in maximum and minimum temperature, Ø is the latitude of the site (Nandha is 28.8482), h is the latitude from the mean sea height. The altitude of Haryana varies between 700 to 3600 ft (200 meters to 1200 meters) above sea level, the monthly mean maximum and minimum temperature is taken from the 'Indian Meteorological Department'

An empirical method for the estimation of the monthly average daily total radiation incident on a tilted surface was developed by **Liu B.Y.H. and Jordan R.C. [15].** In their correlation, the diffuse to total radiation ratio for a horizontal Surface is expressed in terms of the monthly clearness index K_t with the following equation:

$$\frac{H_{diff}}{H} = 1.390 - 4.027K_t\square_\square + 5.5312.5557K_t^2 - 3.108K_t^3$$

Collares P. and M. Rabl A. [14] expressed the same parameter by also considering the sunset hour angle:

$$\frac{H_{diff}}{H} = 0.775 + 0.00653(\omega - 90) - \left(0.505 + 0.00455(\omega - 90)\right)\cos(115K_t - 103)$$

Knowing the value of the clearness index; one can calculate the diffuse component, H_{diff} as follows **(Erbs D.G. et al.) [16].**

For $\omega \leq 81.4°$

$$\frac{H_{diff}}{H} = \begin{cases} 1 - 0.2727K_t + 2.4495K_t^2 - 11.9514K_t^3 + 9.3879K_t^4, & K_t < 0.715 \\ 0.143, & K_t \geq 0.715 \end{cases}$$

Where as $\omega > 81.4°$

$$\frac{H_{diff}}{H} = \begin{cases} 1 + 0.2832K_t - 2.5557K_t^2 + 0.8448K_t^3, & K_t < 0.722 \\ 0.143, & K_t \geq 0.722 \end{cases}$$

Then, the direct daily component can be computed.

The total solar radiation on a tilted surface H_t is made up of the direct or beam solar radiation (H_{dir}), diffuse radiation (H_{diff}), and ground reflected radiation (H_{ref}), on a tilted surface

$$\mathbf{H_t = H_{dir\ on\ a\ tilted\ surface} + H_{diff\ on\ a\ titled\ surface} + H_{ref\ on\ a\ titled\ surface}}$$

Liu, B.Y.H. and Jordan R. C. [15] and anisotropic **Hay, J.E. [17]** ones. The daily beam radiation received on an inclined surface can be expressed as

$$\mathbf{H_{dir\ on\ a\ tilted\ surface} = (HH - H_{diff} H_{diff}) R_b}$$

where H and H_d are the monthly mean daily global and diffuse radiation on a horizontal surface, and R_b is the ratio of the average daily beam radiation on a tilted surface to that on a horizontal surface. The daily ground reflected radiation can be written as

$$\mathbf{H_{ref\ on\ a\ titled\ surface} = H\rho\ (1 - \cos\beta)/2}$$

Liu, B.Y.H. and Jordan R. C. [15] have suggested that R_b can be estimated by assuming that it has the value which would be obtained if there were no atmosphere. For surfaces in the northern hemisphere, sloped towards the equator, the equation for R_b is given as below **Miguel A. et. al. [18]** and is used in the present study.

$$R_b = \frac{\cos(\emptyset - \beta)\cos\delta\sin\omega + (\pi/180)\omega\sin(\emptyset - \beta)\sin\delta}{\cos\emptyset\cos\delta\sin\omega + (\pi/180)\omega\sin\emptyset\sin\delta}$$

Where

$$\omega = \min\begin{bmatrix} \omega = \arccos(-\tan\emptyset\tan\delta) \\ \arccos(-\tan(\emptyset - \beta)\tan\delta) \end{bmatrix}$$

ω ' is the sunset hour angle for the tilted surface for the mean day of the month. ''min'' means the smaller of the two terms in the bracket.

