Concerning the issue of resource assessment for solar energy utilization systems in the climatic conditions of the Russian Federation

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Abstract. The article deals with the distribution of the energy potential of solar radiation in the territory of the Russian Federation. The spatio-temporal regularities are revealed, which make it possible to assess the resource provision of engineering systems in a given renewable energy source. Graphical distributions of solar radiation for the northern latitudes of the Russian Federation, including the energy irradiance of vertical orientation surfaces by cardinal directions, are constructed. Equations are obtained for the possibilities of solar radiation depending on the considered month and latitude of the area. An amendment has been introduced that takes into account the decrease in the radiation intensity with average cloud cover for the regions. Revealed the territorial-temporal variability of the possibility of solar radiation, which makes it possible to assess the prospects of using or another system of utilization of radiation.

1. Introduction

Sustainable development of industry and economy of any state-level association directly depends on the rate of development of the energy sector. In this regard, the Russian Federation has a significant advantage, since it has not only colossal reserves of traditional resources, but also renewable energy sources as a result of its vast territorial location. But, despite the environmental priorities of recent decades [1-2], today the pace of development of alternative energy remains at relatively low rates [3].

This situation is due not only to small volumes of investments, lack of strategic approaches in solving non-traditional energy supply, but also to the applied design methods, which show an insufficiently reliable level of design parameters of systems. Even in the presence of a significant number of orders and the necessary funds for the arrangement of renewable energy complexes, already at the initial stage there is a problem of choosing the initial data for the design: an incomplete list of information, incorrect provision or even inaccuracy. Often, even at the investment stage, for a reliable assessment of the economic efficiency of the projected solar power supply systems, there is no full amount of input and basic data required for calculations.

In this regard, the purpose of the research is the spatio-temporal analysis of actinometric data to identify functional changes in the energy irradiation of different climatic zones, as the main indication for the design of solar plants of various types.
2. Materials and methods
The normative documentation [4] contains a number of actinometric data, which can be used to carry out both preliminary and design calculations. The energy irradiation of the territories of northern latitudes is presented in discrete form [4] for parallels with a step of 4 degrees. Already on this resource allocation, normatively fixed in [4], there is not enough information for the territorial distribution of solar energy supply systems. This situation requires a spatio-temporal analysis of changes in actinometric data and their presentation in the form of functional dependencies, which make it possible to determine the energy potential for specific areas of construction.

The equations obtained on the basis of the approximation of changes in the intensity of solar radiation depending on the month of the year, the latitude of the terrain and the orientation of the surfaces receiving the radiation, make it possible to estimate with high accuracy the available resources at the moment in time and for the given coordinates, which is a necessary condition for the development of an algorithm for decisions design of alternative systems. So, for example, the polynomial dependence on time, covering the sixth power, most adequately describes the monthly input of solar radiation:

\[ E_{40} = 909,56 - 6,7542N - 25,893N^3 + 2,4388N^5 - 0,5294N^7 - 0,0812N^9 + 0,233N^{11} \] (1)

Where \( E_{40} \) is the total direct and scattered radiation arriving in different months on a horizontal surface located at a latitude of 40° northern latitude, MJ / m\(^2\); \( N \) - the average seasonal indicator of the month under consideration, determined by the expression \( N = n - 6 \); \( n \) is the ordinal number of the month.

But to perform engineering calculations, you should use a more convenient polynomial dependence, covering the fourth degree and having a high level of accuracy. So for 40° northern latitude the equation takes the form:

\[ E_{40} = 923,35 + 7,167N - 35,388N^3 - 0,0267N^5 + 0,4186N^7 \] (2)

for 48° northern latitude:

\[ E_{48} = 918,2 + 13,785N - 46,231N^3 - 0,4177N^5 + 0,7062N^7 \] (3)

for 56° northern latitude:

\[ E_{56} = 902,09 + 18,471N - 55,641N^3 - 0,7118N^5 + 0,9547N^7 \] (4)

for 64° northern latitude:

\[ E_{64} = 905,34 + 25,464N - 67,552N^3 - 1,1324N^5 + 1,2702N^7 \] (5)

The high adequacy of the equations is confirmed by the graphical representation in figure 1.

The monthly change in the intensity of solar radiation when moving in latitude generally has a linear relationship (table 1), which fully corresponds to the actinometric data.

