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ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫНЫҢ
Қ. И. Сәтпаев атындағы Қазақ ұлттық техникалық зерттеу университеті

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ИЗВЕСТИЯ

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РЕСПУБЛИКИ КАЗАХСТАН
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OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF KAZAKHSTAN
Kazakh national research technical university named after K. I. Satpayev

ГЕОЛОГИЯ ЖӘНЕ ТЕХНИКАЛЫҚ ҒЫЛЫМДАР СЕРИЯСЫ

♦

СЕРИЯ ГЕОЛОГИИ И ТЕХНИЧЕСКИХ НАУК

♦

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SOLAR-DRIVEN RESOURCES OF THE REPUBLIC OF KAZAKHSTAN

Abstract. The present article considers the solar-driven resources of the Republic of Kazakhstan. To assess the solar energy potential, falling onto the territory in any region, it is necessary to have data on the solar energy potential. Based on actual observations and theoretical calculations generalizing, there exists the data: annual and latitudinal motion of possible monthly and annual sums of the direct solar irradiation falling onto the perpendicular surface under the conditions of clear sky, data on sunshine duration, daily motion of solar radiation for typical days of the year, maps of distributing the average monthly radiation sums for June and December on the territory as well as the maps of distributing «technically applicable and economically profitable solar capacity», developed criteria of defining the notion thereof. All solar systems estimates upon assessing the solar-driven resources on Kazakhstan territory are based on quantitative characteristics of the direct solar radiation onto the horizontal surface from which there might be done recalculation from the horizontal to inclined plane of any orientation. Proceeding from the results of average values of the direct, total irradiation and duration of the sunshine statistical treatment there have been differentiated five zones and compiled a histogram characterizing the possibility of introducing the solar plants onto Kazakhstan territory.

Keywords: solar energy, solar collector, solar-driven resources, solar radiation.

Introduction. Upon specifying the solar plants usage feasibility at any location there conducted preliminary calculations, taking into account the average annual, average monthly total amount of solar radiation, number of clear and dull days, duration of frostless period, cost of solar plant, their efficiency factor, etc.

At that, there was used reference data and passport data of solar stations with their technical specifications.

To assess the solar energy potential falling onto the territory in any region it is necessary to have the data on the solar energy potential.

In the article [1] there is analyzed the current energetic situation in Kazakhstan, including fossil energy sources and renewable energy sources and have been studied political factors in the energetic sector. The main aim of the article [2] is studying the prospects of the energy renewable sources development. It has been proved, that about 18% of the world energy consumption has been received from the renewable energy sources. In the article herein [3] there were presented some offers for developing the solar industry in Kazakhstan, based on the analysis of the global solar energetic model. In the document [4] the principal attention was paid to discussing the new technological components, which might be used for developing the system of renewable sources monitoring. There are being discussed the principles and architectural technologies which can be applied to such system implementation. As well, there were considered several examples of monitoring systems and engineering aspects behind such system. The article [5] considers different potential local resources, unrelated to fossil fuels, water power, solar power, wind, biomass and uranium, and there is being installed the structure of those resources' priority evaluation.

Similar studies are being conducted abroad, the work [6] demonstrates the data on the average monthly, daily global and direct solar radiation in the area of Jordanian University of science and engineering in the North Jordan. Maximum, average and minimum values, of both global and direct radiation were given in the period of 1990-1996 proceeding from the measurement data. Offered mathematical model for computing the maximum global daily radiation has been represented as the day of year function. Other mathematical regressions for various radiation characteristics have been presented as well.

The work [7] used several linear regression models using 9 variables to define the average monthly value of global radiation in the area of Antalya (Turkey) Outcomes show, that the total solar radiation can be defined with a percentage error from –5,7 to 3,9 %, average error 2,0 % and root-mean-square –2,5 %.

The article [8] creates a long-term database of monthly solar radiation in Zimbabwe. There was taken account of meteorological data, pyranometric measurements of semi sphere radiation. Simulation based on the data has been executed by means of two methods, calculation results are failed no more than for 7%.

On the ground of the hourly data on the total solar radiation in Quetta (Pakistan) within 10 years there was carried out the stochastic simulation and obtained Markov transfer matrixes, allowing the calculation of global solar radiation for the area thereof in MJ/m^2 [9].

The data on the solar radiation in Malaysia for the period of 10 years was used in the work [10] to get mathematical description. There were considered the simulation outcomes applying the models of beta distribution for 4 regions of the country with meteorological stations.

