Iranica Journal of Energy & Environment 5 (2): 173-183, 2014
ISSN 2079-2115
IJEE an Official Peer Reviewed Journal of Babol Noshirvani University of Technology
DOI: 10.5829/idosi.ijee.2014.05.02.09

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The Potential and Characteristics of Solar Energy in Yazd Province, Iran

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Received: March 28, 2014; **Accepted** in Revised Form: June 11, 2014

Abstract: In this study, utilizing the obtained data from four distributed locations known as Abarkuh, Behabad, Halvan and Yazd, the solar energy potential and its characteristics in Yazd province of Iran have been evaluated. For the data, daily horizontal global radiation (HGR) and clearness index also their monthly, seasonal and yearly averaged values have been obtained. The results indicate that the four locations enjoy from 300, 294, 289 and 311 sunny and very sunny days; their yearly averaged daily clearness indexes are 0. 66, 0. 66, 0. 64 and 0. 67 and their yearly averaged daily global radiations are 20. 74, 20. 78, 19. 52 and 20. 60 MJ/m^2, respectively. In overall, Yazd province enjoys from sunshine hours in almost 76% of the whole day times and its annually averaged daily HGR and clearness index are 20. 41 MJ/m^2 and 0. 66, respectively. Making comparison between the four nominated locations of Yazd province and 7 other selected cities around the globe, but at the same latitude, except Arizona, revealed that, their monthly mean daily global radiation and clearness index are higher than those of other six selected cities. Due to the great potential of Yazd province more funds and endeavors for solar energy development have to be devoted.

Key words: Solar energy assessment · Global solar radiation · Clearness index · Yazd province · Sunshine duration

INTRODUCTION

Due to pollution problems related to fossil fuels, such as being non-renewable, their impact on environment and increasing their pricedue to uncertainties in future, the global investment to utilize renewable energy sourcesis rapidly growing. The total global investment in renewable energy from $220 billion in 2010 reached to $257 billion in 2011. Also by the end of 2011 the total renewable energy capacity reached to 1, 360 GW with the most contribution belong to hydro power and wind power summing up to 970 GW and 238 GW, respectively [1]. Nonetheless, among various types of renewable resources, solar energy is more attractive due to its almost even distribution in most parts of the world. Solar energy is clean, environmentally friendly and inexhaustible. Nowadays different kinds of solar energy technologies such as solar photovoltaic (PV), concentrating solar thermal power (CSP), solar hot water/space heating systems, solar dryers, solar stills and solar ovens are becoming widespread. By the end of 2011, the global capacity of PV, CSP and solar hot water/space heating reached to 70 GW, 1. 76 GW and 232 GW, respectively [1]. Aligned with augmented utilization of these technologies in the recent years, many studies have been undertaken to enhance the performance of such technologies [2-6].

Due to placement in the solar belt region of the world, Iran enjoys considerable solar radiation, so that the amount of solar radiation in different parts of Iran is estimated in the range of 1800-2200 KWh/m^2 per year[1]. However, in order to design a solar energy system in every region, having accurate information about the potential of solar radiation, clearness index and optimum tilt angle of solar collectors are very essential.

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Please cite this article as: Khorasanizadeh, H., K. Mohammadi and A. Aghaei, 2014. the potential and characteristics of solar energy in Yazd province, Iran. Iranica Journal of Energy and Environment, 5(2):173-183.

Extensive researches have been conducted to analyze measured solar radiation data at various parts of the globe [7-12]. Besides, several investigations have been performed to enlighten different aspects of solar radiation in Iran, from which references are made here only to some of them. Yaghoubi and Sabzevari [13] analyzed global solar radiation on horizontal surface and clearness index using data of seven years for the city of Shiraz. Noorian *et al*. [14] examined the performance of 12 different models to estimate hourly diffuse solar radiation on inclined surfaces based on measured data on horizontal surface in Karaj. Moeeni *et al*. [15] utilized the long term measured solar radiation data and established the Angström model for prediction of the monthly averaged daily global radiation in the city of Yazd. Salvatipour *et al*. [16] theoretically determined the optimum tilt angles for the south facing solar collectors in city of Isfahan for monthly, seasonal and yearly adjustments. They also investigated the effect of earth reflectivity on optimum slope angle and maximum total solar radiation. Behrang *et al*. [17] proposed some newglobal solar radiation models using relative sunshine hours for 17 selected cities across Iran by employing particle swarm optimization (PSO) technique. Dehghan [18] presented a review paper to discuss the status and potential of renewable energies, in particular solar and wind energies, in Yazd province. As for solar energy, his study only involved reviewing the experiences of installing the solar energy technologies in Yazd province, but it has lack of assessment of solar energy and exploration of its characteristics. Khorasanizadeh and Mohammadi [19] tested performance of 11 empirical models from 3 different categories to predict the monthly mean daily global solar radiation over six major cities of Iran. They presented the suitable model for each city, in which the sunshine hours was an important variable. In another study Khorasanizadeh and Mohammadi [20] utilized long-term global solar radiation data to test 6 days of the year based empirical models for prediction of daily global solar radiation in four Iranian cities of Bandarabass, Isfahan, Kerman and Tabass. They employed the statistical non-linear regression technique and were able to establish the best model for every city. In a recent study, Khorasanizadeh *et al*. [21] established a proper model for estimation of horizontal diffuse radiation in Tabass, Iranand determined the optimum tilt angle for south-facing solar surfaces in Tabass region for the fixed monthly, seasonal, semi-yearly and yearly adjustments.

In order to know and evaluate the potential of solar energy in Yazd province of Iran, this study presents an analysis of horizontal global solar radiation (HGR), clearness index (CI), sunshine duration (SD) and ambient temperature (AT) in four very well distributed locations in this province.