For surfaces in the southern hemisphere, sloped towards the equator, the equation for R_b is given as below **Liu, B.Y.H. and Jordan R. C. [15].**

$$R_b = \frac{\cos(\emptyset + \beta)\cos\delta\sin\omega + (\pi/180)\,\omega\sin(\emptyset + \beta)\sin\delta}{\cos\emptyset\cos\delta\sin\omega + (\pi/180)\omega\sin\emptyset\sin\delta}$$

Where

$$\omega' = \min\begin{bmatrix} \omega = \arccos(-\tan\phi\tan\delta) \\ \arccos(-\tan(\phi - \beta)\tan\delta) \end{bmatrix}$$

Optimum tilt angle curve along the year, in winter, the tilt angle approaches to 55°, while in summer it approaches to 8°. Assuming all previous angles are random variables, so the expected values for those variables as follows:

$$E[\beta opt] = E[\delta] - E[\varphi]$$

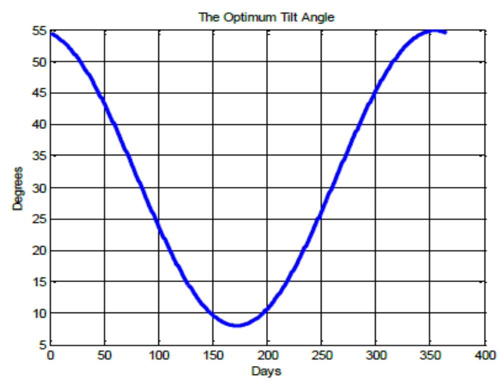

Fig.4- Optimum Tilt angle Vs Days

8- DIFFUSE RADIATION MODELS

The methods for approximation the ratio of diffuse solar radiation on a tilted surface to that of a horizontal are classified as isotropic and anisotropic models. The isotropic models assume that the intensity of diffuse sky radiation is uniform over the sky dome. Hence, the diffuse radiation incident on a tilted surface depends on the fraction of the sky dome seen by it. The anisotropic models assume the anisotropy of the diffuse sky radiation in the circumsolar region (sky near the solar disc) plus and isotropically distributed diffuse component from the rest of the sky dome. The sky-diffuse radiation can be expressed as-

$$H_{ref\ on\ a\ tilted\ surface} = H_d R_d H_{ref\ on\ a\ tilted\ surface}$$

Where R_d is the ratio of the average daily diffuse radiation on a tilted surface to that on a horizontal surface.

The diffuse radiation models chosen for study were as follows **Kamali G.H. [19].**

9- ISOTROPIC MODELS

- **Liu and Jordan model** (1962)

$R_d = [3 + \cos(2\beta)] / 4$

- **Tian *et al.* model** (2001)

$R_d = 1 - \beta/4$

- **Koronakis model** (1986)

$R_d = 1/3\ [2 + \cos\beta]$

- **Badescu model** (2002)

$R_d = [3 + \cos 2\beta] / 4$

10- ANISOTROPIC MODELS

- **Hay model** (1979)

$$R_d = \frac{H_b}{H_\circ} R_d + \left(1 - \frac{H_b}{H_\circ}\right) [(1 + \cos\beta)/2]$$

- **Skartveit and Olseth model** (1986)

$$R_d = \frac{H_b}{H_\circ} R_b + \Omega \cos\beta + \frac{\left(1 - \frac{H_b}{H_\circ} - \Omega\right)(1 + \cos\beta)}{2}$$

Where $\Omega = \left\{max\left[0, \left(0.3 - 2\frac{H_b}{H_\circ}\right)\right]\right\}$

- **Reindl *et al.* model** (1990)

$$R_d = \frac{H_b}{H_\circ} R_b + \left(1 - \frac{H_b}{H_\circ}\right)[(1 + \cos\beta)/2][1 + \sqrt{H_b/H}\sin^3(\beta/2)]$$

- **Steven and Unsworth model** (1980)

$$R_d = 0.51R_d + \{[1 + \cos\beta]/2\} - \frac{1.74}{1.26\pi}\left[\sin\beta - \left(\beta \times \frac{\pi}{180}\right)\cos\beta - \pi\sin^2(\beta/2)\right]$$

11- TOTAL RADIATION ON A TILTED SURFACE, can thus be expressed as

$$H_t = (H - H_{diff})R_b + H\rho(1 - \cos\beta)/2 + H_d R_d$$

12-SITE ANALYSIS

Historical data for the specific site at Stellenbosch suggests that the total energy received on a horizontal surface differs from January to June.

