# Evaluation of the solar conditions for the acquisitions of energy from renewable sources on the base of Sosnowiec city (Poland)

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**Abstract**
The country's energy security risk, as well as a desire to protect the environment from the pollution and degradation which are the results of conventional fuels acquisition – these was a motivation for intensive researches on the use of renewable energy sources in eco – innovative installations. Solar radiation is one of the self – renewable energy sources which can be used both as a source of electricity and heat. The area of research is Sosnowiec city located in the south of Poland in the eastern part of Silesia voivodeship. The solar radiation data covering the years 2003 to 2013 was used. The intra – annual variability of daily averaged solar radiation hesitated in a wide range from 0.6 kWh/m$^2$ (December) to 5.2 kWh/m$^2$ (June). Day duration varies on average from 10 hours in January, November and December to 17 hours in May, June and July. Day occupies 56% of the 8767 hours in year. On average the largest amount of energy reached the analyzed area in July: 157 kWh/m$^2$ (15% of the annual average), while the smallest in December: 18 kWh/m$^2$ (less than 2% of the annual average). The 75% of the average annual total of energy falls on the period from 1$^{st}$ March to 31$^{th}$ August (spring – summer). The range of the annual solar radiation was determined by the minimum of 980 kWh/m$^2$ and the maximum of 1094 kWh/m$^2$. In Sosnowiec the average annual irradiation total on the horizontal surface amounts to 1052 kWh/m$^2$ (2003 – 2013).

**Key words:** solar radiation, global radiation, renewable energy, Sosnowiec, Poland

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## Introduction

Inextricably linked to the civilization development increase in electricity demand contributes to the risk of the conventional fuels depletion. The energy security is threatened due to shortage of the sources covering country's electricity requirements. This situation may negatively impacts the development of social and economic processes. This was a motivation for intensive research on the use of renewable energy sources in eco – innovative installations. Another impulse to commence the research was desire to protect an environment from the pollution and degradation which are the results of conventional fuels acquisition and use. The solar radiation is one of self – renewing energy sources and is emitted in the form of electromagnetic waves by the Sun. Only part of the primary radiation reaches the Earth's surface which is defined as shortwave global radiation (0.4 – 1.0 μm in wavelength). Global radiation consists of direct solar radiation and diffuse sky radiation (Paszyński et al. 1999, Niedźwiedź 2003). Solar energy can be used as a source of electricity and heat. The issue of solar radiation conversion in conjunction with a dynamically developing environmental technology solutions using renewable energy sources and seeking to efficiency increase has often been discussed in the literature.



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**The research area**

Sosnowiec city is located in the south of Poland in eastern part of Silesia voivodeship. It is situated at the confluence of Brynica River, Czarna Przemsza River and Mała Przemsza Rriver belonging to the basin of Vistula. The area of the city is over 91 $km^2$ and it is inhabited by more than 219 thousand residents (PIG 2009).

According to the physical – geographical division by Kondracki (2002), Sosnowiec lies within the Province of Silesian – Cracow Upland, Silesian Upland macroregion, mesoregions: Katowice Upland, Jaworznickie Hills and in a small portion, Tarnogórski Hummock. In terms of topography town is located at the border of several Katowice Upland regions, these are: Bytomsko – Katowicki Plateau – occupying the northern, western and central parts of the Highland, Dąbrowska Upland and Mysłowicka Basin – located to the east. Over the years, Sosnowiec transformed itself from a mining center associated with the operations of the coal, steel industry and engineering to the shopping – service – processing center.

**Materials and methods**

The analysis was performed on the basis of 10 minutes averaged solar radiation data covering the period 2003 – 2013. Measurements were conducted at the meteorological station (50º17.491' N; 19º08.017' E) located in Sosnowiec at the altitude of 263m above sea level. The station is operating at Department of Earth Sciences, University of Silesia in Sosnowiec. This is an urban station which is important from the point of view of the objective of this study which is to assess the real resources of solar energy in the area of intense urban development – a destination for the energy potential use.