The Study Region and Data Collection: Yazd province with an area of 131, 575 km^2 is located in the central part of Iran approximately between 30-35°N latitudes and 52-58°E longitudes. This province is divided to eleven districts; one of them is the city of Yazd, the center of Yazd province. Based on 2011 statistical survey, the total population of Yazd province is1, 074, 428 residents. Yazd province is subjected to the rain shadow effect due to its location east of Zagros Mountain such that its annual average participation is about 100 mm, most of it falling in winter months[2]. Low precipitations as well as high rate of evaporation in summer are two important parameters which make much of this province one of the driest areas of Iran. Based on the Köppen classification, the climate condition in this province is categorized ashot desert climate (BWh), which relates to hot arid desert [22]. This is because of its annual participation which is less than 250 mm and its mean annual temperature which is above 18°C.

For analyzing the status of solar radiation and assessing the solar potential of this province, four station locations of Abarkuh, Behabad, Halvan and Yazd have been selected, which are geographically distributed across the province. Figure 1 displays Yazd province on the map of Iran and placement of the selected siteson this province. Abarkuh and Behabad are small towns and Halvan is a rural area. The geographical locations of these four places and time period of data used in this study are given in Table 1. For the city of Yazd, long-term (five years) measured daily data provided by Iranian Meteorological Organization (IMO) was available, but for the other three locations only one year every ten minute measured data was available. These one-year data were obtained in a survey study by Iranian Renewable Energy Organization, locally called SUNA. As part of this survey study and in order to measure different meteorological parameters such as horizontal global radiation, temperature, relative humidity and wind speed at different heights many temporary stations were positioned at various parts of the country, in particular in Abarkuh, Behabad and Halvan.

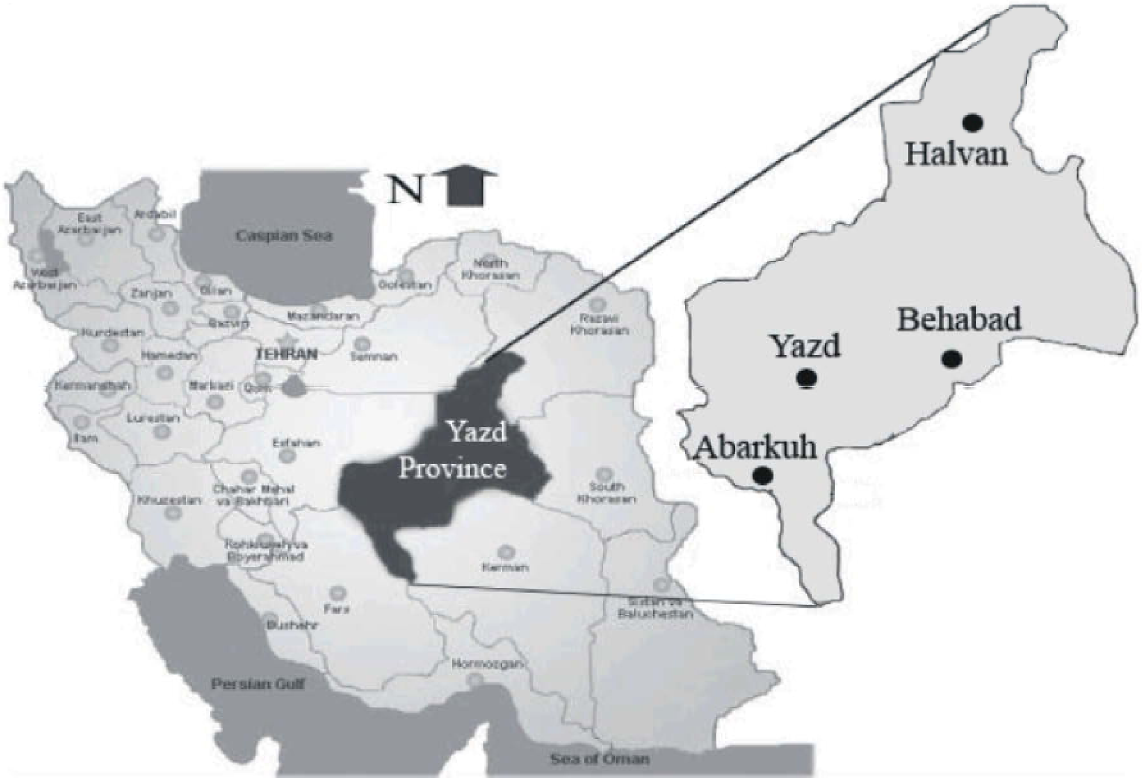


Fig. 1: The position of Yazd province, Abarkuhh, Behabad, Halvan and the city of Yazd on the map of Iran

Table 1: Geographical locations of four nominated locations inYazd province and period of data series

City	Latitude (°N)	Longitude (°E)	Period of data series
Abarkuh	31°30′	53°66′	2007
Behabad	31°77′	56°11′	2007
Halvan	33°96′	56°29′	2007
Yazd	31°53′	54°37′	2003, 2004 & 2007-2009

Caculation Procedure: To analyze solar data some useful parameters are needed. Clearness index is the ratio of terrestrial HGR to extraterrestrial horizontal radiation. The daily clearness index is [23]:

$$K_T = \frac{H}{H_o} \tag{1}$$

where, H is the daily global solar radiation on a horizontal surface and H_oi s the extraterrestrial solar radiation on a horizontal surface at the same geographical location. The extraterrestrial solar radiation on a horizontal surface, H_o, is represented in literature [23]:

$$H_o = \frac{24\times 3600}{\pi} G_{sc}\left(1+0.033\cos\frac{360 n_{day}}{365}\right) \times\left(\cos\varphi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\varphi\sin\delta\right) \tag{2}$$

where, G_{sc} is the solar constant equal to 1367 W/m^2, n is the day number of the year, φ is the latitude of the location, δ is the solar declination angle and ω_s is the sunrise hour angle. The solar declination and the sunrise hour angles are [23]:

$$\delta = 23.45\sin\left(\frac{(n+284)360}{365}\right) \tag{3}$$

$$\omega_s = \cos^{-1}\left(-\tan\varphi\tan\delta\right) \tag{4}$$

For Abarkuh, Behabad and Halvan the ten-minute recorded solar and temperature data were averaged to get hourly HGR. Then these hourly values were used to obtain daily HGR. For Yazd the five years measured daily HGR data were utilized to obtain an average for every day of the year. Moreover, the monthly, seasonal and yearly mean values of daily HGR were obtained by getting average from the daily HGR values, correspondingly.

