COMPARATIVE ANALYSIS OF WEATHER PARAMETERS AT TWO LOCATIONS FOR VIABILITY OF SOLAR ENERGY SYSTEMS

Abdul Qayoom Jakhrani*, Andrew Ragai Henry Rigit**, Muhammad Moosa Jakhrani***, Sikandar Ali Channa****

ABSTRACT

The aim of this work is to analyze the weather parameters for determination of optimum photovoltaic system slope and viability of solar energy systems at two locations namely Nawabshah, Pakistan and Kuching, Malaysia. In order to achieve the objectives, twenty two years (1983-2005) satellite-derived monthly mean data for both locations is acquired from National Aeronautics and Space Administration. The data includes mean daily ambient, maximum and minimum temperatures, daylight hours, relative humidity, atmospheric pressure, rainfall, wind speed, optimal angle and sunset hour angle. First, the data is summarized then it is evaluated with the help of Statistical Package for the Social Sciences software and finally compared. It is discovered from the analysis that Nawabshah, Pakistan is more feasible location for installation of solar energy generators as compared to Kuching, Malaysia. Kuching is located near the equator, where it confronts cloudy skies throughout the year and receives heavy rainfall especially from October to March. The annual optimum solar energy outputs could be achieved at a system slope of 21° towards true south for Nawabshah. Lower system slopes is found to be more practicable at Kuching due to its geographical position.

Key words: *Weather parameters, optimum slope, relative humidity, rainfall, ambient temperature*

1. INTRODCTION

Energy is crucial for the social development and economic growth of any nation. The features of life are associated to the per capita consumption of energy. Energy demand is gradually rising since last few decades in all countries due to the development of agricultural and industrial activities [1]. The increasing energy demand can no longer be satisfied by the conventional energy technologies. It is reported that the major cause of global warming are greenhouse gases, which are emitted from combustion and utilization of fossil fuels [2]. It is also believed that alternative energy sources can help to reduce the greenhouse gas emissions and to enhance the energy security [3]. Out of all alternative energy sources, solar energy is one of the principal green energy sources freely available, clean and abundant in most places throughout the year [4]. Solar energy consists of two parts, namely extraterrestrial and global solar energy. The amount of solar energy above the atmosphere is extraterrestrial, which is almost constant with 1367 W/m^2. The global solar energy is that part of radiation available under the atmosphere and reaches over the surface of earth [5]. The amount of global solar radiation varies from place to place due to different geographical and weather conditions. Therefore, the influence of weather parameters is crucial for growth and development of solar energy systems. Since, different techniques can be applied to determine the influence of weather parameters on amount of exploitable energy. Top down approaches is one of the most widely adapted methods for precise determination of available energy. This approach starts with the calculation of energy potential reaching at the surface of earth. However, this amount is influenced by various factors such as the earth's geometry, revolution and rotation as well as the atmospheric attenuation due to scattering and absorption by gases, solid and liquid particles and clouds [6].

Moreover, the actual amount of solar radiation reaching any particular location also depends upon the prevailing climate and local topography of the area [7]. The design, optimization and performance evaluation of solar technologies on any particular location requires reliable data. Such data can be obtained from various sources, such as ground measurements by pyranometers or derived from satellites or combination of both [6-10]. Since, the data measured by meteorological stations is sometimes questionable because of calibration problems and defective recording equipments. The satellite-based data

* Assistant Professor, Department of Energy and Environment Engineering, Quaid-e-Awam University of Engineering, Science and Technology (QUEST), Nawabshah, Pakistan - Email: aqunimas@hotmail.com

** Professor, Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS), Sarawak, Malaysia

*** Postgraduate Student, Department of Electrical Engineering, Quaid-e-Awam University of Engineering, Science and Technology (QUEST), Nawabshah, Pakistan

**** Assistant Professor, Department of Mining Engineering, Mehran University of Engineering and Technology (MUET), Jamshoro, Pakistan

has proven to be highly valuable for the solar energy community over the last decades. However, it did not consider local geographical conditions, hence overestimates the amount of available solar radiations of the region [8-11]. Such comparative data is given in Figure 1. For that reason, the acquired data requires confirmation by means of comparison against measured or other reference data series. Thus, it is important to work out the similarities or the differences between the two data sets. The purpose of this study was to analyze the data of two different locations namely Nawabshah, Pakistan and Kuching, Malaysia, and to examine the variation and correlation of data sets.

