Analysis of energy supply from renewable sources considering the climate in Riga

Saule Sakipova [a,b], Andris Jakovics [a], Stanislavs Gendelis [a]

[a]*University of Latvia, Riga, Latvia, andris.jakovics@lu.lv, Stanislavs.Gendelis@lu.lv*
[b]*E.A.Buketov Karaganda State University, Karaganda, Kazakhstan, sesaule@mail.ru*

Abstract:

The paper discusses the problem of electricity supply and creating a heating system based on renewable resources, considering local climatic conditions. The authors studied characteristics of the climate and the potential of renewable resources in Latvia, particularly in Riga. In their opinion, it is possible to make a device for converting wind power at low speeds. The article presents the results of monitoring of tests buildings constructed from different materials. The energy efficiency of different heating systems using renewable energy sources is analyzed.

Keywords:

Renewable Energy Resources, Wind Turbine, Flexible Sails, Traction Force, Test Building, Construction Material, Sensor, Heating Pump, Energy Efficiency.

1. Introduction

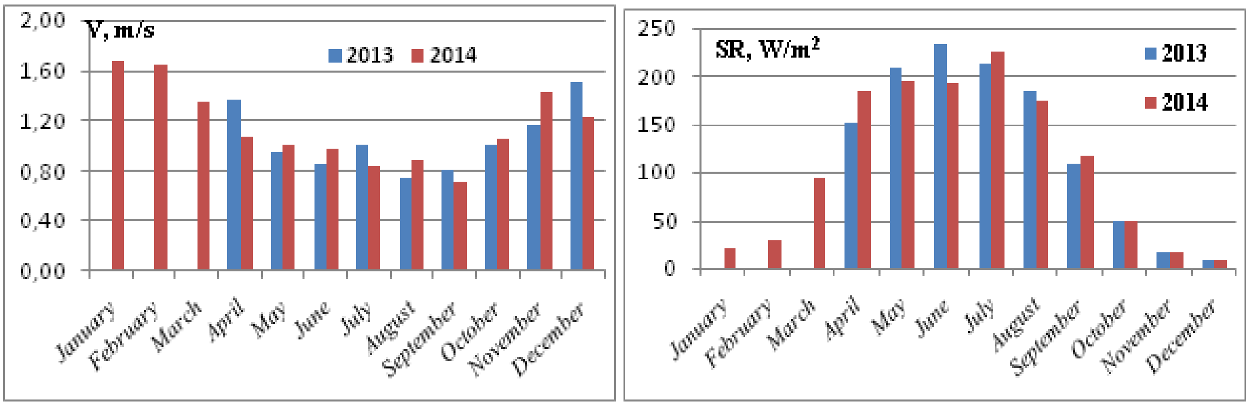
An increasing number of environmental constraints, as well as the growing problems of availability of energy resources not only leads to the development of technologies of the energy sector, but also to use available ones. Practice shows that the development of autonomous power supply using renewable energy sources can facilitate a solution to the strategic objective to strengthen economic and energy independence both of a nation as a whole, and of each owner of private business. In addition, the introduction of "green energy" at all levels helps to reduce the effects of human impact on the environment and human health by reducing environmentally harmful emissions.

Statistics shows that in Latvia in 2012, 35.8% of the energy was produced from domestic resources, but it still provides less than half of its own demands [1, 2]. In order to achieve greater economic and energy independence of Latvia, new technologies with the use of local renewable energy sources are introduced. Latvia as a member state of the EU has set up a goal to increase the share of energy from renewable energy sources up to 40% of total energy consumption by 2020. It is known that the production of energy is always accompanied by a negative impact on the environment, on the biosphere, on human life and health, even when using alternative energy sources. Therefore, in the production of energy, its conversion, transportation and consumption, environmentally friendly technologies should be considered. This article discusses various aspects of the use of renewable energy sources, considering the climate of this specific area, in particular in the city of Riga. In particular, the possibility of using wind energy for independent power supply to a house or a separate building is considered. Besides, as it is important not only to produce the energy it needs, but also to use it effectively, the authors analysed the energy efficiency of different heating systems using renewable energy sources.

