Solar Energy for Cottage Construction

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Keywords: Solar Energy, Alternative Energy, Cottage Construction, Use of Solar Energy, Energy Supply, Solar Panel, Hybrid Solar Inverter, Photovoltaic System.

Abstract: The article is devoted to the study of the process of solar energy conversion and selection of the optimal design of a photovoltaic solar system for an individual cottage located in the city of Taganrog, Rostov region. The use of renewable energy sources in the private sector is relevant due to the following problems: frequent interruptions in the supply of electricity due to the low category of power supply, losses of electricity due to wear and tear of networks, the use of power consumption restrictions for territories of the private sectors. Thus, a properly selected system for using an alternative energy source in a certain area with its climatic and landscape characteristics can become a solution to the above problems, as well as one of the elements of a regional strategy, which determines relevance of the chosen research topic.

1 INTRODUCTION

In Russia, natural non-renewable resources are actively used to provide electricity to residential buildings, various types of industries and other infrastructure facilities of the country. By 2040, such needs will double due to the development of technology and industry, which could lead to an energy crisis and, as a result, higher prices. An increase in emissions into the atmospheric air, pollution of the hydrosphere and lithosphere when using traditional fossil fuels will lead to health problems among the population and other environmental disasters (Shchinnikov et al., 2020; Saidov and Sadykov, 2020). Therefore, the active development of technologies based on the use of renewable energy sources (hereinafter referred to as RES) such as solar and wind energy, water and earth energy, and the use of low-potential energy sources is obvious (Pilyaeva, 2017; Østergaard et al., 2020; Maradin, 2021).

Despite the fact that “green” energy is not so developed in Russia, the state sets certain goals and strategies for it (Maximov, 2020). Currently, there are a number of power plants operating in Kaliningrad, Orenburg, Belgorod, and Rostov regions and geothermal energy facilities in Kamchatka Territory and Sakhalin Region.

The main problems of active development of this area for large objects are (Sukhoruchkina and Otroshchenko, 2016; Degtyarev and Solovyov, 2022; Dyatlov et al, 2020):

- uncompetitiveness of stations using alternative energy sources;
- lack of a complete regulatory framework;
- low level of investment;
- lack of highly qualified personnel.

The identified problems can be partially solved with the help of state support in the early stages of projects until they pay off.

As for the private sectors, the use of renewable energy sources there is also very important, since there are a number of nuances:

- frequent interruptions in the supply of electricity due to the low category of electricity supply;
- losses of electricity due to wear and tear of networks;
- use of power consumption restrictions for private sector areas.

A properly selected system for the use of alternative energy sources in climate, landscape and

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weather conditions can become a solution to the problems discussed above, as well as one of the elements of a regional energy strategy, which proves the relevance of our chosen research topic (Smil, 2012.).

The topic of using renewable energy sources is gaining increasing popularity in the scientific community. This topic was reviewed by the following authors: Tychkov A.Yu., Katkova K.A., Chernyshev N.D., Sidyakina A.Yu., Vissarionov V.I., Deryugina G.V., Kuznetsova V.A., Shchinnikov P.A., Nozdrenko G.V., Borush O.V., Ovchinnikov Yu.V., Pugach L. I., Tomilov V.G., Borodikhin I.V., Elistratov S.L., Lovtsov A.A. and many other researchers.

The purpose of the study is to select the optimal technical solution for energy supply to a cottage located in Rostov region.

2 RESEARCH METHODOLOGY

To achieve the formulated aim, the following tasks were set and solved:

- justification of the relevance of the research topic;
- analysis of energy consumption facilities (cottage) and energy supply (area of cottage location);
- selection of optimal energy supply technology based on comparative analysis;
- justification for choosing a design solution for energy supply technology.

To conduct the research, various scientific methods were used, which were based, first of all, on the analysis and synthesis of natural science knowledge with technical experience. The combination of these methods is adequate to the goals and objectives, subject and object of study of this work.

3 RESEARCH RESULTS

The object considered in the work is located in the city of Taganrog, Rostov region. Consequently, at the first stage of research, an analysis of the climatic characteristics of this area was carried out.