Mean hourly and daily values of the solar radiation intensity, as well as hourly, daily, monthly and seasonal sums of irradiation were calculated. On their basis the analysis allowing to show the solar conditions during the period 2003 – 2013 in Sosnowiec have been made.

**Results**

In the period 2003 – 2013, day duration which means the time from sunrise to sunset, constitutes on average 4920 of 8767 hours a year which accounted for 56%. The mean number of hours per year was calculated taking into account leap years which has occurred in that period.

The figure 1 shows the daily course of the hourly values of global solar radiation. As an example 17 June 2010 was selected which recorded the highest daily total input of energy (8.36 $kWh/m^2$) in the study area during the analyzed period. Midday in Sosnowiec is at 10:44 UTC (11:44 Central – European winter time and at 12:44 'summer time'). The graph shows clear daily course with growing global solar radiation hourly values from early morning hours, peaking around noon and then declining. The maximum intensity of global solar radiation at noon reached more than 900 $W/m^2$.

The figure 2 shows the average, maximum and minimum number of possible sunshine hours (duration of the daytime) in particular months.

In Sosnowiec duration day varies on average from 9.5 hours in December to more than 17 hours in June and July. The minimum number of possible sunshine hours occurs in January and December (8 hours), and the maximum in May, June and July (c.a. 18 hours). Solar activity hours in July account for 10.8% of the annual solar activity hours. Solar activity hours in December constitute 6.1% of the annual total.

The mean annual irradiation that is incident on the flat surface in Sosnowiec during the period 2003 – 2013 is 1052 $kWh/m^2$. This value is higher by 39 $kWh/m^2$ from the average

calculated for the whole Poland for the years 1956 – 1975 (1013 kWh/m$^2$) on the basis of 31 stations (Miara et al. 1987). It is caused by more clear air above the Upper Silesia Industrial Region after 1989. During the period 1956 – 1975 of more polluted atmosphere in Katowice the average annual global radiation in Katowice amounting to 974 kWh/m$^2$ was one of the lowest in the country (Miara et al. 1987). In Central Poland in Łódź during the years 1997 – 2001 mean annual total of global radiation amounted to 1031 kWh/m$^2$ (Podstawczyńska 2007).

