Measurements of Solar Radiation

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Abstract: Measurements of solar radiation on a horizontal surface have been conducted for a period of seven months (January – April 2003 and August – October 2003) using SOLARAD (consists of a pyranometer and a data logger) that was placed on the roof of the Solar Room located in the Physics Department, University of Brunei Darussalam. The maximum and the minimum monthly-averaged solar radiation of 1051 W/m^2 and 23 W/m^2 were recorded for the months of August and October respectively. The variation of insolation can be classified into two distinct categories – low radiation due to the presence of clouds and turbid atmosphere, and high insolation associated with relatively clear skies.

Keywords: Measurements of solar radiation, global radiation, solar radiation on a horizontal surface

Introduction

Just as the fossil-fuel based energy industry relies on exploration and proven resources for discovery and economic support of energy markets, the renewable energy sector depends upon the assessment of resources for planning and selling their energy production technology. For solar-based renewable energy production technologies such as solar thermal or photovoltaic conversion systems, the basic resource or fuel available is solar radiation. Colle et al. [1] have shown that uncertainty in life-cycle savings for solar thermal and photovoltaic systems are linearly correlated with uncertainty in solar resource data. Assessment of solar resources for these technologies is based upon measured data, where available. Such data are essential for optimal design, selection or performance prediction of photovoltaic as well as solar thermal devices [2-12]. This project deals with the measurements of solar radiation for Brunei Darussalam. It was initiated on January 18th , 2003. This report presents the measured data on this radiation for a period of seven months.

Measurement of Solar Radiation

The instrument used for this project is a Kipp and Zonen CM3 pyranometer, which was connected to a handheld digital meter, the CC20 Radiation Indicator (Kipp and Zonen), as shown in Figure 1. The amount of radiation falling on the pyranometer is displayed by the CC20 meter in the units of W/m^2. The SOLRAD system was placed at the roof of the solar room, which is not blocked by local landscape features, such as trees, buildings, hills or mountains that may otherwise shade the CC3 pyranometer during different times of the day. The choice of location is based on the requirement that for the optimum amount of global radiation to be received, the field of view of the pyranometer's sensor must be free from obstructions at all times.

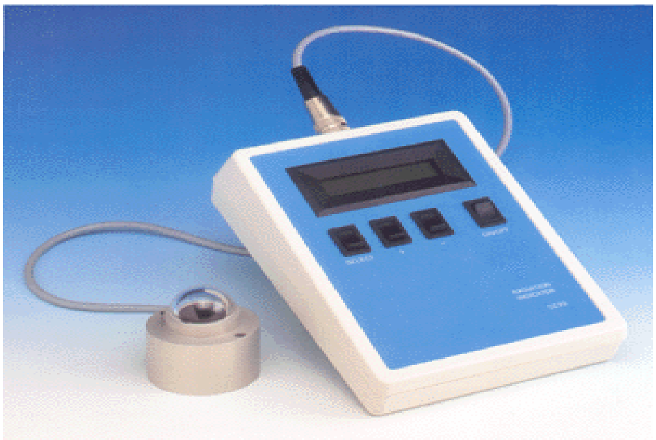

Figure 1. Pyranometer with data logger (SOLRAD System).

Results and Discussion

Two measurements of global solar radiation were made in the month of January 2003 corresponding to the 8th and 25th and the results are shown in Figure 2. The maximum insolation of 578 W/m^2 was recorded at 1215 hours when low altitude clouds were in the sky. The amount of solar irradiance for 18th January 2003 is approximately symmetrical with respect to 1215 hours local standard time that corresponds approximately to solar noon. The maximum and minimum insolation for the 25th January were 970 W/m^2 and 116 W/m^2 respectively. A monthly-averaged maximum insolation for January is 774 W/m^2 and the minimum 269 W/m^2.

Three measurements of solar irradiance were made for the month of February 2003 corresponding to the 8th, 15th and 22nd days of the month and the results are depicted in Figure 3.

