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Determination of Optimum Tilt Angle of Photovoltaic (PV) Solar Module for Each Month of the Year: A Case Study of Offa, Kwara State, Nigeria

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***Abstract* - The optimum orientation and tilt angle with horizontal plane is principal to the performance of photovoltaic (PV) solar module. This paper zeros in on ascertaining the best tilt angle for each month throughout the seasons of the year in Offa, Nigeria; situated at latitude: N8° 7.9075' – longitude: E4° 42.7352', so as to fully harness the power of the sun and sustain optimal solar power generation all year round. The Solar panels were positioned for angles 0^0 – 80^0 in variance of 10^0 apart and were oriented towards North and South respectively. The voltages generated by each panel at various degrees apart were recorded on a daily basis from 09:00 to 18:00 GMT+1 West African Time throughout the year using a multimeter. The data obtained were analyzed and the results showed that, the best tilt angle for each month of the year from January to December varies. Thus, the results were presented in graphical and tabular forms.**

Key Words: Tilt Angle, Solar Energy, Pv Modules, Sun Hour.

I INTRODUCTION

There has been a remarkable increase in the demand and use of energy in many countries due to rapid economic growth and improved life standard [1].Thus, the daily and increasing use of conventional energy and fossil fuel both in domestic and industrial activities over time has a negative impact on our environment and is on its way to exhaustion [2, 3]. While it is declining in major developed countries at a geometrical rate, its declination is at a slow pace in many developing countries and majorly in Africa.

Research has however shown that, one of the main renewable energy resources which are eco-friendly and can curb the negative impact of fossil fuels and environmental problem such as global warming, release of greenhouse gases (GHG) and other pollutants that are facing this age, is Solar energy (2, 4, 5). The present day climate change problems have led to the search for renewable energy sources that are free and eco-friendly in order to maintain a green environment [6, 7].

One of the applications of renewable energy technology (Green energy) is the installation of photovoltaic (PV) systems that generate power without emitting pollutants and requiring no fuel [8]**.** The sun which powers this system is approximately 150 million km from the earth. It has a surface temperature close to 5500^{o}C and it emits radiation at a rate of $3.8x10^{23}$kW per second on an average daily basis [9]. It is worth to note that, only a small fraction of its radiations actually reaches the surface of the earth. Therefore, harnessing this fraction for daily activities becomes very vital in the reduction of the use of hydrocarbon energy sources and maintaining a green environment.

Both the orientation and tilt angles have significant effects on the magnitude of the solar radiation reaching the surface of a panel or collector and consequently affect its performance [10]. The magnitude of solar radiation received by solar panel or collector is a function of many factors such as atmospheric conditions, location latitude, load profile, optical and geometric properties, the sunrise hour angle, the azimuth angle, macro- and micro-climatic conditions, geographical position, and period of use as noted by [11, 12]. The tilt angle is defined as the angle between the solar panel surface and the horizontal plane. The orientation of the solar panel is also defined with respect to the horizontal plane and it is the angle between the line due south and the projection of the solar panel normal to the surface on the horizontal plane [13]. It was reported in the work of [14] that the orientation of the PV surface is described by its tilt angle and the direction, both related to the horizontal. Thus, in the northern hemisphere,

the optimum orientation is when facing south or when facing north in the southern hemisphere and the optimum tilt angle depends only on the latitude.

It has been found that, for every location on earth with specific radiation characteristics, there is an optimal tilt angle for the best solar energy reception. Thus, the solar radiations from the sun can be maximized by varying the tilt or slope of solar panels to an angle at which the solar radiations are maximum. The optimum orientation and tilt angle of a PV panel to the horizontal is central to the design, installation and consequently the generation of peak power needed. This is due to the fact that both the orientation and tilt angle change the solar radiation reaching the surface of the panel or collector.

Several authors have used different simulation methods to establish and determine the tilt angle for specified areas all round. Reference [15] examined the optimum tilt angle for Cyprus. For maximum radiation the results were calculated by varying tilt angle form 0° to 90° with the increment of 10°. Reference [14] 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. Reference [16] 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◦. Reference [17] stated that for Indian stations, the calculations are based upon the measured values of monthly mean daily global and diffuse solar radiation on a horizontal surface.