Taganrog is located in the northwestern part of Rostov region and is an industrial city. The city's climate has a transitional character from mild continental to subtropical due to the Taganrog Bay and the Miusskiy Estuary.

The topography of the city is mostly flat, the slope is no more than 0.2% in the eastern and southern directions. There are also erosion forms in the form of hollows and winding beams, as a result of decompaction of the cover loess-like loams.

During the year, the air temperature has a difference of 32.2 ^{0}C. The coldest month is January, the air temperature warms up to -2 ^{0}C. The warmest month is August with air temperatures up to +30.2 ^{0}C. The temperature gradient is discussed in detail at Figure 1 and Table 1.

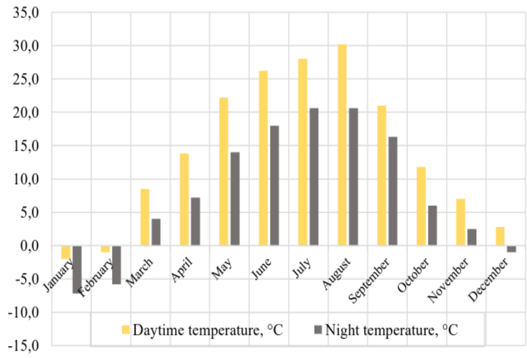

Figure 1: Temperature gradient, °C, Taganrog.

To study the amount of solar radiation and ultraviolet index in the city, data obtained from a weather station installed in the city center was analyzed. The total amount of solar radiation by month is shown in Table 2. The data in Table 2 showed the highest radiation in the summer in June, July and August.

Based on the weather station information, we present the ultraviolet index for each month (Figure 2).

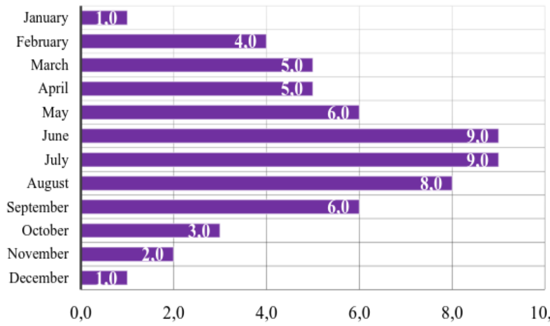

Figure 2: UV Index, Taganrog.

From Figure 2 it can be seen that critical values of the ultraviolet index are reached in June and July.

The results of the study of the number of sunny, cloudy days and the number of days with partly cloudy weather are shown in Figure 3.

Table 1: Average air temperature by month of the year, °C, Taganrog.

The average monthly air temperature, °C	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
During the day	-2.0	-1.0	8.5	13.8	22.2	26.2	28.0	30.2	21.0	11.8	7.0	2.8
During the night	-7.2	-5.8	4.0	7.2	14. 0	18.0	20.6	20.6	16.3	6.0	2.5	-1.0

Table 2: Average solar radiation intensity, W/m^2, Taganrog.

Solar radiation intensity, W/m^2	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
	2108	4872	8618	11220	15345	21180	22785	20212	13050	9951	5370	3968

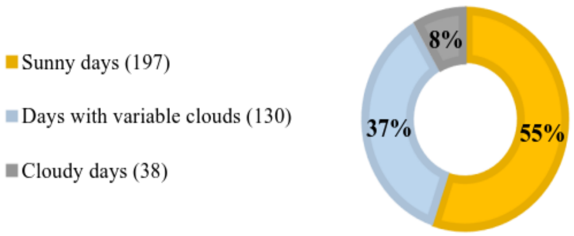

Figure 3: The number of sunny, cloudy days and the number of days with variable clouds, Taganrog.

The following are the results of assessing the amount of precipitation during the year (Figure 4).

