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DESIGN, ANALYSIS AND OPTIMIZATION OF RENEWABLE SOLAR INTENSITY IN AWKA METROPOLIS, ANAMBRA STATE, NIGERIA

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ABSTRACTS

This research work is shows the variability of solar parameters. The parameters that are solar radiation, sun intensity and temperature were optimized and predicted in other to investigate its influence in Awka metropolis, Anambra State, South Eastern part of Nigeria. The research was conducted for the period of five days, 6:00am to 6:00pm daily on 6th to 10th December, 2017. Measuring the intensity of solar radiation is one of the directions used at investigation of solar power and necessary for the implementation of photovoltaic systems in a particular geographical 'area. Instrument used for measuring the solar radiation is solarimeter which is based on the thermal or photovoltaic principles. The device harness two main components for measuring solar radiation, namely- direct radiation and diffuse radiation, with sensors based on the photovoltaic principles. The research tends to optimize and to develop the intended sun intensity and solar radiation principles and properties of the environs. From the optimization results, the maximum sun intensity of the geographical area is 957.620w/m2 while the minimum sun intensity of the area is 2w/m2. However, the maximum temperature of the geographical area is 39.4˚C while the minimum temperature of the geographical area is 18.8˚C. The average sun intensity of the case study is 356.644w/m2**.** The optimization technique employed will ensure the efficiency of solar radiation, sun intensity and

temperature variability of the geographical area in study as a key to climatic issues and solar systems manufacturing.

KEYWORDS: Optimization, Prediction, Factorial Design, Sun intensity, Solar Systems, Solar radiations and Photovoltaic.

INTRODUCTION

1.1 Solar Constant

The Sun is considered to produces a constant amount of energy. The amount of energy produced by the sun is the solar radiation or the short wave energy. The solar radiation intensity falling on a surface is called irradiance or insulation and is measured in W/m^2 or kW/m^2.[1,9] The solar constant can be used to calculate the irradiance incident on a surface perpendicular to the Sun's rays outside and the Earth's atmosphere on any day of the year. At the surface of the Sun the intensity of the solar radiation is about 6.33×10^7 W/m^2 (note that this is a power, in watts, per unit area in meters). The Sun's rays spread out into space the radiation becomes less intense and by the time the rays reach the edge of the Earth's atmosphere they are considered to be parallel.[10]

The solar constant (I_{SC}) is the average radiation intensity[1] falling on an imaginary surface, perpendicular to the Sun's rays and at the edge of the Earth's atmosphere. The word 'constant' is a little misleading since, because of the Earth's elliptical orbit the intensity of the solar radiation falling on the Earth changes by about 7% between January 1st, when the Earth is nearest the Sun, and July 3rd, when the Earth is furthest from the Sun. A yearly average value is thus taken and the solar constant on the earth equals 1367 W/m^2. Even this value is inaccurate since the output of the sun changes by about ±0.25% due to Sun spot cycles.

Figure 1, shows the variation in I_0 over the course of a year. Most solar power calculations use I_0 as a starting point because, for any given day of the year it is the maximum possible energy obtainable from the Sun at the edge of the Earth's atmosphere. The dashed line shows the value of the solar constant (Isc)

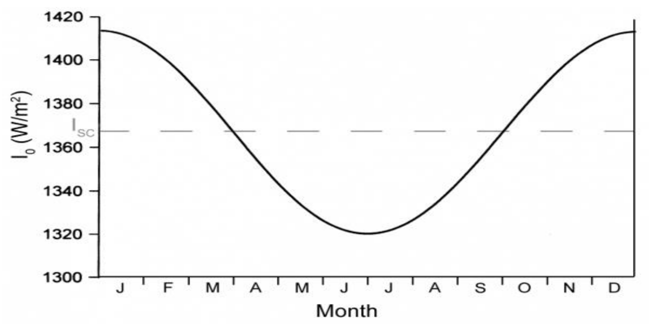

Figure 1: The variation in Io over the course of a year.

1.2 Irradiation

Just to be confusing the intensity of solar radiation is called irradiance and is measures in the units of power per unit area (W/m^2 or kW/m^2) however, the total amount of solar radiation energy is called irradiation and is measures in the units of energy per unit area (J/m^2).[1] Irradiation is given the symbol H, so that:

- H_0 is the total daily amount of extraterrestrial radiation on a plane perpendicular to the Sun's rays;
- H_{0h} is the total daily amount of extraterrestrial radiation on a plane horizontal to the Earth's surface.

Note that these planes are considered to rotate with the Earth so that H_0 and H_{0h} are daily values, and the planes are shaded at night. Figures 2 and 3 show how the values of H_0 and H_{0h} vary throughout the year in the northern hemisphere. Note that for any given day the value of H_0 changes from latitude to latitude despite the value of I0 being constant for all latitudes. This occurs because the length of the day's changes and the effects is most obvious inside the Arctic Circle where much of the year is either 24 hours of darkness or 24 hours of daylight.[12]

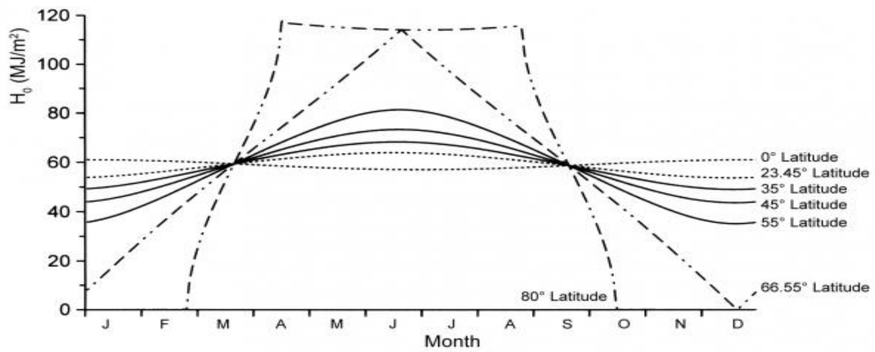

Figure 2: The total daily amount of extraterrestrial irradiation on a plane perpendicular to the Sun's rays (H0) for different latitudes.

