

# The possibility of use of solar energy in the southeastern part of Western Siberia

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**Abstract.** The article presents the results of a study of the regime of solar radiation in the southeastern part of Western Siberia. To characterize the regime of solar radiation, long-term observational data on actinometrical and meteorological stations were used. The dependence of the total annual global radiation on latitude received. The dependence of the sunshine duration on latitude it gives. The potential amount of total solar radiation per year under average conditions cloud cover and atmospheric transparency considered. Common regularities of solar radiation arriving to the slopes of varying steepness and exposure can be distinguished in mountainous areas. On the basis of the potential arriving of the total solar radiation in the southern part of Western Siberia we can distinguish three latitude zones.

## 1. Introduction

In Russia, as in other countries, there is a great need for the introduction of energy-saving technologies and the accelerated industrial development of environmentally safe of energy resources. Solar water heating installation find large-scale application in the private and public sectors of Germany, Sweden, Spain, Denmark, Finland and other countries [1-4].

The feature of Russia and Siberia is the low population density. The vast territory of Siberia is poorly developed industrially. Currently, a large part of Russia's territory is in a zone where there is no centralized energy supply. Under these circumstances, power supply of settlements, industrial and other facilities can only be provided through the creation of decentralized areas. So far, the most common energy source in these areas is diesel power. The delivery of fuel is often possible only in certain seasons by water transport in the summer and by temporary ice routes in the winter. Furthermore, the cost of delivery is often more expensive than the fuel itself.

In particular, almost 40 per cent of the Tomsk region has no centralized power supply. There are 41 settlements in remote areas, where more than 24 thousand people live without a centralized power supply. According to [5] the electrification of these settlements is carried out by 42 local diesel power stations (123 units) with a total capacity of 44,075 kW.

The required annual consumption of diesel fuel for these plants is 15,930 tons. Depending on the location of the station and its operation conditions, the cost of the generated electricity is \$ 0.5 per 1 kWh, which is comparable to the cost of energy derived from renewable of energy resources [6-7]. The introduction of new technologies based on the use of natural renewable energy resources, primarily solar, wind and water energy, can largely solve the problem of energy supply to such areas, reduce budget spending on fuel imports, stabilize the reliability of power and heat supply and improve environmental conditions of life of the population.

The most important advantages of most of the natural renewable energy resources are widespread occurrence, almost inexhaustible potential and environmental safety.



The main disadvantages of renewable energy sources limiting their widespread use include a relatively low energy density and greater variability. Low specific capacity of energy flows leads to an increase in weight and size of power plants. It is necessary to use accumulating devices because of the large variability of the energy resources. All this leads to the increase in the cost of produced energy.

## 2. Solar energy potential

Exploring the potential of the natural renewable energy sources in Siberia is very important for the introduction of new energy technologies and energy saving by consumers. Zoning of Russia in the potential of solar radiation [8-9] has shown prospects of south-eastern part of the West Siberian region in the use of solar radiation.

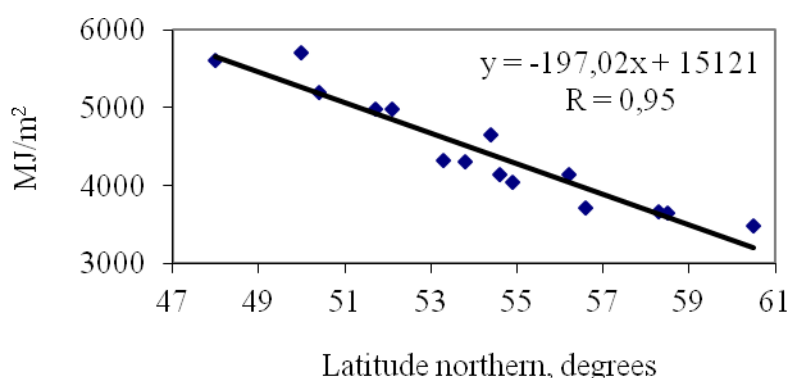
To characterize the regime of solar radiation, long-term observational data on actinometrical and meteorological stations were used [10-12].