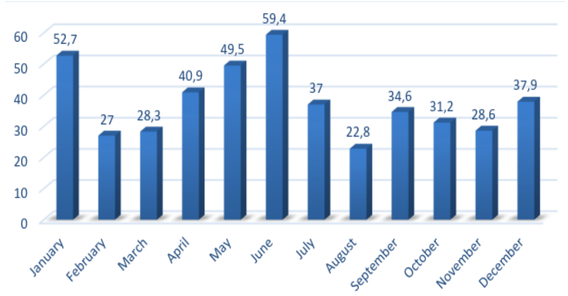

Figure 4: The amount of precipitation by month of the year, mm, Taganrog.

From Figure 4 it can be seen that the maximum monthly precipitation falls in June and is 59.4 mm.

The wind regime as a percentage of the average speed for the winter period is presented in Table 3.

The wind regime as a percentage of the average speed for the summer period is presented in Table 4.

The constructed wind rose for the winter and summer periods (Figure 5, 6).

The analysis of the energy supply facility, that is, the territory under study, allowed us to conclude that this territory is promising for the use of solar energy.

Table 3: Wind regime for the winter period, Taganrog.

Wind mode parameters	The rhumb							
	North	Northeast	East	South-East	South	Southwest	West	Northwest
Repeatability of wind directions, %	4	14	33	10	4	12	17	6
Average wind speed, m/s	3.4	5.8	8.8	4.8	3.3	4.0	4.1	3.1

Table 4: Wind regime for the summer period, Taganrog.

Wind mode parameters	The rhumb							
	North	Northeast	East	South-East	South	Southwest	West	Northwest
Repeatability of wind directions, %	13	13	20	5	3	12	23	11
Average wind speed, m/s	3.4	4.0	4.4	3.2	2.3	3.5	3.8	8.3

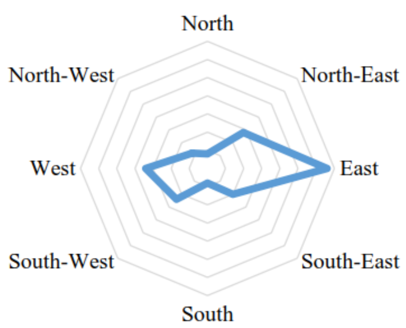

Figure 5: The wind rose for the winter period, Taganrog.

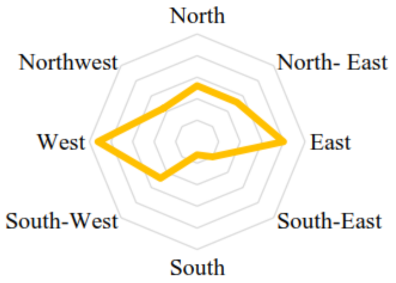

Figure 6: The wind rose for the summer period, Taganrog.

The object of energy consumption is a residential individual cottage. Category of land where the object is located: land of settlements (land of settlements) for the placement of individual housing construction projects. Specified land area: 413 m^2. In the northern direction at a distance of 2.5 m there is a one-story residential building, in the southern direction at a distance of 6.2 m there is a roadway, in the western direction at a distance of 2.1 m there is a single-story residential building, in the eastern direction at a distance of 1.7 m residential one-story house. The development of the territory under consideration is quite dense.

The total building area of the house is 286.44 m^2. On the ground floor there are 4 rooms, a garage and a veranda, on the second attic floor there are 4 rooms and a storage room. The house is designed for a number of residents of four or more. The electricity consumption of an individual cottage directly depends on its size and the number of people living in it. So, for example, one person can consume from 800 kW·h to 1600 kW·h, and a family of four or more from 1400 kW·h to 4700 kW·h. This range is explained by the method of electricity consumption and the energy consumption of available household appliances.

We calculated the electricity consumption consumed by each household appliance in the house and the average time of its use (Table 5).

The total monthly electricity consumption when using an air conditioner in the warm season will be 1635.45 kW·h. During the heating season, when using an electric boiler, consumption will be 2529.45 kW·h.

Table 5: Energy consumption of household appliances in an individual cottage.