3. Results
The actinometric data on horizontal surfaces presented in graphical form (figure 1) confirm the advantage of using solar systems at latitudes from 40 to 64° northern latitude, especially in the summer season. However, it should be noted that the high temperatures of the southern regions (figure 2) result in the degradation of photoconverters [5-12]; therefore, at latitudes from 40 to 48° northern latitude it is advisable to design thermal solar plants. The intensity of solar radiation and the temperature regime within 48-56° northern latitude, allows us to recommend both photocells and thermal solar collectors for use. The low temperature regime in the territories of more northern latitudes leads to significant heat losses, which reduces the efficiency of thermal solar plants and
suggests a more efficient operating mode of photoconversion. However, thermal solar collectors can be successfully operated in the summer season and in these climatic conditions [11].

Figure 1. Distribution of total solar radiation on horizontal surfaces with a cloudless sky depending on the geographical latitude, MJ / m²

Table 1. Equations for determining the inflow of total direct and diffusion solar radiation, in MJ / m², on a horizontal surface depending on the latitude of the area φ, in degrees, for different months of the year.

| Month | Total solar radiation on a horizontal surface, MJ / m² |
|-------|-----------------------------------------------------|
| I     | $E = 789.63 - 14.171\phi + 0.0368\phi^2$            |
| II    | $E = 864.71 - 11.601\phi$                           |
| III   | $E = 1143 - 12.455\phi$                             |
| IV    | $E = 1090.8 - 7.8988\phi$                           |
| V     | $E = 989.05 - 2.4955\phi + 0.0019\phi^2$            |
| VI    | $E = 672.18 - 99.753\phi - 2.0634\phi^2 + 0.014\phi^3$ |
| VII   | $E = 1881.2 - 164.7\phi - 3.21\phi^2 + 0.0205\phi^3$ |
| VIII  | $E = 1031.2 - 5.7857\phi$                           |
| IX    | $E = 1091 - 10.75\phi$                              |
| X     | $E = 1087.8 - 14.179\phi$                           |
| XI    | $E = 715.18 - 10.307\phi$                           |
| XII   | $E = -790.88 + 76.215\phi - 1.7127\phi^2 + 0.0112\phi^3$ |
Figure 2. Average monthly temperatures for urban districts located at latitudes 43, 48, 55 and 64° northern latitude.

Considering the spatial differentiation of the energy potential entering the vertical surfaces and presented in accordance with the data [4] graphically in figures 3 and 4, it can be noted that at latitudes from 40 to 48° northern latitude the maximum energy irradiance is recorded in the southern orientation in January, and at latitudes from 48 to 64° northern latitude in April.

Figure 3. Distribution of the total direct and scattered solar radiation, in MJ / m², on vertical surfaces depending on their orientation in a cloudless sky in January at different geographical latitudes.
4. Discussion

The above equations (1-5), (table 1), as well as the performed correlation of the data on solar radiation inflows to variously oriented surfaces, make it possible to determine the energy irradiance with high accuracy without taking into account the decrease in intensity with average cloud cover. It is the last factor [6-9] that brings it closer to the real design conditions and makes it possible to assess the possibilities of the proposed technical solutions for the utilization of solar energy.

To take into account the attenuation of the intensity of solar radiation from cumulus clouds, one can use the dependence proposed in [10], obtained as a result of long-term actinometric measurements at the Meteorological Observatory of Moscow State University:

\[
\frac{S}{D} = 6.051 - 0.858m + 0.029m^2
\]  

(6)

Where \( \frac{S}{D} \) is the ratio of direct and diffusive solar radiation; \( m \) is the score for the observed cumulus clouds.

In accordance with expression (6), with clear sunshine, that is, with \( m = 0 \), the \( \frac{S}{D} \) ratio is 6.051, with \( m \) greater than 8 points, the scattered radiation exceeds the direct one, and with 10 points corresponding to powerful cumulus and cumulonimbus clouds, the ratio is 0.371.
5. Conclusion
Analysis of the territorial-temporal distribution of solar radiation has shown sufficient resource availability for its utilization in the regions of the Russian Federation. The proposed approximating dependences make it possible to determine with a high accuracy the arrival of solar radiation for any coordinates, and, consequently, to perform engineering calculations adequate to real operating conditions. To do this, it is also necessary to use an amendment that takes into account the decrease in radiation intensity with a point system of assessing the average cloudiness in the construction area.

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