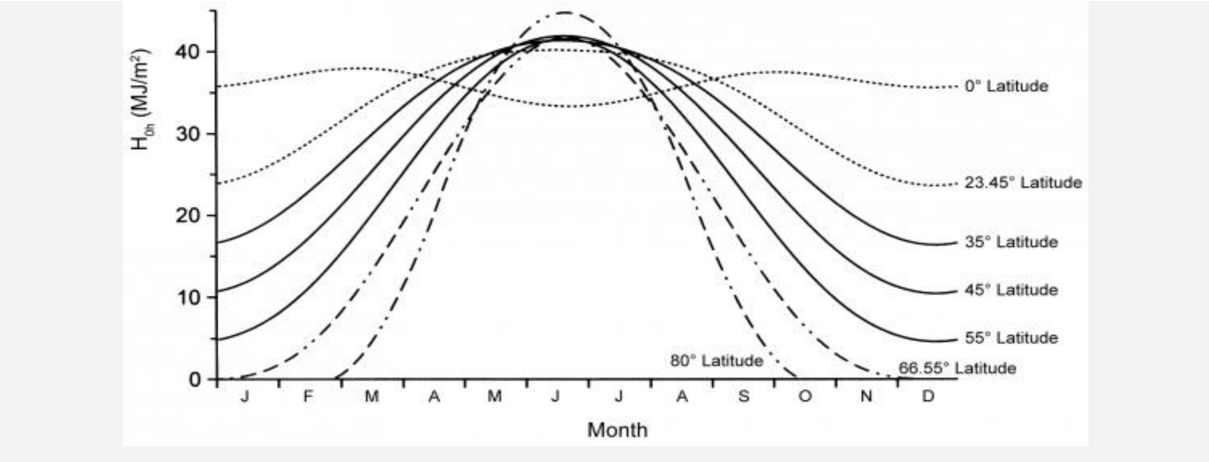

Figure 3: The total daily amount of extraterrestrial irradiation on a plane horizontal to the Earth's surface(H0h) for different latitudes.

1.3. The Solar Spectrum

The Sun's radiation is a good approximation of black body radiation (a continuous distribution of wavelengths with no wavelengths missing) with wavelengths in the range of about 0.2 μm to 2.6 μm (figure 2.5). The solar spectrum consists of ultra-violate rays in the range of 200 to 400 nm, visible light in the range 390 nm (violet) to 740 nm (red) and the infra-red in the range 700 nm to 1mm.[13]

1.4. Solar energy

Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaic, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis.[1,2]

It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air.[11]

The large magnitude of solar energy available makes it a highly appealing source of electricity. The United Nations Development Programme in its 2000 World Energy Assessment found that the annual potential of solar energy was 1,575–49,837 exajoules (EJ).

This is several times larger than the total world energy consumption, which was 559.8 EJ in 2012.[3,4]

In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating global warming, and keep fossil fuel prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments; they must be wisely spent and need to be widely shared.[1]

Sunlight is a portion of the electromagnetic radiation given off by the Sun, in particular infrared, visible, and ultraviolet light.[1] On Earth, sunlight is filtered through Earth's atmosphere, and is obvious as daylight when the Sun is above the horizon. When the direct solar radiation is not blocked by clouds, it is experienced as sunshine, a combination of bright light and radiant heat. When it is blocked by clouds or reflects off other objects, it is experienced as diffused light. The World Meteorological Organization uses the term "sunshine duration" to mean the cumulative time during which an area receives direct irradiance from the Sun of at least 120 watts per square meter.[5] Other sources indicate an "Average over the entire earth" of "164 Watts per square meter over a 24 hour day".[6,15,16]

The ultraviolet radiation in sunlight has both positive and negative health effects, as it is both a principal source of vitamin D_3 and a mutagen.

Sunlight takes about 8.3 minutes to reach Earth from the surface of the Sun. A photon starting at the center of the Sun and changing direction every time it encounters a charged particle would take between 10,000 and 170,000 years to get to the surface.[7]

Sunlight is a key factor in photosynthesis, the process used by plants and other autotrophic organisms to convert light energy, normally from the Sun, into chemical energy that can be used to fuel the organisms' activities.

Researchers may record sunlight using a sunshine recorder, pyranometer, or pyrheliometer. To calculate the amount of sunlight reaching the ground, both Earth's elliptical orbit and the attenuation by Earth's atmosphere have to be taken into account. The extraterrestrial solar illuminance (E_{ext}), corrected for the elliptical orbit by using the day number of the year (dn), is given to a good approximation.[8,15,16]

If the extraterrestrial solar radiation is 1367 watts per square meter (the value when the Earth–Sun distance is 1 astronomical unit), then the direct sunlight at Earth's surface when the Sun is at the zenith is about 1050 W/m^2, but the total amount (direct and indirect from the atmosphere) hitting the ground is around 1120 W/m^2.[1,9]

2. **Research Method**

The research method used is the qualitative method of experimental analysis using optimization tools.[14,15,16] The experimental method applied is the factorial design method, to analyze and to optimize the experimental data of the case study. The results will portray the minimum and maximum optimal solar radiation in the experimental geographical area.

3. Result and Analysis of the Experiment

Table 1: Experimental Data Collected for the Period under Study.

