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Measurement of the Direct Flux of Solar Radiation During Operation of a Big Solar Furnace

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Abstract: Methods for measuring solar radiation are considered and long-term data obtained by actinometric measurements of solar radiation at the location of the big solar furnace of the Academy of Sciences of Uzbekistan Institute of Materials Science Scientific Production Association "Physics-Sun", with a thermal power of 1 MW, are analyzed. Concentrators of solar radiation efficiently operate at high values of the direct flux of solar radiation, whereas photovoltaic stations operate on diffuse and total radiation, too. Therefore, the main attention is paid to the measurement of the direct flux of solar radiation. The first results until 2013 were obtained by a semi-automatic mode with the help of actinometers of the AT-50 type, after that an automated meteorological station of the MHP type with high-precision pyrheliometers CHP1, manufactured by Kipp & Zonen, was produced by the Netherlands, which is the leader in the production of solar sensors. During the operation of the Big Solar Furnace, a direct stream of solar radiation is continuously measured, since the power of the installation is directly proportional to this. The obtained long-term results of measuring the direct flux of solar radiation are processed in order to obtain average statistical data by years. To obtain reliable data on solar energy, solar sensors are annually calibrated. The last verification was carried out in January of 2018 at Kipp & Zonen.

Keywords: Solar Furnace, Solar Radiation, Weather Station, Actinometer, Pyranometer, Pyrheliometer

1. Introduction

It is known that the global community faces the global task of drastically changing the conditions of management and transferring it to energy efficient methods, as well as alternative energy, and primarily to large-scale use of solar energy.

The initial stage in the practical development of solar energy is the correct measurement of its amount entering the surface of the Earth in a particular area during the year, as well as the surface radiation reflected by the earth's surface and the radiation balance of the active surface.

Knowledge of solar resources, on which the development of electrical and thermal energy directly depends, allows us to develop a Technical and Economic Justification for the design and construction of solar power and heat stations and other installations using solar energy.

Information on the radiation balance of the Earth, the albedo of the earth's surface and all that is located on it, as well as sunshine is necessary for many branches of the economy and life of mankind.

Collecting information related to the radiation of the sun perform so-called actinometric devices, they are also called radiometers [1, 2]: pyranometers - to measure the total radiation coming to the horizontal surface, as well as scattered radiation emanating from the sky; actinometers and pyrheliometers for measuring direct solar radiation emanating from the Sun and the near-solar sky zone with a radius of 5°; albedometer for measuring reflected solar radiation from the active earth's surface; balance meter to determine the radiation balance of the active surface; heliograph - to automatically record the duration of sunshine, that is, when the sun is not covered by clouds.

2. Measurement of the Solar Radiation

It should be noted that for decades, actinometric instruments have not undergone fundamental changes. So to this day the receiver of solar radiation is the blackened surface of the thermobattery. The black nonselective coating has a developed rough structure with a large number of microscopic "traps" that effectively absorb 98% of the incident solar radiation in a wide spectral range, i.e. capture the entire solar spectrum reaching the earth (0.3-2.5 microns). A sensitive element of the thermobattery is a set of thermocouples pair-wise paired and electrically connected in series. Absorption of solar radiation by active junction leads to an increase in its temperature. The temperature difference between the active junction and the free (cold) junction maintained at a fixed temperature creates an electromotive force that is directly proportional to the created temperature difference. The sensitivity of actinometric devices for each of them is unique, therefore each radiometer has its own calibration factor, even for devices of the same model. We add that the spectral sensitivity of the black coating of radiometers is less than 2%. Or in other words, within the spectral range of radiometers, the absorption for each wavelength is the same with an accuracy of 2% [3, 4].

In practice, the greatest use was made of pyranometers, which, as we mentioned earlier, measure total and scattered solar radiation. The overwhelming majority of solar stations and other solar plants use total and scattered radiation, i.e. are consumers of measurement results of pyranometers [5].

Figure 1. *The large solar oven in Uzbekistan with a thermal power of 1000 kW.*

2.1. Measurement of the Direct Flux of Solar Radiation in Parkent Region

Measurements of the direct flux of solar radiation in the Parkent region of the Tashkent viloyat of Uzbekistan, where the Big Solar Furnace (BSF) of Uzbekistan has a thermal power of 1000 kW [6], has been in operation since 1986 [7]. The first studies were introduced with the help of actinometers of the AT-50 type, and the clock mechanism was used as a tracking system for the visible path of the Sun and the data was recorded in a journal with a period of 0.5 hours.