For every selected location, in order to obtain the daily clearness index the daily extraterrestrial solar radiation for the corresponding φ, δ and ω_s was utilized. For each month the monthly mean clearness index was obtained by dividing the monthly averaged daily HGR to the daily extraterrestrial radiation of the average day of that month. The monthly average temperature was obtained by averaging all of the hourly measured temperatures. In addition the monthly average minimum and maximum temperatures were obtained by averaging all of the measured daily minimum and maximum values, respectively. Toderive the seasonal and the yearly averaged daily HGR and clearness index their monthly values were also averaged, correspondingly.

RESULTS AND DISCUSSIONS

In this section the daily sunshine hours, HGR and clearness index are presented, analyzed and discussed first. Due to climatic changes occurring in different days of each month and throughout the year, daily analysis is not conclusive; hence, monthly seasonal and yearly studies are required. The monthly results are discussed in the next subsection and the seasonal and yearly results are discussed together in another subsequent subsection.

Daily Results: To determine the potential of a region for installing solar energy systems one important factor is the amount of sunshine hours. According to a particular definition proposed by the World Meteorological Organization (WMO) [24], sunshine duration during a day, *n*, is the sum of periods for which the beam (direct) solar irradiance exceeds 120 W/m^2.

Due to lack of measured data for the three other locations, the study of sunshine duration was done only for the city of Yazd. However, because of similar weather condition in all of the considered locations, the results can be extended to make conclusion about the whole Yazd province. For the city of Yazd, daily sunshine hours, based on averaged values obtained in the five years of measurement, as well as the day length, *N*, throughout the year are shown in Figure 2. The total sunshine duration in a whole year for the city of Yazd is 3342 hours; which is 19% higher than the average estimated sunshine duration of 2800 hours for the whole Iran. It should be noted that the total day lengths for a whole year in Yazd province are 4380 hours. Thus, Yazd province enjoys from sunshine hours in almost 76% of the whole day times.

The ratio of sunshine hours in a day to the maximum possible sunshine hours (the day length) is defined as relative sunshine hours (n/N). One classification for the daily weather condition proposed by the World Meteorological Organization [25] is:

Cloudy sky: $0 \leq n/N < 0.3$
Scattered clouds: $0.3 \leq n/N < 0.7$
Fair weather: $0.7 \leq n/N \leq 1.0$

On this basis, the city of Yazd in 269 days (74% of a whole year) enjoys from fair weather condition, whereas only in 5 and 91 days there exist cloudy sky and scattered clouds, respectively.

To obtain daily characteristics of radiation, particularly the maximum values, study of daily HGR throughout the year is important. For Abarkuh, Behabad, Halvan and the city of Yazd the daily HGRin different days of yearis shown in Figure 3. In Abarkuh the maximum daily HGR of 32. 03 MJ/m^{2}has occurred on 3rd July. For Behabad and Halvan the maximum values of HGR are 31. 38 and 30. 68 MJ/m^2 on May 28 and May 21, respectively. For Yazd, the highest HGR is 35. 06 MJ/m^2 happened on May 31, 2009 whereas the lowest HGR is 1. 93 MJ/m^2 occurred on December 3, 2008. However, for the city of Yazd and based on the five years averaged values the maximum and minimum daily HGR are 29. 69 and 6.15 MJ/m^2, respectively. A general comparison of plots related to different locations showsa similar trend during the year, although fewer fluctuations are observed for the city of Yazd. This isdue to the fact thatfor Abarkuh, Behabad and Halvan only one year measured data have been used, whereas for the city of Yazd five years averaged values of daily HGR have been utilized.

In the design of solar energy systems, clearness index is a very crucial factor. Clearness of sky directly influences the beam (direct) radiation which is essential for concentrating solar systems. The extraterrestrial solar radiation in every geographical location is a constant value for each specific day, irrespective of change of year. However, solar attenuation occurs as radiation passes through the atmosphere due to atmospheric phenomenon such as, aerosol extinction, cloud extinction, permanent gas absorption, ozone absorption, Rayleigh scattering and water vapor absorption. According to Figure 4, which shows the daily clearness index in the four nominated locations, for most of the days the clearness index is high indicating high level of beam (direct) radiation. Nevertheless, low values of HGR and clearness index in some of the days refer to the lessening due to the above mentioned atmospheric incidents.

