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Risk Evaluation in Predicting Solar Radiation Transmissivity (SRT) Based on Latitude-Incident Angle Ratio of the Radiation

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Abstract

Risk evaluation in predicting solar radiation transmissivity, ϑ (SRT) based on the latitude-incident angle ratio of radiation, Φ/θ was carried out. A model; $\vartheta = (\Phi/\theta)^{0.2}$ was derived, validated and used for predicting the SRTs. This implies that SRT is approximately equal to the fifth root of the latitude-incident angle ratio. The SRT values were compared with values calculated from the actual results and associated deviations evaluated as risk. The risk evolving from evaluating SRT based on $(\Phi/\theta)^{0.2}$ instead of the widely accepted experimental method was < 8 %. The evaluated risk translated into over 92% operational confidence for the derived model as well as over 0.92 reliability coefficients for predicting SRT based on the latitude-incident angle ratio of radiation. Comparative analysis of predicted and actual results show very close alignment of curves of SRT, which precisely translated into significantly similar trend of data points distribution. The standard errors incurred in evaluating SRT from actual and predicted results were all < 0.2%. The correlations between SRT and Φ and θ as obtained from actual and predicted results were all > 0.93.

1. Introduction

Economic development and industrialization is basically progressive when there is availability of energy. Energy has also been considered a driving force for rapid industrial growth. Solar energy has globally found application for generating heat and electricity for domestic and industrial uses [1]. Report has shown that the level of applicability of the energy is dependent on some optical elements as environmental weather condition, light transmission losses in collector surface, solar distance (i.e the distance of the array from the sun), degree of sun's radiation on the collector location, time of the day at which the sun's radiant heat is being collected, duration of the radiant inflow, angle of incidence (i.e the angle between the normal to the solar array and a light ray from the sun). Earth`s orientation has been discovered [2] to determine the variation in the length of time and proportion of solar energy reaching various place on earth. Empirical models [3], [4] and [5] have been applied for the calculations, computational analysis, predictive analysis and estimation of some operational parameters involved with solar energy radiation and transmission.[6] presented the transmissivity of the glazing surface of a solar flat plate collector based on the metrological parameters of Yola, Nigeria.

[7] Proposed some solar radiation ratios and their interpretations with regards to radiation transfer in the atmosphere to define relevant radiation coefficients and were used to develop equations for estimating the reflection of the earth's surface and the absorption of the earth's atmosphere. [8] Presented a quantitative review and classification of empirical models for predicting global solar radiation in West Africa. The authors compared the empirical and soft computing models for estimating global solar radiation in West Africa and across the globe; they observed that the soft computer models yielded better. [9] Estimated the variability of clearness index over Lagos, South West Nigeria. [10] Developed a method for calculating the optimal tilt angle based upon the values of the daily global solar radiation on a horizontal surface. [11] Considered the effects of latitude, solar reflectivity, and clearness index in determining the optimal tilt angle analytically.

A derived model [3] has predicted solar energy transmissivity based on the collector exposure time and latitude angle of its location. The two-factorial model was validated for the predictive analysis. The model structure is given as;

$$\zeta = -\ 0.0021\theta\ -\ 5\ \text{x}\ 10^{-6}\vartheta +\ 0.9081 \qquad 1$$

The validity of the derived model was rooted on the core model expression ζ - 0.9081 = - 0.0021θ - 5 x 10^{-6} ϑ where both sides of the expression are correspondingly approximately equal. Results of solar transmissivity were generated using regression analysis to evaluate its trend of distribution which was compared with that from derived model as a way of verifying its validity relative to experimental results. The results of this verification translated into very close alignment of curves and significantly similar trend of data point's distribution for experimental (ExD), derived model (MoD) and regression model-predicted (ReG) results.

Evaluations from generated results indicated that transmissivity per unit exposure time of collector and latitude angle of its location as obtained from experiment, derived model and regression model were 1.0545 x 10^{-5}, 1.0545 x $10^{-5}$and 1.0909 x 10^{-5} $(\text{day})^{-1}$ and 0.0040, 0.0040 and 0.0042 deg $^{-1}$ respectively.