On the basis of the obtained discrete data on the intensity of solar radiation, histograms of the direct current density were plotted daily, weekly, monthly and yearly.

When developing and operating surface solar power plants, it is necessary to have information about the characteristics of solar radiation for the area in question. The number of sunny days per year, the change in the flux density of the incident on the Earth's orbit during the year is determined by calculation, and on the perpendicular surface of the Earth during the day and year is determined as a result of actinometric measurements.

The choice of location of the furnace, in addition to seismological, relief, transport, communication factors, is due to favorable characteristics of solar radiation. Observations of changes in direct solar radiation for many years show that during the year the number of conditioned sunny days varies within 250 - 270 days [7, 8]. However, there are years with abnormal sunny days. For example, in autumn in 2011 there were many rainy and cloudy days.

Figure 2 shows the general view of the actinometric installation with a tracking system for the solar trajectory. The installation is located on the 6th floor of the BSP concentrator, near the laboratory room where the data is recorded (see Figure 3).

2.2. Coordinates for the Installation of Solar Sensors

As is known, the total solar radiation Q, consists of direct and scattered radiation. For solar engineers in the field of high temperatures, an important role is played by the direct flow of solar energy. This part of the energy is collected by different concentrators, with the maximum concentration being achieved in the focus of paraboloid concentrators, such as the BSF concentrator. For photovoltaic stations, total (global) solar radiation is important.

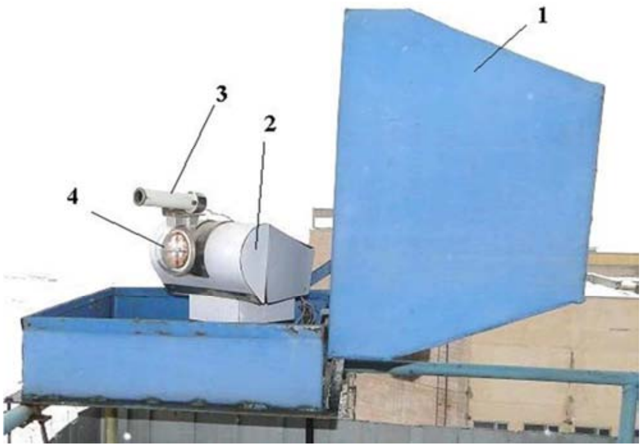


Figure 2. *Shows the general view of the actinometric installation with a tracking system for the solar trajectory. The installation is located on the 6th floor of the BSF concentrator, near the laboratory room where the data is recorded (see Figure 2b).*

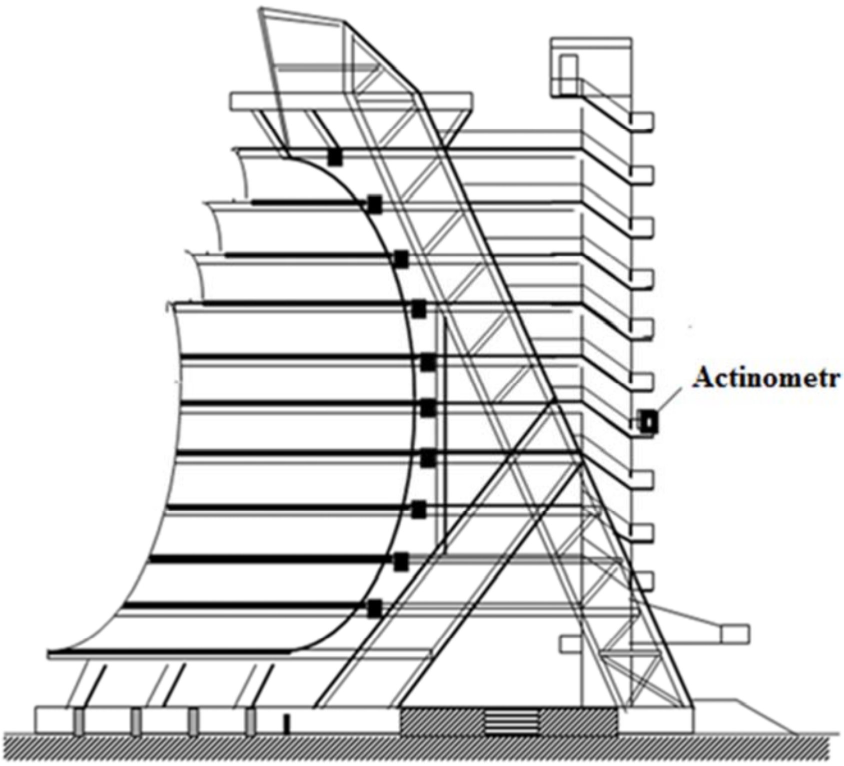


Figure 3. *The location of the actinometric installation on the BSF concentrator.*