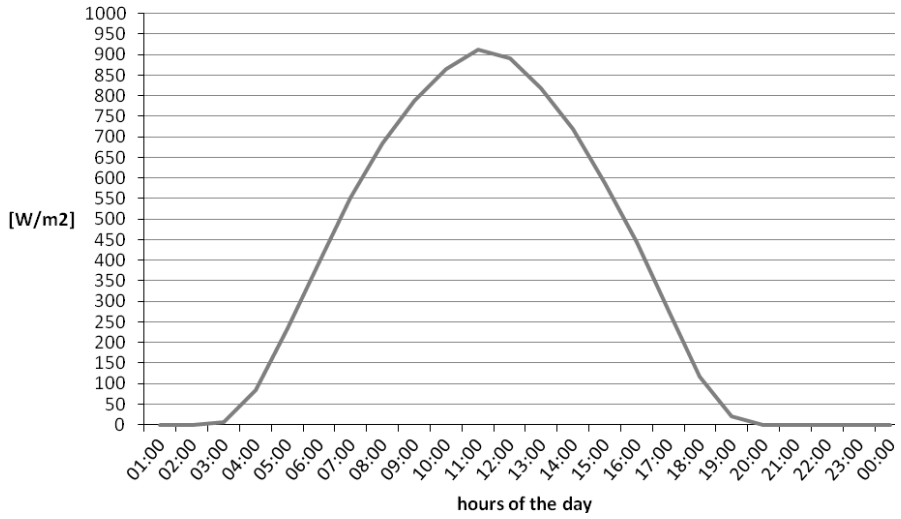


**Fig.1.** Daily course of global solar radiation in Sosnowiec (an example for cloudless day 17 June 2010)

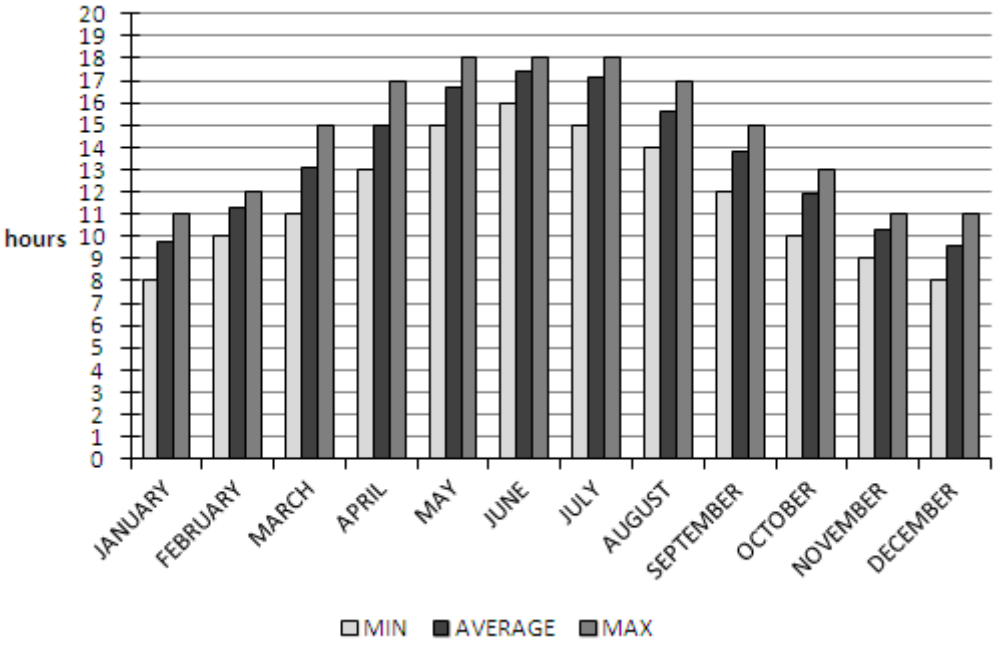


**Fig.2.** Duration of day – time in hours for the particular months in Sosnowiec

The figure 3 shows the annual course of the solar radiation daily average values for Sosnowiec in the analyzed period (2003 – 2013).

The graph shows the uneven solar radiation over the analyzed area during the year. The lowest values (0.44 kWh/m$^2$ in January) occur at the beginning of the year, then grow into the summer months, where they are the highest (6.26 kWh/m$^2$ in June) and then decrease until the end of the year (0.28 kWh/m$^2$ in December). Average daily global solar radiation vary in a wide range from 0.6 kWh/m$^2$ (in December) to 5.2 kWh/m$^2$ (in June).

The figure 4 shows the average amount of energy that reaches the analyzed area in particular months of the year in multi – year period 2003 – 2013. The graph shows a typical annual course of energy amount linked to astronomical factors. On average, the largest amount of energy was recorded in July: 157 kWh/m$^2$, which accounts for 15% of the average annual value while the smallest amount of energy was noted in December: only18 kWh/m$^2$, and constitute less than 2% of the average annual total.