There is known the research work [11], which systematizes the latest data on solar radiation resources in Brazil. It describes geographical distribution of solar radiation in Brazil.. It demonstrates geographical distribution of solar power and those resources dependences on the local climatic conditions. Average annual level of the solar radiation in Brazil is within 18±2 MJ/ (m^2·day). Maximum monthly average level of the solar radiation is in Rio Grande state, located in the south of the country, in December and January (~24 MJ/ (m^2·day), and minimum value of the solar radiation is in June and July in the south coast of the same state and amounts to 8 MJ/ (m^2·day).

The work [12] reports the outcomes of experimental researches concerning the measurement of average monthly hourly diffused solar radiation in two cities of Nigeria: Lagos, a coastal town in the south of the country and Zaire, the town, located in savanna in the north (11, 10° north latitude.) of the country. Experimental data have been compared with prognosis, obtained by means of statistical models, developed for high latitudes. Comparison has shown that the models thereof are incorrect for Nigeria conditions.

Methods. We have offered a complex approach. Unfortunately, it does not grasp all necessary parameters and apart from that, it is schematic, large-scale due to shortage of actinometrical stations.

Multitude of natural factors conditions the task of their correct account upon the sun power plants development. Nevertheless, the work is recommended to be fulfilled based on radiation-climatic zoning of the republic, which seems a complex process. At that, the methodological base is detecting the main climatic elements criteria, account and assessment of radiation regime on the territory being considered.

To use the solar power effectively in combination with other climate components for the needs of the solar heating, the criteria for zoning are the solar intensity, climate meteorological parameters (outside air temperature, wind regime and other atmospheric phenomena). As the base of all solar system factors calculations while assessing solar power resources on the territory of Kazakhstan there were accepted quantitative characteristics of direct solar radiation on the horizontal surface, from which it is possible to perform recalculation from the horizontal to inclined plane of any orientation (table 13). Proceeding from the results of statistical treatment of the direct, total radiation and sunshine duration average values in compliance with the figures 19 and 20 there were differentiated five zones and drawn up a histogram, characterizing the possibilities of introducing the solar stations along the territory of Kazakhstan. Zone 1 occupies forest-steppe zones, located in the Northern Kazakhstan with an average June totals of the direct and global radiation of 11-14 and 20-22 MJ/v^2, i.e. 350-400 and 600-700 MJ/m^2 a month. According to the main features the solar power usage in this region is possible for practical aims of CCTC systems, but it is limited with a climatic, meteorological factor, wind and frequent sharp decrease in temperature in spring-autumn period. Sunshine duration in the year fluctuates from 1900 to 2200 hours.

Zone 2 is on the territory of Turgai valley, southern suburbs of Western-Siberian lowlands. Daily there is 22-24 MJ/m^2 of global radiation, but the most part of it is in the form of direct one, 13-15 MJ/m^2. Monthly amount is 600-700 and 400-500 MJ/m^2. The region thereof is characterized with sufficient amount of sunshine hours, i.e. 2200-2500 approximately, comparing to the Zone 1. But meteorological factors are not favorable either. In spring-autumn period there is stable cold air in Turgai lowlands, conditioning frequent, lasting ground frost.

Zone 3 is moderately-favorable for the solar power usage, which includes Precaspian lowland, Mugodzhary upland, Kazakh hummocky topography, Altai mountain uplift. Daily amount of average total radiation here is in July 23-26 MJ/m^2, whereof 15-18 MJ/m^2 is in the form of the direct radiation, monthly total amounts - to 700-800 and 400-550 MJ/m^2. Annual sunshine duration fluctuates within 2500-2700 hours.

Zone 4 includes Kyzyl Kum, Turan lowland, plain of Balkhash-Alakol basin, Tarbagata, Junggar and Zailiisky Ala Tau mountain ranges. Daily average total solar radiation here is 23-26 MJ/m^2, at that, the big amount is in the form of direct one, 15-18 MJ /m^2. Thus, correspondingly the monthly solar power amount is 700-800 and 500-600 MJ/m^2. Annual sum of direct radiation is higher here, especially in the mountains. Sunshine duration is 2700-2900 hours and the region is characterized as favorable for the solar power usage.

Zone 5 is the deserts Ak-Kum, Betpak-Dala with an average daily solar power intensity totals of correspondingly 18-22 and 25-28 MJ/ m^2, and monthly sums 550-700 and 750-900 MJ/m^2. The region is also favorable for using the solar power, and as we can see, in general, grasps the south of the republic. Sunshine duration in summer is about 390 hours, annual – 2900-3200 hours at minimal amount of dull days.