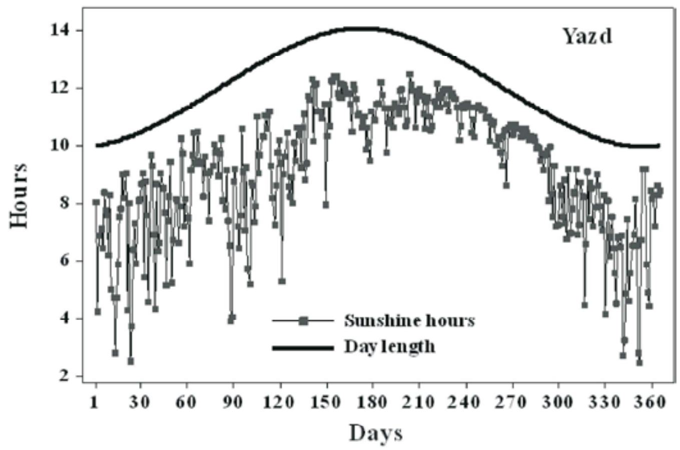


Fig. 2: Daily sunshine hours and day length in the city of Yazd

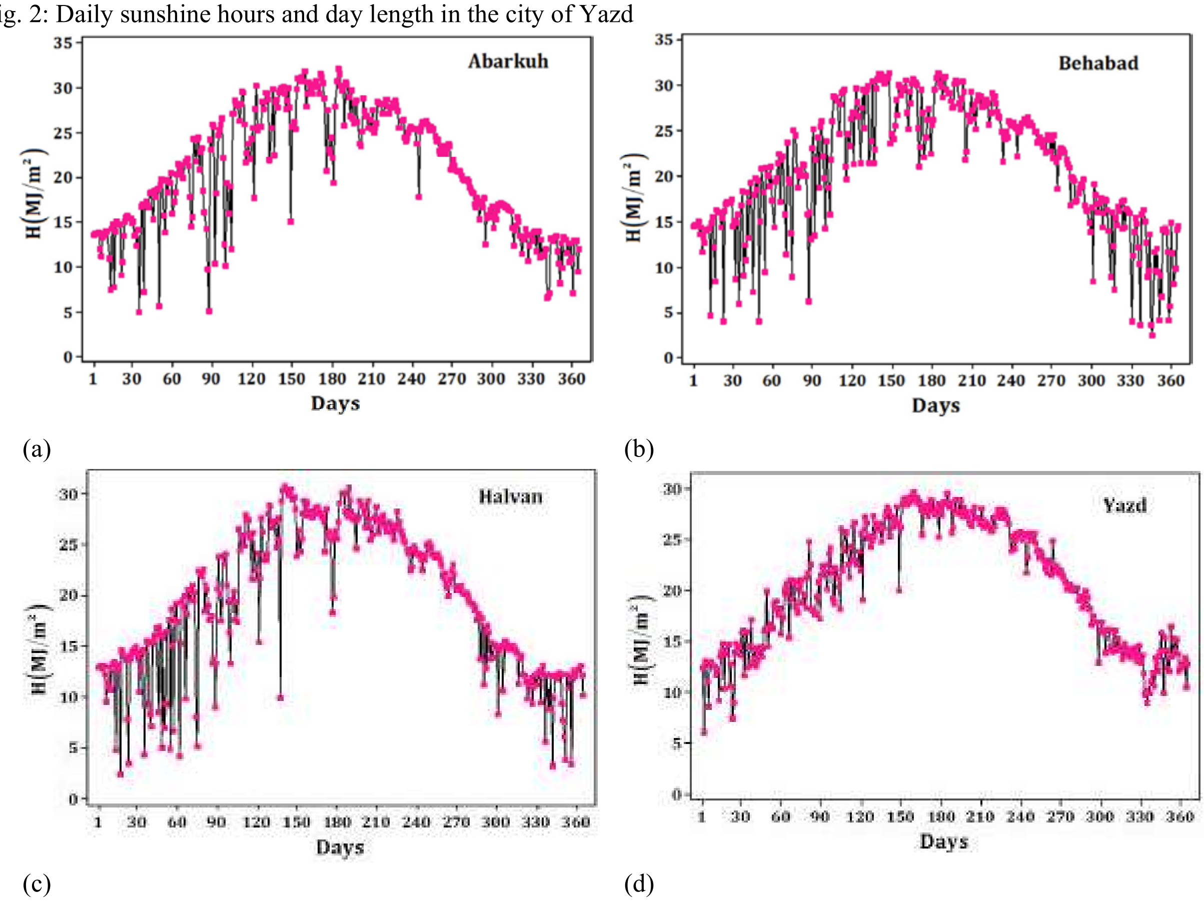


Fig. 3: Daily global solar radiation at different locations in Yazd province

For Abarkuh, Bahabad, Halvan and the city of Yazd the maximum daily clearness indexes are 0. 79, 0. 85, 0. 77 and 0. 88 and the minimum ones are 0. 15, 0. 13, 0. 13 and 0.32, respectively.

Another important parameter that can be helpful to find and understand the characteristics of solar energy is the frequency distribution of daily HGR and clearness index at some specified intervals throughout the year. These two are important parameters inde signing solar systems like PV or solar concentrators. An analysis was conducted for daily HGR from 0 to 35 MJ/m^2 with interval of 5 MJ/m^2, also for daily clearness index from 0 to 1 with interval of 0. 1 andthe results are presented in Tables 2 and 3, respectively.