Table 1- Horizontal Irradiation data for Nandha, Haryana

	Jan	Feb	Mar	Apr	May	Jun	July
kWh/m2/d	3.41	4.31	5.45	6.68	7.43	7.17	5.68
		Aug	Sep	Oct	Nov	Dec	Annual
		5.29	5.55	5.30	4.23	3.36	5.32

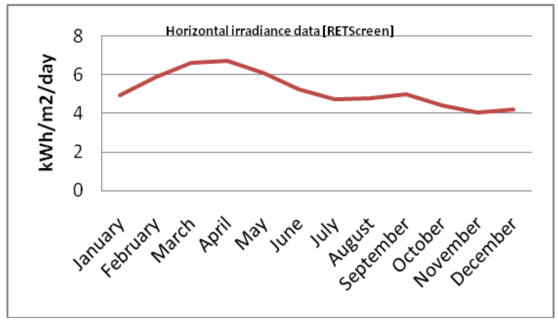

Fig.5 - Daily solar radiation for Village Nandha, Haryana – horizontal

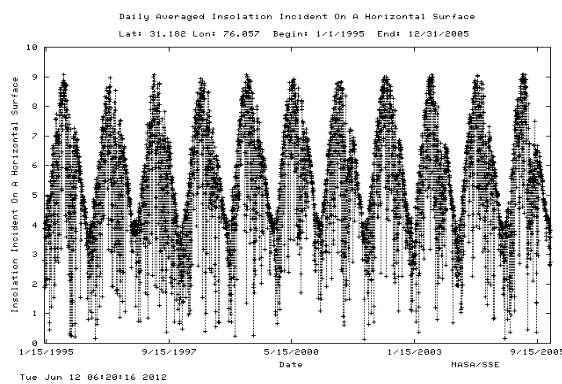

Fig.6.-Daily Averaged Insolation Incident On A Horizontal Surface-Nandha, Haryana

Table.2- Horizontal Irradiation data for New Delhi

Month	Jan	Feb	Mar	Apr	May	Jun	July
kWh/m2/d	3.8	4.68	5.8	6.30	6.42	6.07	5.22
		Aug	Sep	Oct	Nov	Dec	Annual
		4.81	5.06	4.83	4.18	3.52	5.06

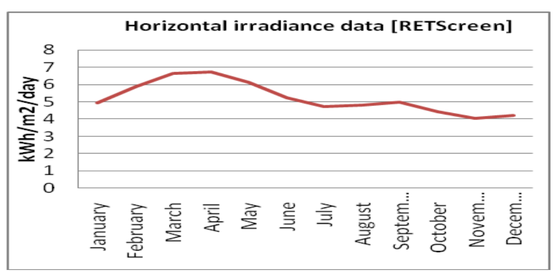

Fig.7 - Daily solar radiation for New Delhi - horizontal

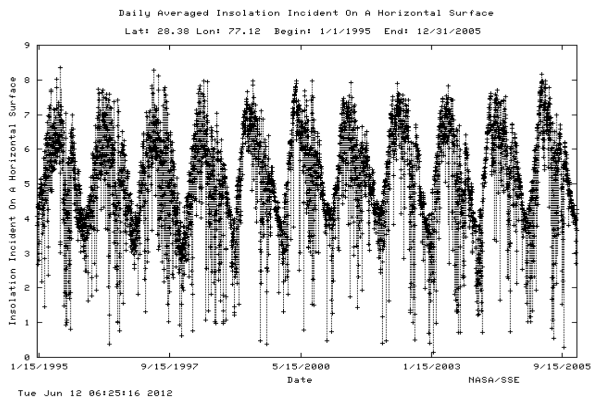

Fig.8-Daily Averaged Insolation Incident On A Horizontal Surface-New Delhi, India.