As it is shown with analysis a wide range of quantitative characteristics, reflecting the solar radiation regime peculiarities, sunshine duration and cloudiness confirms that the separating having been done.

Results. Structural temporary features of the supposed days of “sunny” and "electric" solar plants heating are given for all the zones. The greatest interest from the energy point of view is the amount of days with the sun and electric water heating in the solar plants within a year. It is typical for the 1st zone to

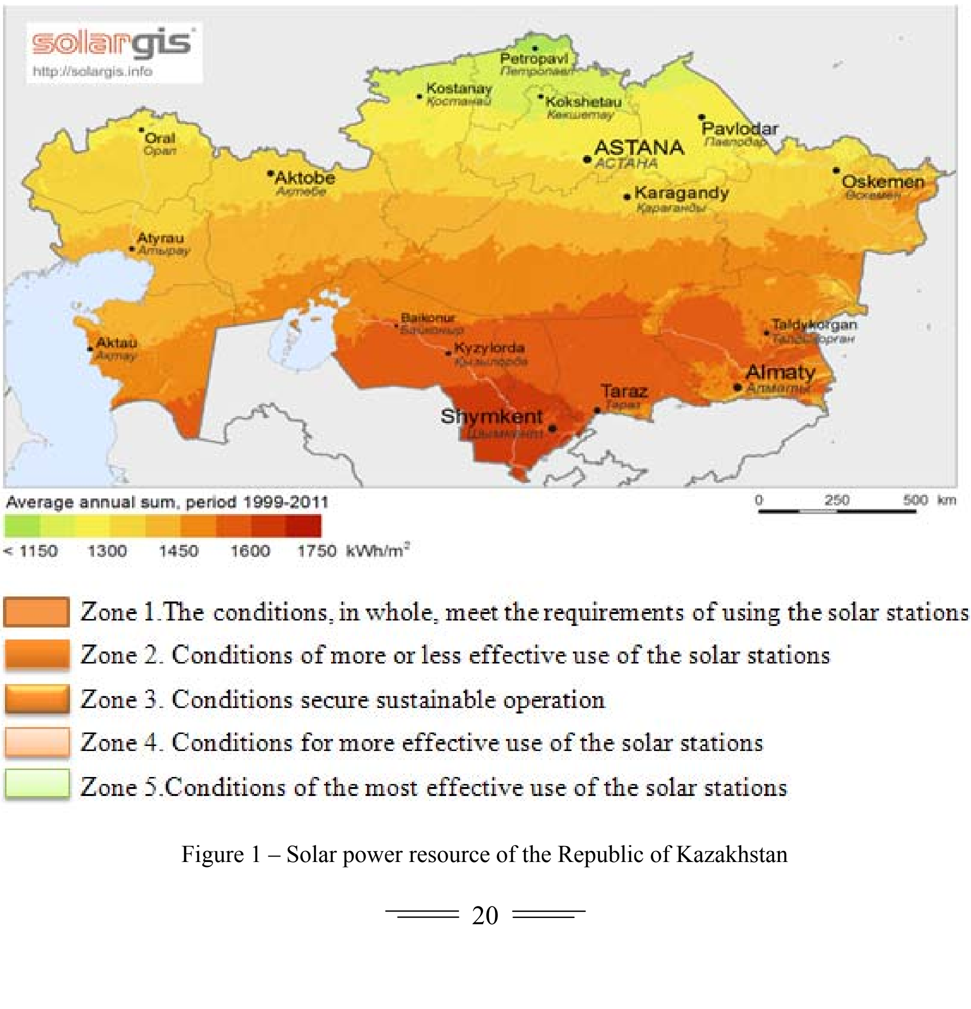

Figure 1 – Solar power resource of the Republic of Kazakhstan

use the solar power during 180 days, the rest 180 days there is the electric heating. For the 2nd, 3rd and 4th zones the number of days when the solar energy is used grows up to 270, and amount of days while using electric water heating decreases to 94. In the 5th zone it is possible to use the solar power more efficiently within a year. Criterion for such evaluation is an average time period, when the radiation amounts to minimum 0,4 kW/m^2 and exceeds 6 hours per day.

Radiation regime characteristics definition has been conducted as exemplified by Almaty hydro-meteorological station (HMS). The solar radiation is the main source for the heat conductor process in the solar station. For that purpose, firstly, it is necessary to get an average background mode of the solar radiation according to available data, many years of observation for Almaty city.

