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EXPERIMENT AND MODEL COMPUTATION OF HOURLY GLOBAL RADIATION ON A TILTED SURFACE IN DHAKA, BANGLADESH

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ABSTRACT

Sattar A, Khatun MA, Mashud AHM, Huda A (2016) Experiment and model computation of hourly global radiation on a tilted surface in Dhaka, Bangladesh. *Ins. Engg. Tech.* 6(1), 31-39.

The hourly global radiation tilt factors for the noon hour were measured for inclination of 10^0, 20^0, 25^0, 30^0, 40^0 and 50^0. We also compute the tilt factor using l4 different models using the experimentally measured global radiation and diffuse radiation. From the comparison for result of the theory and experiment, Klucher model appears to work better for Dhaka.

Key words: *tilt factor, global radiation, diffuse radiation*

INTRODUCTION

Accurate solar radiation data are necessary at every steps of the design, simulation and performance verification of any experiment and project involving solar energy. Most solar energy systems are installed on either fixed tilted surfaces or tracking receivers. For these systems, global irradiance incident on tilted surfaces is the key to the evaluation of the solar resource and of the performance of all these systems. Because of the lack of radiation data on the tilted surface, the solar resource needs to be modeled in most cases. In most countries, the global radiation data and diffuse radiation data are measured for a long period, which can be used to predict the global irradiance on tilted surface using different models.

There are several models for calculating the global radiation tilt factor which is the ratio of total radiation on a tilted surface, H_β to that on a horizontal plane H. We used the Isotropic, Hay, Klucher and Perez models in our computation. The differences between the models arise from the treatment of the diffuse radiation H_d. In this work, experimental measurement were made for the data of global radiation H, global radiation on tilted surface H_β and diffuse radiation H_d. We used these data for the experimental and theoretical values of tilt. We compared the measured and experimental value of tilt factor and obtain the most accurate model for calculating tilt factor.

THE EXPERIMENT

Data for Globar radiation, beam radiation and diffuse radiation were measured at the campus of Jagannath University, Dhaka. Measurements were made with an Eppley pyranometer, which was calibrated against a normal incidence Eppley Pyrheliometer. A Beckman multimeter was used to obtain the output of the pyrheliometer which was capable of measuring up to 10^{-2} millivolts. In order to measure the incident radiation on a tilted surface by a single pyranometer, a narrow tilting table was constructed which had a movable rectangular pyranometer support made of wood over the table top, joined together by hinges and screws at one side of the table to support in order to fix the pyranometer on it using nuts and bolts. Global and diffuse radiations were measured with a separate pyranometer by keeping it horizontal. We used a circular disc to block the direct radiation and measure the diffuse radiation. We used almost the same procedure earlier worked by Duffie and Beckman (2013) for winter season. In this work, the summer time tilt factor is computed using both theory and experiment. According to Huda and Ahmed (2013) proper utilization of solar energy in Bangladesh is also considered in this experiment. Jasmina *et al.* (2013) state that maximizing performances of variable tilt flat-plate for solar collectors in the region of Belgrade (Serbia).

A set of data on global and diffuse radiation incident on the horizontal pyranometer and total radiation on the tilted pyranometer were obtained within a couple of minutes or so and nearly instantaneous values of the tilt factor are computed. Measurements were repeated at an interval of around 15 min for the same tilt angle. Within the 15 min interval, similar data were obtained for four other tilt angles. We exclude the data when radiation is varying continuously to avoid wrong computation. Instantaneous values of tilt factor, averaged over the hour, gave the hourly global radiation tilt factor. Measurements were made in the month of 25.03.2015-27.5.2015 on 50 days.

MODELS USED FOR COMPUTING THE TILT FACTOR

ISOTROPIC MODELS

According to Hussain and Huda (1998) in isotropic model, the sky is assumed to be equally illuminated. The beam radiation tilt factor can be calculated by the expression.

$$R_b = \frac{Cos\theta}{Cos\theta z} \quad (1)$$

Where

$$Cos\theta = Sin\varphi(Sin\delta Cos\beta + Cos\delta Cos\gamma Cos\omega Sin\beta) + Cos\varphi(Cos\delta Cos\omega Co\beta - Cos\gamma Sin\delta Sin\beta) + Cos\delta Sin\gamma Sin\omega Sin\beta$$

and $Cos\theta_z = Sin\varphi Sin\delta + Cos\varphi Cos\delta Cos\omega$.