13- RESULT AND DISCUSSION

The average winter value of H is 1.4858$\times 10^7$ W/m^2day and its average summer value is 2.6843$\times 10^7$ W/m^2day

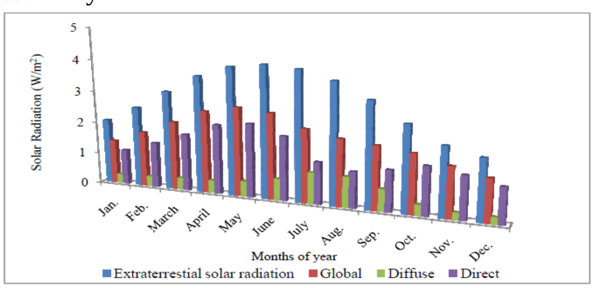

Fig.9- **Monthly Average daily Extraterrestrial, Global, Direct and Diffuse solar radiation on horizontal surfaces at Village Nandha, Haryana**

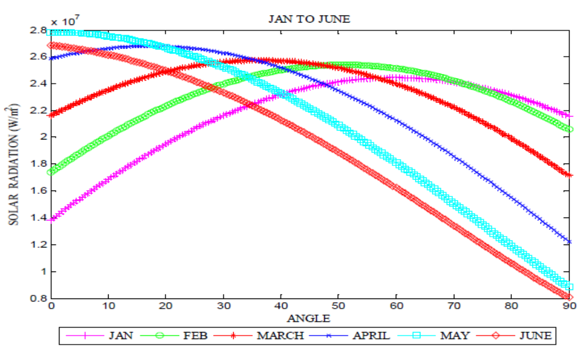

Fig.10-Monthly-average daily solar radiation availability of tilted surface at Village Nandha, Haryana

Fig shows the beam radiation dominates throughout the year where the maximum beam radiation reaches in the month of May (**2.3066 X 10^7** W/m^2 day) whereas the least amount of beam radiation occurs in the month of December (1.1026 **X 10^7** W/m^2 day). The remaining city consider in the study is Delhi. Delhi shows somewhat similar trend as that of Village Nandha, Haryana. Fig. shows the average daily total solar radiation at Village Nandha, Haryana on a south facing surface as the angle of tilt is varied from 0 to 90 in steps of 0.5°. It is clear from these graphs that a unique $\boldsymbol{\beta_{Opt}}$ exists for each month of the year for which the solar radiation is at a peak for the given month. The optimum angle of tilt of a flat-plate collector in January is 60 and the total monthly solar radiation falling on the surface at this tilt is 2.4438$\times 10^7$ W/m^2day.The optimum tilt angle in June goes to a minimum of zero degree and the total monthly solar radiation at this angle is 2.6841$\times 10^7$ W/m^2 day. The optimum tilt angle then increases during the winter months and reaches a maximum of 62° in December which collects 2.5717$\times 10^7$ W/m^2day of solar energy monthly. The optimum angle of tilt of a flat-plate collector in January is 44.5° and the total monthly solar radiation falling on the surface at this tilt is 3.3610$\times 10^7$ W/m^2day. The optimum tilt angle in May goes to a minimum of zero degree and the total monthly solar radiation at this angle is 3.4337$\times 10^7$ W/m^2day.

The average daily total solar radiation at Delhi on a south facing surface as the angle of tilt is varied from 0° to 90° in steps of 0.5°. It is clear from these graphs that a unique $\boldsymbol{\beta_{opt}}$ exists for each month of the year for which the solar radiation is at a peak for the given month. The optimum tilt angle then increases during the winter months and reaches a maximum of 60° in December which collects 2.6844$\times 10^7$ W/m^2day of solar energy monthly. Table gives a list of β_{opt} for each month of the year at **Village Nandha, Haryana** using 2 isotropic models (**Badescu model , Liu and Jordan model)** and 2 anisotropic models (**Reindl *et al.* model, Hay model**) as mentioned previous. The optimum angle of tilt of a flat-plate collector in January is 60° by Liu & Jordan model whereas Reindl model, Hay model, Badescu model indicate the optimum tilt angle as 61.5°, 61°, 60.5° resp. and the total monthly solar radiation falling on the surface at this tilt is 2.4438$\times 10^7$ W/m^2day by Liu & Jordan model whereas Reindl model, Hay model, Badescu model indicate the total monthly solar radiation falling on the surface at this tilt angle is 2.6367$\times 10^7$ W/m^2day, 2.6253$\times 10^7$ W/m^2day 2.4088$\times 10^7$ W/m^2day resp. The optimum tilt angle in June goes to a minimum of zero degree as indicated by all the models and the total monthly solar radiation at this angle is 2.6841$\times 10^7$ W/m^2day. Yearly average tilt was calculated by finding the average value of the tilt angles for all months of the year. The yearly average tilt was found to be 30.61° for Village Nandha, Haryana. when the seasonal average angles are used, and when the yearly average angle is used throughout the year. When the monthly optimum tilt angle was used, the yearly collected solar energy was 2.500775 **x** **10^7** W/m^2 day with the seasonally adjusted tilt angles, the yearly collected solar energy was 2.3669 **x** **10^7** W/m^2 day. Finally, with the yearly average tilt angle, the yearly