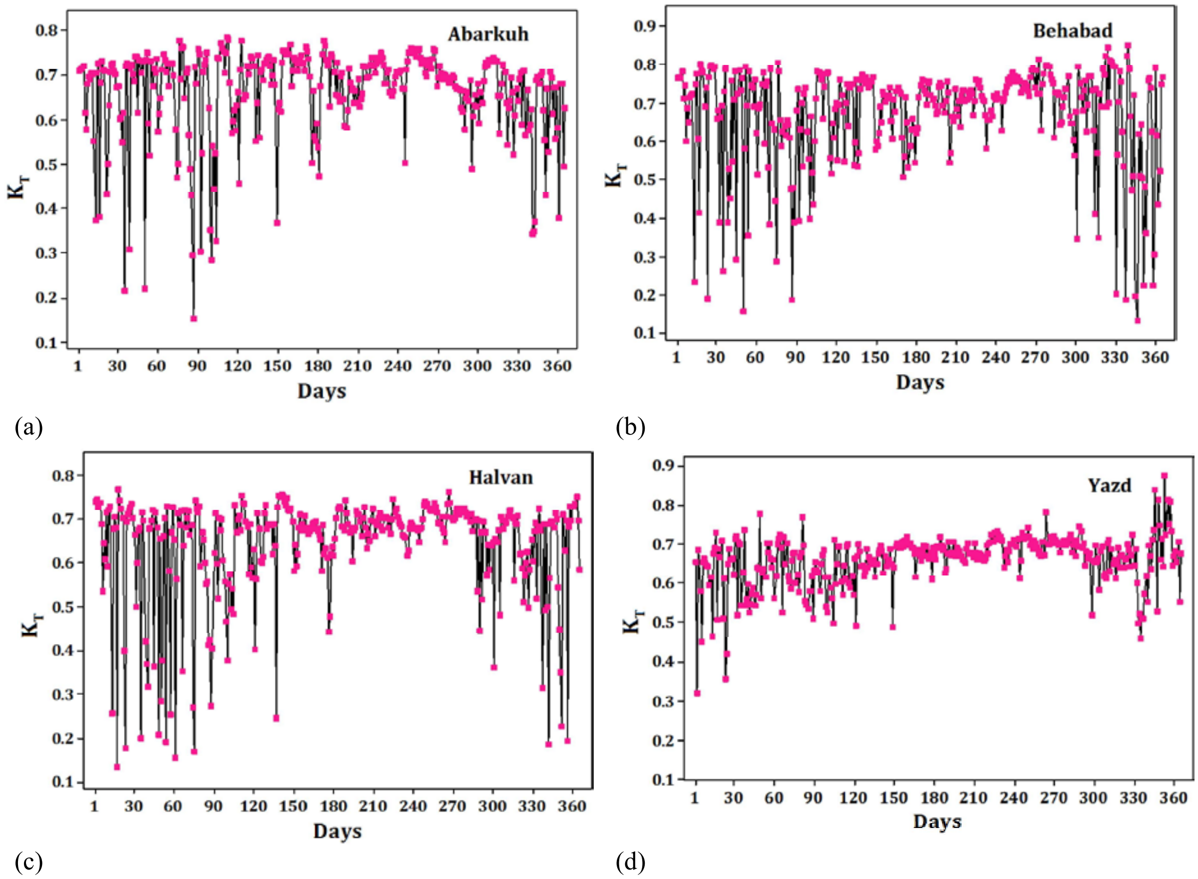


Fig. 4: Daily clearness index in different locations of Yazd province

Table 2: The frequency distribution of days of a year at different intervals ofglobal solar radiation (MJ/m^2)

City/interval	0-5	5-10	10-15	15-20	20-25	25-30	30-35
Abarkuh	1	14	75	80	63	109	23
Behabad	9	20	51	82	77	99	27
Halvan	9	26	83	59	79	100	9
Yazd	0	10	85	69	78	123	0

Table 3: The frequency distribution of days of a year at different intervals of clearness index

City/interval	0.0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1.0
Abarkuh	0	1	4	11	11	38	124	171	0	0
Behabad	0	6	7	11	10	37	90	187	11	0
Halvan	0	8	8	9	17	34	164	125	0	0
Yazd	0	0	0	2	8	44	221	85	5	0

In another classification, Yousif *et al*. [26] proposed four different intervals of K_T for the level of clearness of sky, which are:

Cloudy: $0 < K_T < 0.2$
Partly cloudy: $0.2 \leq K_T < 0.6$
Sunny: $0.6 \leq K_T < 0.75$
Very sunny: $0.75 \leq K_T < 1$

According to this classification, with clearness index more than 0. 6, Abarkuh, Behabad, Halvanand the city of Yazd enjoy from 295, 288, 289 and 311 days, respectively. Figure 5 shows the comparison of frequency distribution of clearness index at different intervals in four nominated locations of Yazd province. It can be concluded that the whole Yazd province has more or less the same status in terms of clearness of sky. Additionally, Yazd province

Table 4: The monthly mean daily HGR (MJ/m^2), clearness index and temperature (°C) of four nominated locations in Yazd province

City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Abarkuh	$\overline{H}$	13.38	16.13	19.69	22.88	27.02	28.40	27.65	26.64	23.61	17.60	14.54	11.36
	$\overline{K}_T$	0.65	0.64	0.63	0.63	0.68	0.69	0.68	0.70	0.72	0.65	0.67	0.59
	$\overline{T}$	4.6	9.2	12.3	18.7	24.7	31.3	32.6	30.1	25.4	21.3	14.1	7.5
Behabad	$\overline{H}$	13.06	15.42	18.55	23.80	27.59	27.19	28.60	26.57	24.75	18.74	14.67	10.43
	$\overline{K}_T$	0.65	0.62	0.60	0.65	0.69	0.66	0.71	0.70	0.75	0.70	0.69	0.55
	$\overline{T}$	5.6	9.0	12.0	20.2	23.8	30.0	30.0	27.7	23.0	22.0	12.3	4.1
Halvan	$\overline{H}$	11.97	12.89	17.17	22.52	26.61	26.80	28.06	25.69	22.69	16.69	12.80	10.40
	$\overline{K}_T$	0.63	0.54	0.57	0.62	0.67	0.65	0.69	0.69	0.71	0.65	0.64	0.59
	$\overline{T}$	7.9	11.8	14.6	23.8	28.3	34.7	34.8	32.8	28.5	26.4	17.3	8.0
Yazd	$\overline{H}$	12.48	15.58	19.56	23.01	25.98	28.18	27.55	26.19	23.04	18.22	14.59	12.79
	$\overline{K}_T$	0.61	0.62	0.63	0.63	0.65	0.68	0.68	0.69	0.70	0.68	0.68	0.67
	$\overline{T}$	7.3	10.1	15.2	21.1	26.1	30.6	33.0	31.3	27.6	21.5	13.2	8.7

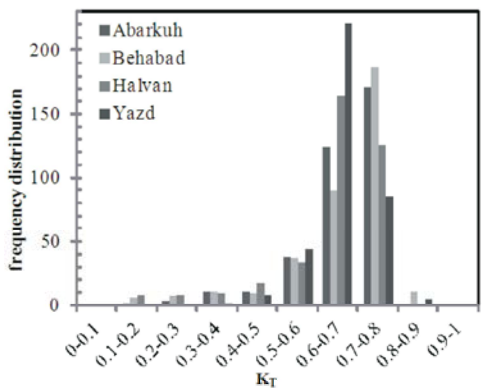


Fig. 5: Comparison of frequency distribution of clearness index at different intervals in the four nominated locations of Yazd province

enjoys from sunny and very sunnydays at least in more than 79% of the days of a whole year. Although the clearness index does not exclusively provide information on the accessibility of beam radiation, desirable level of beam radiation suitable for concentrating solar systems in Yazd province seems inevitable.