Reference [18] 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. While [19] presented a mathematical procedure to compare the optimum tilt angles of solar collectors through monthly diffused radiation and actual monthly diffused radiations. The best orientation for solar collectors in Izmir was south facing. Reference [20] gave a method to calculate the optimum tilt angle of an equator-facing solar collector in the heating seasons. Reference [21] calculated the optimum tilt angle for equator-facing solar collectors, based on only beam radiation. Reference [22] has carried out an analysis to determine the optimum tilt angle by considering the effects of the latitude, number of glass covers, clearing index and the solar reflectivity.

Since there is no definite value given by researchers for the optimum tilt angle. Further review of different researchers' works show that there is a wide range of optimum tilt angle as recommended by different authors, and they are particular for specific locations. It is therefore practical and necessary to orient solar panel or collector at an optimum tilt angle which maximizes the most amount of collected or trapped energy for each month of the year; Hence, the need for this research.

II METHODOLOGY

For the purpose of this research, nine panels were set up and oriented towards the Northern hemisphere from the month of May to the month of September then back to face the southern hemisphere. This is due to the fact that the sun faces the southern hemisphere between the months May and September since Nigeria is situated at latitude: N8° 7.9075' – longitude: E4° 42.7352'. The panels were arranged in such a way that same measure of radiation fall on them without the shadow of one casting on the other. A multimeter was used to record the different voltage readings from each panel for each hour of the day from 09:00 to 18:00 GMT+1 West African Time. The data recorded were then collated and an average for each month was calculated so to determine the best tilt for each month of the year. The analyzed results were then presented in graphs.

Apparatus Used In This Experiment

The following apparatus were used to determine the best tilt angle.

1. MULTIMETRE: used to indicate the voltage.
2. SOLAR PHOTOVOLTAIC PANEL: Solar Photovoltaic panel is a power source having non linear internal resistance and an array which is formed by series/parallel combination of Solar Photovoltaic cells to attain a desired voltage and current level.
3. ELECTRIC CABLES: are insulated conductors used to carry electricity from one place to another.
4. PROTRACTOR: used to determine the angle of inclination i.e. (tilt angle).
5. COMPASS: used to determine the direction of the North Pole or South Pole.

Experimental Setup

The experimental set up consists of nine mono crystalline solar collectors rated 10Watt each along with nine volt meters to keep voltage logs as shown in Fig. 1. Each solar collector (C) was mounted at a different tilt angle as follows; C1:0^0, C2:10^0, C3:20^0, C4:30^0, C5:40^0, C6:50^0, C7:60^0, C8:70^0, C9:80^0, as shown in Fig. 2. Data were captured between the hour of 9 a. m. and 6 p. m. each day for period of 12 months.

Fig. 1 Multimetre showing voltage readings of each panel

Fig. **2** Arrangement of the solar panels at different elevations

III DISCUSSION

Presented in the below graphs are the results of the data collected in order to ascertain the best tilt angle for maximum power output in each month of the year. Thus, from Fig. 3 presented below, the tilt angle that gave the maximum voltage output is at 60^0 with 19.8196volts for the month of January. It was observed that tilt angle 20^0 is closest to it with 19.8085volts as well as tilt angles 10, 30, 40, and 50 degrees. It was also noted that the lowest generated voltage was 16.3629 which is fairly alright. Fig. 4 shows that, for February, tilt angle 60^0 is the best tilt angle for that month as 19.8245volts was recorded. Tilt angle 20^0 with 19.70volts is closest to it. The lowest voltage recorded was 16.4270volts. From Fig. 5, 19.752volts which was the highest volt recorded was against tilt angle 20^0 for the month of March. The record taken for the month of April reveals that the best tilt angle was at 60^0 with 20.1559volts while the lowest volt recorded was for angle 80^0 with 17.5134volts as shown in Fig. 6.