In this work, the standard nomenclature Liu and Jorban (1963) are used.

If the surface is facing towards the equator, azimuth angle $\gamma = 0$ and equation (1) become:

$$R_b = \frac{Sin(\varphi - \beta)Sin\delta + \cos(\varphi - \beta)Cos\delta Cos\omega}{Sin\varphi Sin\delta + \cos\varphi Cos\delta Cos\omega} \quad (2)$$

where ω is the hour angle for that instant.

The value of diffuse radiation tilt factor depends upon the distribution of diffuse radiation over the sky and on the portion of the sky dome seen by the tilted surface. Assuming the sky is an Isotropic source of diffuse radiation, we have:

$$R_d = \frac{1 + Cos\beta}{2} \quad (3)$$

R_d is called the shape factor. This value of the tilt factor depends upon the distribution of the diffuse radiation over the sky and on the portion of the sky dome seen by the tilted surface.

Assuming that the reflection of the beam and diffuse radiation on the ground is diffuse and Isotropic and p is the reflectivity of ground, the reflected radiation tilt factor is:

$$R_r = \frac{\rho(1 - Cos\beta)}{2} \quad (4)$$

So the tilt factor for global radiation is given by:

$$R = \left(1 - \frac{D}{G}\right)R_b + \frac{D}{G}R_b + R_r \quad (5)$$

Where D and G are the diffuse and global radiations at that instant.

Koronakis model

Koronakis (1986) modified the isotropic model also called the Liu and Jordan model (1962). The new expression for the diffuse radiation becoming

$$I_{d,\beta} = \frac{1}{3} I_d (2 + \cos\beta) \quad (6)$$

Badescu model

Badescu (2002) also amended the assumption of an isotropic diffuse sky changing some coefficients of the isotropic model to reach a new expression and obtain acceptable results for different directions simultaneously

$$I_{d.\beta} = \frac{1}{4} I_d [3 + \cos 2\beta] \quad (7)$$

Hay's model

Hay (1979) showed that the assumption of considering the sky as an isotropic source of diffuse radiation is not appropriate and suggested that sky diffuse radiation bring about two sources. The circumsolar component coming from the direction near the solar disk and a diffuse component isotropic ally distributed from the rest of the sky. Those two components are described according to an index of anisotropy F_{Hay} which represents transmittance though the atmosphere of direction irradiance.

$$F_{Hay} = \frac{I_b}{I_0} = \frac{I - I_d}{I_0} \quad (8)$$

Where I is the intensity of total solar radiation on a horizontal plane; I_b is the intensity of beam radiation on a horizontal place and I_0 is the extraterrestrial erythemal irradiance on a horizontal place.

Then, the equation of the intensity of diffuse radiation on a inclined plane is,

$$I_{d.\beta} = I_d \left[F_{Hay}\left(\frac{\cos\theta}{\cos\theta_z}\right) + (1 - F_{Hay})\left(\frac{1 + \cos\beta}{2}\right) \right] \quad (9)$$

When the diffuse radiation is near about global radiation ($I_d \sim I$) i,e on cloudy days global reduced to the isotropic model.

Bugler's model

Bugler (1977) modified the isotropic model to take into account the diffuse irradiance comes from the sun's disc and the rest of the sky, dependent on the angular height of the sun over the horizon.

The expression the diffuse component on an inclined planed on Bugler equation is,

$$I_{d,\beta} = \frac{1}{2} I_d \left(I + \cos\beta\right) + 0.05\, I_{b,\beta} \left[\cos\theta - \frac{1}{\cos\theta_z}\left(\frac{1+\cos B}{2}\right)\right] \tag{10}$$

where θ_z *is* zenith angle of sun.