2. Potential of renewable energy sources in Riga (Latvia)

Latvia has a high potential of wind energy only at the coast of the Baltic Sea. In 2012 it produced 112 GWh of electric power by means of conversion of wind. But so far in the total production of electric power only 2% is produced from wind energy, which is 4% of used renewable sources. This is due to the fact that in most parts of the country, the average annual wind speed is less than (2-3) m/s, at which the use of wind turbine is inefficient [3,4].

The main source of data on wind potential in Latvia is obtained through regular measurements of wind speed at Latvian Centre for Environment, Geology and Meteorology (LCEGM); its meteorological station is located near the Riga International Airport [4]. At the site of LCEGM one can find information on air pressure, temperature and humidity, wind speed and its direction, solar radiation and other climatic parameters throughout Latvia. But we use more accurate data on wind speed in Riga, measured at the weather station at the Botanical Garden of the University of Latvia, which can be obtained on-line. Figure 1a shows the variation of the wind speed during the period from April 2013 to December 2014. The analysis of the data shows that in Riga the average wind speed is 1.12 m/s. More detailed information on wind speed is given in [5].



(a) *(b)*

Fig.1. Weather data in Riga in 2013-2014: change of: a) wind speed; b) level of solar radiation.

The level of solar radiation in Latvia is low, but its magnitude is comparable to the solar radiation in some northern European countries such as Denmark [6, 7]. During the last two years the average level of solar radiation in Riga was 128 W/m^2, Fig. 1b. The use of solar energy is not popular in Latvia, although there is a government program to support the purchase of solar panels and collectors, designed to reduce greenhouse gas emissions. In Latvia, up to date there are only a few examples of the use of solar energy [1]. The total installed power: of on-grid solar power stations is ~ 668 kW; that of the off-the grid solar stations is ~ 37 kW; the same of thermal solar systems is ~ 800 kW.

In general, the climate in Latvia can be characterized as intermediate between maritime and continental. According to long-term observations, the average annual temperature in Latvia is +5.9°C. In winter, it keeps cold for a short time, there is often thaw weather. However, the heating season lasts about 6 months. Therefore, an additional power source is necessary to heat and supply electricity to a house. It is clear that wind is the most suitable alternative energy source. Unlike fossil fuels, wind energy is virtually inexhaustible, widely available everywhere and environmentally friendly. In recent years, the world growth rate of power of wind power plants amounted to average of 26%, it is significantly higher than the power growth rate of other types of power plants. Experts say that by 2020, 18-20% of the world's power will be produced by converting wind energy [3].

3. **Development of wind turbine and results of preliminary tests**

Preliminary assessment of the efficiency of wind turbines shows that at low wind speeds, sail-type turbines are the most suitable. Our experience has shown that to obtain the most useful power by converting the kinetic energy of the wind (considering the ratio of investment and maintenance of one square meter of area, by means of which the wind energy is produced), the best choice is a sail in the form of frame structures, covered with cloth. The advantage of these turbines is that they are capable of generating electric energy at low wind speed, while blade-type wind turbines don't move at wind speed ≤ 3 m/s. Sail-type wind turbines easily adjust in the direction of the wind, practically don't make any noise and vibrations.

Actually, when choosing a wind turbine to supply power to autonomous systems, priorities are determined by many factors, which are dependent on specific customer requirements, quality and price of the product [8, 9]. For experimentations, a sail-type wind turbine model with variable shape of a sail blade was designed. The model consists of a wind wheel, constructed as a metal frame with six flexible sails of triangular shape. Flexible sail is made of lightweight and durable cloth. One end of the sail is attached to the upper part of the frame by means of a twine thread.

During testing, the sail type wind turbine model was developed as a part of an autonomous wind power system to convert wind power into electric power. The model consists of six sail-type blades of triangular shape. The blades are made of lightweight and durable cloth. The diameter of the sail of the wheel is 0.4 m. The model is rigidly attached to the holder via support rods. This model of wind turbine differs from known analogues in its main elements which are triangular sail blades of dynamically variable surface shape. Tests of the model of the sail type wind turbine were carried out at T-1-M wind tunnel [9]. The main characteristics of the open test section of the wind tunnel are the following: its diameter is 0.5 m and its length is 0.8 m. The range of air flow rate change is from 2 m/s to 25 m/s and the turbulence level is 3%.