The big city's radiation regime has Almaty HMS, situated at Zailiisky Ala Tau foothills. Along with the area's height increase the solar radiation grows at the expense of atmosphere's transparent zing. Usually in the summer time's first part the atmosphere is more clear, than in the second part, which is connected with the atmosphere dust content increase, and convective clouds.

Solar power and meteorological zonal characteristics of Kazakhstan's territory

Region appropriate for practical usage	Total direct irradiation onto the horizontal surface (S'), MJ/m^2								
	days		мin max		winter	spring	summer	fall	year
	1	7	1	7	12,1,2	3,4,5	6,7,8	9,10,11	
1	2	3	4	5	6	7	8	9	10
1. Conditions, in whole, meet the requirements of the solar plants usage Kostanai, Astana)	1,2 1,4	11,2 13,5	37,7 41,9	347,7 419,0	138 276	842 771	1064 1185	322 339	2367 2509
2. Conditions more or less effective for the solar plants usage Dzhanybek, Semipalatinsk)	1,2 2,3	13,9 14,5	37,7 71,2	431,6 448,4	150 243	880 1018	1252 1315	440 490	2723 3067
3. Conditions secure sustainable operation of the solar plants (Atyrau, Aktobe Aktau)	1,9 1,75 1,6	17,4 15,8 15,8	58,7 54,5 50,3	540,5 490,2 490,2	230 197 192	1127 934 1009	1596 1446 1454	662 553 636	3616 3129 3293
4. Conditions for more effective usage of the solar stations (Aralsk Sea, Zhezkazgan, Buran)	2,7 3,1 2,9	17,9 15,9 17,0	83,8 96,4 92,2	557,3 494,4 528	276 297 293	1156 1043 1152	1650 1462 1546	708 632 662	3791 3435 3653
5. Conditions for the most effective usage of the solar plants (Barsa-Kelmes, Ak-Kum, Kuigan)	2,9 4,19 3,6	17,4 21,3 19,7	92,2 129,8 113,1	540,5 662,0 611,7	272 360 347	1169 1210 1122	1713 1965 1751	699 972 825	3854 4508 4047

Table continuation

Region appropriate for practical usage	Total of global irradiation on the horizontal surface, (Q), MJ/m^2								
	days		мin max		winter	spring	summer	fall	year
					12,1,2	3,4,5	6,7,8	9,10,11	
1	11	12	13	14	15	16	17	18	19
1. Conditions, in whole, meet the requirements of the solar plants usage Kostanai, Astana)	3,6 4,5	20,1 22	113,2 138,3	624 683	389 473	1520 1529	1839 1935	662 733	4412 4671
2. Conditions more or less effective for the solar plants usage Dzhanybek, Semipalatinsk)	4,0 5,3	22,6 22,8	125,7 163,4	699 708	414 817	1525 1730	2002 2065	775 863	4717 5191
3. Conditions secure sustainable operation of the solar plants (Atyrau, Aktobe Aktau)	5,1 5 4,19	25,5 24,5 23	159,3 155 129,9	792 758 716	469 532 452	1780 1634 1646	2300 2191 2099	1047 905 997	5664 5262 5195
4. Conditions for more effective usage of the solar stations (Aralsk Sea, Zhezkazgan, Buran)	6,0 6,0 5,9	25,4 23,7 24,5	188,5 188,5 184,4	787 737 762	624 607 607	1872 1726 1784	2317 2149 2208	1076 993 1013	5891 5476 5614
5. Conditions for the most effective usage of the solar plants (Barsa-Kelmes, Ak-Kum, Kuigan)	5,9 7,3 7,3	24,6 27,9 26,7	184,4 226,3 226,3	762 867 829	578 695 720	1822 1851 1826	2312 2543 2384	1030 1324 1206	5744 6414 6138