S/N	Months	Rainfall (2020)	(2021)	(2022)	Relative Humidity (2020)	(2021)	(2022)	Temp (2020)	(2021)	(2022)	Solar Intensity (2020)	(2021)	(2022)
1	Jan	5.4	20.3	18.8	47.75	54.5	35.35	29.72	29.85	28.55	512.67	492.147	502.485
2	Feb	24.7	36.2	15.4	52.4	27.1	43.3	29.75	30.425	29.05	479.82	489.541	481.68
3	March	81.9	73.1	70.3	67.8	63.6	55.5	30.3	30.25	30.4	350.728	426.33	384.59
4	April	112.3	143.9	130.1	88.45	87.8	151.65	28.95	29.525	28.85	338.912	357.921	342.465
5	May	206.1	171.7	217.2	201.05	125.25	249.1	28.6	28.45	28.4	351.652	368.49	360.71
6	June	300.2	361.8	251.9	246.25	199.25	170.95	27.1	27.19	27.35	330.108	345.12	337.64
7	JULY	226.8	134.8	241.9	219.7	143.1	235.55	27.27	26.9	27.35	310.45	303.39	305.92
8	Aug	91.7	187.5	237.1	161.85	227.85	157.4	26.4	27.25	26.35	295.249	302.32	294.745
9	Sep	179.2	203.2	292	142.5	125.95	213.25	27.1	27.65	27.19	341.24	356.199	345.795
10	Oct	158.5	58.6	200.9	129.65	73.95	126.9	27.7	27.75	27.10	365.78	377.437	371.685
11	Nov	65.9	114.1	12.1	36.05	45.35	58.45	28.9	29.05	28.95	407.522	384.126	401.284
12	Dec	13.7	21.2	7.7	37.65	38.7	42	28.25	28.95	28.5	488.923	479.54	482.135

Source: Nigerian Metrological Agency, Awka

Table 2: Input Factors Analysis.

Factor	Name	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
A	Rainfall	Numeric	Continuous	5.4	361.8	-1.0=5.4	1.0=361.8	130.228	98.1192
B	R. humidity	Numeric	Continuous	27.1	249.1	-1.0=27.1	1.0=249.1	116.192	72.1913
C	Temperature	Numeric	Continuous	26.35	30.425	-1.0=26.35	1.0=30.42	28.37	1.18402

The table above shows the statistical description of the input factors used for the conduct of these experimental trials. The input factors show the minimum and the maximum values of the input factors in the experiment. The table also shows the coding values of the factors, the mean and standard deviations of the input process factors used for the conduct of these experimental trials.

Table 3: Response Variable Analysis.

Response	Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
R1	Solar Intensity	W/m2	36	Polynomial	294.745	512.67	385.187	68.3602	1.73937	None	Cubic

The table above shows the statistical description of the response variable generated during the conduct of these experimental trials. The response variable shows the minimum and the maximum values of the input factors in the experiment. The table also shows the type of model analysis developed which is a polynomial cubic model of the response variable. The mean, standard deviations and Model ratio of the response variable used for the conduct of these experimental trials were also developed in this study.

Table 4: Sequential Model Sum of Squares Analysis.

Source	Sum of Squares	df	Mean Square	F Value	p-value	
Mean vs Total	5.341E+006	1	5.341E+006			
Linear vs Mean	1.051E+005	3	35048.50	19.20	< 0.0001	
2FI vs Linear	37254.76	3	12418.25	17.02	< 0.0001	Suggested
Quadratic vs 2FI	806.25	3	268.75	0.34	0.7942	
Cubic vs Quadratic	12733.71	10	1273.37	2.67	0.0386	Suggested
Quartic vs Cubic	7232.73	15	482.18	1.25	0.6151	
Fifth vs Quartic	386.28	1	386.28			Aliased
Residual	0.000	0				
Total	5.505E+006	36	1.529E+005			

Sequential Model Sum of Squares analysis applied is used to adopt the highest polynomial with fewer errors. The selection of the highest order polynomial is based on where the additional terms are significant and the model is not aliased. The cubic model is more appropriate based on the selection of the highest polynomial model the additional terms are significant with insignificant errors in the model.

Table 5: Model Summary Statistics.

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	42.73	0.6429	0.6094	0.5277	77242.00	
2FI	27.01	0.8706	0.8439	0.8057	31772.96	Suggested
Quadratic	27.98	0.8756	0.8325	0.6919	50400.47	
Cubic	21.82	0.9534	0.8981	0.3317	1.093E+005	Suggested
Quartic	19.65	0.9976	0.9173		+	

The model summary statistics shows that the cubic model has the best coefficient determination of the variables(R-Squared) between the independent and the dependent variables. The R-Squared of the variables is 95.34% which shows that 95.34% of the independent variables can be explained in the dependent variable. However, the cubic model has the least possible probability error sum of square (PRESS). Cubic model is suggested to be more appropriate for predicting and optimizing the solar intensity system.

Table 6: Analysis of Variance for Solar Intensity.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.559E+005	19	8207.38	17.24	< 0.0001	significant
A-Rainfall	*2745.66*	*1*	*2745.66*	*5.77*	*0.0288*	
B-Relative humidity	*1100.16*	*1*	*1100.16*	*2.31*	*0.1480*	
C-Temperature	*618.56*	*1*	*618.56*	*1.30*	*0.2712*	
AB	*580.53*	*1*	*580.53*	*1.22*	*0.2859*	
AC	*4.81*	*1*	*4.81*	*0.010*	*0.9212*	
BC	*214.78*	*1*	*214.78*	*0.45*	*0.5114*	
A^2	*0.029*	*1*	*0.029*	*6.136E-005*	*0.9938*	
B^2	*281.00*	*1*	*281.00*	*0.59*	*0.4536*	
C^2	*281.85*	*1*	*281.85*	*0.59*	*0.4529*	
ABC	*370.81*	*1*	*370.81*	*0.78*	*0.3906*	
A^2B	*331.24*	*1*	*331.24*	*0.70*	*0.4165*	
A^2C	*595.19*	*1*	*595.19*	*1.25*	*0.2801*	
AB^2	*924.02*	*1*	*924.02*	*1.94*	*0.1827*	
AC^2	*1075.03*	*1*	*1075.03*	*2.26*	*0.1524*	
B^2C	*39.70*	*1*	*39.70*	*0.083*	*0.7765*	
BC^2	*72.18*	*1*	*72.18*	*0.15*	*0.7022*	
A^3	*193.10*	*1*	*193.10*	*0.41*	*0.5333*	
B^3	*684.38*	*1*	*684.38*	*1.44*	*0.2480*	
C^3	*811.93*	*1*	*811.93*	*1.71*	*0.2101*	
Residual	7619.01	16	476.19			
Cor Total	1.636E+005	35				

The Model F-value of 17.24 implies that the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A is a significant model term. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms, model reduction may improve your model.