As a result of the experiments dependences of aerodynamic forces and the drag force when flowing past the model at various airflow modes were obtained. The test section of the wind turbine model is attached to a cubic frame connected to the aerodynamic scales by thin metal wires to minimize resistance of auxiliary parts. The traction force was measured using a spring dynamometer rigidly attached to the sheave of the wind turbine model. The error of the measurement of airflow rate in the test section using an installed sensor does not exceed 3-5%. The highest value of traction force F_{tr} of this model is observed in the forward direction of the wind flow (perpendicular to the plane of the wind wheel), as in this case, it flows the maximum surface area of wind wheel. It is found that when the direction of air flow is reversed, the thrust moment changes substantially in the same way as in the forward direction, Figure 2.

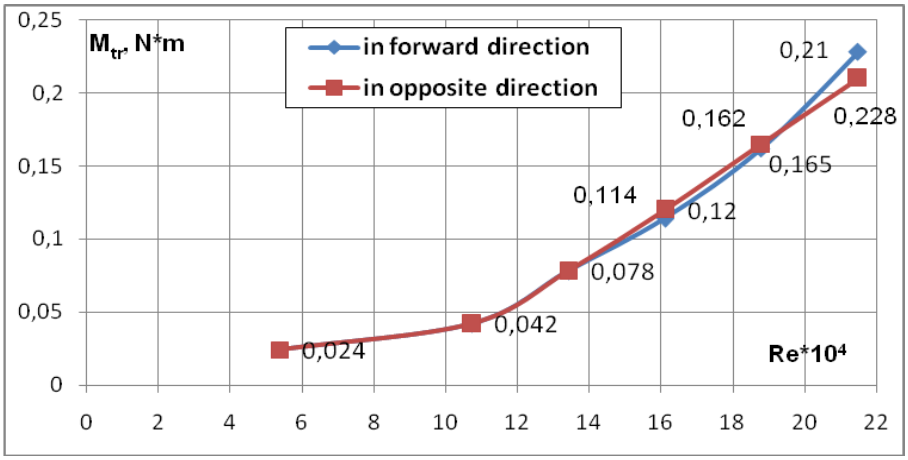


Fig. 2. Dependence of the thrust moment on Reynold's number for different directions of the air flow.

The difference between values is observed at high speeds, it rises slightly with increasing speed. This effect can be explained by the principle of operation of the wind turbine model. When the air flow presses a triangular blade, the traction force converts the energy of the airflow into the rotation motion of the wind turbine.

To calculate the dimensionless drug force coefficient and Reynolds number the following formulas were used:

$$C_M = \frac{2M_{tr}}{\rho u^2 \cdot S \cdot l}, \tag{1}$$

$$\mathrm{Re} = \frac{u \cdot L}{\nu}. \tag{2}$$

Here M_{tr} is the friction coefficient moment, ρ, ν are the density and viscosity of air, u is the air flow rate, S is the characteristic mid-section area, l is the length of the lever arm, which is equal to the sheave radius l= 0.06 m.

When the airflow direction is perpendicular to the surface of the wind wheel, the maximum cross-sectional (midship) area is flown, which is equal to the sum of the areas of all six sails $S = 0.0825\,\mathrm{m}^2$. If the axis of the wind wheel is mounted at an angle α to the direction of airflow, the air-flow surface area is determined as $S_\alpha = S \times \sin\alpha$. In the formula (2) the value of L is determined by the characteristic size of the wind turbine model, in our case it is equal to the diameter of the wheel sail L = 0,4 m. The parameters of air under conditions of the experiment are: $\rho = 1.21$ kg/m^3, $\nu = 1.49 \times 10^{-5}$ m^2/s.

The experiments showed that the developed model of the sail-type wind turbine has good aerodynamic properties thanks to a flexible, self-regulating form of the sail blade surface. Under airflow the wind turbine operates as a self-guided device efficiently converting the wind energy into energy of rotational motion. The flexibility of the construction with a dynamically variable surface shape of the sail provides a slight aerodynamic drag. This model of the wind turbine operates within a wide range of variation of the wind direction. Figure 3 shows the variation of the dependence of the thrust moment coefficient of the wind turbine model on the Reynolds number, when the airflow is reversed. The graph shows that the values of the thrust moment coefficient of the model vary virtually in the same way at forward and opposite direction of the airflow.

