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Ground measurements of Global Horizontal Irradiation in Doha, Qatar

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ABSTRACT

The present work shows an analysis of ground measurements of Global Horizontal Irradiation (GHI) taken at the Doha International Airport for the period 2008–2012. Inter-annual variability and monthly averages of GHI values were calculated from the available records of daily total irradiation values, analysed and discussed along with the daily averages. The average daily GHI value in Doha for the whole 5-year period is 5.61 kWh/m^2/day, a total of 2048 kWh/m^2/year. The highest monthly average is 6.97 kWh/m^2/day during the month of June, followed by May with 6.92 kWh/m^2/day. Day 149 of the year, which corresponds to the 29th of May, shows the highest daily average for this period, with 7.49 kWh/m^2/day. In addition to global solar radiation, the daily and monthly average clearness indices along with three meteorological parameters (air temperature, relative humidity and air pressure) are presented and analysed. The annual average of clearness index for Doha obtained from ground measurements is 0.62, somewhat higher than the 22-year averaged value provided by the NASA-SSE database, 0.57. GHI and clearness index values are important parameters for solar-related projects; GHI assessment, for instance, is vital for PV applications. Even though the measurements were taken in Doha, a coastal and an expanding city, the values found in this study indicate that Doha has a good potential for this kind of applications and better conditions could be expected in other areas of Qatar.

1. Introduction

Any project aiming to exploit solar radiation requires a correct assessment of the availability of this resource; in particular, measurements of the Global Horizontal Irradiation (GHI) are the input for the current design of PV systems. Various models based on existing climatic parameters have been developed and used for GHI estimation, see for example [1–3]. GHI values can also be derived from satellite images using models, combined or not with several meteorological and climatic variables measured at ground level or derived from satellite data, see for example [4]; however, satellite-derived or any model-based values of solar irradiation depend strongly on the input variables, the model used to process the inputs and its validity in the region. Ground measurements, on the other hand, currently provide the most accurate information when performed following certain standards, but they are not always available at many locations and for long periods of time, while satellite data can be found for many locations on Earth, sometimes for 2 decades or more; for instance, the GeoModel Solar database [5] provides data from 1994 onwards, and HelioClim [6] from 1985. The bare minimum for obtaining a site-specific typical year is one year of ground measurements. At least 10 years of available data is advisable [7,8], about a full solar cycle; the best estimate can be achieved by combining limited ground measurement periods with long-term satellite data [9].

Different studies have been conducted in the Arabic Gulf region for measuring and estimating GHI. In UAE, an analysis of GHI measurements in Abu Dhabi is presented for the year 2007 in Ref. [10]. In Saudi Arabia, GHI data in the north-eastern part is investigated for one complete year in Ref. [11]. Another study in Saudi Arabia was conducted in Jeddah and includes an analysis of global and diffuse solar radiation on horizontal and tilted surfaces for the period 1996–2007; empirical correlations for estimating the diffuse solar radiation were proposed [12]. GHI Measurements for Oman over a period of 6 years can be found in Ref. [13]. Some methods of predicting global solar radiation in Doha, Qatar, were investigated in Ref. [14].

In the present study, five years of GHI ground measurements in Doha are analysed. The following sections describe the equipment used, the data collected, and an analysis of the GHI as measured with one automatic weather station; also included is a calculation of the clearness index K and a comparison with long-term values of K obtained by NASA-SSE (Surface Meteorology and Solar Energy programme) [15] from satellite data.

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2. Instrumentation and data

For this study, the global solar radiation in Doha as measured with an automatic weather station is presented and analysed for a five-year period from 2008 to 2012. The ground measurement station is located at the Doha International Airport (25.25° N, 51.57° E) and is operated and maintained by the Qatar Meteorological Department (QMD) of the National Aviation Authority, Qatar, since January 2008. For the solar radiation measurements, this station is equipped with a Kipp & Zonen pyranometer of type CM6B used to measure global solar radiation on the horizontal surface. The CM6B pyranometer is compliant with all ISO-9060 specification criteria for that of an ISO First Class pyranometer; it has a spectral range between 305 and 2800 nm, a response time (95%) of 30 s and a non-linearity $< \pm 1.2\%$ (<1000 W/m^2). The data presented here is based on the daily total global radiation in J/cm^2, provided by QMD. Other meteorological parameters are also presented and studied for the same period and location; daily values were obtained from the Weather Underground database [16] and consist of air temperature, relative humidity and air pressure.

3. Data analysis and results

All the results presented in this study are based on the daily global irradiation values provided by the station described above. In the calculations of the averages presented in this section, days with missing values are ignored because there is not enough available information to fill in the gaps.