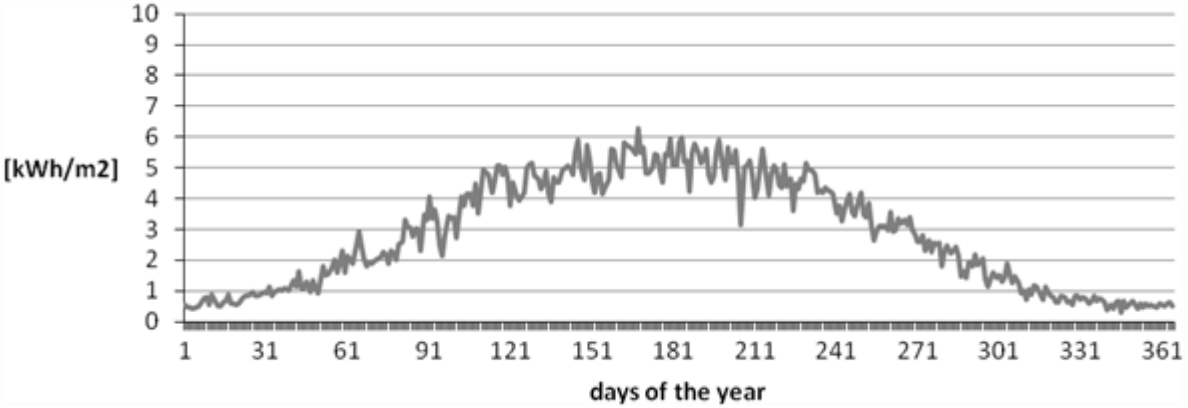


**Fig.3.** Annual course of daily averages radiation energy totals in Sosnowiec (2003 – 2013)

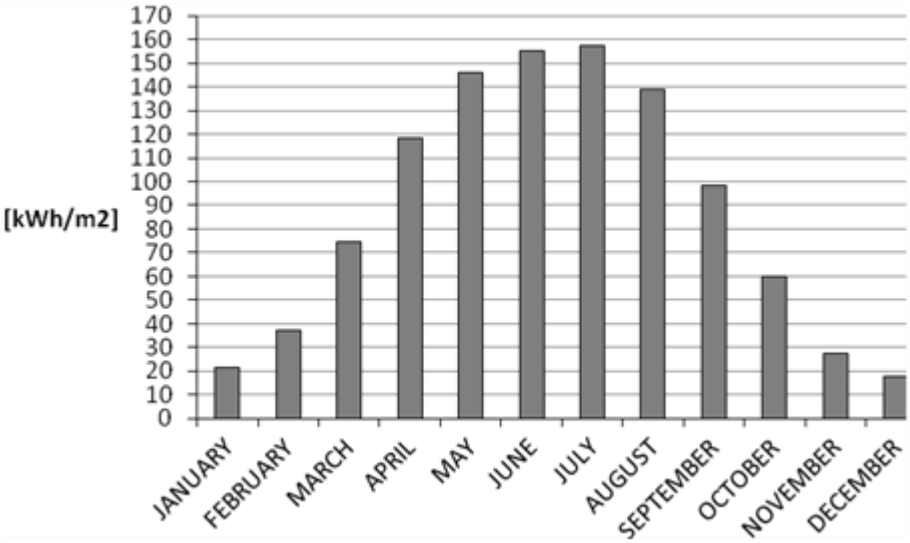


**Fig.4.** Annual course of the average monthly totals of irradiation on a flat surface in Sosnowiec (2003 – 2013)

The figure 5 shows the average seasonal irradiation totals incident on a flat surface. The total energy in the period from the 1st March to the 31th August (spring and summer time) constitute the 75% of the average annual total, while in the autumn time 18% and in the winter time 7%.

The figure 6 shows the temporal variability in the annual totals of irradiation in the period 2003 – 2013.Annual amount of irradiation varied from 980 kWh/m$^2$ to 1094 kWh/m$^2$. Two highest values were noted in 2011 (1094 kWh/m$^2$) and 2012 (1093 kWh/m$^2$), while the lowest occurred in 2004 (997 kWh/m$^2$) and 2010 (980 kWh/m$^2$) . This variability is mainly connected to cloudiness.