Direct solar radiation and scattered radiation belong to the short-wave part of the spectrum (with wavelengths from 0.17 to 4 microns, in fact, the rays reach the earth's surface with a wavelength of 0.28 microns). Solar radiation and the energy distribution along the wavelengths in the spectrum change significantly due to the absorbing factor of the atmosphere. Even on clear sunny days, the intensity of radiation changes both during the year, during the day, and during shorter time periods due to random factors [9].

As is known, the BSF of Uzbekistan has the following coordinates: latitude - 41^o18'57 "; longitude of the terrain - 69^o44'28 "; Height above sea level - 1075 m; Local time = UT + 5 hours, where UT is universal time.

3. Results

Figure 4 shows the daily sums of direct, scattered, and total radiation on cloudless days by months. It can be seen that high values of solar radiation are observed during the months of May-July.

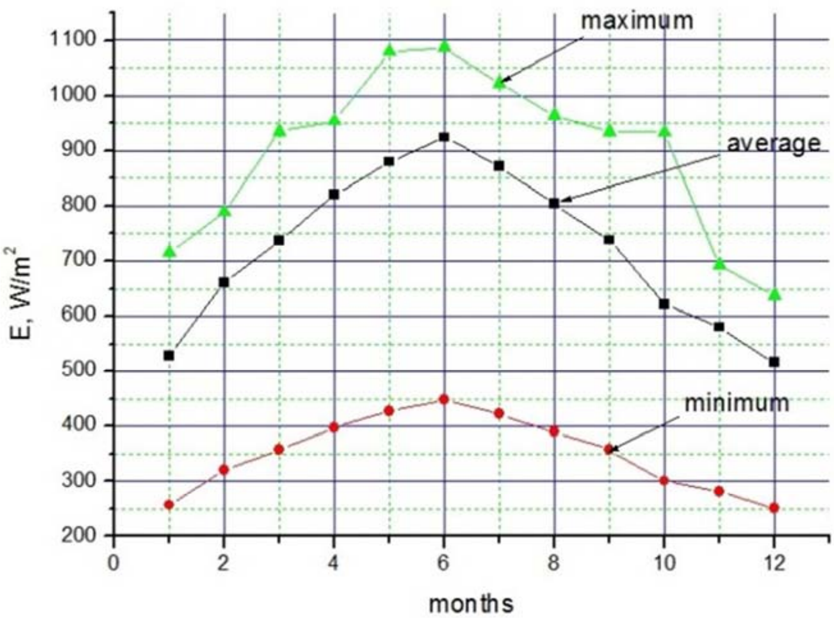


Figure 4. *The daily sums of direct, scattered and total radiation on cloudless days.*