Nawabshah is located in the heart of Sindh Province, Pakistan in South Asia and Kuching is located in the western side of Borneo Island, East Malaysia in South East Asia. Nawabshah city is considered as one of the hottest city in Pakistan. The climate is generally dry and hot, but sometimes the temperature falls to 0°C in January. On the other hand, Kuching has tropical rainforest climate moderately hot but very humid at all times and receives substantial amount of rainfall. Kuching is the wettest populated area in Malaysia with an average of 247 rainy days per year. The temperature stays almost constant throughout the year and rarely falls down up to 19°C [12].

Malaysia changed the Four-Fuel Policy based on oil, gas, coal and hydropower to the Five-Fuel Policy with the addition of renewable energy as the fifth source of fuel [13]. In addition, Pakistan heavily depends on fuel imports to meet its growing energy needs. However, it is gifted with large deposits of lignite coals as well as substantial amounts of renewable energy resources including hydro, wind and solar. Currently, Fauji Fertilizer Company Energy Limited is building 49.5 MW Wind Energy Farm at Jhimpir near Karachi and also work is in process to achieve financial close for two wind projects, 50MWs each at Gharo, Thatta District, Sindh [14].

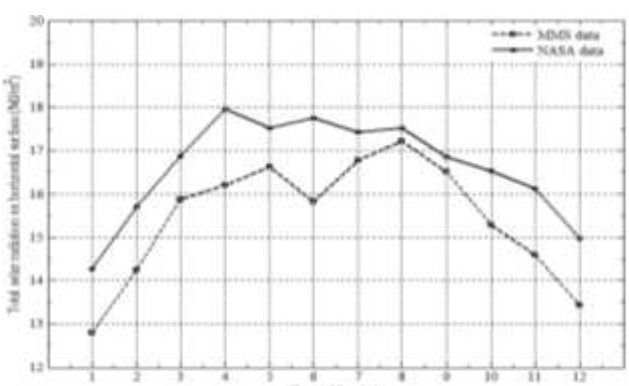

Figure-1. Measured global solar radiation data at Kuching by MMS and NASA

2. METHODOLOGY

The study was carried out to compare the weather data of Nawabshah (26.3°N and 68.4°E), Pakistan and Kuching (1.48º N, 110.33º E) Malaysia. The meteorological data of both locations were acquired from NASA Surface Meteorology and Solar Energy [15]. The methods, parameters methodology of acquired data are shown in Table 1. The data is analyzed and investigated with the help of SPSS software. The results of meteorological parameters are graphically shown in Figures 2-5.

Table 1. Methodology and Techniques Used for Acquiring of Satellite Derived Data

Parameters and Methods	Methodology
Database method	NASA SSE 6
Extent	Global
Data inputs	GEWEX/SRB, 3 + ISCCP Satellite, Clouds + NCAR, Reanalysis
Period	1983–2005
Time resolution	3-h
Spatial resolution	1 arc-degree x 1 arc-degree
Global horizontal radiation	Satellite model [16]
Diffuse fraction	Diffuse Radiation Model [17]
Inclined surface (diffuse model)	RetScreen Model [18]

3. RESULTS AND DISCUSSIONS

The different weather parameters such as ambient temperature, relative humidity, rainfall, wind speed, system slope and hour angle were considered this analysis. The results of these parameters were evaluated with the help of SPSS software and critically examined by comparing their values.