Temps Coulson's model

Temps and Coulson (1977) suggested that two factors in the Liu and Jordan equation simulate the anisotropy of the sky in clear conditions, considering the Isotropic model as valid for overcast skies.

The first factor representing diffuse radiation coming from the vicinity of the sun's disc (P_1) and the second factor takes into account the brightness of the sky near the horizon.

where, $P_1 = 1 + \cos^2\theta.\sin^3\theta_z$

and, $P_2 = 1 + \sin^3\left(\beta/2\right)$

Ultimately, the Temps and Coulson equation is as follows,

$$I_{d,\beta} = \frac{1}{2} I_d \left(1+\cos\beta\right)\left[1 + \sin^3 \beta/2\right]\left(1 + \cos^2\theta\sin^2\theta_z\right) \tag{11}$$

Ma Iqbal model

Ma and Iqbal (1983) proposed a model where diffuse radiation dividing into two terms, the circumsolar region and radiation emitted by the rest of the sky.

The Ma-Iqbal model not like the Hay model used the clearness index as an index of anisotropy K_T,

$$K_T = \frac{I}{I_0} \tag{12}$$

The Ma-Iqbal model is described by this equation,

$$I_{d,\beta} = I_d \left[K_T \frac{\cos\theta}{\cos\theta_z} + \left(1 - K_T\right)\cos^2\left(\beta/2\right)\right] \tag{13}$$

Olseth and Skartveit model

Skartveit and Olseth (1987) was proposed another anisotropic model. Solar radiation measurements carried out by them in Bergen (Norway) showed that significant part of sky diffuse radiation overcast sky conditions comes from the sky region around the zenith. They suggest introducing a correction factor Z as a linear function of the anisotropy index of Hay, F_{Hay}

$$\begin{cases} Z = 0.3 - 2F_{Hay} & for\ F_{Hay} \angle 0.15 \\ Z = 0 & when\ F_{Hay} \geq 0.15 \end{cases}$$

Then the expression of the diffuse component on an inclined plane on olseth and skartveit model is,

$$I_{d,\beta} = I_d \left[F_{hay}\frac{\cos\theta}{\cos\theta_z} + z\cos\beta\right] + I_d \left[\left(1 - F_{Hay} - z\right)\left(1 + \frac{\cos\beta}{2}\right) - s\left(\omega, \Omega_i\right)\right] \tag{14}$$

where $s\left(\omega, \Omega_i\right)$ is the portion of solid angle with obstacles on the real horizon. In most cases, obstacles on the horizon are virtually nonexistent, and the latter term can be neglected, since the order of magnitude in much smaller than in the other terms.

Reindl model

Reindl *et al.* (1990) added a module for the diffuse radiation coming from the region near the horizon line. They found that the intensity of diffuse radiation originating from this region decreases as sky overcast increases and so they included modulating function f_R in the module:

$$f_R = \sqrt{\frac{I_b}{I}} \tag{15}$$

The Reindl equation is as follows:

$$I_{d,\beta} = I_d \left[\left(1 - F_{Hay}\right)\left(\frac{1+\cos\beta}{2}\right)\left(1 + f_R.\sin^3\left(\frac{\beta}{2}\right) + F_{Hay} r_b\right)\right] \tag{16}$$

The function modulating the intercity of diffuse radiation coming from the region near the horizon line works relatively simply. When the sky is fully overcast, beam radiation intensity I_b is close to zero and so function f_R also becomes zero. At this moment the model assumes that the diffuse radiation in the region near the horizon line is isotropic.

Pérez-2 model

We use the most simplified form of the Perez *et al.* (1987) model. In this version, the circumsolar radiation is considered to come from a point source, and the diffuse radiation tilt factor is given by

$$R_d = \frac{1}{2}(1+\cos\beta)(1-F_1') + F_1'(\cos\theta/\cos\theta_z) + F_2' \sin\beta \quad (17)$$

where F_1' and F_2' are the circumsolar brightness coefficient and horizontal brightness coefficient, respectively. These are defined as

$$F_1' = F_{11}'(\varepsilon) + F_{12}'(\varepsilon)\Delta + F_{13}'(\varepsilon)\theta_z$$
$$F_2' = F_{12}'(\varepsilon) + F_{22}'(\varepsilon)\Delta + F_{23}'(\varepsilon)\theta_z$$

Here, ε is the sky clearness parameter given by ε = $(H_d+H_{bn})/H_0$, and $F_{11}', F_{12}', F_{13}'$ etc. are functions of ε whose values are obtained from the table given by Perez model, while ε is called the sky brightness parameter given by: Δ = mH_d/H_0 and $H_{bn} = (H-H_d)/\cos\theta_z$.