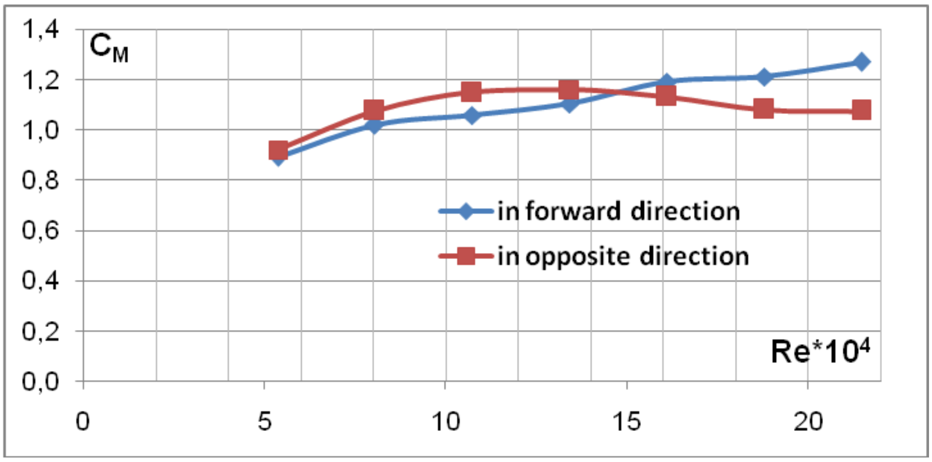


Fig.3. Dependence of thrust moment coefficient on Reynolds number at different air flow directions.

The experiments confirmed that even when the direction of the air flow is reversed, the wind turbine continues to rotate in the previous direction. Consequently, such a turbine can be effectively used, if it is installed in house arches or in the narrow space between the buildings where the wind blows at a higher speed and, mainly in the forward and backward directions. The test results of the experimental model of the wind turbine with a dynamically changeable form of blades in the wind tunnel under different airflow conditions proved its good performance, especially in the case of small buildings remote from centralized electric power transmission lines.

4. Assessment of energy efficiency of using renewable energy sources considering climate

When designing and constructing the building, its power supply should be carried out with minimum energy supply and not be accompanied, as far as possible, by adverse environmental impact. As part of the project, five buildings were constructed of different conventional in Latvia construction materials. The tested buildings have the same geometrical parameters; they are located in the Botanical garden of the University of Latvia, i.e. they have the same geographical environment. To assess the energy efficiency of heating systems and quality of heat-insulating building materials of the tested buildings, monitoring data and energy consumption were analysed.

When designing the buildings, minimization of heat losses and elimination of thermal bridges were specified. To construct walls, five different high-quality construction materials had been chosen [5, 10]. For all types of exterior wall construction designed *U*-value is 0.16 W/(m^2K), which is determined according to EN ISO 6946.

The structure and composition of test buildings construction materials (Fig.4) are as follows:

- AER – aerated concrete blocks with flexible stone wool layer on the external side;
- CER – perforated ceramic blocks with flexible stone wool insulation layer outside
- PLY – modular plywood panels with flexible stone wool filling and fibrolite inside
- EXP – perforated ceramic blocks with cavities filled with insulating granules of polystyrene foam;
- LOG – laminated beams with flexible stone wool insulation layer and wood panelling inside

Fig.4. Main construction materials of different test buildings

All test stands are equipped with the same set of 40 different sensors to measure parameters such as temperature and humidity (T/H); air flow rate; solar radiation level; electric power; pressure difference; heat flux; atmospheric pressure, and others. Monitoring of the sensors readings is carried out automatically; the data is recorded every minute. In addition, special measuring equipment is connected to a local weather station. During the two years of continuous measurements large amounts of data were obtained. The most realistic assessment of the energy efficiency of building materials can be obtained by comparing the energy consumption for heating/cooling of different test buildings.

Heating/cooling systems usingrenewable energy sources are installed in the test buildings [5]. They are an "air-air" heat pump (Figure 5a) and an "air-water" system with a low temperature convector (Figure 5b). The analysis of the energy consumption of these heating systems compared to conventional electric oil heater during a season, taking into account changes in ambient temperature. The experiments showed that the energy efficiency of buildings and heating systems most appropriately can be calculated using the SPF coefficient, which is determined as the ratio of produced energy to the amount of consumed energy. During the heating season the indoor temperature of 19-20°C was maintained. It is obvious that energy efficiency depends on the type of heating system of the type of building, i.e. the structure and composition of the construction materials of the building.