Table continuation

Region appropriate for practical usage	Sunshine duration, hours							Solar and electric heating duration (hours)	
	days		winter	spring	summer	fall	yr	annual	
	1	7	12,1,2	3,4,5	6,7,8	9,10,11		solar	electric
1	20	21	22	23	24	25	26	27	28
1. Conditions, in whole meet the requirements of the solar plants usage (Kostanai, Astana)	2,3 2,7	10,2 10,2	241 266	664 640	861 876	371 404	2137 2186	1900 2000	6900 6800
2. Conditions more or less effective for the solar plants usage (Dzhanybek, Semipalatinsk)	2,0 3,6	10,9 10,4	215 339	714 737	996 937	499 507	2424 2523	2200 2300	6600 6500
3. Conditions secure sustainable operation of the solar plants (Atyrau, Aktobe, Aktau)	2,4 3 2,2	11,3 11,3 11,4	249 301 257	724 712 701	1021 1032 1021	585 548 584	2579 2593 2563	2400 2400 2400	6400 6400 6400
4. Conditions for more effective usage of the solar stations (Aralsk Sea, Zhezkazgan, Buran	3,7 3,3 4,5	11,9 11,2 11,1	350 350 395	799 750 793	1090 1014 1003	624 589 587	2863 2703 2778	2700 2600 2700	6100 6200 6100
5. Conditions for the most effective usage of the solar plants (Barsa-Kelmes, Ak-Kum, Kuigan)	3,3 4,3 4,7	12,2 13 12	324 391 420	813 770 761	1132 1160 1102	648 758 695	2917 3079 2978	2800 2900 2900	6000 5900 5900

Table continuation

Region appropriate for practical usage	Cloudiness, total number of clear and dull days		Average daily air temperature, 0C								Frostless period duration, days in a year
	annual		monthly								
	in points	clear	dull.	4	5	6	7	8	9	10	
1	29	30	31	32	33	34	35	36	37	38	39
1. Conditions, in whole meet the requirements of the solar plants usage (Kostanai, Astana)	5,9 6,2	48 37	88 123	2,5 2,1	12,7 12,4	18,7 17,8	20 20	18 18	12 11	2,7 2,5	113..156 98…123
2. Conditions more or less effective for the solar plants usage (Dzhanybek, Semipalatinsk)	6 5,7	43 44	119 106	7,4 3,8	15,9 13	21,1 19	23 21	22 18	15 12	6,5 3,8	139..161 85…129
3. Conditions secure sustainable operation of the solar plants (Atyrau, Aktobe, Aktau)	5,1 5,9 5,2	68 52 65	98 110 91	8,6 10,6	17,4 17,6	22,8 22,6	25 25	24 24	16 19	7,6 12,2	190..172 126..176
4. Conditions for more effective usage of the solar stations (Aralsk Sea, Zhezkazgan, Buran	4,8 4,8 5,2	75 86 40	78 71 118	8,3 6,2 6,2	17,4 15,5 14,4	23,6 21,6 20,1	26 24 22	24 22 20	17 14 13	7,8 4,8 4,7	170…213
5. Conditions for the most effective usage of the solar plants (Barsa-Kelmes, Ak-Kum, Kuigan)	4,1 4 4,7	119 117 97	60 77 64	6,5 8,8 9,1	15,3 17,3 17,2	22 23,3 20,5	25 26 24	24 24 22	19 16 15	3,5 7,2 7,2	165…201 85…183