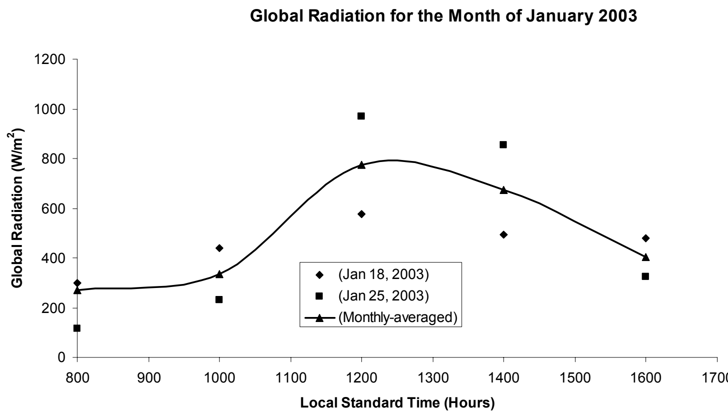

Figure 2. The amount of solar radiation falling on a horizontal surface in the month of January 2003.

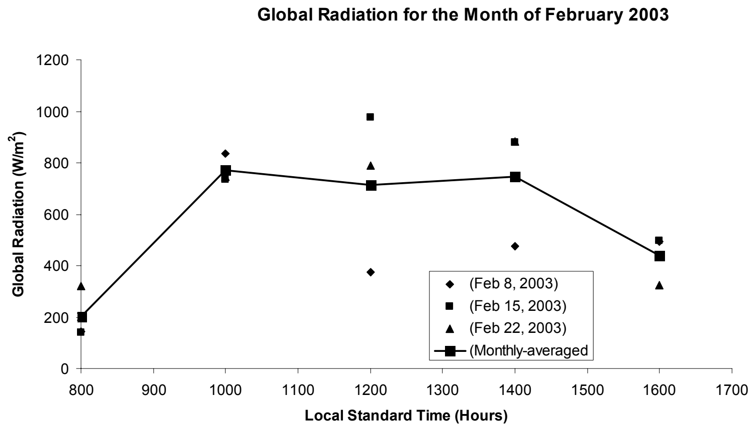

Figure 3. The amount of solar radiation falling on a horizontal surface in the month of February 2003.

There was haze on 8 February due to the forest fires at Anduki Seria. The presence of haze and dark clouds caused the insolation at 0800 hours to be very low. The maximum insolation of 836 W/m^2 was recorded at 1015 hours. There is an unusual dip at 1215 hours, when the measured solar radiation was 374 W/m^2. This is due to an increase in the scattering of solar radiation because of haze. The solar irradiance recorded at 0800 hours on 15 February 2003 was low (140 W/m^2) due to clouds covering the sun. Later, the sky became clear and the amount of solar radiation increased. On 22nd February 2003, insolation measured at 0800 and 1000 hours were relatively high as there were no clouds in the sky. The maximum insolation was recorded at 1415 hours (884 W/m^2) instead of 1215 hours (788 W/m^2). This is because at 1215 hours the sky was partially cloudy, while it was clear at 1415 hours. There was a big drop in the amount of solar radiation measured at 1600 hours (423 W/m^2), due to the presence of thick dark grey clouds reducing the intensity of solar radiation. The monthly-averaged solar radiation for the month of February showed a dip at 1215 hours local standard time that indicates the presence of clouds attenuating the incoming solar radiation. The maximum and minimum insolation was 772 W/m^2 (at 1000 hours) and 202 W/m^2 (at 0800 hours) respectively.

Out of the 5 measurements (1st, 8th, 15th, 22nd, 29th) recorded for the month of March 2003 (Figure 4), the symmetrical aspect of solar irradiance with respect to the solar noon is seen only on 8th March 2003 (Figure 4) with a peak of 1220 W/m^2. The curves for 15th and 22nd March 2003 show a dip at 1400 hours indicating substantial attenuation of solar radiation by clouds. The presence of clouds at 1400 hours on both days causes the curves to be asymmetrical about solar noon. The graph obtained for 29th March appears to be reflection of curve obtained on 1st March. This indicates that the morning of 1st March was as cloudy as the afternoon of 29th March. It might be due to the localized climate favouring the formation of clouds in mornings in early March and later this trend moved to the afternoons. The maximum monthly-averaged insolation was 1109 W/m^2 while the minimum was 274 W/m^2.

