Statistical inter-comparison study of empirical models to estimate the monthly-average daily global irradiation on tilted south oriented surfaces

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Abstract. Accurate determinations of the global solar irradiation received by a tilted surface during the average day of each month ($H_{G\,(s,\,0)}$) are a prerequisite in different solar energy applications, particularly in design methods. Validation of empirical models to estimate such values is of paramount importance, given the limited number of solar radiation observation sites and meteorological stations capable of providing the real information. Using the information of global irradiation on horizontal surface (H_G) recommended in the Schedule of Conditions System Technologies of Low Temperature (SCT) for 52 Spanish provinces, four solar irradiation models of estimation were investigated: Liu and Jordan [1], Aláiz [2], Klein [3] and the one proposed by Censolar. A comparative study based on the statisticians of the distribution of the calculated information indicates that the values of $H_{G\,(s,\,0)}$ estimated with the model of Aláiz agreed well with the reference dates. On the contrary, the Censolar model has got the maximum diversion.

Key words

Solar irradiation, tilted surfaces, empirical models estimation, statistical analysis.

1. Introduction

The design of majority of solar active or passive systems, as photovoltaic or solar panels, solar dryers or buildings bioclimatic, is based in the knowledge of quality dates referred to the quantity of incidental irradiation on tilted surfaces. Generally, the design of these systems of solar power needs information of solar irradiation measured in the studied zone or in a sufficiently near point to be able to apply technologies of interpolation. For a great number of cities exists available information of global solar irradiation on a horizontal surface (H_G). Nevertheless, generally does not exits dates of solar irradiation on a tilted surface, due to the disposition of relatively few radiometric stations that measure the components of the solar irradiation in the above mentioned surfaces, which makes the availability of information in interesting place difficult. In these occasions, it is necessary to resort to same empirical models developed by different researchers to estimate these values from other variables commonly measured. With this intention, different authors have proposed several models based on global and diffuse components of the solar irradiation on horizontal surface as Liu and Jordan hourly method [1], the model of brief calculation described by Aláiz [2], the Klein one [3], or the method of calculation developed by CENSOLAR (software censol5.0).

On the other hand, some authors have developed approximations of statistical analyses to study dates of solar irradiation in different territories and geographical locations [4]. These authors, whom use a widespread distribution of type lambda (GLD), conclude that it fits well the information analyzed. The description of the distribution frequency is based on the values obtained for the skewness and kurtosis coefficients. The distribution extent is determined by the value of the mean and the variation coefficient which determine the diversions in each calculated parameters.

In this work, a statistical analysis is developed for each series of dates obtained from each model of estimation used, with the purpose of determining the typical parameters of the normal distribution, to be able to compare them and conclude which of them fits better the real or reference values.

2. Methods and Reference Dates.

The H_G used as starting point for the estimation of $H_{G(s,\,0)}$, were recommended by SCT, whose source is Censolar.

$H_{G(s,\ 0)}$ has been calculated for 52 Spanish provinces, following the methodology described by the empirical models [1-3] and the Censolar one. It was done determinations varying the tilted angle from 0 to 90º. In this study was included the tilted angle of local latitude.

A statistical treatment of the dates was developed with a program called Surfer version 8.0. The statistical analysis consisted in obtaining the typical characteristics of the values distribution. The median, the variation, skewness and kurtosis coefficients were considered for the comparison of Liu and Jordan method [1] against the other models.

The validity of the analysis described before, was determinated by the regression coefficients (R^2), calculated from the plot $H_{G(s,0)}$(reference dates) versus $H_{G(s,0)}$(estimated values). This study was developed for each month and for the annual average.

3. Results and discussion

First of all, $H_{G(s,0)}$ were calculated, for 52 Spanish provinces varying the tilted angle. After plotting $H_{G(s,0)}$ versus tilt, it was observed that the values represented follow a normal distribution. The statement mentioned before can be certified with Figure 1, which shows the plot for the annual average.