Also, Fig. 7 shows that tilt angle 60^0 with 20.135volts stand the best tilt for the month of May as against the 16.845volts recorded for tilt angle 80^0. Average Voltage of 20.152volts was recorded for tilt angle 60^0 in the month of June as the highest voltage. The Average voltage (17.154volts) from tilt angle 20^0 is closest to it as in Fig. 8. Fig. 9 which gives the average recorded data for the month of July has shown that the best tilt angle is angle 60^0 with 20.1896volts. While tilt angle 80^0 with 16.9016volts has the lowest voltage, it was noted also that tilt angle 20^0 with

20.0272volts is closest to the best tilt angle. The best tilt angle for the month of August is 20^0 which has 19.895volts as in Fig. 10.

Furthermore, as shown in Fig. 11, the tilt angle with the highest recorded volts was 20^0 with 19.8932volts. Tilt angles 40, 50, and 60 degrees volts are closest to that recorded for angle 20^0 for the month of September. For the month of October, as shown in Fig. 12, the best tilt angle was found to be 20^0 as 19.5962volts was recorded.

Finally, from Fig. 13 and Fig. 14, the best tilt angles for both the month of November and December is 50^0 with 19.6666volts and 19.6762volts respectively. There is no significant difference in the voltages recorded between each tilt angle for both months.