3.1. Average, Minimum and Maximum Ambient Temperature

The behavior of air temperature of both places is shown in Figure 2. It was observed that the maximum mean value of ambient temperature (T_a) at Nawabshah was 32.9°C in the month of June and the minimum value was 16.0°C in January with an annual mean value of 26.3°C. Similarly, the maximum value of ambient temperature (T_a) in Kuching was 27.2°C in the month of August and the minimum value was 25.1°C in January with an annual average value of 26.1°C. Besides average ambient temperature, the maximum mean value of minimum air temperature (T_{min}) in Nawabshah was 27.6°C in the month of June and the minimum value was 10.1°C in the month of January with an annual mean value of 20.7°C. The results show that the maximum value of minimum air temperature (T_{min}) in Kuching was 24.3°C in the month of August and the minimum value was 23.3°C in January with an annual average value of 23.7°C.

The analysis exposed that the maximum mean value of maximum air temperature (T_{max}) in Nawabshah was 39.2°C in the month of May and the minimum value was 23.3°C in January with an annual mean value of 32.6°C. Similarly, the maximum value of maximum air temperature (T_{max}) in Kuching was found to be 30.3°C in the month of August and the minimum value was 27.1°C in January with an annual average value of 28.6°C. The results showed that the range of ambient temperature at Nawabshah was around 15°C and at Kuching, it was not more than 2.0°C as shown in Figure 2. The trend of ambient temperature at Nawabshah is totally different than that of Kuching. As in winter season, the temperature is too low and in summer season it is too high and sometimes reaches up to 50°C at Nawabshah.

3.2. Daylight Hours, Relative Humidity and Atmospheric pressure

The statistical values of day light hours, relative humidity and atmospheric pressure are demonstrated in Figure 3. It was observed that the maximum average daylight hours (N) at Nawabshah were 13.7 hours in the month of June and the minimum value was 10.5 hours in the month of December. The maximum average daylight hours (N) in Kuching was found to be 12.2 hours in the months of June and July and the minimum value was 12 hours in the months of January, February, October, November and December. As shown in Figure 3, the range of daylight hours at Nawabshah was almost 3.5 hours, it means that in winter season, the days were very short and nights were too long and in summer vice versa. However, at Kuching the days and nights were almost same throughout the year as the difference between day and nights in the summer and winter was just 0.2 hours. In addition, the maximum mean value of relative humidity (RH) at Nawabshah was found to be 61.7% in the month of August and the minimum value was 26.7% in November with an annual mean value of 38.2%. The maximum value of relative humidity (RH) at Kuching was found to be 84.5% in the month of January and the minimum value was 69.9% in August with an annual average value of 78.6%. The higher percentage of RH in the months of July and August at Nawabshah was due to the monsoon season otherwise the climate is usually dry. It was found from the analysis that the average difference between higher and lower relative humidity at Nawabshah was 35%, whereas, at Kuching, it was just 14%. However, the average relative humidity at Kuching was found to be almost double than that of Nawabshah, due to higher percentage of vapors in the atmosphere.

Moreover, the maximum mean value of atmospheric pressure (P_{atm}) at Nawabshah was 100 kPa in the months of January and December and the minimum value was 98.2 kPa in the months of June and July with an annual mean value of 99.2 kPa. Similarly, the maximum mean value of atmospheric pressure (P_{atm}) at Kuching was 100 kPa in all months except 99.9 kPa in the month of May. In general, the average atmospheric pressure of Nawabshah was found to be slightly lower than that of Kuching with a difference of only 1.7 kPa.

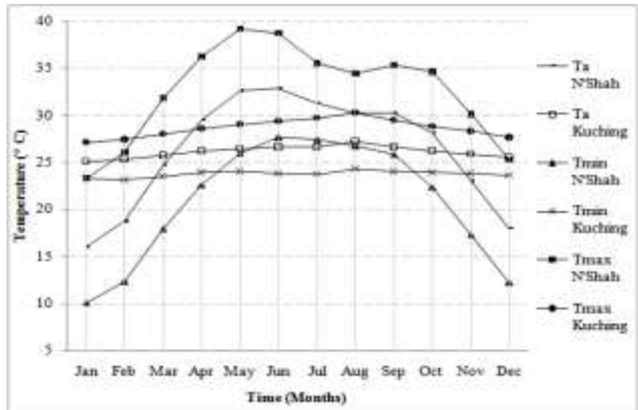

Figure-2. Comparative Analysis of Ambient Air Temperature at Nawabshah and Kuching