Munner model

The Muneer (2004) anisotropic model considers separately planes illuminated with sunlight and the shaded ones. In addition, it divides planes illuminated with sunlight depending on sky cloudiness.

The equation of the intensity of diffuse radiation onto shaded planes and planes illuminated with sunlight under a cloudy sky (a theoretical possibility of illumination exists because of the position of the Sun over the plane) is as follows:

$$I_{d,\beta} = I_d\left[\cos^2\left(\frac{\beta}{2}\right) + \frac{2b}{\pi(3+2b)}.\left(\sin\beta - \beta\cos\beta - \pi\sin^2\left(\frac{\beta}{2}\right)\right)\right] \quad (18)$$

while for planes illuminated with sunlight under a cloudless sky it has this form:

$$I_{d,\beta} = I_d\left[\cos^2\left(\frac{\beta}{2}\right) + \frac{2b}{\pi(3+2b)}.\left(\sin\beta - \beta\cos\beta - \pi\sin^2\left(\frac{\beta}{2}\right)\right)\right](I - F_{Hay}) + I_d.F_{Hay}\left(\frac{\cos\theta}{\cos\theta_z}\right) \quad (19)$$

According to Munner model, coefficient b in Equation (18) is constant and amounts to 2.5. It is variable in Equation (19) and is calculated from the following relation derived for data coming from 14 locations all over the world.

Klucher model

This model is based on a study of clear sky conditions by temps and coulson. Their model are modified by klucher, who incorporated condition of cloudy skies. Temps and coluson observed that clear sky condition can be depicted by modifying the basic Isotropic formulation. The expression for instantaneous tilt factor is:

$$R = \left(1-\frac{D}{G}\right)R_b + \frac{D}{G}R_b + R_r \quad (20)$$

Where R_b is evaluated by equation (2) and from the Klucher model

$$R_d = \frac{1}{2}(1+\cos\beta)\left[1+FSin^3(\beta/2)\right]\left[1+FCos^2\theta Sin^3\theta_2\right] \quad (21)$$

where, $F = 1-\left(D/G\right)^2$ (22)

The term F was absent in the Temps Coulson model. This term was introduced by Klucher, which incorporate cloudy sky condition. When the skies are overcast F=O. When the skies are clear F→1.

The hourly lilt factor can be evaluated by following the same procedure using the mid hour values of θ and θ_z.

The general expression for lilt factor in this case.

$$r = \left(1-\frac{I_d}{I_g}\right)r_b + \frac{I_d}{I_g}r_d + r_r \quad (23)$$

Where R_b is evaluated using formulas of section (2) and I_d and I_g are the hourly diffuse and global radiation and R_d can be evaluated by expression (21).

where $F = 1-\left(I_d/I_g\right)^2$ (24)

The daily tilt factor can be obtained by averaging the hourly tilt factor.

Hay Willmott model

Willmott *et al.* (1982) used the same assumptions as Hay and defined a new anisotropic index *as*,

$$K_\beta = \frac{I_{b,n}}{I_0}\cos\theta \tag{25}$$

now considering the incidence angle instead of the solar zenith angle. In this model the diffuse irradiance for anisotropic sky will be:

$$I_{d,am} = \frac{I_d K_\beta}{\cos\theta_z} \tag{26}$$

and diffuse irradiance for an isotropic sky :

$$I_{d,iso} = I_d c_\beta \left(1 - \frac{K_0}{\cos\theta_z}\right) \tag{27}$$

where K_0 is the Willmott anisotropy index for a horizontal surface, being:

$$K_0 = \frac{I_{b,n}}{I_0}\cos\theta_z \tag{28}$$

which coincides with the anisotropy index originally proposed by Hay, F_{Hay}

The term C_β Revfeim (1987) is an isotropic reduction factor for inclined planes:

$$C_\beta = 1.0115 - 0.20293\beta - .080823\beta^2 \tag{29}$$

for $0.5 \leq C_\beta \leq 1.0$ with β in radians.