Table 7: Model Fitness Analysis.

Std. Dev.	**21.82**	**R-Squared**	**0.9534**
Mean	385.19	Adj R-Squared	0.8981
C.V. %	5.67	Pred R-Squared	0.3317
PRESS	1.093E+005	Adeq Precision	13.873
-2 Log Likelihood	294.94	BIC	366.61
		AICc	390.94

Table 7 shows the predicted R-Squared of 0.3317 is not as close to the adjusted R-Squared of 0.8981 as one might normally expect; that is the difference is more than 0.2. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs. Adequate precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 13.873 indicates an adequate signal. This model can be used to navigate the design space.

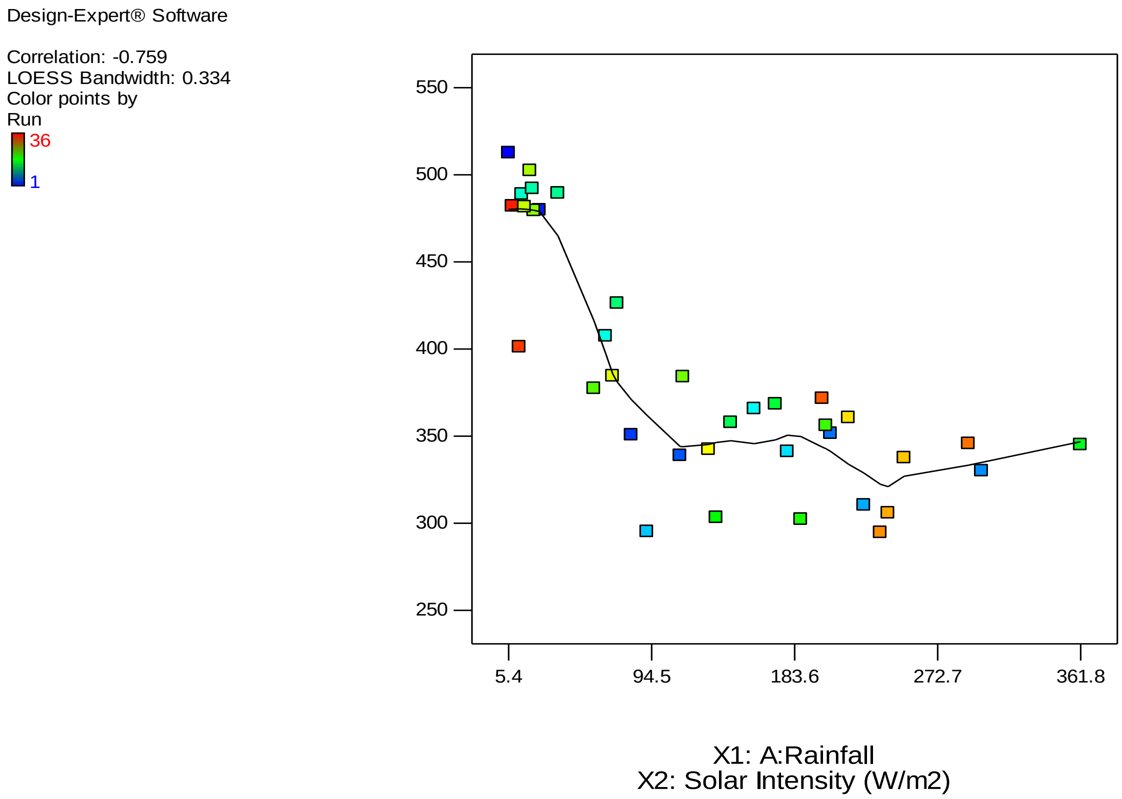

Figure 1: Correlation Analyses of Rainfall and Solar Intensity.

Figure 1 shows that the correlation analysis of rainfall factor and solar intensity response variable is 0.759. The correlations of these parameters have strong relationship between the two variables, although the relationship is polynomial relations of the two variables.

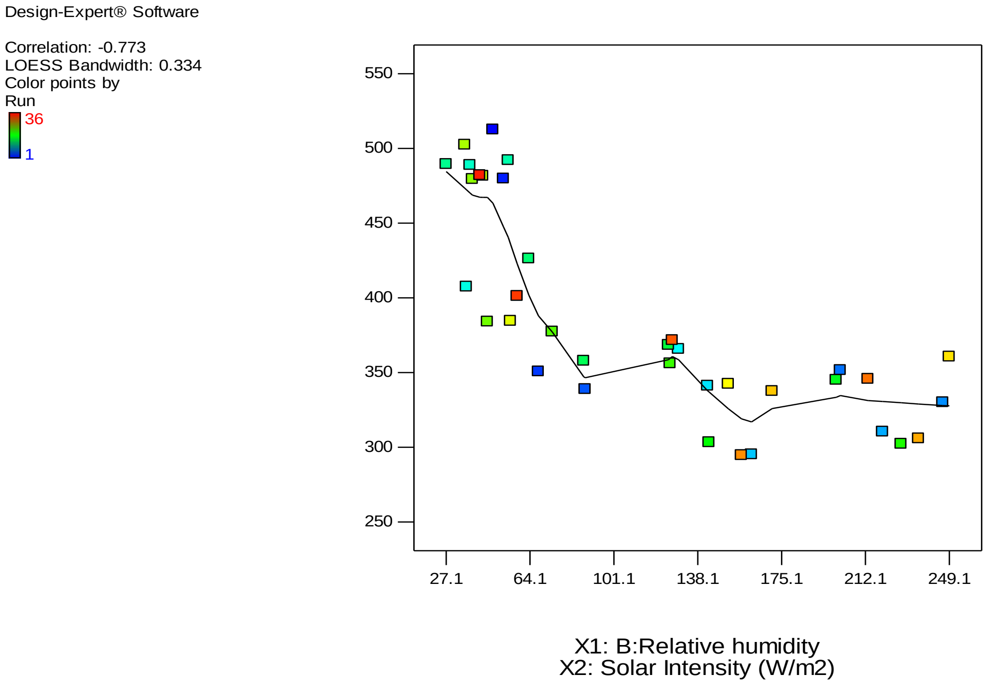

Figure 2: Correlation Analyses of Relative Humidity and Solar Intensity.