Name of the device	Number of devices, pcs.	Power, kW	Working hours per day, h	Consumption per day, kWh	Consumption per month, kWh
Refrigerator	1	0.20	24	4.8	144
Microwave	1	1.00	2	2.0	60
Electric kettle	1	0.70	1	0.7	21
Dishwasher	1	1.20	1	1.2	36
Multicooker	1	1.00	2	2.0	60
Food Processor	1	2.00	0.5	1.0	30
Electric stove	1	2.50	4	10	300
Coffee Maker	1	0.75	0.25	0.2	6
Vacuum cleaner	1	0.60	0.5	0.3	9
TV	1	0.30	5	1.5	45
Iron	1	1.10	0.25	0.275	8.25
Conditioner	2	2.60	7	18.2	546
Computer	1	0.20	5	1	30
Lighting (lamps of 60 watts each)	27	1.62	7	11.3 4	340.20
Electric boiler	1	4.00	12	48	1440

The total electricity consumption for the year, $\sum E_{total}$, kWh/year, can be found using the following expression:

$$\sum E_{total} = E_{summer\ period} \cdot n_i + \\ + E_{winter\ period} \cdot n_j + E_{stable} \cdot n_k, \quad (1)$$

where $E_{summer\ period}$ – the amount of electricity consumed in the summer using an air conditioner, kW·h;

n_i – number of months in summer using air conditioning;

$E_{winter\ period}$ – the amount of electricity consumed during the heating period, kW·h;

n_j – number of months in the heating period;

E_{stable} – stable electricity consumption per month without the use of air conditioning and an electric boiler, kW·h;

n_k – number of months with stable electricity consumption.

Let's calculate the total electricity consumption for the year:

$\sum E_{total} = 1635.45 \cdot 3 + 2529.45 \cdot 6 +$ $+1089.45 \cdot 3$ = 23351.4 kW·h

Based on the obtained values, we can conclude that the annual energy costs for maintaining an individual two-story cottage are quite large, so its maintenance will be expensive, especially during the heating season.

At the next stage of the study, to select the optimal energy supply technology, we analyzed the alternative sources available on the territory of the location of the residential individual cottage. The following types of alternative energy were accepted for consideration: solar, wind, bio-, hydro- and geothermal energy.

The sun is an inexhaustible source of energy that can be converted into electricity or used as a source of thermal energy. Electricity can be generated directly using photovoltaic cells or indirectly using concentrated solar power technology (Hayat, 2019).

Solar energy has wide applications in various industries: in agriculture, primarily for water purification and irrigation, used for charging electric vehicles and for domestic purposes such as heating rooms or providing electricity for appliances used in everyday life (Hayat, 2019).

However, the biggest challenge facing the future of solar energy is its unavailability year-round, coupled with high capital costs and shortages of solar cell materials. These problems can be solved by developing an efficient energy storage system and developing cheap and efficient photovoltaic solar cells.

Assessing the practice of using solar energy-based technologies, the following advantages can be highlighted:

- long service life;
- no noise;
- no negative impact on the environment;
- availability.
- Among the shortcomings, the most significant are:
- long payback period;
- in some cases, insufficient efficiency;
- dependence of work on weather conditions.

For residential properties, solar energy can reduce appliance costs by reducing the load on electrical grids. Technological equipment using solar energy will not occupy large areas in a densely built-up city and will not disturb residents in the neighborhood with high noise levels. For an individual cottage, this is the best option for using alternative energy sources.

Wind energy is considered the most developed area compared to other areas. Wind energy technology is based on the ability to capture energy contained in air movement. The power of the wind determines the rate at which this kinetic energy is extracted. The efficiency of wind energy extraction is a balance of slowing the wind while maintaining sufficient flow (Samarskaya et al., 2023).

The advantages of using wind power plants include (Samarskaya et al., 2023):

- no polluting emissions into the atmosphere;
- location of the working elements of the installation at a high altitude;
- ability to use in isolated areas;
- minimal maintenance.
- Disadvantages of using wind power plants:
- dependence on weather conditions;
- high costs for start-up capital;
- distortion of natural landscapes;
- presence of aerodynamic noise.

For our energy consumption facility, the location of a wind power plant within the city is not practical due to its scale and noise during operation. Wind systems can be used for larger objects, but for an individual cottage such construction will not be economically viable.