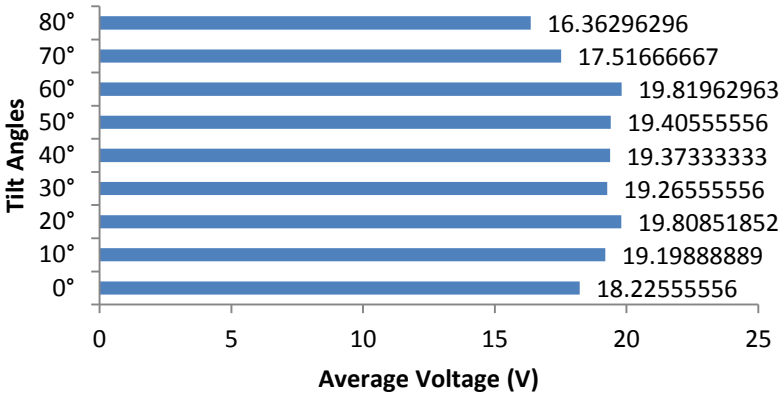


Fig. 3: Tilt Angle vs Average Voltage for the month of January

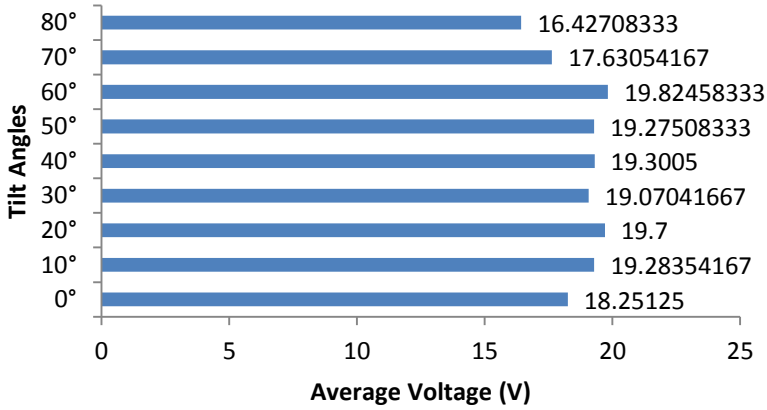


Fig. 4: Tilt Angle vs Average Voltage for the month of February

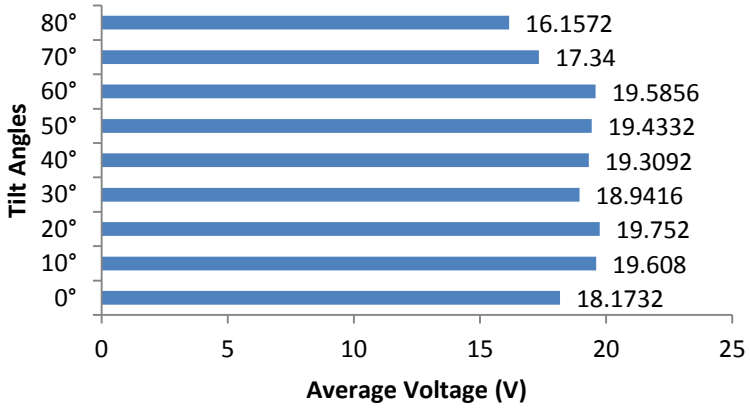


Fig. 5: Tilt Angle vs Average Voltage for the month of March