Figure 2 show that the correlation analysis of relative humidity input factor and solar intensity response variable is 0.773. The correlations of these variables have strong relationship between the two variables, although the relationship of the two variables is polynomial relations in nature. However, relative humidity input factor and solar intensity response variable have more stronger correlations than rainfall and solar intensity and also temperature and solar intensity relationships

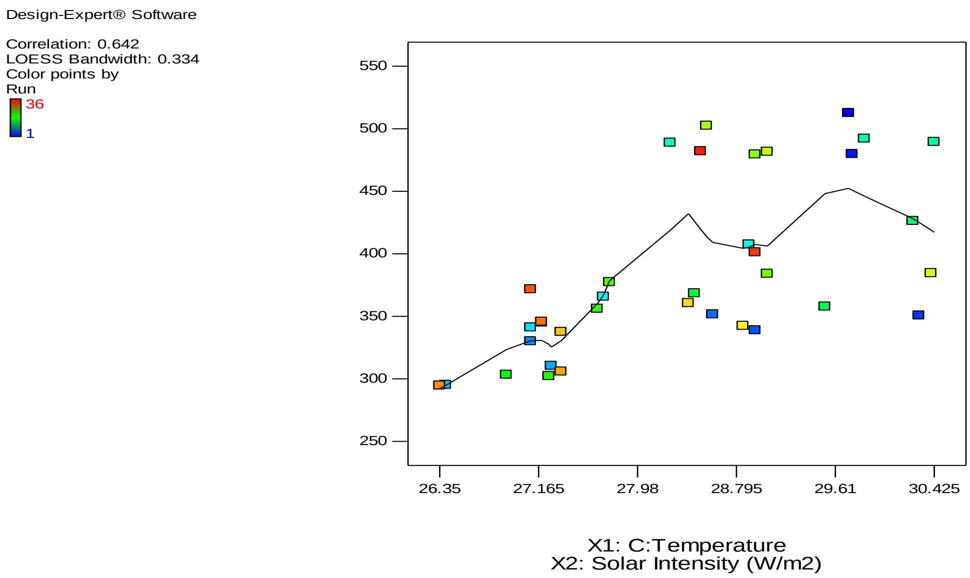

Figure 3: Correlation Analyses of Temperature and Solar Intensity.

Figure 3 show that the correlation analysis of temperature input factor and solar intensity response variable is 0.642. The correlations of these variables have strong relationship between the two variables, although the relationships of the two variables are polynomial relations in nature. However, temperature input factor and solar intensity response variable have more weaker correlations than rainfall and solar intensity and also relative humidity input factor and solar intensity relationships.

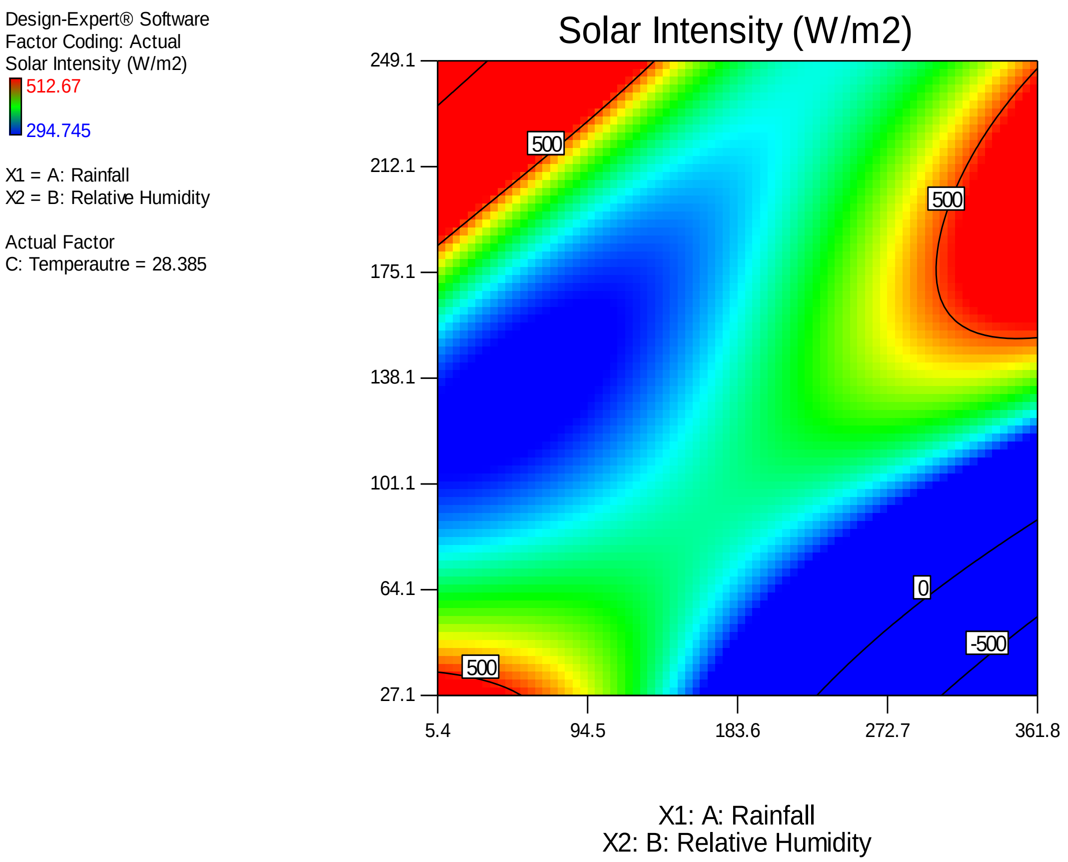

Figure 4: The Contour Plot for Rainfall and Relative Humidity.