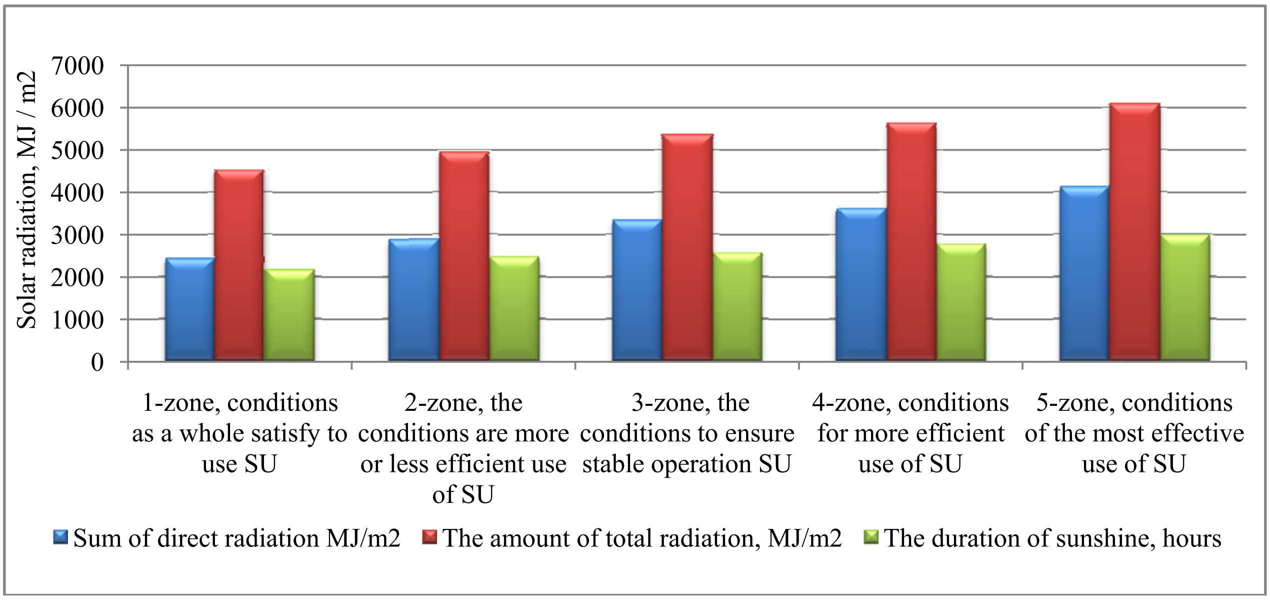

Figure 2 – Histogram of the solar stations usage dependence
from average values of direct, total radiation and duration of the sunshine

We have studied actinometric and climatic characteristics, used in the methodology of the solar energy usage assessment for the following Hydro Meteorological Stations, located on the territory of Kazakhstan:

1. Araljsk Sea (Kyzyl-Orda oblast).
2. Barsa-Kelmes (Kyzyl-Orda oblast).
3. Ak-Kum (Kyzyl-Orda oblast).
4. Almaty, GMO (Almaty oblast).

Figure 3 – Average daily solar radiation intensity in Kyzyl-Orda oblast, settlement Barsa-Kelmes

Figure 4 – Average daily solar radiation in Araljsk sea

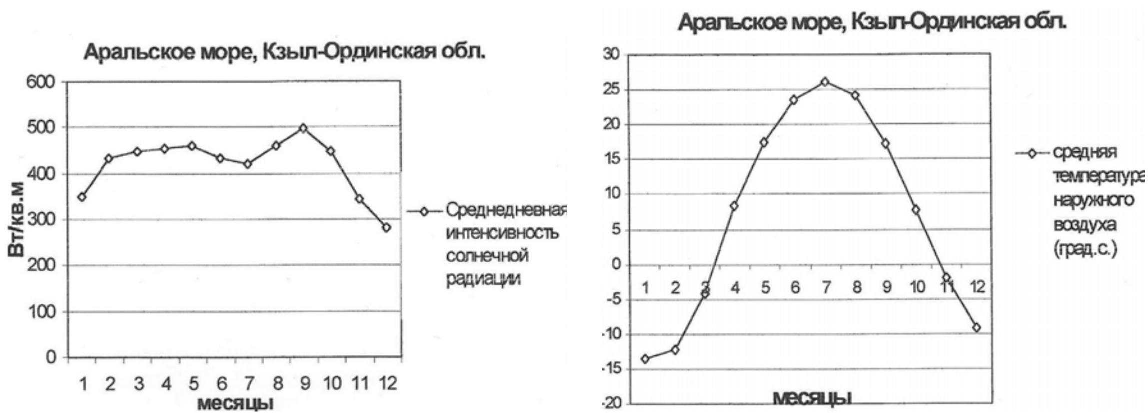

Figure 5 – Outside air average temperature in Araljsk Sea

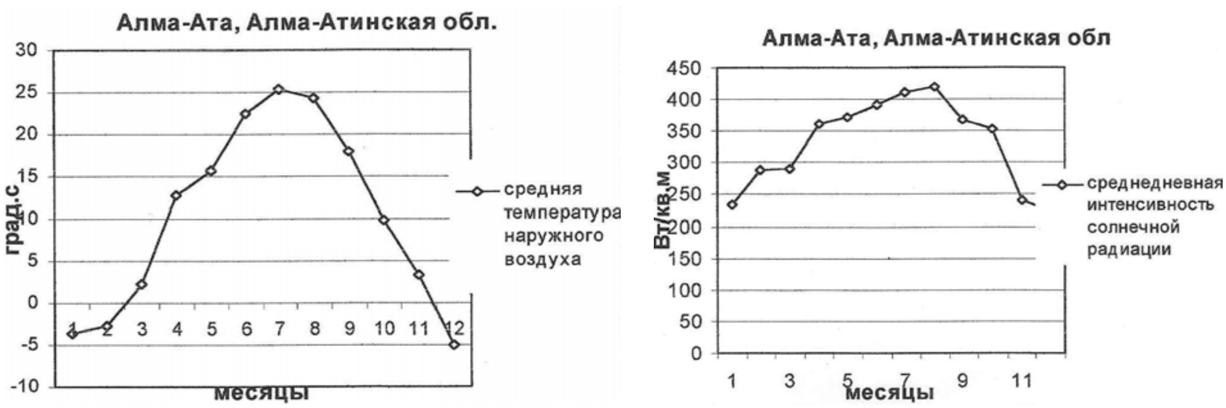

Figure 6 – Outside air average temperature and average intensity of the solar radiation
in Almaty and Almaty oblast