Hydropower is based on a simple process that uses the kinetic energy released by falling water. In practice, this process is applied in many different ways depending on the required electrical energy production and the specific conditions of the construction site using dams, hydraulic turbines, hydro generators (Egré and Milewski, 2002). Such systems can provide electricity to large areas and have a huge, cost-intensive scale.

Advantages of hydropower:

- independence from fuel suppliers;
- cheap electricity;
- ability to regulate the power of hydroelectric power plants.

Disadvantages of using hydropower:

- possibility of land flooding;
- unnatural changes in river channels;
- water vapor emissions;
- large scale;
- Possibility of use only in certain hydrological conditions of the regions.

Our study examines the possibility of using alternative energy sources within one residential private household. Hydropower is used for larger scale research. Therefore, this type of renewable energy source is not suitable for us.

Bioenergy plays a large and growing role in the global energy system, but is resource intensive and only scales up when using vast areas of land. Because of limited land resources, initially low energy output per unit land area, and rapid technological advances in competing technologies, bioenergy makes most sense as a transition element in the global energy mix, playing an important role over the next few decades (Reid et al., 2020).

Advantages of bioenergy:

- continuity of biofuel production;
- possibility of efficient use of waste;
- great potential in agro-industrial areas;
- less emissions into the air than when using traditional energy sources (gas, oil, coal).

Disadvantages of bioenergy:

- use of large scale land areas, which may affect the ecological balance;
- when biofuel is burned, sulfur oxides enter the atmospheric air;
- difficulties in transporting and storing solid biomass.

Bioenergy is limited in its use. Suitable for agriculture and industry, where relevant production waste is generated to create fuel (agricultural waste, crop production waste, food industry waste, wood waste), and the free space allows for placement of biogas plants, processing equipment, pyrolysis plants (Reid et al., 2020). As a consequence of this, this method of energy generation is inappropriate for the energy consumption object we have chosen.

Geothermal energy involves the use of heat from the bowels of the Earth and sources of geothermal waters that are accessible to humans (geysers). Most often, geothermal stations are located in seismically active areas; it is necessary to monitor the awakening of volcanoes, earthquakes and soil movement. Many countries are developing geothermal energy, for example, New Zealand, Kenya, Iceland, and Russia.

Advantages of use:

- large reserves and production of electrical energy;
- significant savings on fuel;
- cost-effectiveness in maintenance.

Disadvantages of use:

- use only in certain conditions;
- coolant temperature is not less than 150 °C;
- difficulties at all stages of design (obtaining a construction permit, searching for areas suitable for the conditions);
- stopping work at any time.

Taganrog is a seismically inactive city; there are no volcanoes or geothermal waters at a temperature suitable for generating energy. Geothermal energy is also aimed at application on a large scale, for example, a city or town. It is impossible to take it for further research.

Based on the results of the analysis, we can conclude that for an individual cottage located within dense buildings, solar energy technologies are most suitable. Based on the results of a study of an energy supply facility, it was found that sunny days predominate in the city of Taganrog (55%), and solar radiation ranges from 2108 W/m^2 to 22785 W/m^2 per month. Consequently, according to all placement conditions, we can use photovoltaic solar panels to provide electrical energy to the selected energy consumption facility.

Currently, there are several design solutions for solar panels. We will choose three of them and conduct a comparative analysis of their designs for the purpose of further application at the energy consumption facility under study.

Among the wide variety of elements from which photovoltaic panels are made, silicon elements are the most widespread:

- monocrystalline (efficiency – 21.5%);
- polycrystalline (efficiency – 17%);
- amorphous (efficiency – 8%).

A feature of monocrystalline panels produced using silicon (monocrystalline) is the uniform color of the surface of the working plate.

This appearance is due to the peculiarities of production, as a result of which all the constituent elements become identical in appearance.

The main advantages of such designs of photovoltaic panels are:

- high efficiency (modern modules have an efficiency of up to 22%);
- take up minimal space compared to other types of solar panels;
- durability guaranteed by manufacturers from 25;
- work in low light, the quality of which depends on the manufacturer.

The disadvantage of such designs is the cost. Monocrystalline modules are the most expensive on the market of similar designs.