$$I_{d,\beta} = I_d\left[\frac{K_\beta}{\cos\theta_z} + C_\beta\left(1 - \frac{K_0}{\cos\theta_z}\right)\right] \tag{30}$$

Pérez-1 model

The Pérez *et al.* (1986) model is one of the most widely used anisotropic model because of its results most accurate calculation modes. This model assumes the three sub-components with different diffuse radiation intensities: the circumsolar, horizon diffuse and the rest of the sky which is isotropic.

The expression of the diffuse component onto an inclined plane looks as follow:

$$I_{d,\beta} = I_d\left[(1+F_1)F_1 + \frac{a}{b} + F_2 \sin\beta\right] \tag{31}$$

The terms a and b are calculated as,

a = max $(0, \cos\theta)$

b = max $(\cos 85^0, \cos_z)$

Coefficients F_1 and F_2 are called coefficients of brightness reduction. F_1 and F_2 are function of three variables $(\theta_z, \varepsilon, \Delta)$ that describe the sky conditions.

$$\varepsilon = \frac{\dfrac{I_d + I_b + 1.041\theta^3{}_z}{I_d}}{1 + 1.041\theta_z^3}$$

$$\Delta = \frac{I_d m}{I_0 n} = \frac{I_d}{I_{0,n}\cos\theta_z}$$

where m is the optical mass and is the sky clearness index and the sky brightness index of Perez model.

F_1 and F_2 are calculated according to expression,

$$F_1 = \max\left[0, F_{11} + F_{12}\Delta + F_{13}\theta_z\right]$$

$$F_2 = F_{21} + F_{22}\Delta + F_{23}\ \theta_z$$

F_{ij} coefficients were found by a statistical analysis of empirical data for a specific location (valencia), depending on the value of the sky clearness index, ϵ Utrillas and Martínez-Lozano (1994).

COMPARISON TECHNIQUE

In this work, the values of the experimental and calculated tilt factor are compared using the root mean square error (RMSE) and mean bias error (MBE) were determined using the following expressions;

$$RMSE = \left\{\sum_i \frac{(R_i^{cal} - R_i^{exp})^2}{n}\right\}^{1/2}$$

$$MBE = \left\{\sum_i \frac{(R_i^{cal} - R_i^{exp})}{n}\right\}$$

We also present the %RMSE and %MBE in our computation.

RESULTS

The following results are obtained from this experiment and comparison of different models

- Klucher model in low tilt angle gives an overestimated value and in high tilt factor it is underestimated values.
- Temps and Coulson model is overestimated in all the tilt angle.
- Klucher model performs best among these models in both (summer and winter) climatic condition of Bangladesh.

CONCLUSION

In this work, we used a wooden frame to measure the Global and Diffuse radiation on a horizontal surface and global radiation on six different tilted surfaces 10^0, 20^0, 25^0, 30^0, 40^0 and 50^0 the ratio between the global radiation on tilted surface and global radiation on a horizontal surface give us the experimental tilt factor and using the global and Diffuse radiation on a horizontal surface we calculated the model computed tilt factor. We used fourteen different models in our calculations.

Table-1-6 presents, the mean tilt factor, the mean bias error and root mean square error for 10^0, 20^0, 25^0, 30^0, 40^0 and 50^0. From all the tables it is observed that most of the models except models of Klucher and Temps and Coulson give an underestimated value of tilt factor, Klucher model in low tilt angle gives an overestimated value and in high tilt factor it is underestimated values. Temps and Coulson model is overestimated in all the tilt angle.