Figure 4 shows the effect of relative rainfall along with relative humidity on solar intensity of the material. The solar intensity shows that the increase in relative humidity decrease solar intensity, while the slight increase in rainfall will increase the solar intensity of the geopolitical location.

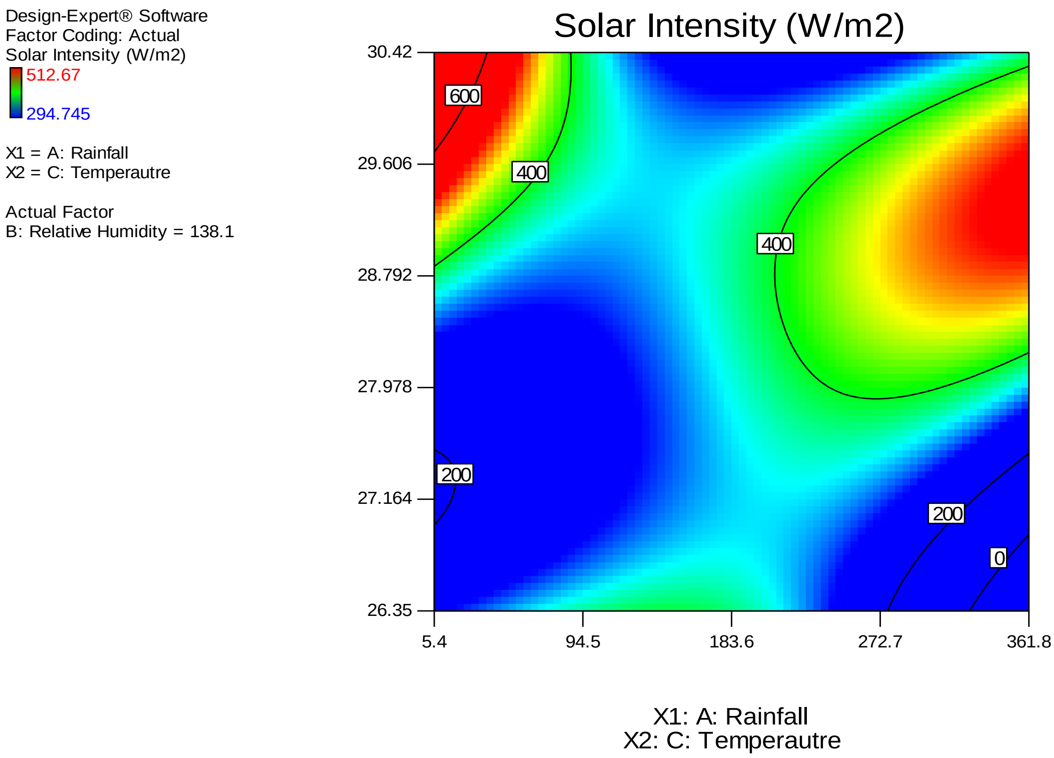

Figure 5: The Contour Plot for Rainfall and Temperature.

Figure 5 shows the effect of relative rainfall as well as the temperature on solar intensity of the zone. The solar intensity shows that the increase in relative temperature slightly increases solar intensity, while the slight increase in rainfall will increase the solar intensity of the geopolitical location.

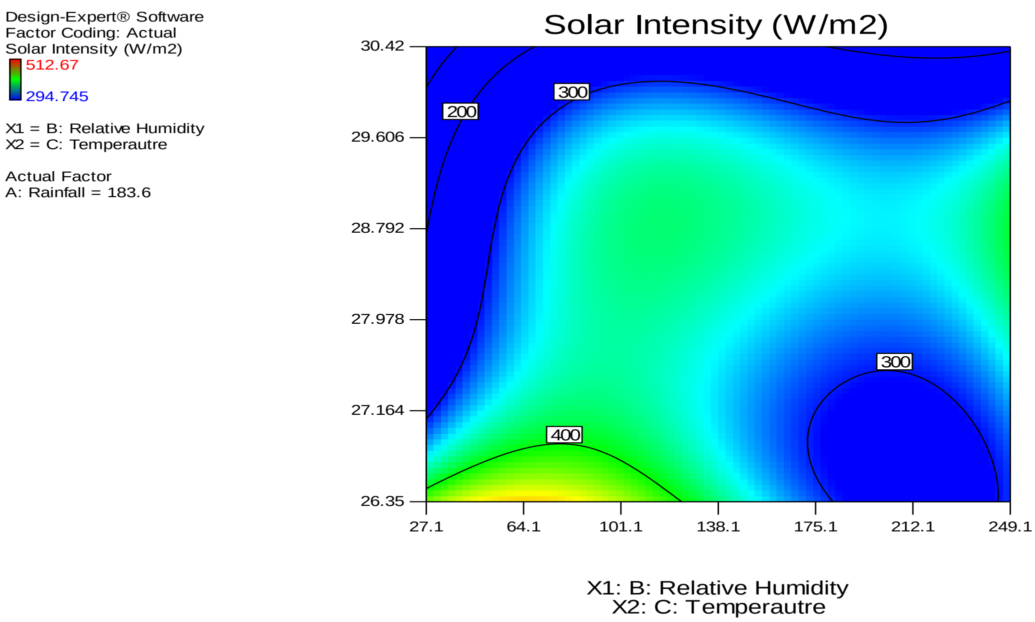

Figure 6: The Contour Plot for Temperature and Relative Humidity.

Figure 6 shows the effect of temperature along with relative humidity on solar intensity of the geopolitical zone. The solar intensity shows that the increase in relative humidity decrease solar intensity, while the increase in temperature slightly increase the solar intensity of the geopolitical location.