Monthly Results: Table 4 represents monthly mean daily HGR, clearness index and average temperature in different months for Abarkuh, Behabad and Halvan and the city of Yazd. For Abarkuh and the city of Yazd, the maximum monthly mean HGR occur in June were 28. 40 and 28. 18 MJ/m^2, respectively. While for Behabad and Halvan the maximum mean HGR in occur in July were 28. 60 and 28. 06 MJ/m^2, respectively. On the other hand, for Abarkuh, Behabad and Halvanthe minimum monthly mean HGR occur in December were 11. 37, 10. 43 and 10.40 MJ/m^2, respectively. Whereas for the city of Yazd the minimum HGR happens in January is 12. 48 MJ/m^2. For Abarkuh, Behabad, Halvan and the city of Yazd the maximum monthly mean daily clearness index occur in September were 0. 72, 0. 75, 0. 71 and 0. 70, respectively. For Abarkuh and Behabad, the minimum monthly clearness indexes, happening on December are 0.59 and 0.55 , respectively; while for Halvan the minimum is 0.54 belonging to February and for the city of Yazd, the minimum is 0. 61 belonging to January. The results denote that the monthly averaged daily HGR and clearness index in all of the locations ofYazd province are high throughout the year. A further comparison of the monthly averaged daily HGR and clearness index in different locations of Yazd province at the same months express that the status of solar radiation across this province is more or less the same.

To study the comparison of the status of solar radiation in Yazd province with some other places around the globe, 7 cities in different continents but all located in almost the same latitude asYazd province (Table 5) have been selected. Table 6 presents the monthly averaged daily HGR, clearness index and average temperature in these designated cities.

A comparison between the data in Tables 4 and 6 for all of the months reveals that, except Arizona, the monthly mean daily HGR and clearness index in different locations of Yazd province are higher than those of other six designated cities. Arizona is considered as one of the sunniest locations across the world [23]. However, in the last and first months of the year Yazd province enjoys from higher HGR and clearness index than Arizona does. The high values of HGR and clearness index indicate that Yazd province isa suitable region for investment in solar systems utilized by solar concentrators or PV.

In designing solar systems, the ambient temperature is an important parameter. The monthly mean maximum, minimum and average temperatures for all of the nominated locations are shown in Figure 6. The results indicate that Halvan and the city of Yazd compared with Abarkuh and Behabad have a bit higher minimum, average

Table 5: Geographical locations of the 7 nominated cities around the globe

City	Country (Continent)	Latitude	Longitude
Arizona	USA (North America)	33.89 °N	112.10 °W
Baghdad	Iraq (Asia)	33.32 °N	44.39 °E
Cairo	Egypt (Africa)	30.00 °N	31.20 °E
Casablanca	Morocco (Africa)	33.60 °N	7.62 °W
Georgia	USA (North America)	32.96 °N	83.11 °W
Jerusalem	Israel (Asia)	31.78 °N	35.22 °E
Texas	USA (North America)	30.30 °N	97.50 °W

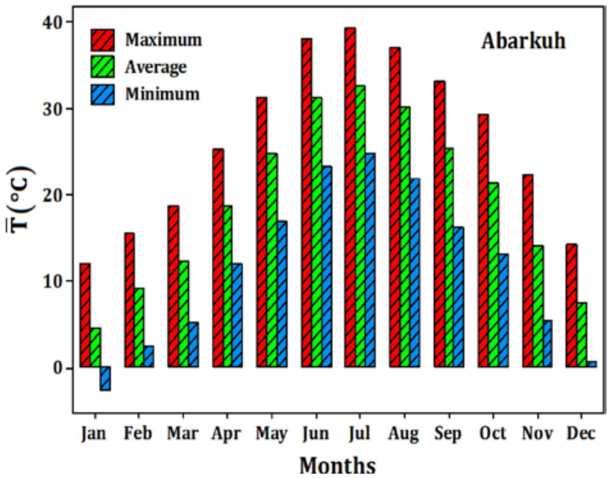
Table 6: The monthly mean daily HGR (MJ/m^2), clearness index and temperature (°C) in 7 nominated cities around the globe [8, 23]

City		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Arizona	$\overline{H}$	11.60	15.60	20.59	26.73	30.38	31.10	28.23	26.02	22.88	17.90	13.06	10.57
	$\overline{K}_T$	0.60	0.65	0.68	0.74	0.76	0.75	0.69	0.69	0.71	0.69	0.64	0.59
	$\overline{T}$	11	13	15	20	25	29	33	32	29	22	15	11
Baghdad	$\overline{H}$	10.80	13.68	17.28	20.52	23.4	26.28	25.92	23.76	20.52	15.84	11.88	9.72
	$\overline{K}_T$	0.55	0.59	0.58	0.53	0.58	0.65	0.62	0.64	0.61	0.54	0.52	0.52
	$\overline{T}$	9.77	11.5	16.2	23	29.1	33.3	36.1	35.7	32	26.2	17.8	11.5
Cairo	$\overline{H}$	11.84	15.60	19.32	23.15	26.32	27.95	27.10	25.23	21.97	17.86	13.24	11.12
	$\overline{K}_T$	0.56	0.60	0.61	0.63	0.66	0.68	0.67	0.66	0.66	0.65	0.59	0.56
	$\overline{T}$	14	15	17	25	27	28	28	28	26	24	19	15
Casablanca	$\overline{H}$	9.72	11.88	16.20	19.44	22.68	23.40	23.04	21.04	18.00	13.68	9.72	8.64
	$\overline{K}_T$	0.51	0.61	0.63	0.66	0.64	0.66	0.67	0.68	0.64	0.57	0.52	0.48
	$\overline{T}$	11.6	13.1	16.5	20.6	25.8	30.5	33.0	32.9	28.3	23.4	17.5	13.1
Georgia	$\overline{H}$	8.14	11.00	14.80	19.14	21.05	21.73	20.57	19.39	16.14	13.62	10.02	7.66
	$\overline{K}_T$	0.43	0.46	0.49	0.53	0.53	0.52	0.51	0.52	0.50	0.53	0.50	0.43
	$\overline{T}$	6	7	11	16	21	24	26	25	22	17	11	6
Jerusalem	$\overline{H}$	9.72	12.24	18.00	21.60	24.84	27.36	27.36	25.92	21.96	17.28	12.60	9.36
	$\overline{K}_T$	0.49	0.50	0.54	0.59	0.62	0.67	0.66	0.63	0.61	0.55	0.52	0.49
	$\overline{T}$	10.6	11.3	14.1	18.8	22.1	24.2	26.0	26.3	25.0	21.7	17.0	12.3
Texas	$\overline{H}$	9.81	12.77	16.22	18.22	20.81	23.52	23.90	21.92	18.23	15.13	11.20	9.37
	$\overline{K}_T$	0.47	0.50	0.52	0.50	0.52	0.57	0.59	0.58	0.55	0.55	0.51	0.47
	$\overline{T}$	10	12	15	20	24	28	29	29	26	21	15	11