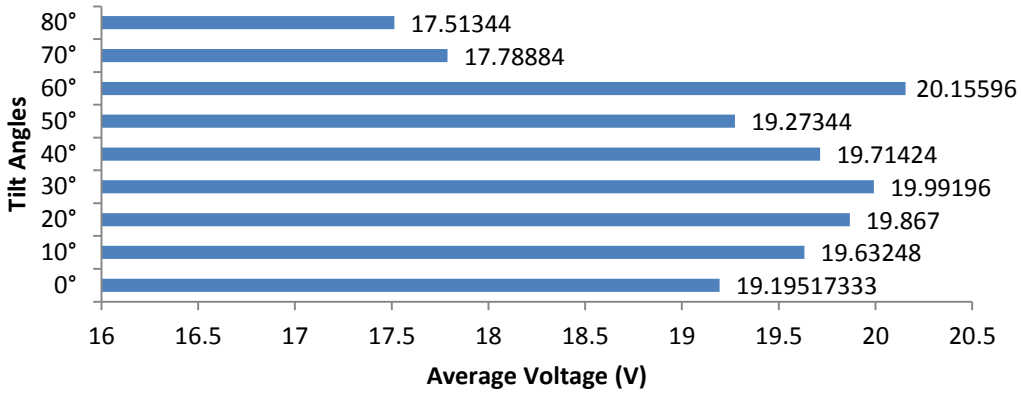


Fig. 6: Tilt Angle vs Average Voltage for the month of April

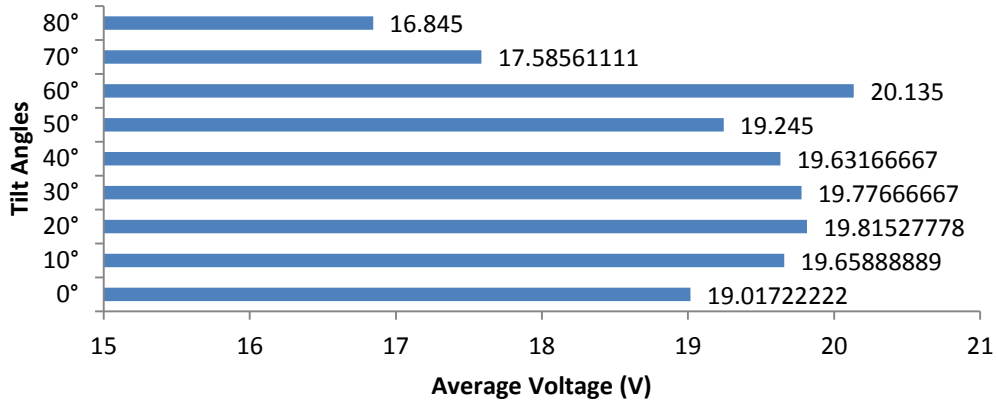


Fig. 7: Tilt Angle vs Average Voltage for the month of May

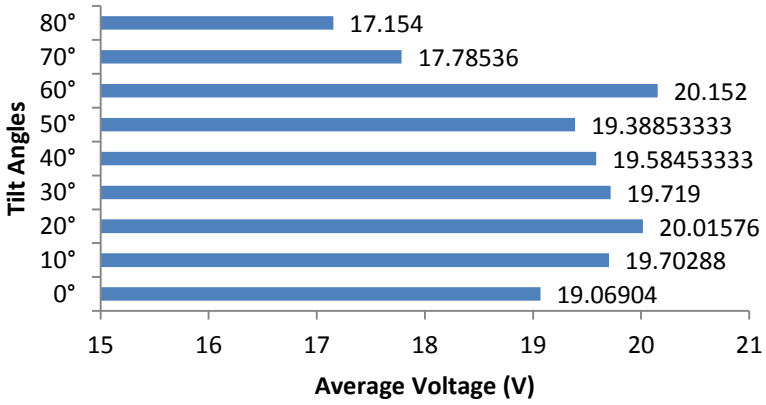
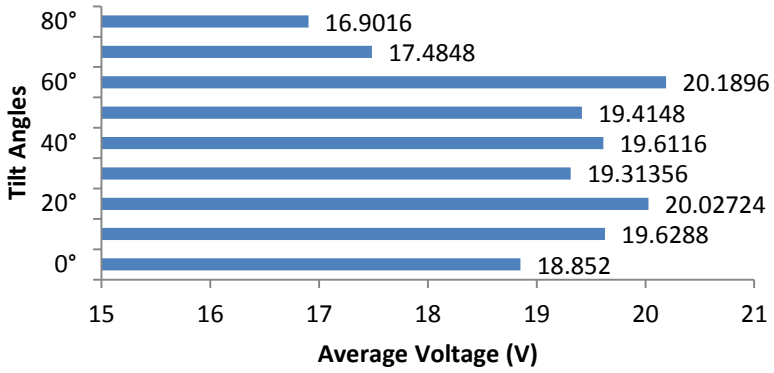