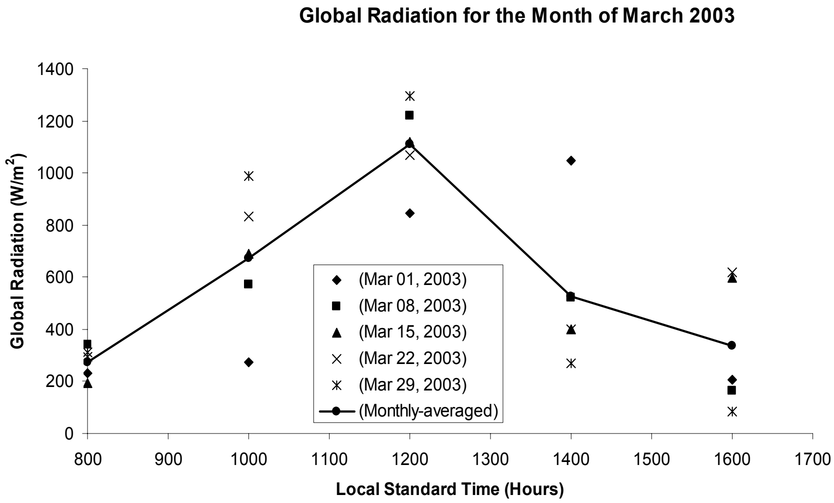

Figure 4. The amount of solar radiation falling on a horizontal surface in the month of March 2003.

Two measurements of solar radiation were recorded in the month of April 2003 and the results are depicted in Figure 5. The amount of solar radiation at 0800 hours on 5th April was low due to overcast. The sky became relatively clear at 1000 hours and the insolation was 880 W/m^2. However the amount of solar radiation suddenly dropped to 300 W/m^2 at 1215 hours (solar noon) as the sun was blocked by thick dark grey clouds. The solar irradiance then increased to 920 W/m^2 at 1400 hours and later decreased to 600 W/m^2 due to changes in the appearance of the sky.

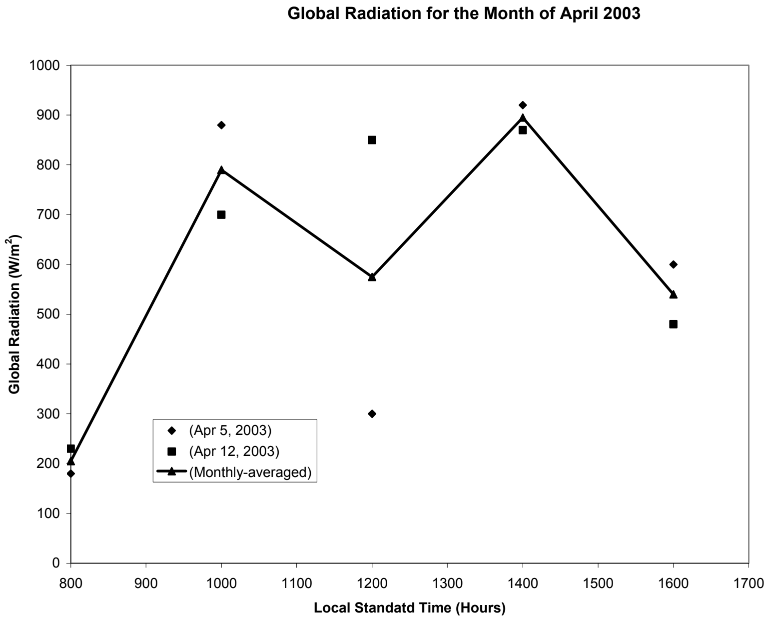

Figure 5. The amount of solar radiation falling on a horizontal surface in the month of April 2003.