The following factors have an impact on the amount of total solar radiation: latitude, height above sea level, amount of clouds and related duration of sunshine, clarity of horizon, a different orientation of slopes and mode of clouds in the various relief forms. The direct solar radiation is the most variable over a distance [13-14]. According to the results of long-term observations of actinometrical stations located in the south of Siberia, spatial variation of annual amounts of total radiation was assessed. Gradients of sums of total solar radiation were calculated.

The greatest changes in the value of the total radiation in the direction from south to north per month are 40–48 MJ/m<sup>2</sup> per 100 km. They are observed in the spring (April, May) and early autumn (August, September) [15].

Annual sum of total radiation increases in the direction from north-west to south-east. The horizontal gradient of the total solar radiation is about 320 MJ/m<sup>2</sup> per 100 km. The increase of total solar radiation from the north-west to south-east is due to the increasing of continentality, the overall increase of altitude, the decrease of cloudiness and precipitation, and other related climatic factors.

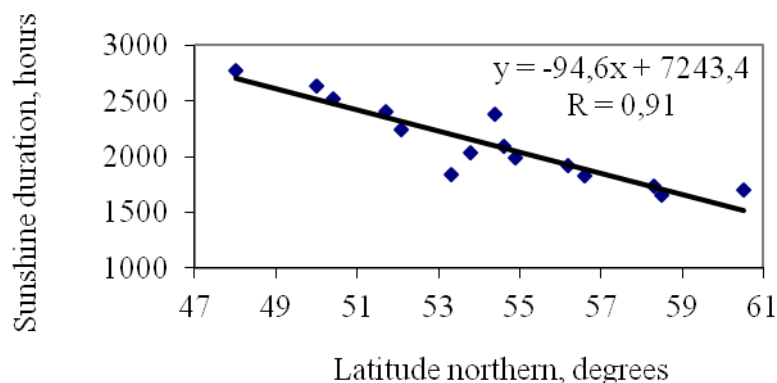
According to actinometrical stations located in the south of Siberia, it was established that there is the close, statistically significant correlations between the latitude of the place and the annual sums of total radiation (figure 1).



**Figure 1.** The dependence of the total annual global radiation on latitude

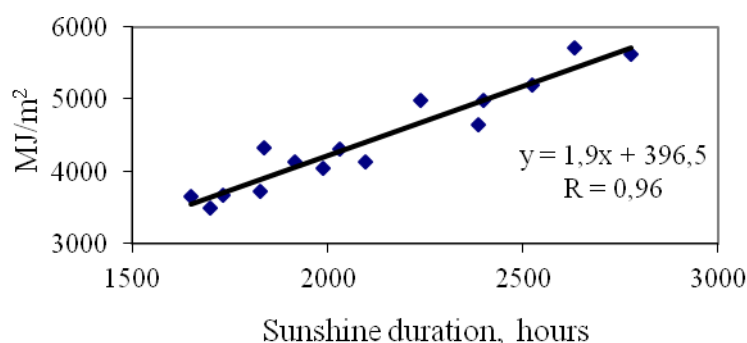
Observational data on sunshine duration are important additions and clarifications to the actinometric information in assessing of annual total solar radiation. Sunshine duration depends on latitude and cloud amount.

The dependence of the duration of sunshine on latitude in Western Siberia is shown in figure 2. It is important that the periods of observation of sunshine duration are much longer than the periods of observation of other components of the radiation balance. The duration of sunshine is recorded at all weather stations.



**Figure 2.** The dependence of the sunshine duration on latitude

The annual total solar radiation is closely dependent on the duration of sunshine (figure 3).