Fig. 8: Tilt Angle vs Average Voltage for the month of June



F ig. 9: Tilt Angle vs Average Voltage for the month of July

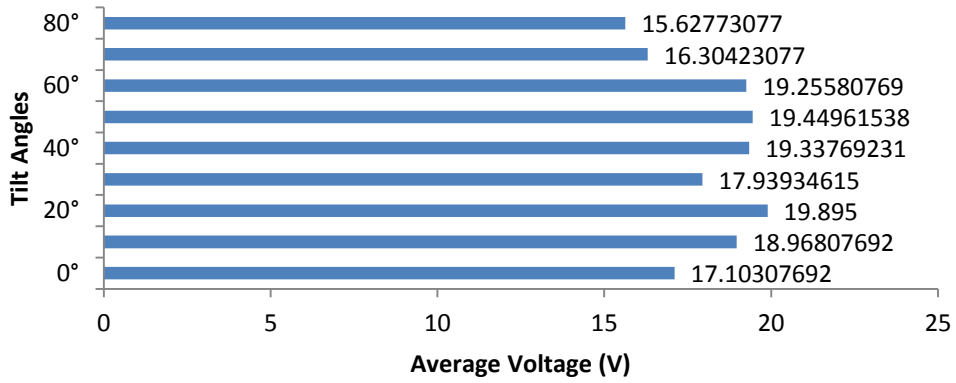


Fig. 10: Tilt Angle vs Average Voltage for the month of August

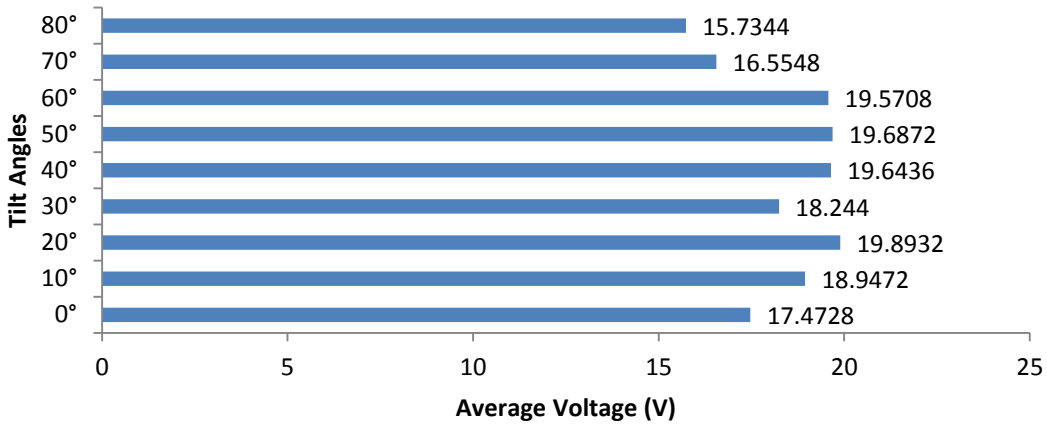


Fig. 11: Tilt Angle vs Average Voltage for the month of September

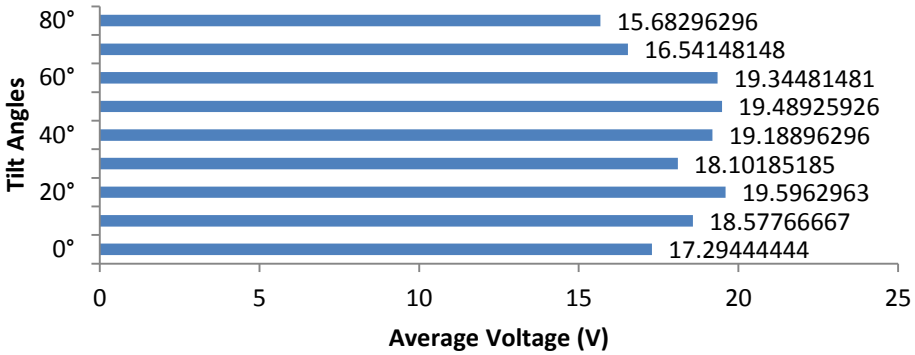


Fig. 12: Tilt Angle vs Average Voltage for the month of October

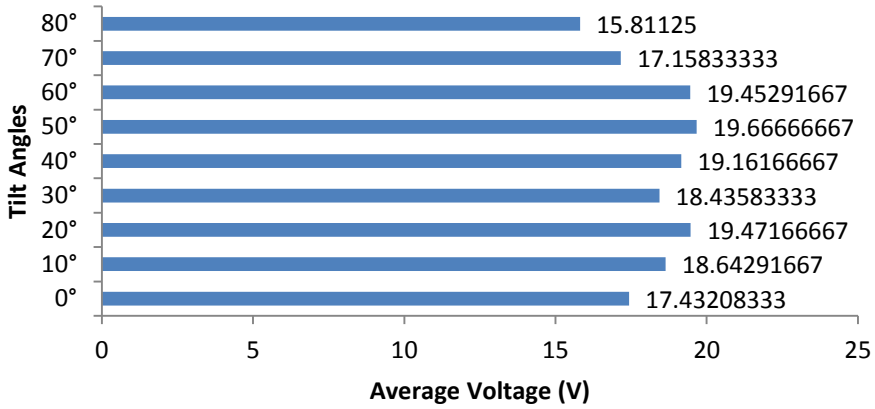


Fig. 13: Tilt Angle vs Average Voltage for the month of November

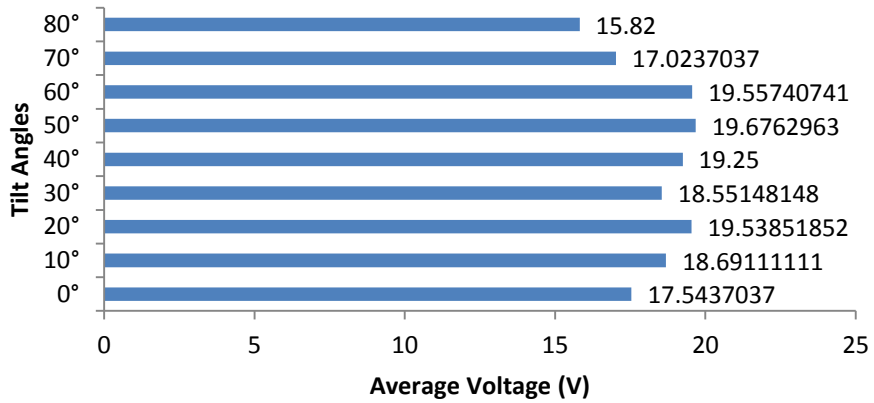


Fig. 12: Tilt Angle vs Average Voltage for the month of December

IV CONCLUSIONS

From the analyzed data in this research work carried out in Federal Polytechnic, Offa, Kwara State; the conclusions drawn in reference to the best tilt angle which gave the maximum voltage for each month of the year are summarized in Table 1.