The solar irradiance for 12th April 2003 ranges from a minimum of 230 W/m^2 to a maximum of 870 W/m^2 as shown in Figure 5. The insolation recorded at 1215 hours and 1415 hours differ by 3 W/m^2. This is because at 1215 hours, the sun was partially blocked by thick grayish clouds while 1t 1415 hours; the sun was partially covered by thin wispy clouds.

Four experiments were carried out in the month of August (9, 16, 23 and 30), 2003 and results are shown in Figure 6. The maximum amount of solar radiation (1049 W/m^2) on 9th August was recorded at 1200 hours local standard time. The amount of solar radiation is not symmetrical with reference to the solar noon due to the presence of clouds in the morning. The radiations are in the range of 22 W/m^2 to 1049 W/m^2. A deep dip in graph for amount of solar radiation recorded on 16th August represents the presence of thick clouds in the sky that blocked the Sun. The sky was almost clear at 1400 hours and the amount of solar radiation declined as the Sun's apparent motion proceeded towards the sunset position. The amount of solar radiation for August 23rd, 2003 is shown in Figure 6 that illustrates the presence of clouds in the morning. The maximum radiation of 1138 W/m^2 was at 1300 hours local standard time and the minimum of 85 W/m^2 at 1800 hours. The irradiations recorded on August 30, 2003 demonstrate the presence of clouds at 1000 and 1200 hours respectively. The maximum and the minimum irradiation of the day were 1051 W/m^2 and 155 W/m^2 corresponding to 1200 and 1800 hours local standard time. The monthly-averaged irradiation for the month of August demonstrates the presence of clouds in the mornings and sky become clear in the afternoons. The maximum and the minimum monthly-averaged radiations are 891 and 75 W/m^2 respectively corresponding to 1300 and 1800 hours.

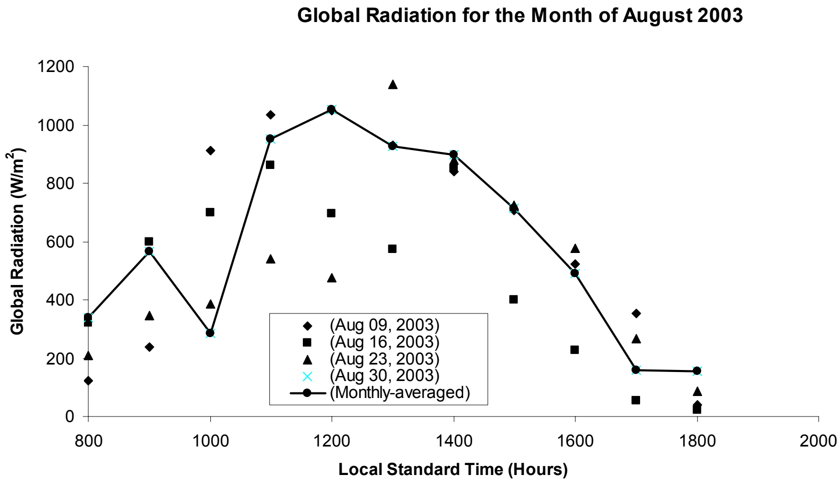

Figure 6. The amount of solar radiation falling on a horizontal surface in the month of August 2003.

In September, four measurements for solar radiation were recorded (6, 13, 20 and 25), 2003 and the results are shown in Figure 7. The maximum and the minimum irradiation of 973 W/m^2 and 53 W/m^2 were measured on September 6th, 2003 that corresponds to 1230 and 1800 hours respectively. A deep dip in the graph for amount of solar radiation on September 6th, 2003 represents the presence of dark clouds at 1000 hours local standard time in the sky. At 1200 hours a drop in the amount of solar radiation was due to the fact that the sun was partially blocked by clouds. In the afternoons the sky was clear and the radiation was increased. The measured amount of irradiation for September 13th, 2003 is depicted in Figure 7 demonstrates a symmetrical behavior with reference to the solar noon. The maximum and the minimum radiation of 1111W/m^2 and 8 W/m^2 are corresponding to 1230 and 1800 hours respectively.