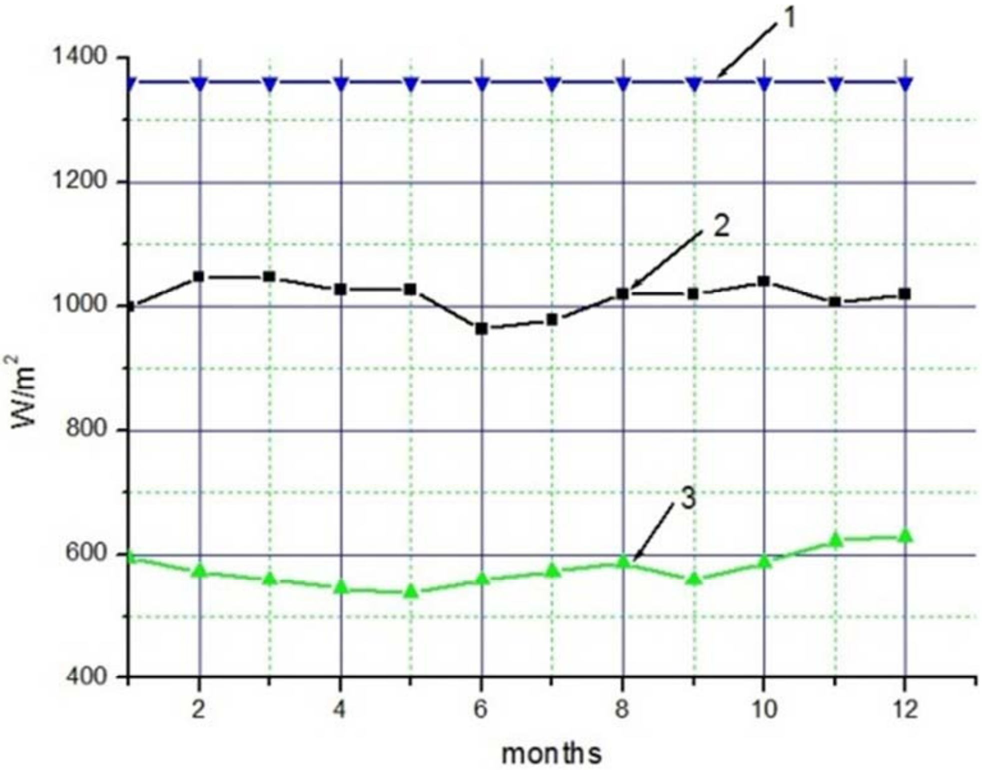


Figure 5. *Extremal values of the intensity of direct radiation on the perpendicular surface (W/m^2) on cloudless days at noon (1- solar constant, 2 maximal, 3-minimum).*

As observations showed, the extreme values of the intensity of direct radiation on the perpendicular surface in cloudless days at noon were 950-1050 W/m^2 (maximum) and 530-600 W/m^2 (minimum) (Figure 5).

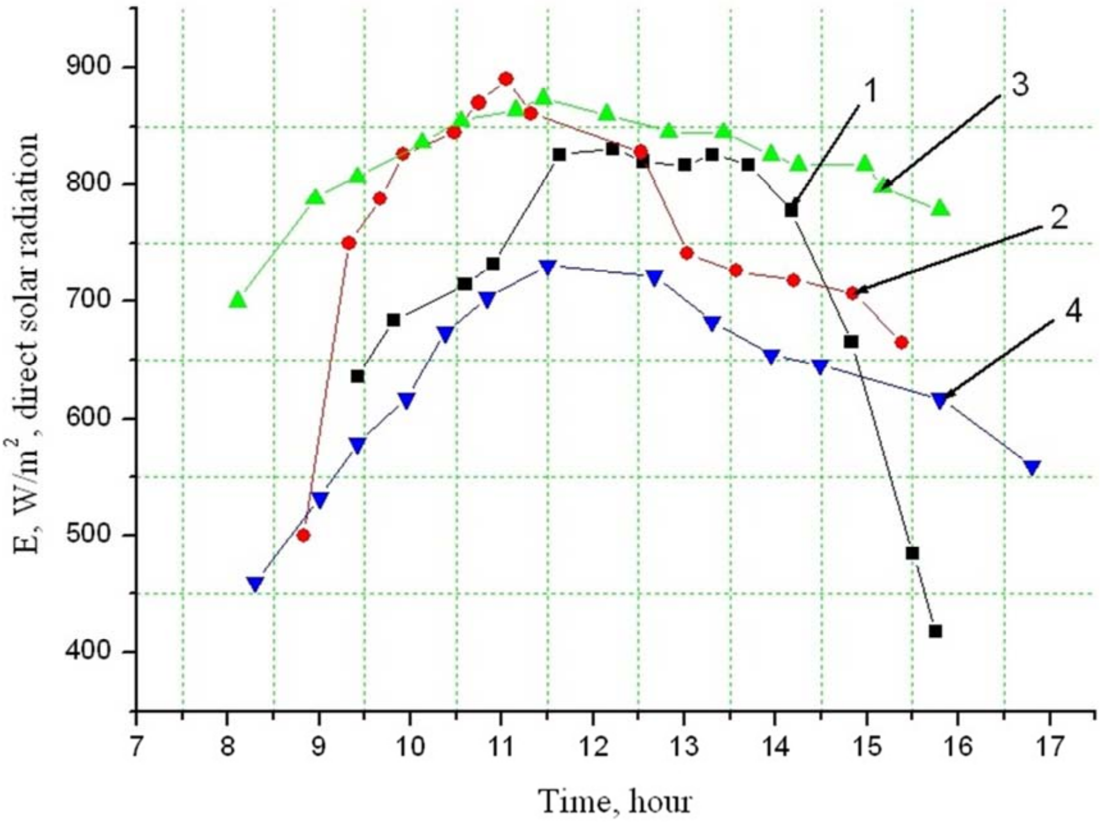


Figure 6. *Daytime variations of solar radiation for different times of 2011. 1-10.01.2011., 2-9.03.2011., 3-1.06.2011., 4- 12.09.2011.*