(a)

(b)

Fig.5. Overview of heating systems: a) «air-air» heat pump; b) «air-water» heat pump.

Table 1 shows the average energy consumption of two heat pumps and electric heater in three test buildings for three time periods. The experiments also showed that the efficiency of the heating system also depends on the ambient temperature.

Table 1. Energy efficiency assessment of heating systems installed in test buildings

Periods	Outdoor temperature, T_{out} (°C)	The average consumed power (W)			Energy efficiency factor, SPF	
		CER	LOG	PLY	“air-air” (LOG)	“air-water” (PLY)
February ‘14	2.6	224	159	89	1.4	2.5
March ‘14	4.6	188	127	64	1.5	2.9
April ‘14	8.4	110	73	41	1.5	2.7

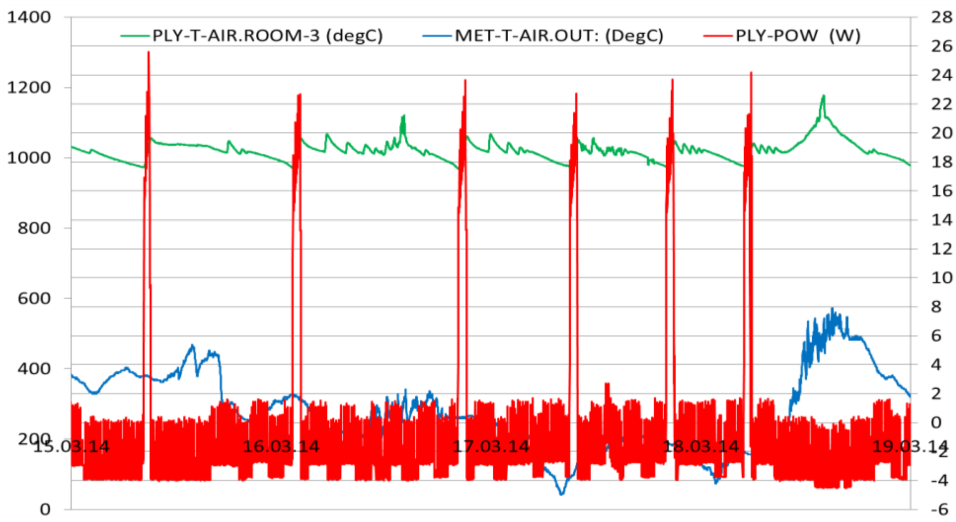
The resulting heat amount can be estimated from the readings of the electric heater in the building CER, because in this case as much heat is produced as is consumed, i.e. SPF = 1.0. And as in the other two buildings the same temperature is maintained, then the same amount of thermal energy is produced in them. Thus, an «air-water» system is the most energy-efficient in the PLY test building, because it produces 2.7 times more energy than it consumes. The use of "air-air" system is less effective – in this case, the system produces on an average 1.5 times more energy.

Figure 6 shows the assessment results of the energy efficiency of the "air-water" system in the PLY test building during March-April 2014. The lines on the graph indicate the following:

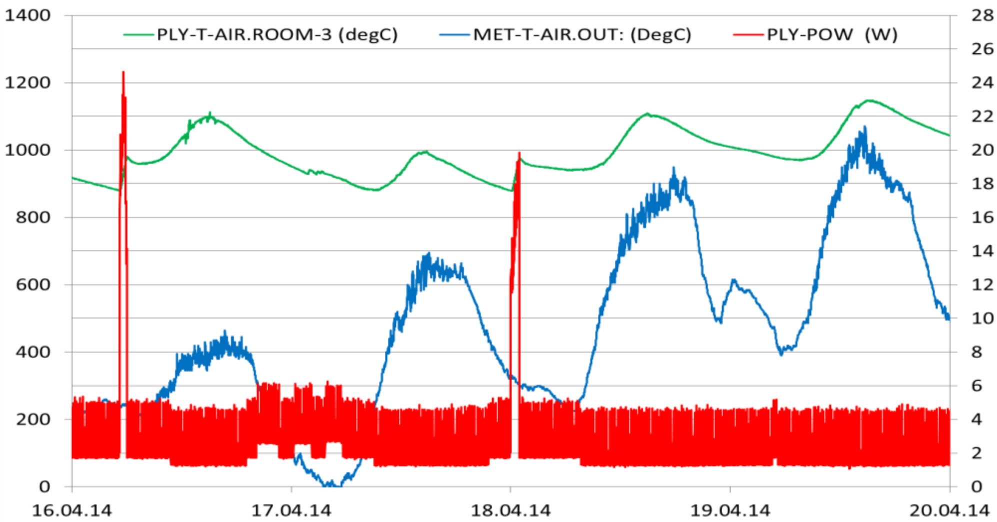
- PLY-T-ROOM is the air temperature inside the building; numerical values are shown on the right, by °C;
- MET-T-AIR.OUT is the outdoor air temperature, °C;
- PLY-POW is power consumption, numerical values are shown on the left, by W.