Most of the models deviated very highly in the higher tilt factor except the Klucher and Temps and Coulson model. We observe that Temps and Coulson model mean bias error [%] is lowest among all the models.

At 10^0, the best result as regards MBE is obtained from the Koronakis model. The other models, e.g. Isotropic, Hay, Ma and Iqbal, Olseth and Skartvit, Perez-1, Muneer, Badelscu, Perez-2 etc. result are close to the koronakis model. We observe that with the increase to tilt factor the rms errors are increasing. At 20^0 tilt, the best results with respect to rms are from Kluche. The next best models are, Koronakis, Hay, Isotropic and Temps and Coulson model. We found that the results from bugler, Ma Iqbal, Reindel, Muneer Hay Willmott models are not satisfactory. At 25^0 tilt, the best result is obtained from the Temps and coulson model. The Klucher, Koronakis and Hay model also have good performance. Similarly at 30^0 and 40^0 tilt angle, we observed that the performance in Klucher, Koronakis and Hay model. We can use any of this four models in our calculation. However considering also the winter data, Klucher model performs best among these models in climatic condition of Bangladesh.

Table 1. Mean experimental value and statistical indicators of different models at an inclination of 10^0

Models	Mean experimental tilt factor	MBE	RMSE	MBE%	RMSE(%)
Isotropic	0.982509	-0.0075	0.1049	-0.789	10.5261
Hay		-0.0059	0.1049	-0.5967	10.5248
Klucher		0.0463	0.1162	4.6495	11.6587
Koronakis		-0.0062	0.1047	-0.6265	10.5065
Bugler		-0.278	0.1103	-2.788	11.0619
Temps & Culson		0.0495	0.1173	4.9663	11.7633
Ma-Iqbal		-0.0122	0.1062	-1.2258	10.6527
Olseth & Skartvit		-0.0093	0.1053	-0.9317	10.5638
Renidl		-0.0157	0.1071	-1.5765	10.7442
Pérez-1		-0.0091	0.1052	-0.9083	10.5493
Muneer		-0.0101	0.1059	-1.0115	10.6238
Badescu		-0.0068	0.1052	-0.6868	10.5583
Hay-Willmott		-0.0111	0.1056	-1.1108	10.5919
Pérez-2		-0.0092	0.106	-0.9257	10.6308

Table 2. Mean experimental value and statistical indicators of different models at an inclination of 20^0

Models	Mean experimental tilt factor	MBE	RMSE	MBE%	RMSE(%)
Isotropic	0.980312	-0.0344	0.124	-3.4549	12.6883
Hay		-0.0282	0.1252	-2.8323	12.5609
Klucher		0.0146	0.1247	1.4619	12.5109
Koronakis		-0.0296	0.1248	-2.9678	12.5211
Bugler		-0.0550	0.1359	-5.5150	13.6337
Temps & Culson		0.0274	0.1256	2.7489	12.6088
Ma-Iqbal		-0.0488	0.1334	-4.8963	13.3866
Olseth & Skartvit		-0.0400	0.1290	-4.0188	12.9437
Renidl		-0.0538	0.1358	-5.4020	13.6286
Pérez-1		-0.0385	0.1280	-3.8677	12.8492
Muneer		-0.0430	0.1308	-4.3157	13.1275
Badescu		-0.0311	0.1269	-3.1200	12.7337
Hay-Willmott		-0.0481	0.1321	-4.8263	13.2536
Pérez-2		-0.0417	0.1311	-4.1883	13.1550

Table 3. Mean experimental value and statistical indicators of different models at an inclination of 25^0

Models	Mean experimental tilt factor	MBE	RMSE	MBE%	RMSE(%)
Isotropic	0.979281	-0.0491	0.1514	-4.9504	15.2687
Hay		-0.0393	0.1488	-3.9604	15.0102
Klucher		-0.0027	0.1450	-0.2738	14.6214
Koronakis		-0.0415	0.1485	-4.1907	14.9754
Bugler		-0.0696	0.1623	-7.0195	16.3686
Temps & Culson		0.0174	0.1442	1.7565	14.5421
Ma-Iqbal		-0.0700	0.1621	-7.0602	16.3501
Olseth & Skartvit		-0.0573	0.1553	-5.7810	15.6602
Renidl		-0.0738	0.1640	-7.4454	16.5443
Pérez-1		-0.0546	0.1536	-5.5045	15.4967
Muneer		-0.0618	0.1582	-6.2381	15.9558
Badescu		-0.0440	0.1514	-4.4354	15.2757
Hay-Willmott		-0.0696	0.1610	-7.0175	16.2344
Pérez-2		-0.0606	0.1587	-6.1074	16.0094