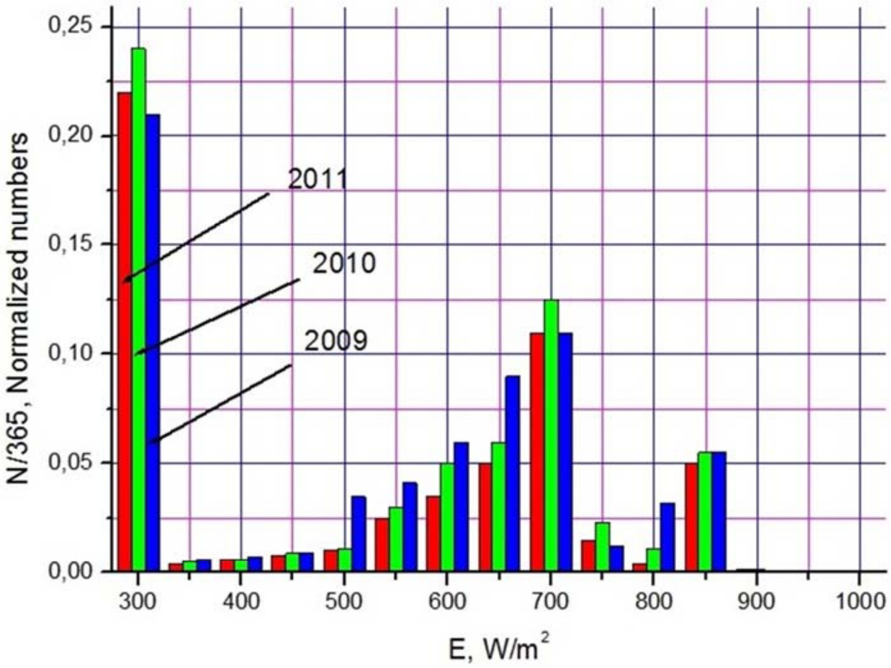


Figure 7. *Results of measurement of radiation during 2009-2011. for the Parkent region of the Tashkent viloyat.*

Data (2011) on daytime variations in the density of the direct solar radiation flux over the seasons were also obtained (Figure 6). These dependences show a nonmonotonic character with a maximum of 875 W/m^2 at noon.

Based on data obtained during the experiments carried out in the period 2009 - 2011, on the measurement of solar radiation for the area of the Parkent district of the Tashkent region (the location of the BSP), the dependences of the number of sunny days per year on the intensity of the solar flux have been constructed (Figure 7). As can be seen from the graph, a decrease in sunny days was observed, especially 2011 was anomalous - only 196 days of sunshine per year, and in 2010 there were 230 sunny days and in 2009 the number of sunny days was 244.

Currently in Uzbekistan there being developed a draft of the law on development of alternative energy, as well as a number of legal documents in this sphere. The first major steps in the practical use of solar energy were initiated. In the Republic's six regions automatic weather stations measuring data collection on solar resources had been installed by CSP Services (Germany) company with the technical assistance of the Asian Development Bank (ADB). Five measuring stations were installed on meteorological plots of the Uzhydromet: Dagbit (Samarkand viloyat), Karmana (Navoi viloyat) Guzar (Kashkadarya viloyat) Sherabad (Surkhandarya viloyat), Pap (Namangan viloyat), as well as on the territory of the SPA "Physics-Sun" in Parkent (Tashkent viloyat). In these viloyats in the coming years it is planned to build five commercial and one solar energy station for demonstration.