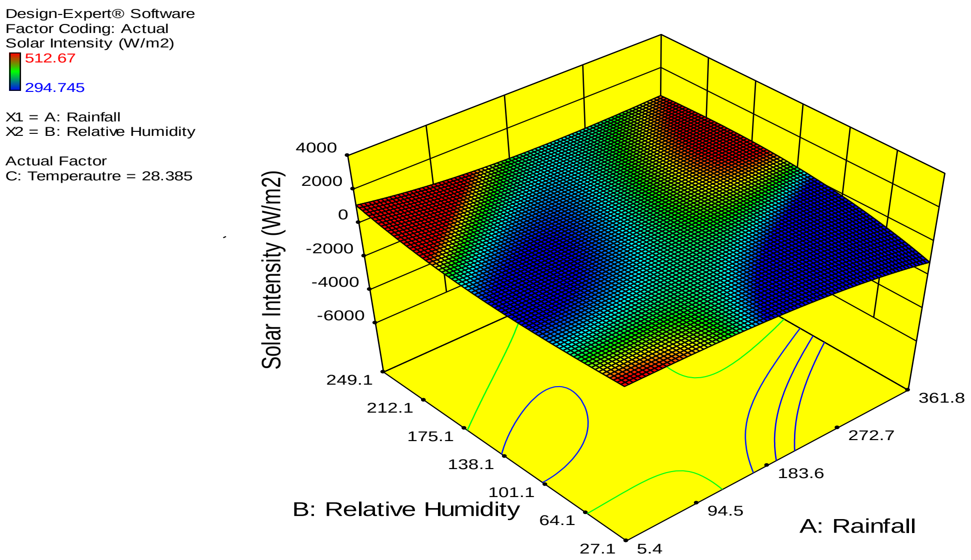

Figure 7: The Surface Plot for Rainfall and Relative Humidity.

Figure 7 shows the effect of relative rainfall along with relative humidity on solar intensity of the material. The solar intensity shows that the increase in relative humidity decrease solar intensity, while the slight increase in rainfall will increase the solar intensity of the geopolitical location.

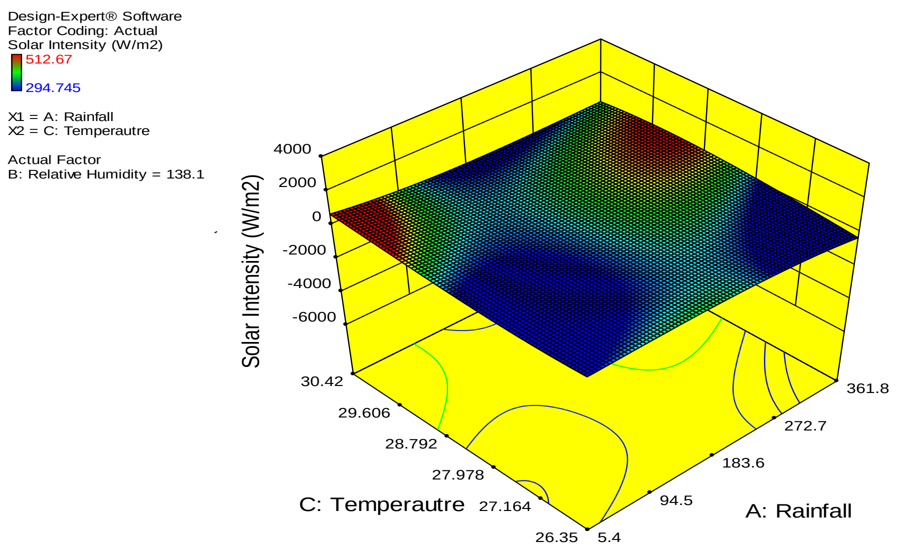

Figure 8: The Surface Plot for Rainfall and Temperature.

Figure 8 shows the effect of relative rainfall as well as the temperature on solar intensity of the zone. The solar intensity shows that the increase in relative temperature slightly increases solar intensity, while the slight increase in rainfall will increase the solar intensity of the geopolitical location.

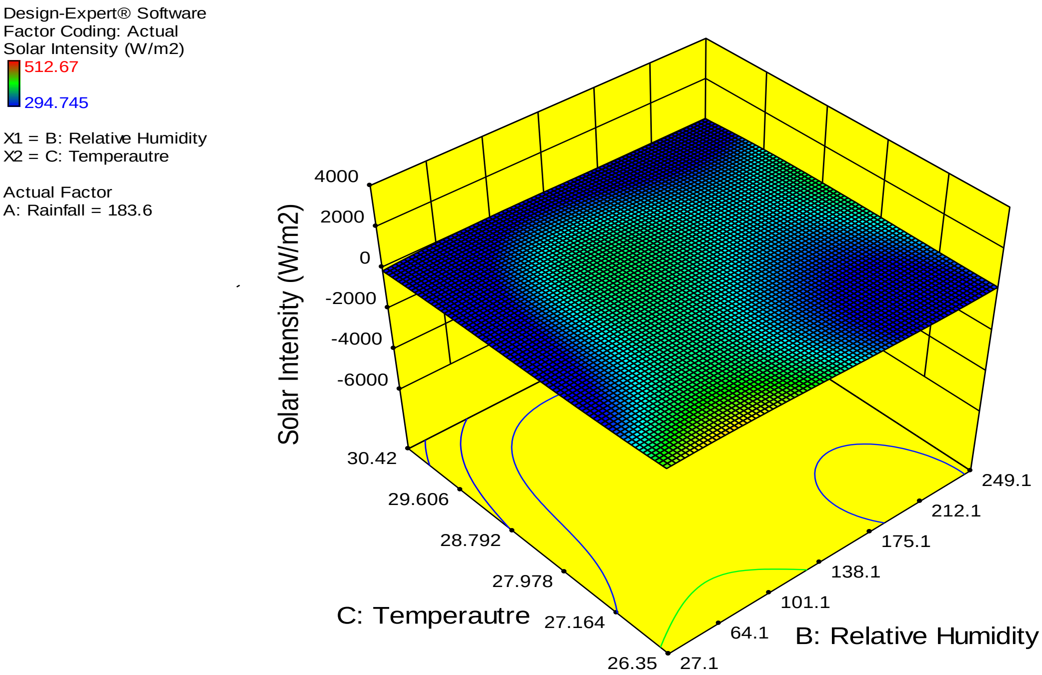

Figure 9: The Surface Plot for Temperature and Relative Humidity.