**Figure 3.** The dependence of the annual total solar radiation on sunshine duration

Sums of annual total radiation are required to determine the potential solar resources of area. To calculate annual sums, authors established the multiple regression equation with three variables (formula 1). Annual sums of total solar radiation depend on latitude and annual sum of hours of sunshine duration. To establish the equation, we used data of 15 stations, which monitor the solar radiation in Western and Eastern Siberia. Selected stations are located in the range of from 48 to 60 degrees of middle latitude. The values of long-term average sums of total solar radiation and the number of sunshine hours are taken from the handbooks on Climate [10, 11]

$$Q = 1.17ss - 23.5 \varphi + 3,230, \quad (1)$$

$Q$  is annual total solar radiation, MJ/m<sup>2</sup>;

$\varphi$  is latitude, degrees north latitude;

$ss$  is annual number of sunshine hours, hours.

Observational data on sunshine duration is an important indicator in assessing the sums of total solar radiation. Cloud amount affects the number of sunshine hours (table 1). It is particularly

important that the periods of observation of sunshine duration are much longer than the observation periods of other components of the radiation balance.

Thus, the use of such meteorological parameter as sunshine duration should be considered essential in characterizing the sums of total solar radiation of any territory. Various sunshine duration determines the spatial variability of the solar radiation and the formation of microclimates depending on the closeness of the horizon or the cloud amount.

The ratio between the number of hours of actually observed sunshine duration to the possible sunshine duration indirectly characterizes the ratio between the direct and diffuse solar radiation in areas where there are no observations of solar radiation. Number of days with no sun shows the length of the period with a minimum value of total radiation.

**Table 1.** Comparative characteristics of annual sunshine duration ( $ss, h$ ), the ratio between observed sunshine duration to possible sunshine duration ( $ss/ss_{possible}, \%$ ) and number of days without the sun

Observing station	Latitude northern, degrees	$ss, h$	$ss/ss_{possible}, \%$	Number of days without the sun
Aleksandrovskoe	60.5	1,700	38	98
Tomsk	56.5	1,733	39	92
Kemerovo	55.4	1,922	39	90
Kuzedeevo	53.3	1,956	41	80
Ogurtsovo (Novosibirsk)	54.9	2,083	47	66
Barabinsk	55.4	2,193	49	60
Barnaul	53.4	2,025	45	70
Blagoveschenka	52.8	2,385	56	48
Kosh-Agach	56.0	2,713	65	19

Closeness of the horizon, which reduces the sunshine duration, has a great influence on the total radiation. The increase of the horizon closeness in all cases leads to losses in direct and total solar radiation. The cloud regime has a big impact on the total radiation. With an increase in cloud cover, there is a decrease in sunshine duration and in direct coming solar radiation.

We have investigated the dependence of sunshine duration and cloud amount for the south of Western Siberia. According to the station in Ogurtsovo, the correlation between the mean monthly number of sunshine hours and an average score of total cloud amount was estimated (table 2). The correlation coefficients are statistically significant at the 0.05 level of significance. The relationship between cloud amount and sunshine duration is close enough.

**Table 2.** The correlation coefficient ( $r$ ) between the number of sunshine hours and an average score of total cloud cover. The station in Ogurtsovo

Correlation coefficient	Month				Year
	I	IV	VII	X	
<b>r</b>	-0.60	-0.75	-0.78	-0.85	-0.73

It should be taken into account that the cloud cover is determined by meteorological stations around the clock, while the number of hours of sunshine is determined only by daylight hours. In this regard, closer relations are marked in summer with a maximum length of daylight hours.

The annual total solar radiation was calculated for the south-eastern part of West Siberia using a regular grid in 2 degrees of latitude and 4 degrees of longitude, this corresponds to approximately 220×280 km (table 3).