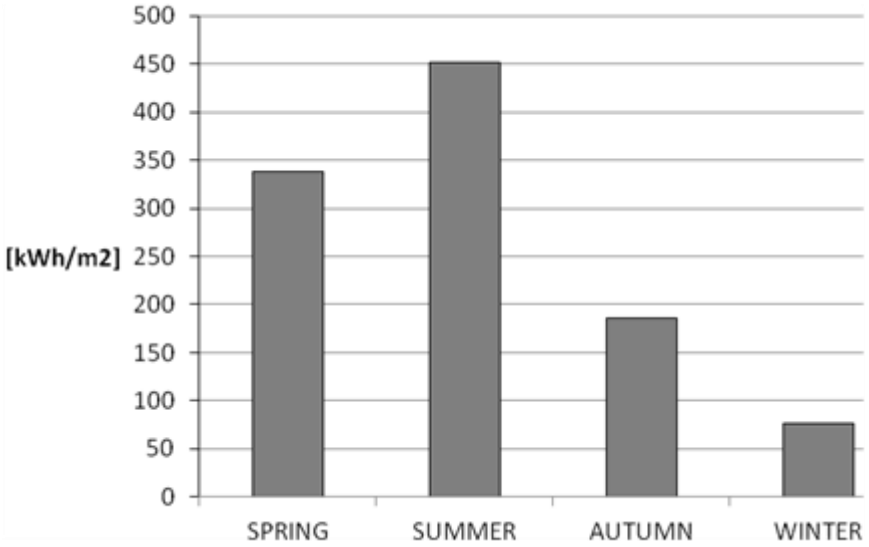


**Fig.5.** Average seasonal totals of irradiation on flat surface in Sosnowiec (2003 – 2013)

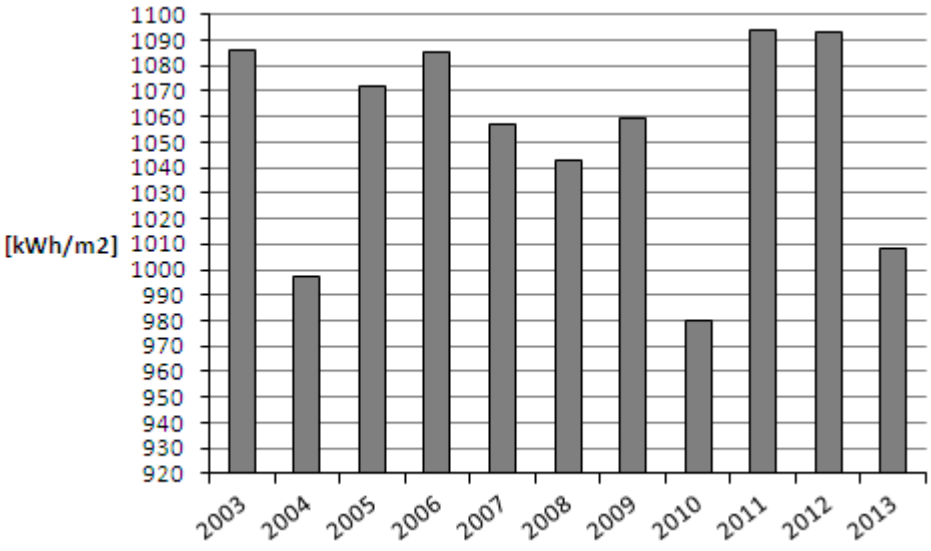


**Fig.6.** Changes of annual totals of irradiation on flat surface in Sosnowiec during the period 2003 – 2013

**Discussion**

The intensity of solar radiation is spatially and temporally variable. Both diurnal and annual courses of these characteristics show cyclicity. Daily variability in the solar energy quantity supplied to the ground is a result of Earth's rotation around its own axis, which causes day and night, while the seasonal variability is associated with circulating motion of the Earth around the Sun and the inclination of the globe axis to the orbital plane of the movement – such a system results in a year, depending on latitude, changing of Sun height above the horizon at noon (seasons) and the length of days and nights. The variability of the amount of energy delivered to the land surface is also connected with the height above sea level. The value of the solar radiation intensity is also dependent on the variability of solar activity occurring on its surface and in the atmosphere. In addition, there are periodic changes in insolation caused i.a. by climate phenomena, meteorological phenomena such as for example type and size of the aerosols content in the atmosphere and cloudiness.