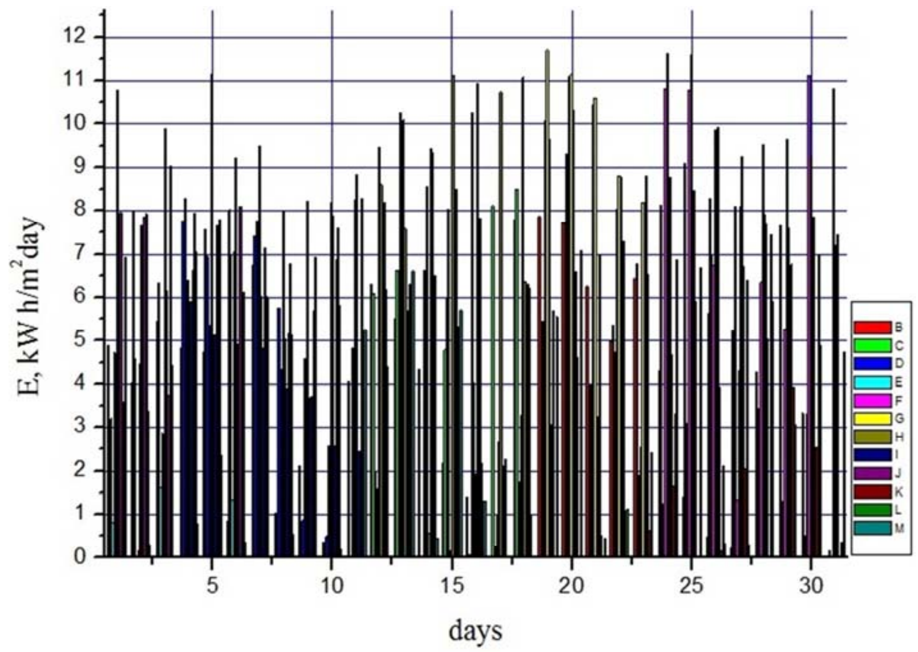
Figure 8. *General view of the Parkent automated weather station built in 2013, next to the Big Solar Furnace.*

The annual value of the direct flux of solar radiation measured by the CHP1 pyrheliometer of Kipp & Zonen company is 1708.72 kWh/m^2 year.

Table 1 shows the values of the direct flux of solar radiation, kWh / m^2 day, measured in 2016 with the help of the CHP1 pyrheliometer of Kipp & Zonen (Netherlands).

Table 1. *Direct flux of solar radiation, kWh/m² day, measured in 2016.*

№	January	February	March	April	May	June	July	August	September	October	November	December
1	4.90	1.99	3.21	0.80	4.72	2.44	10.78	6.43	7.96	0.04	3.59	6.92
2	4.02	7.99	4.59	0.01	0.16	4.44	7.67	6.31	7.85	7.93	3.36	0.29
3	0.00	5.44	6.35	1.62	2.87	1.12	9.88	6.16	3.73	9.03	4.43	0.00
4	0.01	4.82	7.76	8.28	4.85	6.40	3.21	5.92	6.60	7.95	7.05	0.77
5	4.72	7.58	6.95	4.59	5.35	11.16	0.36	5.13	7.67	7.43	7.78	2.36
6	0.84	8.02	6.98	1.33	7.05	9.22	4.31	4.92	8.10	5.88	6.11	0.34
7	0.02	6.74	7.43	7.76	6.21	9.47	6.04	4.82	7.15	6.03	6.01	0.00
8	1.02	0.19	5.76	0.79	4.33	8.00	5.05	3.91	5.15	6.77	5.13	0.53
9	2.12	0.00	0.87	4.58	3.27	8.23	3.42	3.71	1.61	5.69	6.93	0.00
10	0.36	0.00	0.50	2.57	1.15	8.20	7.87	2.57	6.87	7.61	5.81	0.20
11	0.00	4.06	0.05	4.82	3.27	8.26	8.84	2.44	0.92	8.27	4.19	5.25
12	6.32	6.09	1.95	1.59	0.54	9.46	8.61	5.42	8.20	6.17	4.39	0.00
13	5.52	6.63	1.10	10.27	5.01	10.09	7.59	5.68	2.25	6.29	5.43	6.61
14	4.34	0.01	0.00	6.61	0.74	8.56	0.56	9.42	9.33	2.27	6.49	0.44
15	2.17	4.79	6.01	8.02	0.16	0.09	11.12	2.37	8.51	2.21	5.34	5.71
16	1.41	0.07	0.00	10.27	4.01	1.92	10.95	0.09	7.81	2.16	0.00	1.31
17	0.05	8.12	0.00	0.25	0.97	2.67	10.74	0.06	2.11	2.27	0.04	0.00
18	7.80	8.51	0.23	1.75	3.29	11.08	6.37	0.01	6.29	6.22	0.96	0.00
19	7.87	1.92	5.45	5.04	10.07	11.70	9.64	0.00	3.05	5.69	0.00	5.55
20	7.74	2.79	9.31	1.33	11.11	11.14	10.32	0.01	6.57	4.61	0.00	7.08
21	6.26	1.37	3.96	1.49	10.45	10.60	3.25	2.30	7.00	0.51	0.00	0.44
22	4.98	5.34	4.74	3.97	8.04	8.82	8.78	3.00	7.31	0.93	1.12	0.00
23	6.44	6.76	0.68	1.91	2.55	8.19	8.14	8.80	6.52	0.62	2.43	0.00
24	4.29	8.14	0.36	1.24	10.81	11.61	8.78	8.77	4.66	1.64	3.32	6.87
25	1.39	9.10	3.09	2.21	10.79	11.59	8.14	8.46	5.90	0.04	0.02	6.66
26	0.47	5.64	8.27	6.96	6.73	9.86	8.17	9.93	3.93	0.15	2.12	0.32
27	0.22	5.24	2.99	8.11	1.33	4.31	8.11	9.25	6.69	2.04	6.40	0.27
28	0.01	4.26	0.03	3.43	6.36	9.52	7.91	7.69	5.04	0.04	7.45	5.89
29	0.00	7.65	0.38	1.31	5.26	9.64	7.60	4.54	6.76	3.93	3.07	0.00
30	3.33		0.50	3.31	11.13	9.24	7.30	7.84	0.10	2.54	6.98	4.88
31	0.04		0.17		10.81		7.19	7.45		0.36		4.73