Table:3- Optimum Tilt Angle β_{opt} for Each Month of the Year at Nandha, (Haryana)

Months	Liu & Jordan Model		Reindl Model		Hay Model		Badescu Model	
	β_{opt} (°)	$H_t(\beta_{opt})$ 10^7 W/m^{2}day	β_{opt} (°)	$H_{t(\beta_{opt})}$ 10^7W/m^{2}day	β_{opt} (°)	$H_{t(\beta_{opt})}$ 10^7W/m^{2}day	β_{opt} (°)	$H_{t(\beta_{opt})}$ 10^7W/m^{2}day
Dec	62	2.5717	63.5	2.7521	63	2.7437	62.5	2.5449
Jan	60	2.4438	61.5	2.6367	61	2.6253	60.5	2.4088
Feb	50	2.5391	53	2.6799	52	2.6710	50.5	2.5023
Mar	36	2.5746	38.5	2.6482	38	2.6438	35	2.5465
Apr	17.5	2.6801	18.5	2.6960	18	2.6954	16	2.6720
May	0	2.7839	0	2.7839	0	2.7839	0	2.7839
Jun	0	2.6841	0	2.6841	0	2.6841	0	2.6841
Jul	0	2.2942	0	2.2952	0	2.2941	0	2.2952
Aug	8	2.0969	9	2.1023	8.5	2.1021	6	2.0938
Sep	27.5	2.1374	28.5	2.1920	27.5	2.1874	22	2.1112
Oct	48.5	2.4989	48	2.6167	47.5	2.6095	44.5	2.4639
Nov	58	2.7239	59.5	2.8826	59	2.8755	58	2.6958
Average	**30.61**	**2.5024**	**31.66**	**2.5808**	**31.20**	**2.5764**	**29.58**	**2.4835**

Table 4- Optimum Tilt Angle β_{opt} for Each Month of the Year at Delhi

Months	Liu & Jordan Model		Reindl Model		Hay Model		Badescu Model	
	β_{opt} (°)	$H_t(\beta_{opt})$ 10^7 W/m^{2}day	β_{opt} (°)	$H_{t(\beta_{opt})}$ 10^7W/m^{2}day	β_{opt} (°)	$H_{t(\beta_{opt})}$ 10^7W/m^{2}day	β_{opt} (°)	$H_{t(\beta_{opt})}$ 10^7W/m^{2}day
Dec	60	2.6844	61	2.8476	59.5	2.8401	60	2.6575
Jan	57.5	2.5059	59.5	2.6870	59	2.6760	57.5	2.4692
Feb	48.5	2.5727	50.5	2.7011	50	2.6930	47.5	2.5362
Mar	34	2.6558	35.5	2.7145	35	2.7114	32.5	2.6327
Apr	14.5	2.7274	15	2.7380	15	2.7377	14	2.7220
May	0	2.7804	0	2.7804	0	2.7804	0	2.7804
Jun	0	2.5742	0	2.5742	0	2.5742	0	2.5742
Jul	0	2.1796	0	2.1796	0	2.1796	0	2.1796
Aug	5	1.9561	5.5	1.9582	6	1.9582	4	1.9548
Sep	21.5	2.0467	24.5	2.0890	24	2.0853	18	2.0253
Oct	43	2.5412	45	2.6456	44.5	2.6392	42	2.5081
Nov	55.5	2.7641	56.5	2.9143	56	2.9074	55.5	2.7344
Average	**28.29**	**2.4990**	**29.41**	**2.5691**	**29.08**	**2.5652**	**27.58**	**2.4812**

collected solar energy was 2.27168 **x** **10^7** W/m^2 day. The seasonal optimum tilt angle for Delhi using different models out of which the Badescu model is very close to the data available in **[14]**.