The next type of design solutions is polycrystalline silicon elements. Solar cells produced from polycrystalline silicon cells are made by melting and pouring into ready-made molds to cast the raw materials. Next, the cooled blocks are divided into plates of standard sizes, having the correct square shape. The result is low-cost, easy-to-use polycrystalline modules.

The most important advantages of such structures are:

- production cost, because the process of growing polysilicon is much simpler and less energy-intensive;
- less affected by temperature than monocrystalline modules.

In addition to the advantages of the structures under consideration, the following disadvantages have been identified:

- low efficiency due to the low purity of silicon in the polycrystal. Modern polycrystalline

modules have an efficiency of 15-18%.
- large required area to accommodate the structure.

In addition to classic monocrystalline and polycrystalline panels, amorphous silicon solar cells began to become very popular several years ago. With the beginning of the transition to thin-film manufacturing technology, the productivity of amorphous solar panels has increased significantly. Currently, their use is quite widespread.

Amorphous solar panels are a flexible film surface made of amorphous silicon. Such designs are excellent for use in areas with frost. The production of flexible panels is based on spraying technology. Hydrogen silica is sprayed in a very thin layer onto a special substrate. The substrate material is most often stainless steel, but glass, ceramics, and polymers can also be used. The sprayed layer is covered with protection.

Taking into account the above features, we can highlight the following advantages of such design solutions:
- high efficiency;
- affordable price;
- slight heating in hot weather;
- minimal risk of manufacturing defects;
- easy installation.

Among the main disadvantages are:
- low efficiency;
- unreliable top coating;
- large panel size.

In addition to the considered designs of solar panels, film batteries based on cadmium telluride, copper-indium selenide and polymers are also known, but they still cause controversy regarding toxicity and disposal without harming the environment.

The variety of design solutions for solar panels poses a question of choice to the consumer. Therefore, the next stage of the study was the selection of the optimal design solution for energy supply technology based on a patent search for Russian inventions.

The best, in our opinion, design solution, the basis of which is the use of photovoltaic panels, is the autonomous kit Energovolt A5.21-230V.

It is designed for autonomous power supply of equipment with a power of up to 5 kW, including in remote and hard-to-reach areas. The energy stored in batteries and replenished during the day from the sun is enough to power lighting, a refrigerator and freezer, a TV, a washing machine, heating pumps, water supply pumps, an electric kettle, a microwave oven and other electrical appliances. A carbon battery is not afraid of deep discharge and can be charged at higher currents than a helium battery, which means faster. 3760 cycles at 70% depth of discharge. In the future, it is possible to add solar panels, increasing the charging power and adding batteries. Lithium batteries can be used. Remote monitoring from a computer or smartphone of the state of charging and energy generation is carried out using the Wi-Fi/LAN module through the SOLARMAN Smart mobile application.

Scope of application: for home, cottage, remote settlement in the taiga, in the mountains, in the forest, on an island, in the absence of power supply, it will significantly save fuel when using a generator. The kit of such a system will include eight solar panels 550W Half-Cut NEOSUNTM Ultra M6 9BB 144. This is a series of solar panels with power up to 550W, manufactured using the latest technologies available on the market: 9BB Half-Cut cells with PERC technology.

Thanks to the use of the latest HalfCut technology, the internal cell resistance is reduced, which provides an additional increase in module power even in conditions of partial shading, cloudy weather or low light conditions. Solar cells with an efficiency of up to 23.4% are used, providing a final module efficiency of up to 21.5%.

Half-Cut Cell technology consists of dividing the panel into two parts using an infrared laser, as a result of which the operating current is divided in two. Thanks to this technology, the panel power increases by 2%, since the percentage of heat losses is significantly reduced. In addition, when dividing the panel, its reliability also increases.

During operation, the Vektor Energy VPbC 12-200 carbon fiber battery does not emit any substances harmful to health due to its sealed housing. Therefore, it does not require a separate room or additional ventilation, and can be used in residential areas. The battery is suitable for operation in both cyclic and buffer modes.

The power supply system also includes a hybrid solar inverter EB-5K-HYB-48V.