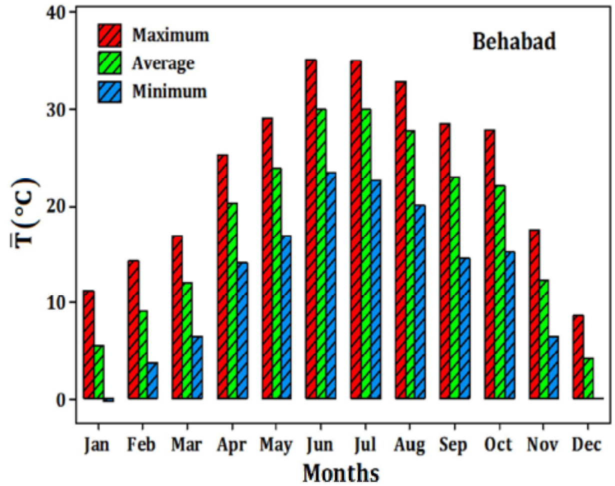
and maximum temperatures throughout the year. However, the overall condition in terms of temperature is not much different across the province.

Seasonal and Yearly Results: In the northern hemisphere the seasons consist of: (1) Winter: December, January and February; (2) Spring: March, April and May; (3) Summer: June, July and August; (4) Autumn: September, October and November. The seasonal and yearly averaged daily HGR, clearness index and average temperature for Abarkuh, Behabad, Halvanand the city of Yazd are presented in Table 7. Apparently, they are high and despite distribution of the geographical locations are not much different; so thatthe relative difference of yearly averaged daily HGR and clearness indexfor Abrakuh, Behabad, Halvan and the city of Yazdat most is 6%. Therefore, in order to present mean values for the whole province, it is possible to average the yearly values related to the four nominated locations. In this regard the annually averaged daily HGR and clearness index for Yazd province would be 20.41 MJ/m^2 and 0. 66, respectively.

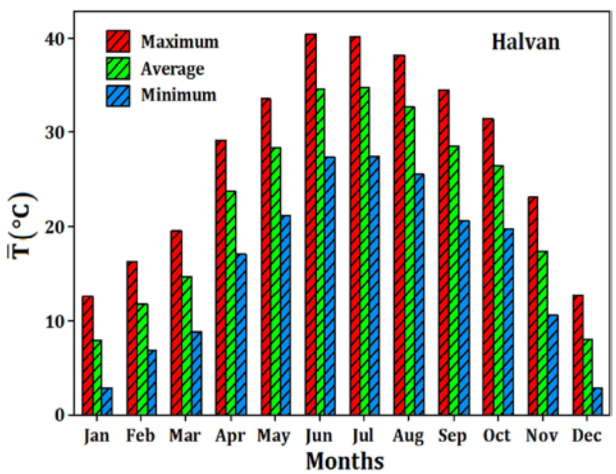
To make comparison, the seasonal and the yearly averaged daily HGR, the clearness index and the average temperature for the seven selected cities around the globehave been listed in Table 8. Comparison among the corresponding values in Tables 7 and 8 indicates that, except Arizona, the averaged seasonal and yearly HGR and clearness indexin different locations of Yazd province are higher than those of the internationally selected cities. In addition, in autumn and winter all of the nominated locations in Yazd province, except Halvan, enjoy from higher HGR and clearness index values compared to those of Arizona. This conclusion highlights the great potential of solar energy inall of the selected locations, which are geographically distributed in Yazd province.



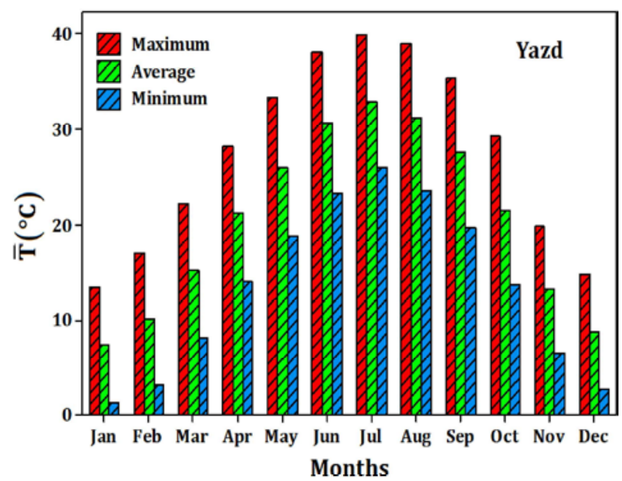
(a)



(b)



(c)



(d)

Fig. 6: Monthly maximum, average and minimum temperatures for different locations in Yazd province

Table 7: The averaged seasonal and annual daily HGR (MJ/m^2), clearness index and temperature (°C) in four locations of Yazd province

City		Winter	Spring	Summer	Autumn	Annual
Abarkuh	$\overline{H}$	13.62	23.20	27.57	18.58	20.74
	$\overline{K}_T$	0.63	0.64	0.69	0.68	0.66
	$\overline{T}$	7.2	18.6	31.3	20.3	15.5
Behabad	$\overline{H}$	12.97	23.31	27.46	19.39	20.78
	$\overline{K}_T$	0.61	0.65	0.69	0.71	0.66
	$\overline{T}$	6.2	18.7	29.2	19.1	18.3
Halvan	$\overline{H}$	11.75	22.10	26.85	17.39	19.52
	$\overline{K}_T$	0.59	0.62	0.67	0.67	0.64
	$\overline{T}$	9.2	22.2	34.1	24.1	22.4
Yazd	$\overline{H}$	13.62	22.85	27.31	18.62	20.60
	$\overline{K}_T$	0.63	0.64	0.68	0.69	0.67
	$\overline{T}$	8.7	20.8	31.6	20.7	20.5