3.1. Inter-annual variability

The main causes of the inter-annual variability of solar radiation are changes in cloudiness and aerosol loads in the atmosphere from year to year. Knowledge of this inter-annual variability is very important for the economic feasibility study of any solar energy related projects. It has been shown that one or two years of local measurements may be sufficient to estimate the long-term annual average of GHI within ±5% of uncertainty [17].

Fig. 1 shows, in blue (in web version), the year-to-year variation of the daily averages of GHI in Doha for 5 years, from 2008 to 2012, in kWh/m^2/day; the red dashed line is the average of the 5 years. The average for the i-th year is calculated as follows:

$$\mathrm{Avg}_i = \frac{\sum_{n=1}^{N_i} \mathrm{GHI}_{i,n}}{N_{i,\mathrm{valid}}},$$

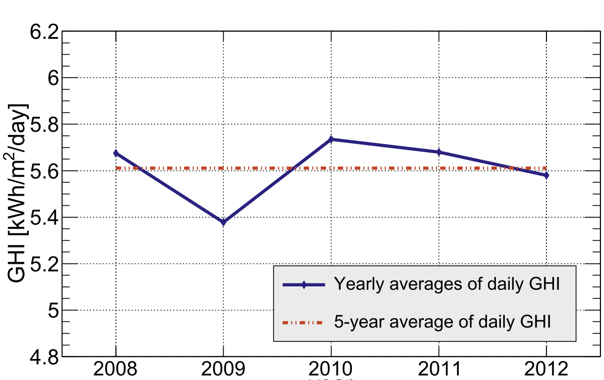

Fig. 1. Annual variability of daily GHI averages.

Table 1
Annual means of daily GHI for Doha, and the corresponding number of days with no missing daily GHI values.

Year	Daily GHI [kWh/m^2]	Valid days
2008	5.675	286
2009	5.377	324
2010	5.735	360
2011	5.679	353
2012	5.579	348

where N_i is the total number of days in year i, $\mathrm{GHI}_{i,n}$ is the GHI value on day n of year i, and $N_{i,\mathrm{valid}}$ is the number of valid days in year i.[1]

Table 1 shows the number of valid days for each year, along with the calculated annual averages of daily GHI. The highest number of missing daily data was found in year 2008, with 22% of missing days, or about 2.6 months; the data gaps of that year are mostly present in January, February and March. The other years show better data availability.

The average daily GHI value in Doha for the whole 5-year period is 5.611 kWh/m^2/day, or a total of 2048 kWh/m^2 in one year.

The year 2009 shows a lower value than the average by 4%. This deviation falls within common variability values of annual GHI, ranging between 2 and 7% from the average [18,19]. A more detailed analysis with higher temporal resolution (monthly averages) is presented below.

3.2. Monthly averages and maxima

Fig. 2 shows the monthly averages and peaks of global radiation in blue and red (in web version), respectively. The individual years are also shown in thinner lines, highlighting in green the years 2008 and 2009. The average for the i-th month of the year is calculated as follows:

$$\mathrm{Avg}_i = \frac{\sum_{\mathrm{days}_i} \sum_{\mathrm{yrs}} \mathrm{GHI}_{i,\mathrm{yrs}}}{N_{i,\mathrm{valid}}},$$

which is the sum of all daily GHI values in month i for the 5 years, and $N_{i,\mathrm{valid}}$ is the total number of valid days in this month during this 5-year period.

The graph shows that GHI monthly averages are above 6 kWh/m^2/day from April to September. The range during the whole year is between 4 and 7 kWh/m^2/day. The highest average is 6.97 kWh/m^2/day, in the month of June, closely followed by May with 6.92 kWh/m^2/day. The lowest is 3.87 kWh/m^2/day, in December. The highest peak is found in June, with a value of 8.41 kWh/m^2/day, and the lowest peak is 4.77 kWh/m^2/day, in December.

To investigate the lower yearly average in 2009 (Fig. 1), this year is highlighted in green in Fig. 2, and shows values lower than the average in July, August, and December. The low average observed in August 2009 could be attributed to the fact that there are only 6 valid days during this month; therefore, although the calculated monthly average only considers the valid days, this value is not necessarily representative of the whole month. Year 2008 (green dashed line) also shows low values in July, August, and January; however, these low values are compensated by values higher than average in other months. An analysis of meteorological parameters is presented in Section 3.5 for a more in-depth study of the low values of year 2009.

[1] In this article, valid days are those with non-missing daily GHI values.