Table 1 Summary of Monthly Solar Panel Tilt Angle

MONTH	BEST TILT ANGLE (Degrees)
January	60
February	60
March	20
April	60
May	60
June	60
July	60
August	20
September	20
October	20
November	50
December	50

REFERENCES

[1] H. Yoshino, "Current status of energy use and low GHG emission strategies for residential buildings in Japan and China," Journal of Harbin Institute of Technology, vol. 14, no. 1, pp. 1–5, 2007.

[2] Baptiste Jean Lesourd, "Solar Photovoltaic Systems: The Economics of A renewable energy resource"; Environmental Modeling and Software, vol. 16, issue 2, 2001.

[3] J. Changa, Y.C. Dennis, B. Leung, C.Z. Wu a, Z.H. Yuan, "A review on the energy production, consumption, and prospect of renewable energy in China", Renewable and Sustainable Energy Reviews, vol. 7, issue 5, 2003.

[4] A. Zahedi, "Solar photovoltaic (PV) Energy," Latest developments in the building integrated and hybrid PV systems"; Renewable Energy, vol. 31, issue 5, 2006.

[5] China Light Power Group, "Social and environmental report," China Light and Power Holdings Limited, HKSAR, China. 2005.

[6] E. Cetin, A. Yilanci, Y. Oner, M. Colak, I. Kasikci, and Ozturk, H.K., (). Electrical analysis of a hybrid photovoltaic/hydrogen/fuel cell energy system in Denizli, Turkey. Int. J. Energ. Build., 41: 975-998, 2009.

[7] B.P. Chandrakumar, L.B. Jiwanlal, Development and performance evaluation of mixed-mode solar dryer with forced convection. IJEEE4, 23, 2013.

[8] K. Kurokawa, and O. Ikki, The Japanese experience with national PV system programmes. *Solar Energy*,70(6): 457-466, 2001.

[9] k. Lovegrove, and M. Dennis, Solar thermal Energy systems in Australia. International journal of Environmental studies. 63(6), pp. 791-802, 2006.

[10] M. Benghanem, Optimization of tilt angle for solar panel: case study for Madinah. Saudi Arabia Applied Energy88, 1427–1433, 2011.

[11] H. Gunerhan, and. A. Hepbasli,. Determination of the optimum tilt angle of solar collectors for building applications. Build. Environ., 42: 779-783, 2007.

[12] S. Kumarasamy, S. Tulika, S. Guddy, and P. Manicam, Modelling and estimation of photosynthetically active incident radiation based on global irradiance in Indian latitudes. IJEEE 4, 21, 2013.

[13] S. P. Suhatme, Solar energy principles of thermal collection and storage. New Delhi: Tata McGraw-Hill, 1996.

[14] M. Ahmad Jamil, and G.N. Tiwari, "Optimization of Tilt Angle for Solar Collector to Receive Maximum Radiation", *The Open Renewable Energy Journal;* 2: 19-24, 2009.

[15] D. Ibrahim, "Optimum tilt angle for solar collectors used in Cyprus Renewable Energy"; 6:813 – 819, 1995.

[16] Koray Ulgen and Arif Hepbasli, "Prediction of Solar Radiation Parameters Through Clearness Index for Izmir, Turkey", Energy Sources, Part A: Recovery, Utilization, and Environmental Effects; 24: 8, 773 – 785,2002.

[17] B. Bekker, Methods to extract maximum electrical energy from PV panels on the earth's surface. University of Stellenbosch, 2004.

[18] E.D. Mehleri, P.L. Zervas, H. Sarimveis, J.A. Palyvos, and N.C. Markatos, "Determination of the optimal tilt angle and orientation for solar photovoltaic arrays", Renewable Energy; 35: 2468 – 2475, 2010.

[19] R. Tang, and W. Tong, "Optimum tilt angles for solar collectors used in China", Applied Energy; 79:239-248, 2004.

[20] J.P. Chiou, and M.M. EI-Naggar, Optimum slope for solar insolation on a flat surface tilted towards the equator in heating season. Solar Energy, 36, 471, 1986.

[21] J. Kern, and L. Harris, On the optimum tilt of a solar collector. *Solar Energy*, 17, 97, 1975.

[22] M. M. EI-Sayed, Optimum orientation of absorber plates. Solar Energy, 42, 89, 1989.