B-January, C-February, D-March, E-Aprel, F-May, G-Jun, H-July, I-August, J-September, K-October, L-November, M-December

Figure 9. *The direct flux of solar radiation in kWh/m² day, measured by the pyrheliometer CHP1 in 2016.*

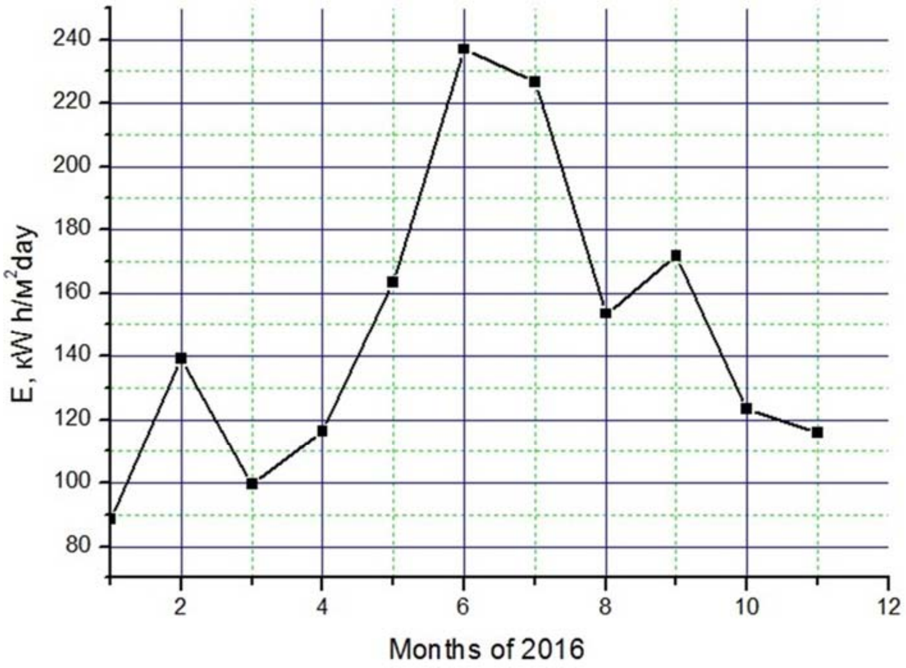


Figure 10. *Quantities of direct solar radiation flux, falling on a horizontal surface by the months of 2016.*

4. Discussion

Built in 2013, a modern automated weather station on the territory of the Institute of Materials Science [9, 10] allowed more accurate determination of solar resources and meteorological data on this site. According to the meteorological station 2013, sunny days were 310 days. (If we assume, "a sunny day" - the density of the direct flow of only a few tens of W/m^2 lasting several tens of minutes during the day.)