Table 4. Mean experimental value and statistical indicators of different models at an inclination of 30^0

Models	Mean experimental tilt factor	MBE	RMSE	MBE%	RMSE (%)
Isotropic	0.97762	-0.0587	0.1579	-6.0091	16.1511
Hay		-0.0444	0.1536	-4.5387	15.7085
Klucher		-0.0148	0.1495	-1.5140	15.2970
Koronakis		-0.0480	0.1535	-4.9077	15.7002
Bugler		-0.0790	0.1698	-8.0771	17.3668
Temps & Culson		0.0143	0.1474	1.4589	15.0789
Ma-Iqbal		-0.0873	0.1742	-8.9291	17.8156
Olseth & Skartvit		-0.0700	0.1640	-7.1635	16.7713
Renidl		-0.0887	0.1743	-9.0685	17.8325
Pérez-1		-0.0656	0.1613	-6.7079	16.4991
Muneer		-0.0765	0.1681	-7.8217	17.1954
Badescu		-0.0518	0.1577	-5.2968	16.1283
Hay-Willmott		-0.0867	0.1722	-8.8722	17.6167
Pérez -2		-0.0752	0.1686	-7.6972	17.2461

Table 5. Mean experimental value and statistical indicators of different models at an inclination of 40^0

Models	Mean experimental tilt factor	MBE	RMSE	MBE%	RMSE(%)
Isotropic	0.924948	-0.0847	0.1800	-8.9558	19.0321
Hay		-0.0581	0.1698	-6.1416	17.9461
Klucher		-0.0442	0.1675	-4.6728	17.7022
Koronakis		-0.0659	0.1717	-6.9659	18.1485
Bugler		-0.1042	0.1940	-11.020	20.5109
Temps & Culson		0.0075	0.1611	0.7937	17.0355
Ma-Iqbal		-0.1316	0.2106	-13.910	22.2607
Olseth & Skartvit		-0.1034	0.1918	-10.926	20.2761
Renidl		-0.1246	0.2046	-13.171	21.6263
Pérez-1		-0.0940	0.1862	-9.9321	19.6851
Muneer		-0.1145	0.1979	-12.100	20.9241
Badescu		-0.0743	0.1784	-7.8591	18.8567
Hay-Willmott		-0.1280	0.2051	-13.527	21.6837
Pérez -2		-0.1137	0.1988	-12.025	21.0158

Table 6. Mean experimental value and statistical indicators of different models at an inclination of 50^0

Models	Mean experimental tilt factor	MBE	RMSE	MBE%	RMSE(%)
Isotropic	0.885867	-0.0836	0.2088	-9.5558	23.8749
Hay		-0.0398	0.1952	-4.5574	22.3299
Klucher		-0.0437	0.1981	-4.9963	22.6616
Koronakis		-0.0548	0.1986	-6.2704	22.7089
Bugler		-0.1011	0.2215	-11.561	25.3334
Temps & Culson		0.0369	0.1967	4.2241	22.4945
Ma-Iqbal		-0.1523	0.2512	-17.419	28.7314
Olseth & Skartvit		-0.1110	0.2245	-12.695	25.6791
Renidl		-0.1331	0.2369	-15.219	27.0976
Pérez -1		-0.0948	0.2163	-10.841	24.7345
Muneer		-0.1279	0.2344	-14.622	26.8131
Badescu		-0.0710	0.2077	-8.1209	23.7566
Hay-Willmott		-0.1389	0.2380	-15.891	27.2183
Pérez -2		-0.1281	0.2365	-14.647	27.052

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