This inverter has the ability to sell electricity to the network, as well as the function of mixing the missing energy from the network with solar energy. First of all, the equipment is powered from solar panels, secondly from batteries or from the network, and lastly, the loads are powered and the batteries are charged from a generator (diesel, gasoline). If the owner does not use a generator, then an additional electric boiler can be connected to this separate input to heat water, or a grid-tied solar inverter or microgrid inverter can be connected to add power.

Also, to operate the system one will need a cable for solar panels with a cross section of 4 mm2 with an MC4 connector, a set of cable with a cross section of 35 mm2 with bolt ends, 1.5 meters (from the inverter to the battery), 1 set, a surge protection device ZBeny BUD-40/2R DC, 2-pole DC circuit breaker 16A (20A) ABB S201 (C) 6kA 16 A, fuse 250A "IEK ППНИ-37 with holder – 2 pieces.

4 DISCUSSION OF THE RESULTS

For the energy consuming object considered in the work, located in certain climatic and natural conditions, an optimal technological solution has been determined that makes it possible to obtain electricity in an alternative way through photovoltaic panels. Let's consider our solutions from the point of view of environmental safety and the possibility of recycling structural elements of the system.

The process of recycling silicon-based photovoltaic panels begins with disassembling the product itself to separate the aluminum and glass parts. Almost all glass (about 95%) can be reused, and all external metal parts are used to re-mould the cell frames. The remaining materials can be processed thermally. When exposed to high temperatures, the encapsulating plastic evaporates, leaving the silicon cells ready for further processing.

After heat treatment, 80% of what is separated can be easily reused, while the remaining 20% is further purified. Silicon particles in the connecting layer of the wafers are etched away by acid. Warped and spent wafers are melted down for reuse in the production of new silicon modules, resulting in 85% silicon reuse.

Carbon batteries Vektor VPbC 12-200 belong to the second hazard class waste according to Russian standards; they are prohibited from being taken to landfills or used for indirect purposes. Disposing of batteries at a specialized facility is the only correct way for a used power source. Recycling batteries mechanically assumes that the device will first be divided into its component fractions, and then each group of components will undergo individual recycling at a special enterprise.

Today, there are three methods for recycling cables for solar panels. The first, most primitive, is annealing the cable over fire. The essence of this method is to simply burn polymer insulation to obtain pure metal cores. This is an extremely harmful technology both for the environment and for the processors themselves. The second recycling method is to manually separate the cable from its insulation. This process is labor-intensive and time-consuming. Only small amounts of cable can be recycled in this way. The third method is mechanical processing of the cable in a high-performance, specialized installation. As a rule, such processing consists of shredding the cable, after which polymers and metals are separated by various methods, including electromagnetic methods. The third method is more rational.

The surge protection device ZBeny BUD-40/2R DC after the end of its service life is subject to transfer to organizations that process ferrous and non-ferrous metals. The design does not contain substances and metals that are hazardous to human health and the environment.

Thus, we can conclude that the use of a photovoltaic system, if properly disposed of, does not pose a hazard to the environment, and recycled system elements can be reused.

When choosing the optimal technical solution for cottage construction, not only the environmental safety of the design solution is important, but also the service life.

Elevated temperatures lead to degradation of solar modules and shorten the service life of the entire system. Therefore, to solve this problem, it is important to effectively protect the work surface from overheating.

The following factors can influence the increase in panel surface temperature: wind speed, ambient temperature, relative humidity, accumulated dust and solar radiation. High ambient temperatures and high operating surface temperatures of PV modules cause them to overheat, which affects the current-voltage characteristic and radically reduces the efficiency of the device. Each increase in the surface temperature of a solar module by 1 °C compared to the standard temperature of 25 0 C leads to a decrease in its efficiency by 0.5%. The preferred operating temperature of solar modules is in the range from 0 °C to 75 °C (Kirpichnikova et al., 2019).