Statistical analysis of generated results shows that the standard errors incurred in predicting transmissivity for each value of the solar collector exposure time and latitude angle considered as obtained from experiment, derived model and regression model were 0.0003, 0.0002 and 2.1422 x 10^{-5} % and 0.0001, 0.0005 and 2.8396 x10^{-5} % respectively. Maximum deviation of model-predicted transmissivity (from experimental results) was less than 0.03% which is insignificant, implying a model operational confidence level above 99.9%.

Response evaluation of solar energy transmissivity to the combined influence of radiation incident angle and latitude angle of solar collector location were carried out using a derived empirical model [4]. The validated model is given as:

$$\zeta = 0.513\theta^{-0.0603} + 0.165\text{e}^{-0.0002\vartheta} \qquad 2$$

The validity of the derived model was rooted on the core model expression 1.9493 $\zeta = \theta^{-\ 0.0603}$ + 0.3216 $\text{e}^{-0.0002\vartheta}$ where both sides of the expression are almost equal. Transmissivity per unit incident angle of the radiation and latitude angle of collector location as obtained from experiment, derived and regression model were 1.8 x 10^{-4}, 1.2 x $10^{-4}$and 1.6 x 10^{-4} deg $^{-1}$ and 0.0046, 0.003 and 0.0042 deg^{-1} respectively.

Statistical analysis of result of the investigation indicates that the standard errors in predicting transmissivity for each value of the radiation incident angle and latitude angle of collector location considered as obtained from experiment, derived model and regression model are 0.0003, 0.0002 and 2.1422 x 10^{-5} % and 0.0001, 0.0005 and 2.8396 x10^{-5} % respectively. The maximum deviation of model predicted transmissivity (from experimental results) was less than 0.95%. A synergistic evaluation of the Reflectivity of Beam Component of Solar Radiation (BeCSR) was carried out [5] based on its Solar Energy Transmissivity (SET) and Solar Collector Exposure Time (SCET). Evaluation of BeCSR while the solar collector is serving under atmospheric condition was carried out using an empirical model expressed as;

$$\xi = 174.73\beta - 45896\vartheta + 38403.25 \quad 3$$

The validity of the derived model was rooted in the core expression $\xi - 38403.25 = 174.73\beta - 45896\vartheta$ where both side of the expression correspondingly approximately equal. Results generated from both experiment and model prediction indicates that BeCSR increases with increasing SCET and decreasing SET. Evaluated results indicated that the correlations between BeCSR and SET and SCET as well as the standard error incurred in predicting BeCSR for each value of the SET and SCET considered, as obtained from experiment, derived model and regression model were all > 0.99 as well as 5.56 x 10^{-4}, 7.74 x 10^{-4} and 3.99 x 10^{-5} and 9.06 x 10^{-4}, 8.25 x 10^{-4} and 2.76 x 10^{-5} % respectively.

The maximum deviation of the model-predicted BeCSR (from experimental results) was less than 4.5%. This translated into over 95.5% operational confidence for the derived model as well as over 0.95 effective response coefficients for the dependence of BeCSR on SET and SCET.

The aim of this work is to evaluate the risk in predicting solar energy transmissivity, ϑ (SET) based on the radiation latitude-incident angle ratio, Φ/ θ.

2.0. Materials and method

The solar collector was positioned at different latitude angles for influx of varying amount of incident radiations from the sun to the collector. Details of the experimental procedure and associated process conditions are as stated in the past report [6].

Table 1: Variation of radiation transmissivity with incident and latitude angles

	(θ)	(Φ)
0.8816	16.11	12.46
0.8812	19.45	12.47
0.8803	22.80	12.74
0.8792	26.89	13.06
0.8790	27.39	13.01

Computational analysis of these data shown in Table 1gave rise to Table 2 which indicate that;

$$\vartheta^{K} \square \left(\frac{\Phi}{\theta}\right) \quad 4$$

Introducing the value of K into equation (4) reduces it to;

$$\vartheta^{5} \square \left(\frac{\Phi}{\theta}\right) \quad 5$$

$$\vartheta \square \left(\frac{\Phi}{\theta}\right)^{1/5} \quad 6$$

$$\vartheta \square \left(\frac{\Phi}{\theta}\right)^{0.2} \quad 7$$

Where, (ϑ) = Solar radiation transmissivity, (θ) = Incident angle of solar radiation (deg), (Φ) = Latitude angle of solar radiation (deg) and K and Ђ are equalizing and empirical constants; 5 and 0.2 respectively.