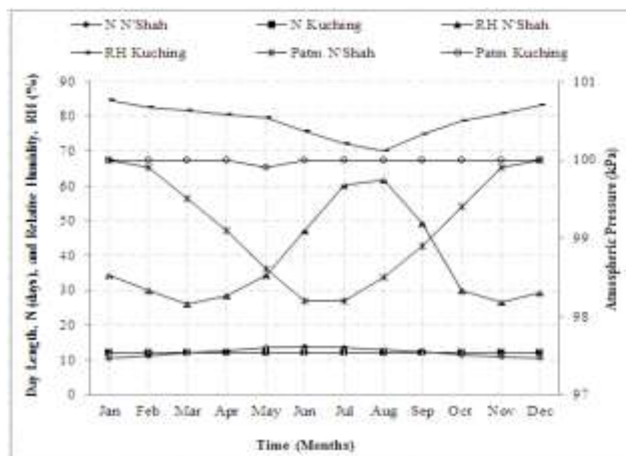

Figure-3. Comparative Analysis of Monthly Mean Daylight Hours (N), Relative Humidity (RH) and Atmospheric Pressure (P_{atm}) at Nawabshah and Kuching

3.3. Rainfall Conditions and Wind Speed

The rainfall conditions and behavior of winds are graphically shown in Figure 4. It was discovered from the analysis that the maximum average of rainfall at Nawabshah was 2.36 mm/day in the month of July and the minimum value was 0.04 mm/day in the month of November and annual average value was found to be 0.56 mm/day. The maximum average of rainfall in Kuching was found to be 12.0 mm/day in the month of January and the minimum value was 6.51 mm/day in the month of July, whereas, the annual average rainfall was 8.79 mm/day. It was found from the analysis that Kuching is one of the rainiest places of the world and Nawabshah confronts low rainfall except monsoon season. However, at Kuching, the rainfall was rather low in the months from

May till August as compared to other months. Moreover, the maximum average of wind speed (V_w) at Nawabshah was found to be 4.57 m/s in the month of June and the minimum value was 3.22 m/s in the month of November and annual average value was 3.75m/s. Similarly, the maximum average of wind speed (V_w) at Kuching was found to be 3.74 m/s in the month of August and the minimum value was 1.79 m/s in the month of July, whereas, the annual average rainfall was 2.67 m/s. In contrary to the rainfall, the wind speed at Kuching was found to be lower than that of Nawabshah due to equatorial position.

3.4. Optimum Slope and Hour Angle

The values of optimum slope and hour angle for PV system installations at both places are given in Figure 5. It was observed that the maximum optimum angle (β_{opt}) at Nawabshah was 50.0° in the month of January and the minimum value was 0° in the months of May, June and July with an annual mean value of 24.8°. Likewise, the maximum optimum angle (β_{opt}) at Kuching was found to be 25.0° in the month of December and the minimum value was 1.0° in September with an annual average value of 14.1°. The results showed that the range of slope at Nawabshah was 50.0°, whereas at Kuching, it was only half of that value e.g. 25.0°. It is because the sun is going far away from the location (Nawabshah) in winter and reaching towards location in summer. In contrary, Kuching is located near the equator, where the sun is almost at same distance in summer as well as in winter months. Furthermore, the maximum hour angle (ω) at Nawabshah was 102.0° in the month of June and the minimum value was 77.9° in the month of December. The maximum hour angle (ω) at Kuching was found to be 90.6° in the month of June and the minimum value was 89.3° in December. The range of hour angle at Nawabshah was 24°, whereas at Kuching it was within 2°.