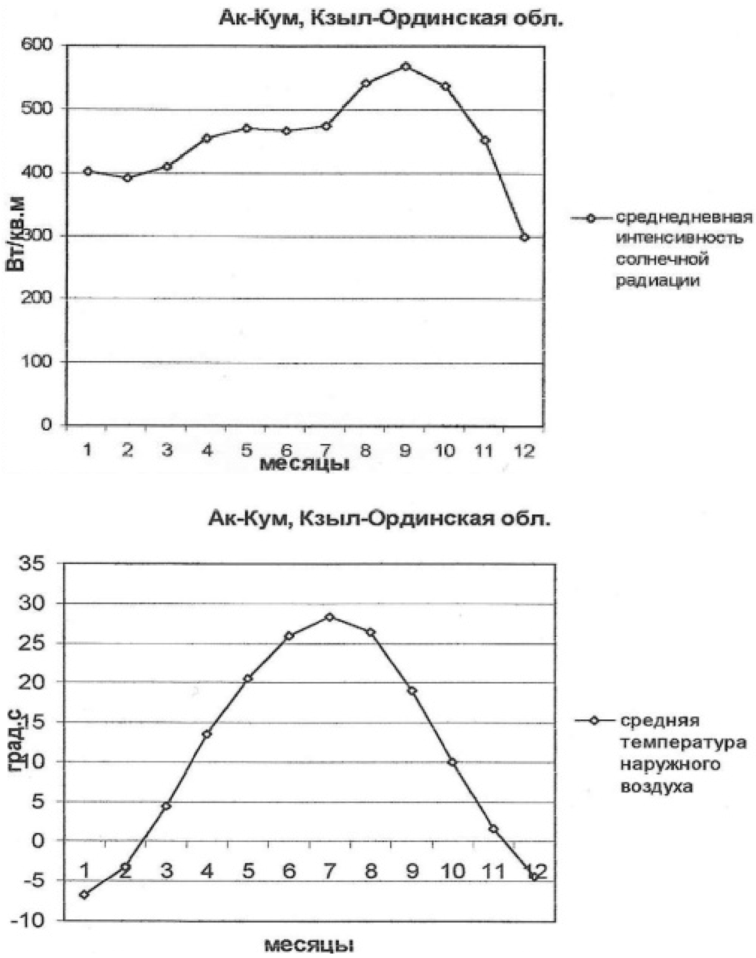

Figure 7 – Outside air average temperature and average daily solar radiation intensity in the settlement Ak Kum, Kyzyl-Orda oblast

Cloudiness increase decreases the direct and increases the diffused radiation. Diffused radiation flow, though partially, compensates the direct solar radiation weakening in the atmosphere but the compensation is not complete. Therefore the total radiation flow under cloudiness conditions, if the sun is not covered with clouds, will be bigger comparing to the clear sky conditions.

Apart from transparency and cloudiness the big influence at diffused radiation is exerted with the nature of underlying surface. Upon the snow cover there is increased the reflection of the direct solar radiation, secondary diffusion of which in the atmosphere brings to the diffused radiation growth.

Along with the elevation increase the direct solar radiation flow is growing, which is explained by lessening the optical width of the atmosphere. Hereupon the solar radiation flow maximum values in mountainous regions are bigger, than on the flat topography. Value of the diffused radiation flow with elevation over sea level decreases at clear sky, as the thickness of atmosphere's scattering layers decreases. Upon cloudiness the diffused radiation flow in the layers lower than the clouds increases according to the elevation. Appearance of direct and global radiation decreases in the areas, located in the floors of valleys or pits due to the closed horizon. Direct, diffused and total solar radiation has well defined annual motion, which is distinctly seen on the figures 1 and 2.

Conclusion.

Criterion 1. Average time duration. When radiation is no lower than 0,4 kW/m^2 and exceeds 6 hours per day. The table 2 demonstrates averaged long-term data of total daily accumulated radiation.