Some significant statisticians of the dates plotted in Figure 1 and the regression coefficients of the plot $H_{G(s,0)}$(reference dates) versus $H_{G(s,0)}$(estimated values) are presented in Table 1.

A qualitative valuation of the characteristic parameters showed in Table 1, reflects diversion in values obtained from different models. Figure 2 shows the dates corresponding to the mean values and variation coefficient in Table 1, apart from others calculated for tilted angle that doesn't appear in the graph.

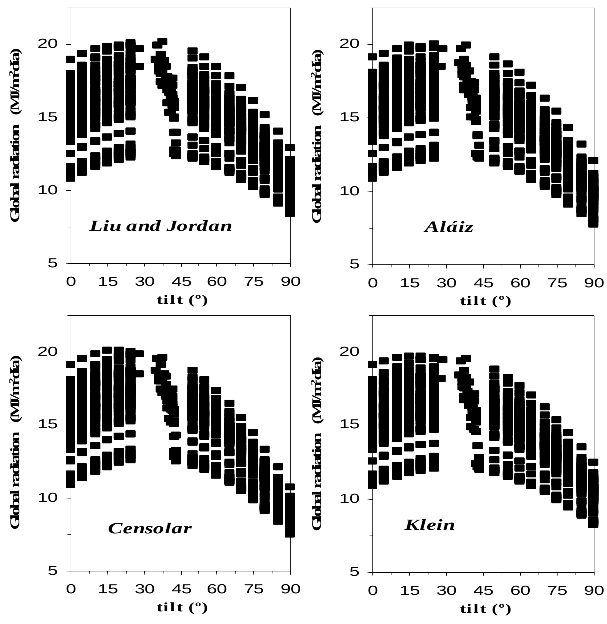

Figure 1. *Monthly-average daily global irradiation variation overage annual, estimated with the different models for 52 Spanish provinces.*

Table 1. ***Statistical analysis***

Tilt (º)	Parameters	Models			
		Liu y Jordan	Aláiz	Censolar	Klein
0	1	14.8280	14.8910	14.8910	14.8910
	2	15.0630	15.1250	15.1250	15.1250
	3	0.1329	0.1333	0.1333	0.1333
	4	-0.3990	-0.3910	-0.3910	-0.3910
	5	-0.2830	-0.2790	-0.2790	-0.2790
	6	1.0000	1.0000	1.0000	1.0000
15	1	16.1530	16.1730	15.9370	16.3110
	2	16.4140	16.4060	16.1930	16.6430
	3	0.1279	0.1281	0.1230	0.1282
	4	-0.5230	-0.4990	-0.5020	-0.5370
	5	-0.3090	-0.3190	-0.2600	-0.3070
	6	1.0000	0.9999	0.9973	0.9998
30	1	16.6510	16.5890	16.2460	16.7490
	2	16.9450	16.8530	16.5030	17.1120
	3	0.1229	0.1229	0.1141	0.1228
	4	-0.5980	-0.5720	-0.6580	-0.5850
	5	-0.2640	-0.2740	-0.1860	-0.2690
	6	1.0000	0.9998	0.9901	0.9995
45	1	16.2870	16.1800	15.7760	16.0590
	2	16.6220	16.3460	16.5170	16.0560
	3	0.1176	0.1173	0.1060	0.1170
	4	-0.6340	-0.6010	-0.7590	-0.6410
	5	-0.1790	-0.1880	-0.0470	-0.1850
	6	1.0000	0.9997	0.9790	0.9990
60	1	15.0870	14.6830	14.5550	14.6390
	2	15.3840	14.9820	14.8450	14.9490
	3	0.1115	0.1106	0.0977	0.1105
	4	-0.6270	-0.5840	-0.8160	-0.6640
	5	-0.0770	-0.0460	0.0980	-0.0720
	6	1.0000	0.9994	0.9631	0.9979
75	1	13.1320	12.6730	12.2420	12.5220
	2	13.3640	12.6970	12.4530	12.9560
	3	0.1041	0.1036	0.0890	0.1027
	4	-0.5500	-0.4990	-0.7960	-0.6370
	5	0.0030	0.0330	0.1950	0.0350
	6	1.0000	0.9986	0.9364	0.9958
90	1	10.5560	10.2930	9.1364	9.7555
	2	10.6300	9.8019	9.3060	10.4250
	3	0.0953	0.0956	0.0803	0.0936
	4	-0.3410	-0.2630	-0.6400	-0.5230
	5	-0.0710	-0.0670	0.0410	-0.0830
	6	1.0000	0.9968	0.8737	0.9865