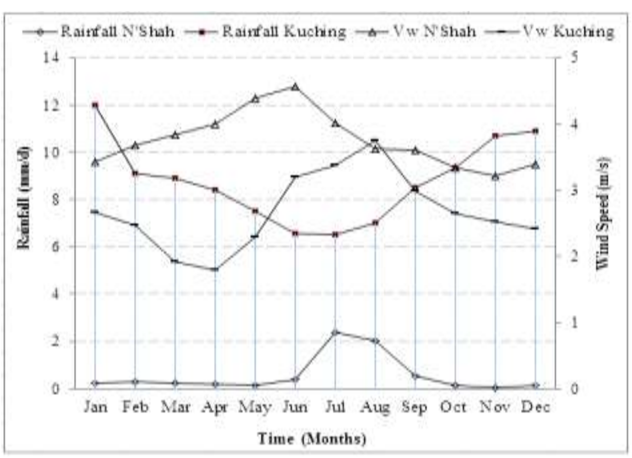

Figure-4. Comparative Analysis of Rainfall and Wind Speed above 10 m height at Nawabshah and Kuching

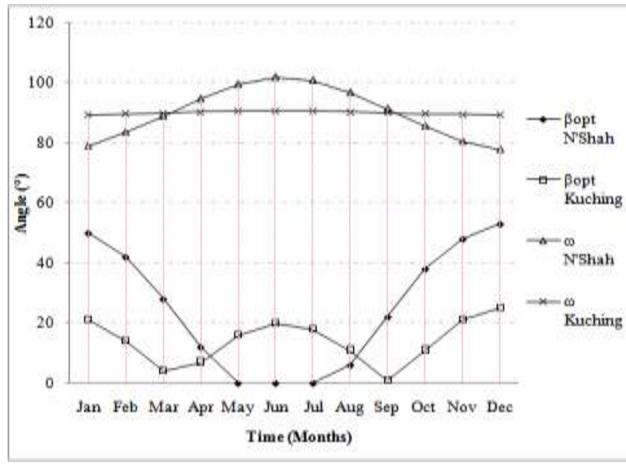

Figure-5. Comparative Analysis of Optimal Angle, β° and Sunset Hour Angle, ω at Nawabshah and Kuching

In general, it was exposed from the analysis that the propensity of ambient temperature at Nawabshah was found to be totally different than that of Kuching. At Nawabshah, the temperature was found to be too low in winter and too high in summer where it sometimes reaches up to 50°C. At Kuching, the range of ambient temperatures throughout the year was quite low. Moreover, the relative humidity in the months of July and August at Nawabshah was found to be high due to the monsoon season otherwise it is rather dry. Study reveals that the average difference between higher and lower relative humidity at Nawabshah was 35%, whereas, at Kuching, it was just 14%. Furthermore, the range of solar system angle at Nawabshah was quite high with 50° and at the Kuching it was only 25° due to geographical position. In Nawabshah, the lengths of days in winter season were short and nights were long and vice versa in summer. The lengths of days and nights at Kuching were found to a same throughout the year with a difference of only 0.2 hours. The relative humidity at Kuching was found to be almost double than that of Nawabshah, due to presence of large amount of vapors in the atmosphere due to in equatorial position. In general, the average atmospheric pressure of Nawabshah was quite low as compared to Kuching with a difference of only 1.7 kPa.

4. CONCLUSIONS

The weather data of Nawabshah, Pakistan and Kuching, Malaysia was acquired from National Aeronautics and Space Administration (NASA) Surface Meteorology and Solar Energy website. The data was then summarized, evaluated and compared with the help of SPSS software. It was revealed from the analysis that the average ambient and maximum temperature was higher at Nawabshah, while Kuching faces higher values of average minimum temperature as well as relative humidity. At Kuching, the sky dome was found to be almost covered with clouds and receives heavy rainfall throughout the year. In contrary to Nawabshah, the temperature and wind speed as well as other weather parameter values were found to be uniform at Kuching because of its equatorial position. The annual optimum system outputs could be achieved with system installation at an angle of 21° tilted towards true south for Nawabshah, whereas, lower system slopes are feasible at Kuching.

The results revealed that the variation and range of parameter values were higher at Nawabshah as it confronts less rainfall and cloud cover in the whole year. It was concluded that Nawabshah is more suitable location for the development of solar energy systems as compared to Kuching due to clear sky conditions.