Criterion 2. Average number of clear days shall be no less than a half of an average number of dull days. With account of that the provision of daily totals of accumulated radiation is 4,6 kW·h/m^2 and higher and according to long-term data of Almaty station amounts to (%):

Table 2 – Averaged daily global radiation

Month	1	2	3	4	5	6	7	8	9	10	11	12
	–	8	20	50	72	83	79	60	55	40	15	–

The most favorable period to use the solar energy in Almaty is from March to November, according to provision of daily totals of global radiation from April to September (table 2).

According to the data on long term observations of the sunshine duration in compliance with the sunshine recorder we differentiate the periods of the solar continuous shining 5,6,7, etc. At that, we exclude the time during one hour after and till the sun up. Results in Almaty city are given in the tabular form.

Table 3 – Solar station operational capacity (hour) depending on the solar continuous shining (for 10 years period)

	2	3	4	5	6	7	8	9	10	11	12
Almaty	4	4,8	7	8,2	8,4	8,3	8	6	5	4,8	4

Analysis of Table 3 demonstrates, that it is inappropriate to use the solar plants in Almaty city in March and November, much more successfully they will operate from April to October.

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ҚАЗАҚСТАН РЕСПУБЛИКАСЫНЫҢ ГЕЛИОЭНЕРГЕТИКАЛЫҚ РЕСУРСТАРЫ

Аннотация. Мақалада Қазақстан Республикасының гелиоэнергетикалық ресурстары қарастырылады. Белгілі бір аумақтағы территорияға түсетін күн энергиясының потенциалын бағалау үшін күн энергиясының потенциалы туралы деректер болу қажет. Іс жүзіндегі бақылаулар мен теориялық есептеулерді жалпылау негізінде, келесі мәліметтер алынды: ашық аспан кезінде перпендикуляр бетке түсетін тікелей күн радиациясының мүмкін болатын ай сайынғы және жыл сайынғы қосындыларының жылдық және ендік мөлшері, күн сәулесінің ұзақтығы туралы мағлұмат, жылдың ерекше күндеріне арналған күн радиациясының тәуліктік мөлшері, маусым және желтоқсан айлары үшін радиацияның орташа айлық қосындысының территория бойынша үлестіру картасы, сонымен қатар «техникалық түрде қолданылатын және экономикалық тиімді күн қуаттылығының» үлестірілу картасы туралы, осы тұжырымдаманы анықтау критериі әзірленді. Қазақстандағы күн энергетикалық ресурстарын бағалаудағы күн жүйелерінің барлық есептік көрсеткіштерінің негізінде, кез келген бағыттан көлденең жазықтыққа дейін қайта есептеуге болатындай, көлденең бетке тікелей күн радиациясының сандық сипаттамалары қабылданды. Күн сәулесінің тікелей, қосынды радиациясының және ұзақтығының орташа мәнін статистикалық өңдеу нәтижелері бойынша бес аймақ белгіленді және ҚР территориясы бойынша гелиоқондырғыларды енгізу мүмкіндіктерін сипаттаушы гистограмма құрылды.

Түйін сөздер: күн энергиясы, гелиоколлектор, гелиоэнергетикалық ресурстар, күн радиациясы.

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ГЕЛИОЭНЕРГЕТИЧЕСКИЕ РЕСУРСЫ РЕСПУБЛИКИ КАЗАХСТАН

Аннотация. В статье рассматривается гелиоэнергетические ресурсы Республики Казахстан. Для оценки потенциала солнечной энергии падающей на территорию в том или ином районе необходимо иметь данные о потенциале солнечной энергии. На основе обобщения фактических наблюдении и теоретических расчетов, имеются данные: годового и широтного хода возможных месячных и годовых сумм прямой солнечной радиации поступающей на перпендикулярную поверхность при условиях ясного неба, сведения о продолжительности солнечного сияния, суточный ход солнечной радиации для характерных дней года, карты распределения по территории средних месячных сумм радиации за июнь и декабрь, а также карты распределения «технически применимой и экономически выгодной солнечной мощности», разработанные им критерий определения этого понятия. В основу всех расчетных показателей гелиосистем при оценке гелиоэнергетических ресурсов территории Казахстана приняты количественные характеристики прямой солнечной радиации на горизонтальную поверхность, с которой можно произвести перерасчет с горизонтальной на наклонной плоскость любой ориентации. По результатам статистической обработки средних значении прямой, суммарной радиации и продолжительности солнечного сияния выделены пять зон и составлена гистограмма характеризующих возможности внедрения гелиоустановок по территории РК

Ключевые слова: солнечная энергия, гелиоколлектор, гелиоэнергетические ресурсы, солнечная радиация.

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