Poland is located between the 49 – 54.5ºN latitudes in a moderate climate zone under an influence of the continental and maritime climate. Polish climate conditions are characterized by a very high variation of the solar radiation intensity during the daily and annual cycle. Annually, the sum of the solar energy in Poland which reaches the earth's surface hesitate between 950 – 1250 kWh (Miara et al. 1987, Bogdańska and Podogrocki 2000), depending on the area of the country. Central and eastern part of the Poland, i.e. about 50% of the country area, receive more than 1000 kWh/m$^2$/y; southern, western and northern part of the country receives about 1000 kWh/m$^2$/y. The least yearly energy supply characterizes the region of Silesia, the field located at the junction of the Czech Republic, Germany and Poland as well as the region covering the northern coastal strip with the exception of the west coast – below 1000 kWh/m$^2$/y. In the winter time the solar radiation intensity has very low value and the daylight time is very short – in the summer time the situation is reversed. The time of 'solar energy demand' and 'solar energy supply' are quite opposite. About 80% of the total annual insolation falls in six – month period, spring – summer, from early April to late September. Daylight hours vary from several hours in December to over a dozen in June. In June, the daylight hours constitute the 71.5% of the monthly hours in the north of country, 69% in the center of Poland and 67% in the south. In December, the situation changes and the daylight hours constitute only the 29.5% of the monthly hours in the north of country, 31.7% in the center of Poland and 34.7% in the south. Poland daylight time accounts for 51% of the 8767 hours in a year (Zimny 2010, Chwieduk 1997, 2010).

**Conclusions**

As mentioned above, the regularities observed in Sosnowiec city are consistent with generally accepted and confirm the fact of solar radiation variability at the time. The examples presented in the article clearly show the daily and seasonal cyclic variations, which are related to various factors, including the climatological, meteorological, geographical and astrophysical.

There is a clear variation in the daily course of hourly values of solar radiation intensity with the peak in the afternoon hours and the lack of solar radiation in the late evening hours and night. During the year, uneven solar radiation intensity over the analyzed area is observed. Mean daily values of solar radiation intensity of multi – year during the year, varies over a wide range of 0.6 kWh/m$^2$ (December) – 5.2 kWh/m$^2$ (June). Solar activity time varies from on average of 10 hours in January, November and December to 17 hours in May, June and July. In the annual course of mean daily values, in the months of May, June and July visible is the maximum amount of sunshine hours and it is 18

hours, the minimum is seen in January and December and is 8 hours. Daylight interval for the analyzed area is 56% of 8767 hours a year – it is 5 percentage points more than the daylight interval for the Poland area, which is about 439 hours more. During the multi – year period, solar activity hours in the month of July include 10.80% of the solar hours in a year, and solar activity hours in the month of December include 6.06%. On average, the largest amount of energy in a multi – year period reached the analyzed area in the month of July: 157 kWh/m$^2$ (15% of the annual average of multi – year period), while on average, the smallest amount of energy reached the month of December: 18 kWh/m$^2$ (less than 2% of the annual average of multi – year period). For the period spring – summer, from 1$^{st}$ March to 31$^{th}$ August, falls 75% of the average annual total energy. Therefore, visible is a clear seasonal variability in the amount of energy – the peak values of available solar radiation and the heat demand are in opposite time. The average annual values of solar radiation intensity recorded for each year in the analyzed period show diversity – ranging between 980 kWh/m$^2$ (2010) – 1094 kWh/m$^2$ (2011 and 2012). Obtained as a result of the conducted analyzes average value of irradiation for Sosnowiec of multi – year period 2003 – 2013 is 1052 kWh/m$^2$. Performed analyzes allow to conclude that the conditions of solar conditions in Sosnowiec are nowadays not the worst, but there are not also the very favorable in terms of energy use of the sun.

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