**Table 3.** The potential amount of total solar radiation per year ( $\text{kW}\cdot\text{h}/\text{m}^2$ ) under average conditions cloud cover and atmospheric transparency

Latitude northern, degrees	Longitude eastern, degrees					
	70	74	78	82	86	90
56	847	858	869	880	891	902
54	959	970	981	992	1,003	1,015
52	1,172	1,184	1,195	1,206	1,217	1,228
50	1,387	1,398	1,409	1,420	1,431	1,442
48	1,598	1,609	1,621	1,632	1,644	1,656

Values of total annual radiation given in table 3 are background values. They do not show the influence of the terrain. These sums are typical for the conditions of the open horizon, average cloud conditions and average values of transparency of the atmosphere. The data in this rather dense grid allow to reliably interpolating and extrapolating the values of total solar radiation for all areas of the investigated area [16].

### 3. Solar radiation in the mountains

In the mountain valleys of the Altai-Sayan highland, incoming total radiation is 10–15 per cent less than the background values. The main reason for the decrease of the total radiation are a high degree of closeness of the horizon and high clouds over the valleys and slopes as a result of the influence of slope and valley winds, especially in the summer [13-17].

Slope exposure influences on the direct solar radiation arriving to a great extent. The slopes of northern exposure with steepness of  $10^\circ$  receive the direct radiation at 10–15 per cent less than the horizontal surface in the summer. Characterizing the regime of scattered radiation under the conditions of complex terrain, the closeness of the horizon must also be considered. By the closeness of the horizon  $30^\circ$  the loss of scattered radiation can be 7–12 per cent. The character of distribution of the total radiation on the slopes with varying steepness corresponds to the character of distribution of direct solar radiation. However, the contrast of the total solar radiation arriving to various slopes is significantly smaller than the contrast of direct solar radiation.

In watershed areas with a high degree of openness of the horizon, sums of total solar radiation are close to the average values.

Common regularities of solar radiation arriving to the slopes of varying steepness and exposure can be distinguished in mountainous areas. The greatest inflow of total solar radiation is observed on the southern slopes, then on the eastern slopes, the horizontal surface, the western and northern slopes. With increase in the steepness of southern slopes the radiation flow to them growing, while on the other slopes radiation flow decreases.

Comparative analysis of actual and calculated data showed that in high hollows (Chuiskaya etc) total solar radiation arriving is 5–10 per cent more than calculated characteristics. This is due to a decrease in cloud cover over the mountain hollows. In the hollows there is a relatively large number of sunshine hours, the maximum number of clear days and the least number of days without sun. In the depressions the ratio of an actual number of sunshine hours to a possible sunshine duration reaches its maximum 64–65 per cent (taking into account the closeness of the horizon).

### 4. Conclusion

On the basis of the potential arriving of the total solar radiation in the southern part of Western Siberia we can distinguish following latitude zones:

a) 48–50 N, average annual sums of total radiation on a horizontal surface are 1,400–1,600 kWh/m<sup>2</sup> at average values of cloud cover, atmospheric transparency and openness of the horizon. Under these conditions, solar power plants of various types can be effectively used;

b) 50–52 N, at these latitudes the background value of total annual solar radiation is 1,200–1,400 kWh/m<sup>2</sup>, while providing stable operation of medium-sized solar power plants

c) 52–54 N, annual potential sums of total solar radiation are 1,000–1,200 kWh/m<sup>2</sup>;

d) 54–60 N, annual potential sums of total solar radiation are only 800–1,000 kWh/m<sup>2</sup>. These conditions are considered unfavorable for the operation of large and medium-sized solar power plants.

It is expedient to orient constantly their adoptive surfaces perpendicular to the sun's rays to increase the efficiency of solar power. These devices enable to receive solar energy by 30–35 per cent higher than it is supplied to the horizontal surface. These devices maximize the use of arriving solar energy.

The location of receiving surfaces of solar power plants on the southern side at 45–50 improves their use at midday hours by 15–20 per cent compared with a horizontal surface [18, 19]. In all of these considered areas it is advisable to use low-temperature solar systems (solar collectors) for hot water supply in the warm season. The annual output of thermal energy can be 700–1,000 kWh/m<sup>2</sup>.

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