2.1. Boundary and Initial Condition

Range of latitude angles of collector, incident angles of radiation and radiation transmissivities considered are 12.46 -13.01 deg., 16.11 - 27.39 deg., 0.8816 - 0.8790 respectively [6].

3.0 Results and Discussion

3.1 Model validation

The model was validated using graphical, statistical, computational and deviational methods. The derived model was rooted in equation (2). Equation (2) agrees with Table 2 following the values of ϑ^5 and Φ / θ evaluated from Table 1.

Table 2: Variation of ϑ^5 and (θ / Φ)

ϑ^5	(θ / Φ)
0.5325	0.77
0.5313	0.64
0.5286	0.56
0.5253	0.49
0.5247	0.48

3.2. Graphical Analysis

Critical analysis of Figs 1 and 2 shows close alignment of curves of model-predicted solar transmissivities (relative to latitude and incident angles of radiation) and those from the actual results.

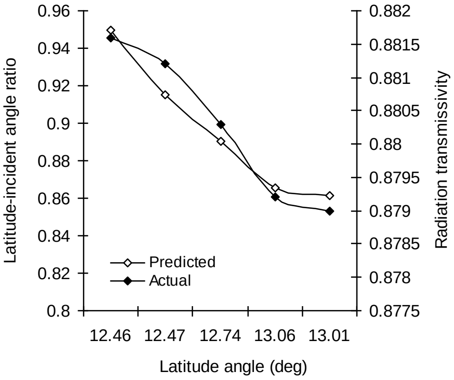

Fig.1: Comparison of solar transmissivity (relative to latitude angle) as obtained from actual and predicted results

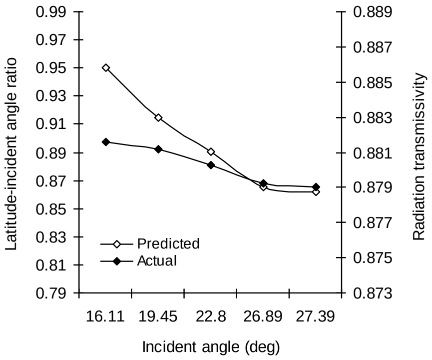

Fig.2: Comparison of solar transmissivity (relative to incident angle) as obtained from actual and predicted results

3.3. Statistical Analysis

The correlations between solar transmissivity and latitude and incident angles as evaluated from actual and predicted results were all > 0.93. Furthermore, the standard error incurred in predicting solar transmissivity as a function of latitude and incident angles carrying out conventional the experiment were all < 0.2%.

3.4. Deviational Analysis

Analysis of solar radiation transmissivity as obtained from actual and derived model reveal deviation of model-predicted values from those of the actual. This is believed to be due to the fact that some considered assumptions and experiment-oriented conditions which prevailed during the actual field work were not considered during the model formulation. This necessitated the introduction of correction factor, to bring the model-predicted values to those of the actual. Deviation (Dv) (%) of the model-predicted solar radiation transmissivity from that of the actual is given by;

$$D_y = \left(\frac{\vartheta_p - \vartheta_a}{\vartheta_a} \right) x100 \qquad 8$$

where, ϑp = Model-predicted solar radiation transmissivity and ϑa = Solar radiation transmissivity evaluated from actual results.