1.- Mean. 2.- Median. 3.- Coefficient of variation. 4.- Coefficient of skewness. 5.- Coefficient of kurtosis 6.- Coefficient of regression

If the mean values contained in Figure 1 are analyzed, it is observed that these values obtained from Aláiz and Klein models have got similar diversions in respect of the reference values (obtained from Liu and Jordan) and lower than the Censolar one, calculated up to an angle close to 30º. In the tilted angle interval between 28.2 and 43.5, which tally with a tilted equal to the latitude of the 52 provinces studies (shaded band in Figures 2-4), Aláiz model shows lower diversion than Klein model. Meanwhile the Censolar one has got the worst results. Finally, from 45º, the three models diversions increase in that way: Aláiz ≤ Klein <Censolar.

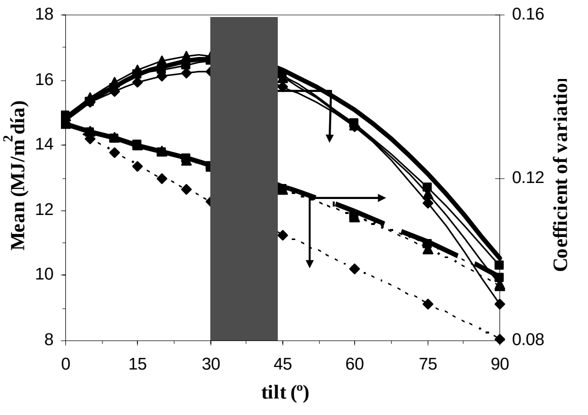

Figure 2. *Mean and variation coefficient evolution. Thick lines: Liu and Jordan Model. Symbols:■ Aláiz Model; ♦ Censolar Model; ▲ Klein Model.*

The discussion showed in the paragraph above can be confirmed if the Figure 2 is analyzed, which present the plot variation coefficient versus tilted. In this case, Aláiz and Klein models have got similar results and they are near to the reference ones. The results calculated by Censolar model are dispersed. At first, it can be thought that the results of this parameter are wrong as a consequence of the decrease of the variation coefficients with an increase in tilted angle. However, logically, they must be null or similar to zero. The $H_{G(s,0)}$ interval considered by the statistical analysis for the determination of the mean value decreases with an increase in tilted angle (Figure 1). Consequently, is obvious that the parameters values come closest to zero.

With the results summarized in Table 1 and showed in Figure 3, corresponding to skewness and kurtosis coefficients, it can be concluded: a) The kurtosis coefficient obtained from Aláiz and Klein models are practically the same as the ones calculated by Liu and Jordan models up to 45º. Nevertheless, the coefficients obtained from Censolar model have got the highest diversion. The conclusion refers to skewness coefficients are similar, but in this case the three models diversion are bigger. b) With regard to the characteristics that describe these parameters, it serves to confirm that the estimated dates by the different models follow a normal distribution, because the mean values and median one are closer to each other.

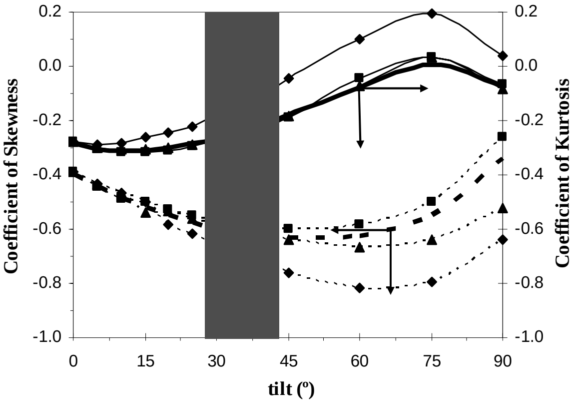

Figure 3. *Skewness and kurtosis coefficients Evolution. Thick lines: Liu and Jordan Model. Symbols:■ Aláiz Model; ♦ Censolar Model; ▲ Klein Model.*