Insolation for September 20th, 2003 indicates the presence of thick clouds throughout the day that reduces the amount of solar radiation reaching at the Earth surface. The maximum and the minimum irradiation of 524 W/m^2 and 37 W/m^2 were recorded that correspond to 1300 hours and 1800 hours local standard time respectively. The amounts of irradiance for September 25th demonstrate the presence of thick clouds at 1000 and 1200 hours. The maximum and the minimum irradiance of the day were 788 W/m^2 and 100 W/m^2 corresponding to 1100 and 1800 hours respectively. The monthly-averaged insolation for September demonstrates the presence of clouds in the mornings at about 1000 hours during this month and sky become clear in the afternoon. The maximum and minimum monthly-averaged radiations of 862 W/m^2 and 33 W/m^2 were recorded for 1300 and 1800 hours.

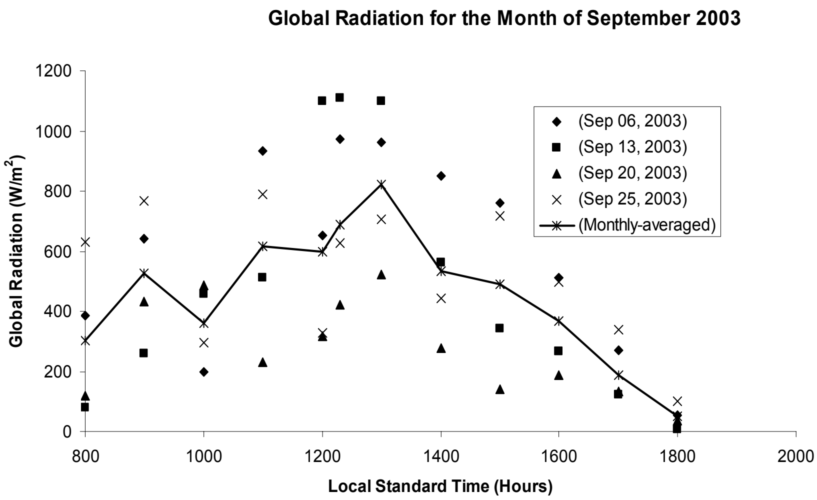

Figure 7. The amount of solar radiation falling on a horizontal surface in the month of September 2003.

Four measurements were taken for the month of October (4, 11, 18 and 25), 2003 and results on only one of these are depicted in Figure 8. The data reveal that the amount of irradiation is low in the morning of 4th October due to the presence of clouds and sky become clear in the afternoon. A deep dip in Figure 8 illustrates the presence of thick clouds blocking the sun. The amount of irradiation then gradually declined until the 1800 hours. The amount of solar radiation for October 11th, 2003 indicates the presence of clouds in the morning. The maximum and minimum irradiation of 1121 W/m^2 and 22 W/m^2 are corresponding to 1200 and 1800 hours local standard time, respectively. The sky was overcast in the morning of 18th October and became clear in the afternoon. As, it was raining in the late afternoon; therefore, the amount of irradiation drops to a minimum of 17 W/m^2. The recorded data for 25th October demonstrates that the irradiation was low in the morning due to the presence of thick clouds in the sky. The maximum and the minimum insolation of 1153 W/m^2 and 26 W/m^2 were recorded corresponding to 1200 and 1800 hours, respectively.