The effect of temperature on the electrical efficiency of solar panels can be analyzed using the following equation:

$$\eta_{PV} = \eta_{TR} \cdot [1 - \beta_R \cdot (T_C - T_R), \qquad (2)$$

where η_{PV} – the efficiency of the photovoltaic module measured at ambient temperature;

η_{TR} – module efficiency at the reference cell temperature;

T_R– reference cell temperature, °C (T_R=25 °C);

β_R – temperature coefficient for cell efficiency, °C;

T_C – surface temperature of the photovoltaic module, °C (Kirpichnikova et al., 2019).

It follows from the formula that the higher the surface temperature of the module, the lower its efficiency (Kirpichnikova and Makhsumov, 2020). Thus, for solar energy technology to be viable, various ways to solve this temperature problem (such as the use of holographic film) must be found, which should lead to improved overall conversion efficiency.

5 CONCLUSIONS

In most cases, the use of solar energy to power individual cottages is a promising alternative to traditional energy supply.

The technical solutions proposed in the work for the implementation of a solar system can be applied to objects with similar characteristics and climatic conditions of the region.

To obtain maximum operating efficiency of solar modules, it is necessary to comply with climatic and operating conditions. An increase in air temperature during operation of solar modules reduces the generation of electrical energy and leads to premature degradation of the modules.

REFERENCES

Shchinnikov, P.A., Nozdrenko, G.V., Borush, O.V., 2020. *Comprehensive studies of power units of power plants and power plants*, Novosibirsk State Technical University. Novosibirsk.

Saidov, K.U., Sadykov, M.A., 2020. Problems of energy development in modern conditions, *Science and Innovative Technologies*, 16, 111-117.

Pilyaeva, O.V., 2017. Renewable energy sources and development prospects, *The Age of Science*, 11, 120-122.

Østergaard, P.A., Duic, N., Noorollahi, Y., Mikulcic, H., Kalogirou, S., 2020. Sustainable development using renewable energy technology, *Renewable energy*, *146*, 2430-2437.

Maradin, D., 2021. Advantages and disadvantages of renewable energy sources utilization, *International Journal of Energy Economics and Policy*, *11* (3), 176-183.

Maximov, A.G., 2020. Renewable energy 2.0: A new program for the development of "green" energy in Russia, *Energy policy*, 11 (153), 22-27.

Sukhoruchkina, T.Yu., Otroshchenko, O.S., 2016. Problems of development of renewable energy sources in Russia, *Energy and Resource Conservation: Industry and Transport*, 2, 40-43.

Smil, V., 2012. A skeptic looks at alternative energy., *IEEE Spectrum*, 49 (7), 46-52.

Degtyarev, K., Solovyov, D., 2022. Problems and prospects for the development of renewable energy in Russia in new conditions, *Energy policy*, 6 (172), 55-69.

Dyatlov, S.A., Didenko, N.I., Ivanova, E.A., Soshneva, E.B., Kulik, S.V., 2020. Prospects for alternative energy sources in global energy sector. In *IOP conference series: Earth and environmental science*. IOP Publishing.

Hayat, M.B., Ali, D., Monyake, K.C., Alagha, L., Ahmed, N., 2019. Solar energy – A look into power generation, challenges, and a solar-powered future. *International Journal of Energy Research*, 43(3), 1049-1067.

Samarskaya, N., Lysova, E., Kotlyarova, E., 2023. A Scientifically Based Choice of the Most Appropriate Design Features of a Wind Power Plant to Improve the Environmental Safety of the Region. In *2023 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)*. IEEE.

Egré, D., Milewski, J.C., 2002. The diversity of hydropower projects. *Energy policy*, 30(14), 1225-1230.

Reid, W.V., Ali, M.K., Field, C.B., 2020. The future of bioenergy. *Global change biology*, 26(1), 274-286.

Kirpichnikova, I., Makhsumov, I., Madiyar, Z., Abdulloev, I., Boboev, K., Shohnazarov, P., 2019. Study of the operation of solar modules using holographic thermal protection. In *E3S Web of Conferences*. EDP Sciences.

Kirpichnikova, I.M., Makhsumov, I.B., 2020. Increasing the energy efficiency of solar modules by reducing the surface temperature. *Proceedings of Tula State University. Technical Sciences*, 2, 489-499.