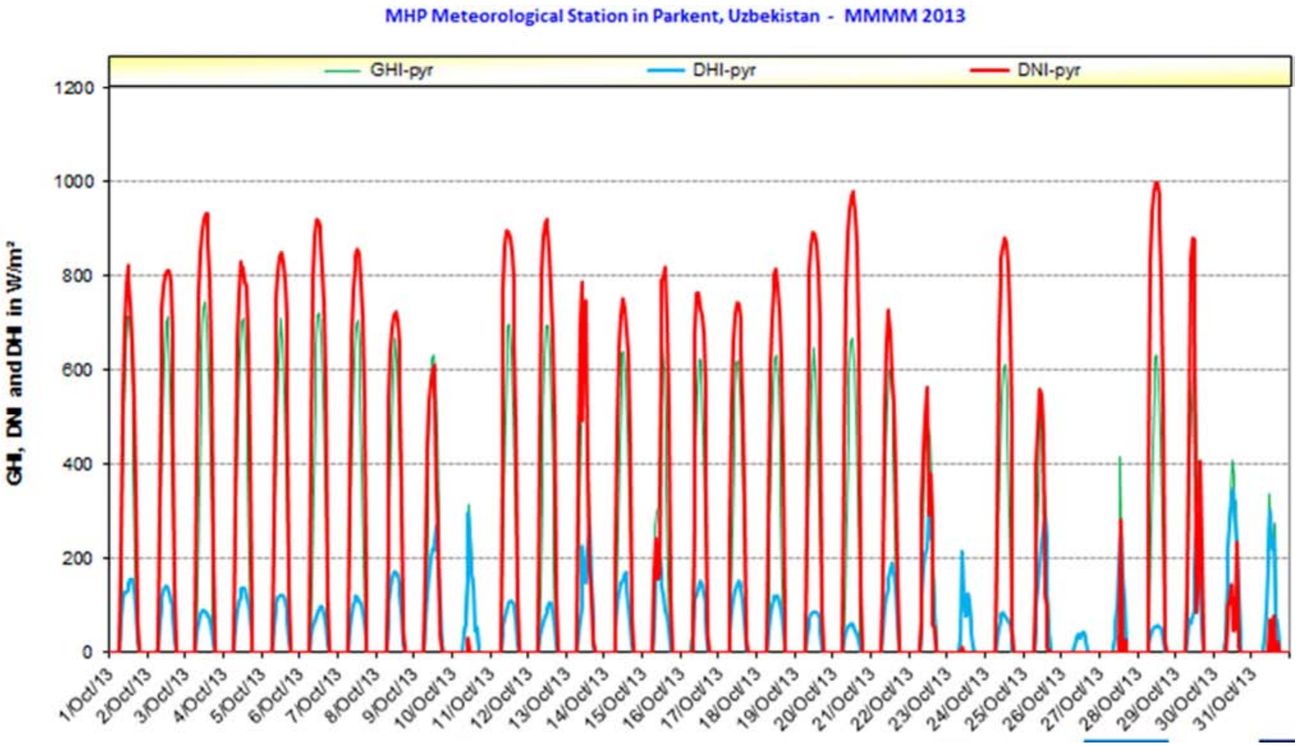


Figure 11. *Meteodata for October month 2013, obtained with the help of the Parkent Automated Weather Station.*

The experience of operating a modern automated weather station shows that around the weather station there should be no structures, equipment or installations that obscure or reflect the sun's rays towards the meteorological station. On the example of the Parkent meteorological station the following pictures are observed:

(1) In the summer seasons, at sunrise, the design of a two-block concentrator is partly obscured by the pyrheliometer of a weather station;
(2) In the summer seasons, at sunset, heliostats BSF partially obscure the pyrheliometer of the meteorological station;
(3) Fresnel mirror-concentrating installation at installation - before adjustment of mirrors reflected solar beams in the direction of pyranometer Li cor.

Unlike the other 5 meteorological stations, the Parkent meteorological station consists of two sensors for measuring solar resources: the Li-cor RSP G-4 pyranometer and the pyrheliometer CHP 1, comparing the data from the two sensors allows to determine the correct operation of the solar sensors during operation. Normal operating conditions data from the two sensors coincides within the error sensors.

From experience. In normal operation Air filters of pyranometers CM21, it is recommended to clean or change after 6 months of operation of the weather station. However, in November 2013, when, excavated land around the meteorological station for the purpose of landscaping the territory, air filters in a month came to an unfit condition.

5. Conclusion

These data can be used during construction and during the operation of helio-technical installations.

Knowing the multi-year data of solar resources, you can predict the performance of solar power plants in a given area.

Modern automated weather stations allow you to get a set of data on solar resources every second and save them for a long time in the date of the logger for further processing.

Only long-term, ground-based measurements of solar resources make it possible to more accurately predict the average solar energy incident on this terrain.

The results of the conducted studies show that the geographic location of the BSF of Uzbekistan has favorable weather conditions that contribute to the realization of the inexhaustible unique functional and optical-energy capabilities of the furnace for solving scientific, technical and practical problems.

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