Figure 9 shows the effect of temperature along with relative humidity on solar intensity of the geopolitical zone. The solar intensity shows that the increase in relative humidity decrease solar intensity, while the increase in temperature slightly increase the solar intensity of the geopolitical location.

Table 8: Optimization Solutions.

Number	Rainfall	Relative Humidity	Temperautre	Solar Intensity	Desirability	
1	329.200	169.543	29.437	538.939	1.000	Selected
2	323.114	145.748	29.402	517.441	1.000	
3	323.180	185.750	28.707	546.209	1.000	
4	55.543	49.425	26.978	641.338	1.000	
5	33.440	33.367	28.025	530.011	1.000	
6	51.671	30.737	27.808	561.581	1.000	
7	343.891	214.930	28.314	534.050	1.000	
8	8.200	93.152	30.091	560.152	1.000	
9	27.140	27.600	28.340	525.751	1.000	

10	339.958	154.945	28.548	528.294	1.000	
11	11.005	72.236	30.215	552.137	1.000	
12	334.301	199.502	28.321	535.013	1.000	
13	11.421	67.043	30.379	568.378	1.000	
14	28.315	31.821	28.029	538.675	1.000	
15	111.453	242.422	29.659	652.749	1.000	
16	329.330	139.501	29.176	516.876	1.000	
17	99.547	238.867	28.647	589.409	1.000	
18	337.762	141.258	28.976	522.590	1.000	
19	348.467	199.211	28.727	582.276	1.000	
20	43.840	27.372	28.112	538.477	1.000	
21	127.027	87.646	26.543	524.256	1.000	
22	358.907	224.450	28.342	547.023	1.000	
23	88.120	51.233	27.145	570.556	1.000	
24	355.200	226.425	29.112	520.690	1.000	

The optimization global solution occurs at a hundred local solutions. The selected global solution is achieved at the hundred local solutions. The desirability results of the selected global solution are shown in figure 10 below.

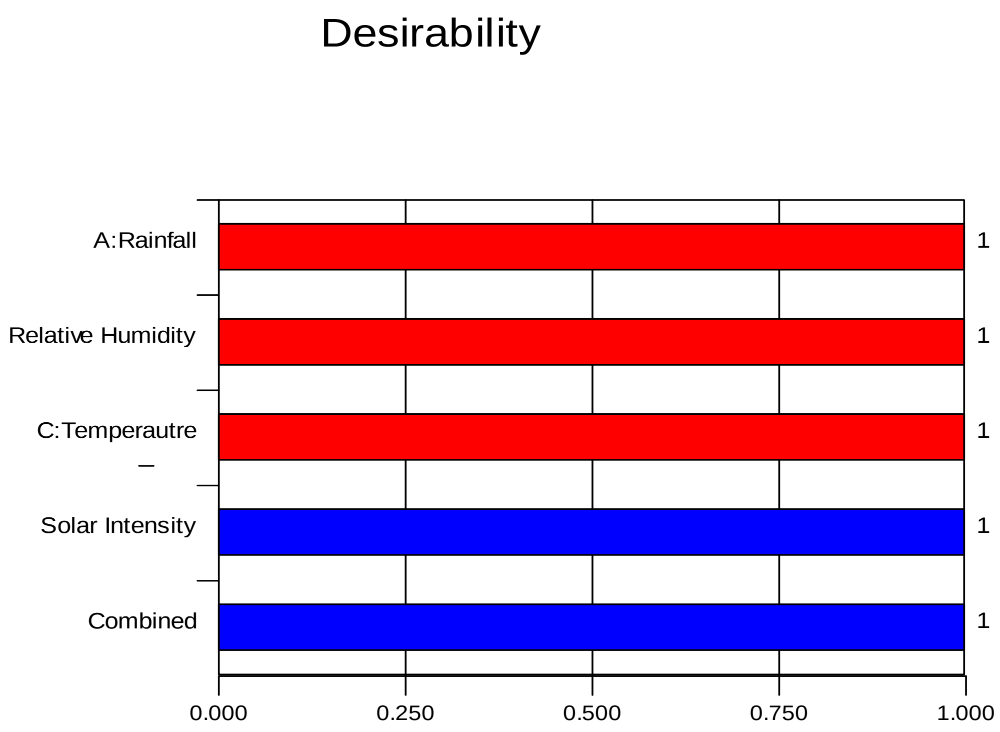

Figure 10: Desirability Plot for the Response Surface Optimization Solutions.

Figure 10 shows the desirability plot of the input factors and the response parameters. The input factors of temperature, relative rainfall, relative humidity and number of employees shows that the desirability are 100%, however, the desirability of the response parameters are said to be average of a hundred percent (100%). The desirability of the input factors shows that the input factors can hundred percent determine the responses variables.

5. CONCLUSION

The study explains the optimal sun intensity of Awka metropolis using the solar power meter (solarimeter) and the temperature of the day was also recorded with mercury -in -glass thermometers. Readings were tabulated and graph where plotted to show the optimal level of solar intensity at the extension site and its environment. This research work will be of great value for the researchers, importers and dealers of solar systems, manufacturers of solar systems and federal government documentation of sun intensity and climatic issues for periodic appraisal use of sun intensity and solar systems in the geographical area. The optimization technique employed will ensure the efficiency of solar intensity and temperature variability of the geographical area as a key to climatic issues and solar systems manufacturing.

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