REFERENCES

[1] F.R. Martins, E.B. Pereira, S.A.B. Silva, S.L. Abreu, S. Colle. Solar energy scenarios in Brazil, Part one: Resource assessment, Energy Policy 36 (2008) 2853–2864.

[2] G. Wu, Y. Liu, T. Wang. Methods and strategy for modeling daily global solar radiation with measured meteorological data- A case study in Nanchang station, China, Energy Conversion and Management 48 (2007) 2447–2452.

[3] A.A. El-Sebaii, F.S. Al-Hazmi, A.A. Al-Ghamdi, S.J. Yaghmour, Global, direct and diffuse solar radiation on horizontal and tilted surfaces in Jeddah, Saudi Arabia, Applied Energy 87 (2010) 568–576.

[4] T.Khatib, A.Mohamed, K. Sopian, A review of solar energy modeling techniques, Renewable and Sustainable Energy Reviews 16 (2012) 2864– 2869.

[5] J.L. Torres, M. De Blas, A. Garcia, A. de Francisco, Comparative study of various models in estimating hourly diffuse solar irradiance, Renewable Energy 35 (2010) 1325–1332.

[6] A.Angelis-Dimakis, M.Biberacher, J. Dominguez, G. Fiorese, B. Espinar, L.Ramirez, A. Drews, H.G. Beyer, L.F. Zarzalejo, J.Polo, L. Martin, Analysis of different comparison parameters applied to solar radiation data from satellite and German radiometric stations, Solar Energy 83 (2009) 118–125.

[7] J.C. Lam, K.K.W. Wan, L.Yang, Solar radiation modelling using ANNs for different climates in China, Energy Conversion and Management 49 (2008) 1080–1090.

[8] M. Journee, R. Muller, C. Bertrand, Solar resource assessment in the Benelux by merging Meteosat-derived climate data and ground measurements, Solar Energy 86 (2012) 3561–3574.

[9] A.Q. Jakhrani, A.K. Othman, A.R.H. Rigit and S.R. Samo, Assessment of Solar and Wind Energy Resources at Five Typical Locations in Sarawak. Journal of Energy & Environment, Vol. 4 (1), 2012, 1-6. ISSN: 1985-7462.

[10] A.Q. Jakhrani, A.K. Othman, A.R.H. Rigit, S.R. Samo, and S.A. Kamboh, A Simplified Analytical Method for Size Optimization of a Standalone PV System. NED University Journal of Research-Applied Sciences, X (2), 2013, 9-18. ISSN 1023-3873.

[11] A.Q. Jakhrani, S.R. Samo, S.A. Kamboh, J. Labadin, and A.R.H. Rigit, An Improved Mathematical Model for Computing Power Output of Solar Photovoltaic Modules. International Journal of Photoenergy, 2014, Article ID 346704, 9 pages.

[12] World Climate (WC), Kuching, Malaysia Weather History and Climate Data. Available at http://www.worldclimate.com/.

[13] Department of Statistics Malaysia, Sarawak (DSMS), Meteorological Observations at Meteorological Station, Kuching International Airport. Monthly Statistical Bulletin, Kuching, January 2009: 09 November, 2013. ISSN 1823-1640.

[14] K. Y. Awan, A. Rashid, Overview of Pakistan's Electricity Crisis, Generation-Mix and Renewable energy scenarios, International Journal of Engineering and Technology 1 (4) (2012) 321-334.

[15] NASA Surface Meteorology and Solar Energy, Available at: https://eosweb.larc.nasa.gov/sse/

[16] R.T. Pinker, I. Laszlo, Modeling surface solar irradiance for satellite applications on a global scale, Journal of Applied Meteorology 31 (1992)194–211.

[17] D.G. Erbs, S.A. Klein, J.A. Duffie, Estimation of the diffuse radiation fraction for hourly, daily and monthly average global radiation, Solar Energy 28 (1982) 293–302.

[18] J. Duffie, A. Beckman, Solar engineering of thermal processes, 3rd Edition, John Wiley & Sons., 2006.