The optimum seasonally tilt angle is maximum in winter ie.57.33° and minimum i.e. 2.67° in summer by Liu and Jordan model. Optimum seasonally tilt angle is maximum in winter ie.57.83° and minimum i.e. approximately zero in summer by Badescu model. The optimum seasonally tilt angle is maximum in winter ie.51.33° and minimum i.e. approximately zero in summer by Liu and Jordan model. Optimum seasonally tilt angle is maximum in winter ie.48.66° and minimum i.e. approximately zero in summer by Badescu model.

The optimum seasonally tilt angle is maximum in winter ie.41.50° and minimum ie.0.33° in summer by Liu and Jordan model. Optimum seasonally tilt angle is maximum in winter ie.40.66° and minimum ie.1.66° in summer by Badescu model. The daily variation of optimum slope has been extended to evaluate the yearly optimum tilt angle, **($\beta_{opt(y)}$)** the yearly optimum tilt angle is a fixed value for any

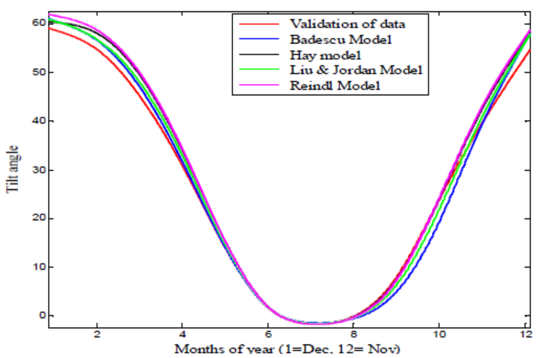

Fig.11 -Comparison of Monthly optimum tilt angle for Delhi

solar collector throughout the course of a year. It is 30.61° for Nandha, Haryana and oriented towards the south. The amount of solar radiation received by the solar collector tilted at yearly optimum angle facing south was computed. Comparison of yearly optimum tilt angle for Village Nandha, Haryana using different models which is further compared from the working setup install at Nandha, Haryana shows that P.V panel at Village Nandha, Haryana is installing at 30° the entire model shows that the yearly optimum tilt angle is close to 30° but Badescu model shows very closeness to the setup install at Village Nandha, Haryana it underestimate the angle just by 0.43%.

Fig.12- Solar panels installed at Village Nandha, Haryana at 30° tilt angle

14-CONCLUSIONS

In this study the solar radiation output of solar collector is investigated at various tilt between angles 0° to 90° for south facing to calculate daily and monthly optimum tilt angles, seasonal optimum tilt angles and yearly optimum tilt angle for different locations in India.

The beam radiation dominates throughout the year where the maximum beam radiation reaches in the month of May whereas the least amount of beam radiation occurs in the month of December at Village Nandha, Haryana.

The optimum tilt angle in June goes to a minimum zero degree as indicated by all the models.

1-The optimum tilt angles increases during the winter months and reaches a maximum of 62° in December by Liu & Jordan model whereas Reindl model, Hay model, Badescu model indicate the optimum tilt angle as 63.5°, 63°, 62.5° resp.

2-When the monthly optimum tilt angles were used, the yearly collected solar radiation was 2.500775×10^7 W/m^{2}day When the seasonal optimum tilt angles were used the yearly collected solar radiation was 2.3669×10^7 W/m^{2}day Finally, when the yearly optimum tilt angle was used, the yearly collected solar radiation was 2.27168×10^7 W/m^{2}day.

3-In winter, a panel fixed at the winter angle will be relatively efficient, capturing 81 to 88 percent of the energy compared to optimum tracking. In the spring, summer, and autumn, the efficiency is lower (74-75% in spring/autumn, and 68-74% in summer), because in these seasons the sun travels a larger area of the sky, and a fixed panel can't capture as much of it.

4. The proper tilt and azimuth angle choice is by far more important for photovoltaic systems design than solar thermal system design.

15- SCOPE FOR FUTURE WORK

1. The optimization tilt angle for other cities can be carried out for India and other location exterior of India.
2. For optimization of tilt angle, we can use isotropic models.
3. If your solar panels will have a fixed tilt angle, and you want to get the most energy over the whole year, A fixed angle is convenient, but notes that there are some disadvantages. As mentioned above, you'll get less power than if you adjusted the angle.

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