Table 8: The mean seasonal and yearly daily HGR (MJ/m^2), clearness index and temperature (°C) in the 7 selected cities around the globe [8, 23]

City		Winter	Spring	Summer	Autumn	Yearly
Arizona	$\overline{H}$	12.59	25.90	28.45	17.95	21.22
	$\overline{K}_T$	0.61	0.73	0.71	0.68	0.68
	$\overline{T}$	11.7	20.0	31.3	22.0	21.3
Baghdad	$\overline{H}$	11.40	20.40	25.32	16.08	18.30
	$\overline{K}_T$	0.55	0.56	0.64	0.56	0.58
	$\overline{T}$	10.9	22.8	35.0	25.3	23.5
Cairo	$\overline{H}$	12.85	22.93	26.76	17.69	20.06
	$\overline{K}_T$	0.57	0.63	0.67	0.63	0.63
	$\overline{T}$	14.7	23.0	28.0	23.0	22.2
Casablanca	$\overline{H}$	10.08	19.44	22.49	13.80	16.45
	$\overline{K}_T$	0.53	0.64	0.67	0.58	0.61
	$\overline{T}$	12.6	21.0	32.1	23.1	22.2
Georgia	$\overline{H}$	8.93	18.33	20.56	13.26	15.27
	$\overline{K}_T$	0.44	0.52	0.52	0.51	0.50
	$\overline{T}$	6.3	16.0	25.0	16.7	16.0
Jerusalem	$\overline{H}$	10.44	21.48	26.88	17.28	19.02
	$\overline{K}_T$	0.49	0.58	0.65	0.56	0.57
	$\overline{T}$	11.4	18.3	25.5	21.2	19.11
Texas	$\overline{H}$	10.65	18.42	23.11	14.85	16.76
	$\overline{K}_T$	0.48	0.51	0.58	0.54	0.53
	$\overline{T}$	11.0	19.7	28.7	20.7	20.0

CONCLUSION

Every ten-minute global solar radiation and temperature data measured from January to December 2007 in Abarkuh, Behabad, Halvanand the long term daily measured data in the city of Yazd, all placed in Yazd province of Iran, were utilized to evaluate the potential of solar energy in this province. Results indicated that the yearly averaged daily HGR for Abarkuh, Behabad, Halvan and Yazd are 20. 74, 20. 78, 19. 52 and 20. 60 MJ/m^2, respectively. From the obtained data, the mean value for the whole province Yazd is 20. 41 MJ/m^2. Comparison of the status of solar radiation in Yazd province with those of some other world wide places at the same latitude showed that, except Arizona, the rank of Yazd province is superior. The yearly averaged clearness indexes for the four nominated locations are 0. 66, 0. 66, 0. 64 and 0. 67, respectively; which resultsin the mean value of 0. 66 for the whole province. In addition, the number of sunny and very sunny days, for which the daily clearness index is more than 0. 6, is 295, 288, 289 and 311, respectively. On the other word, Yazd province enjoys from sunshine hours in almost 76% of the whole day times. Due to the fact that this province has a great potential for solar investment, it is hoped that the local and central authorities will pay enough attention for providing funds and supporting installation of solar technologies in the region.

ACKNOWLEDGMENTS

The authors are grateful to the Energy Research Institute of University of Kashan for supporting present research [Grant No. 158576/9]. Our thanks are also extended to Iranian renewable energy organization (SUNA) and Iranian meteorological organization (IMO) for providing the solar data.

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Persian Abstract

DOI: 10.5829/idosi.ijee.2014.05.02.09

چکیده

در این مطالعه، با استفاده از داده‌های اندازه‌گیری‌شده در چهار منطقه توزیع شده جغرافیایی ابرکوه، بهاباد، حلوان و شهر یزد در استان یزد پتانسیل انرژی خورشیدی و مشخصات آن در این استان ارزیابی شده است. برای این مناطق تابش خورشیدی کل روزانه روی سطح افقی و شاخص روزانه صافی هوا و همچنین مقادیر متوسط ماهانه، فصلی و سالانه آن‌ها بدست آمده است. نتایج نشان می‌دهند که این مناطق به‌ترتیب از ۳۰۰، ۲۹۴، ۲۸۹ و ۳۱۱ روز آفتابی بهره می‌برند و همچنین متوسط سالانه شاخص صافی هوای روزانه آن‌ها به‌ترتیب ۰/۶۶، ۰/۶۶، ۰/۶۴ و ۰/۶۷ و متوسط سالانه تابش کل روزانه آن‌ها به‌ترتیب ۲۰/۷۴، ۲۰/۷۸، ۱۹/۵۲ و ۲۰/۶۰ مگاژول بر مترمربع است. در استان یزد ۷۶ درصد از کل طول روزهای سال آفتابی هستند و متوسط سالانه تابش کل روزانه ۲۰/۴۱ مگاژول بر مترمربع و متوسط سالانه شاخص صافی هوای روزانه ۰/۶۶ است. مقایسه شرایط این چهار منطقه از استان یزد با هفت شهر انتخاب شده دنیا در عرض جغرافیایی مشابه، نشان می‌دهد که به‌جز آریزونا متوسط ماهانه تشعشع کل روزانه و متوسط ماهانه شاخص روزانه صافی هوای این مناطق بیشتر از شهرهای منتخب دیگر است. با توجه به پتانسیل بالای انرژی خورشیدی در استان یزد، تلاش و سرمایه‌گذاری بیشتری در زمینه توسعه استفاده از انرژی خورشیدی ضروری به‌نظر می‌رسد.