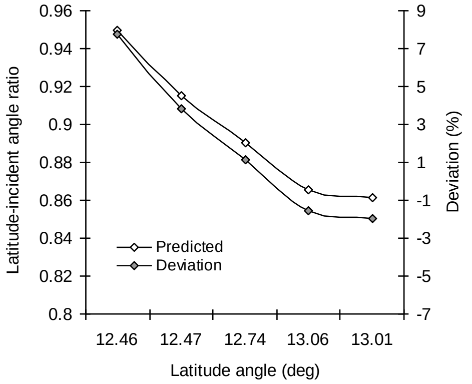

Fig.3: Variation of model-predicted solar transmissivity (relative to latitude angle) and its associated deviation

Figs. 3 and 4 show that the least and highest deviations of model-predicted results (from actual results) are 1.11 and 7.75%. These deviations correspond to model-predicted solar radiation transmissivities: 0.8901 and 0.9499; latitude angles: 12.74 and 12.46 and incident angles: 22.80 and 16.11 respectively.

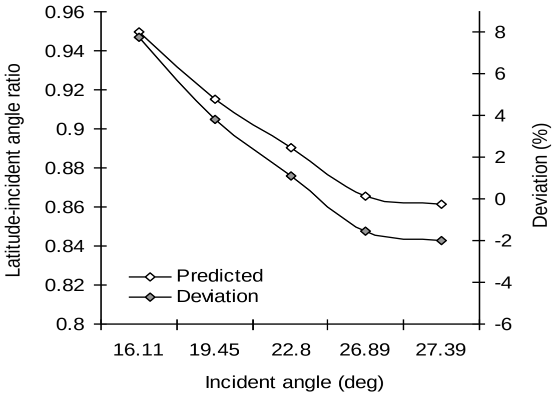

Fig.4: Variation of model-predicted solar transmissivity (relative to incident angle) and its associated deviation

Figs. 3 and 4 show that the maximum deviation of the predicted solar radiation transmissivity from the corresponding actual values is less than 8%. This translates into over 92% operational confidence for the derived model as well as over 0.92 reliability coefficients for predicting solar radiation transmissivity based on the latitude-incident angle ratio of radiation.
Correction factor, C_y to the model-predicted results is given by;

$$C_y = -\left(\frac{\vartheta_p - \vartheta_a}{\vartheta_a}\right) x100 \qquad 9$$

where ϑp and ϑa are solar radiation transmissivities evaluated from actual and predicted results respectively.

Equation (9) shows that correction factor is the negative of the deviation. It is strongly believed that the correction factor takes care of the assumptions made and experimental condition prevailing during the field works which were not considered during the model formulation.

Table 3: Variation of predicted solar radiation transmissivity with its associated correction factor

$\vartheta_{Predicted}$	Correction factor (%)
0.9499	- 7.75
0.9149	- 3.82
0.8901	- 1.11
0.8655	+ 1.56
0.8617	+ 1.97

Table 3 indicates that the least and highest correction factor to the model-predicted solar radiation transmissivity are – 1.11 and – 7.75%. These correction factors correspond to model-predicted solar radiation transmissivities: 0.8901 and 0.9499; latitude angles: 12.74 and 12.46 and incident angles: 22.80 and 16.11 respectively.

It is important to state that the deviation of model predicted results from that of the experiment is just the magnitude of the value. The associated sign preceding the value signifies that the deviation is a deficit (negative sign) or surplus (positive sign).

4.0. Conclusion

Risk evaluation in predicting solar radiation transmissivity, ϑ (SRT) based on the latitude-incident angle ratio of radiation, Φ/θ was carried out. A model; $\vartheta = (\Phi/\theta)^{0.2}$ was derived, validated and used for predicting the SRTs. The SRT is approximately equal to the fifth root of the latitude-incident angle ratio. The risk evolving from evaluating SRT based on $(\Phi/\theta)^{0.2}$ instead of the widely accepted experimental method was < 8 %. This translated into over 92% operational confidence for the derived model as well as over 0.92 reliability coefficients for predicting SRT based on the latitude-incident angle ratio of radiation. Predicted and actual results show very close alignment of curves of SRT, which precisely translates into significantly similar trend of data points distribution. The standard errors incurred in evaluating SRT from actual and predicted results were all < 0.2%. The correlations between SRT and Φ & θ as obtained from actual and predicted results were all > 0.93.

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