The analysis of the experimental data shows that the power efficiency depends not only on the ambient temperature, but on the duration of the heating system operation as well.

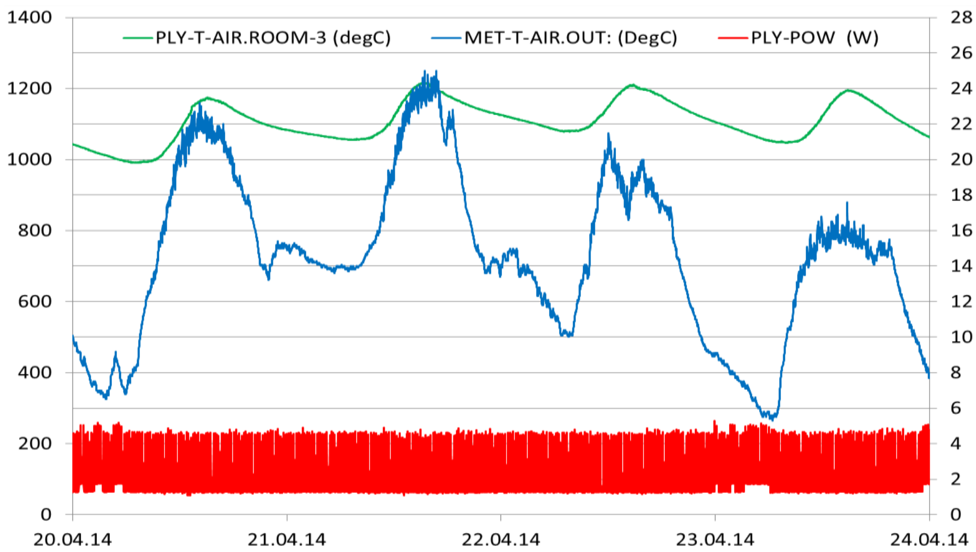
During the period from 15.03.2014 to 19.03.2014 at the lowest ambient temperatures about 2°C, the heat pump was switched on more often, in this case the SPF index reached the maximum, (Fig.6a). During the period from 16.04.2014 to 20.04.2014, when the ambient temperature changed from 2°C to 10°C the heat pump was switched on only twice, the SPF index was low - 1.1(Fig.6b). During the period from 20.04.2014 to 24.04.2014, when the ambient temperature was relatively high, the value of the efficiency coefficient was very low - the heat pump actually did not operate and produced only 10% of consumed energy (Fig.6c).



(a) SPF_{av} = 2.6



(b) SPF=1.1



(c) SPF=0.1

Fig.6. Estimated efficiency factor of air-water heat pumpfor different outside temperatures.

The experiments showed that the higher the outdoor temperature, the less often the "air-water" system was turned on. Besides, when analysing the energy efficiency of buildings and heating systems under real operating conditions, it is necessary to consider not only the temperature difference between the outside and inside the building, but also the mode of operation of the heating system and category of thermal comfort conditions in rooms. It should be noted that these results are valid in the climatic conditions of Riga for the considered test buildings and heating systems.

5. Conclusion

The analysis of the use of renewable energy sources under the local climatic conditions confirms that we live in an age of three "Es": economy, energy, and environment. Indeed, the economic power and wealth of any country depends on the level of scientific and technological potential, which is impossible without development of the energy sector. It is clear that the current level of knowledge and the development of modern technologies give optimistic predictions: humanity is not in danger of running out of energy resources and environmental degradation. There are real opportunities for the transition to alternative energy sources (inexhaustible and green). From this standpoint, the results presented in this article can be viewed as a small contribution to the development of modern technologies for energy supply based on renewable energy sources and methods for its effective use.

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