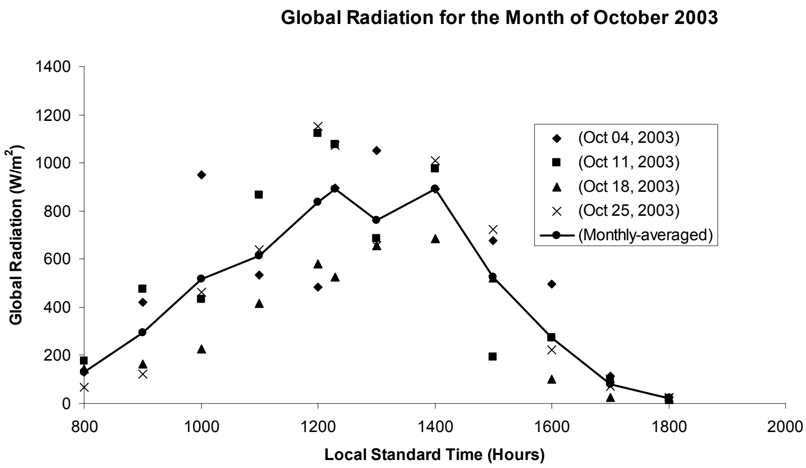

Figure 8. The amount of solar radiation falling on a horizontal surface in the month of October 2003.

The monthly-averaged insolation for the month of October show a symmetrical behaviour with respect to solar noon. The maximum and the minimum irradiation of 892 W/m^2 and 23 W/m^2 were measured at 1230 and 1800 hours, respectively.

Considering the overall average, the major and minor maxima occur in the month of August 2003 and March 2003 respectively. The major and minor minima are respectively in the months October and September. The best month, August 2003, with a monthly-averaged daily mean amount of global solar radiation of 594 W/m^2, contributes 16 % of the total amount of solar radiation incident horizontally at the Earth's surface in Brunei Darussalam during the period of six months. The results also show that high values of global solar irradiation are associated with days/months when the atmosphere has less clouding activity. This can be seen in the month of March.

Therefore, the variation could be divided into two distinct groups - the low irradiation values being associated with cloudy and turbid months while the high values are associated with less turbid and cloudy months.

In the absence of clouds, solar radiation passing through the atmosphere is attenuated by Rayleigh scattering, absorption by water vapor and permanent gases, aerosol scattering and absorption. Absorption by each of these components is strongly dependent on wavelength and the optical air mass. In the presence of large particles, light of all colors is scattered almost equally. The sky appears less blue and eventually becomes pale when sufficient numbers of large particles are present as in the case of water droplets or heavy dust. In cloudy sky conditions, clouds are the largest moderation of solar energy flux (Udo and Aro 1999). Brunei Darussalam has a humid climate and even on a very clear day the attenuation of solar radiation by water vapor is substantial.

The global solar radiation received at the ground, within the spectral region 0.3 to 4 μm, is composed of direct and diffuse components, which may vary quite considerably in regard to both intensity and spectral composition. So routine measurements of the solar radiation flux penetrating to the lower layers of the atmosphere are not only of direct solar radiation, but also include diffuse and reflected solar radiation.

It is necessary that radiometers used for solar radiation measurements should respond equally to equal amounts of energy, whatever the wavelength of the radiation within the wavelength range they are intended to cover, i.e. detectors should be fully black, with a sensitivity which is constant for all wavelengths. The technical data provided by the manufacturer of Kipp & Zonen demonstrates that it has a high and uniform absorptivity over a wide range of wavelengths.

It is important to note that wrong measurements are worse than no measurements. After choosing an instrument having the necessary accuracy and reliability and having its calibration factor determined at the World Meteorological Organization (WMO) laboratories, or a similar laboratory authorized and equipped to carry out such calibration, it is necessary to install it correctly and maintain it carefully, if reliable data are to be obtained. Periodic intercomparison of the instrument with traveling standards once a year is essential, if the data are to be considered dependable. With the increase in recent years in the number of radiation instruments in use in this region, a system of verification and quality control of radiation measurements should be organized and the data processed and published regularly, so that a reliable radiation database will be available to all current and potential users of solar energy in the region.

Conclusions

The monthly-averaged daily global radiation on a horizontal surface varies from 23 W/m^2 to 1109 W/m^2. The variations of global solar radiation in Bandar Seri Begawan, Brunei Darussalam can be divided into two groups – the low irradiation values being associated with cloudy periods while the high values are associated with low cloud cover.

The high values of global solar radiation and relatively small range of variation shows that Brunei Darussalam has a high potential for solar energy utilization.

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