To support the conclusions obtained from the statistical analysis, the Figure 4 shows the plot regression coefficients (Table 1) versus tilted angle. Again it may be deduced that Aláiz and Klein models give the best results (R^2> 0.99 in all cases), but on the contrary the Censolar model provides a gradual fall, which increases from tilted angle interval tallies with the provinces latitudes (R^2 <0.99 for angles bigger than 30 º).

In order to select the best empirical model to be able to to estimate $H_{G(s,\ 0)}$, a quantitative valuation with the result in Table 1 has been carried out. For this, the experimental error between the three models and the reference values were calculated. These results are shown in Table 2, where is indicated which model provides the minimum diversion. It can be deduced that the Aláiz model is the best one for all tilted angles, cause it provides the best main and variation coefficients results. There is a greater diversion in reference to the skewness and kurtosis coefficients (tilted angle > 60º, Aláiz is better and tilted angle <60º, Klein is better). All of this results conclude that the Aláiz model is the best one which leads to the $H_{G(s,0)}$ to the real values. Finally, the results propose in that section can be extrapolated to the rest of the calculations obtained and evaluated for each month.

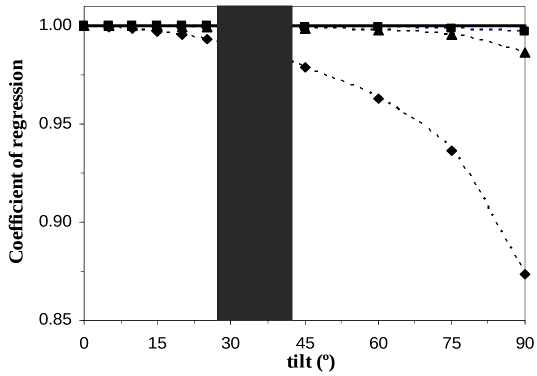

Figure 4. ***R****egression coefficient evolution. Thick lines: Liu and Jordan Model. Symbols:■ Aláiz Model; ♦ Censolar Model; ▲ Klein Model.*

Table 2. ***Quantitative results of the comparative analysis***

Tilt (º)	Parameters	Inter-Comparison of models		
		Aláiz	Censolar	Klein
0	1	OK	OK	OK
	2	OK	OK	OK
	3	OK	OK	OK
	4	OK	OK	OK
	5	OK	OK	OK
	6	OK	OK	OK
15	1	OK		
	2	OK		
	3	OK		
	4			OK
	5			OK
	6	OK		
30	1	OK		
	2	OK		
	3	OK		
	4			OK
	5			OK
	6	OK		
45	1	OK		
	2		OK	
	3	OK		
	4			OK
	5			OK
	6	OK		
60	1	OK		
	2	OK		
	3	OK		
	4			OK
	5			OK
	6	OK		
75	1	OK		
	2			OK
	3	OK		
	4	OK		
	5	OK		
	6	OK		
90	1	OK		
	2			OK
	3	OK		
	4	OK		
	5	OK		
	6	OK		

1.- Mean. 2.- Median. 3.- Coefficient of variation. 4.- Coefficient of skewness. 5.- Coefficient of kurtosis 6.- Coefficient of regression

4. Conclusion

1.-Three empirical models were studied for estimating $H_{G(s,0)}$. Aláiz and Klein models provide similar values each other and values close to the reference one, while the Censolar one leads to greater diversions.

2.-Considering that in most of the solar installations, the optimum tiltle angle is the same as the latitude value, it concludes that Aláiz model is the best for the estimate of the $H_{G(s,0)}$ average value.

3.-The $H_{G(s,0)}$ dates for 52 Spanish provinces suggests a normal distribution adjust.

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