Artículo de investigación

Energy-saving system development based on heat pump

Desarrollo de sistemas de ahorro energético basados en bomba de calor
Desenvolvimento de sistema de poupança de energia baseado em bomba de calor

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Abstract

This article describes the structure and the operation of energy-saving systems based on a heat pump with the use of renewable energy sources. Using the method of an experiment three-factor active planning, the response surfaces and their two-dimensional cross sections were constructed in the isolines of the transition process duration and the amount of the energy carrier heat from the the electric heater power. The developed energy-saving systems support the temperature regime of an agricultural object by using solar energy, low-potential and artificial energy sources throughout the year. The developed system (option one), installed in hard-to-reach places at agricultural facilities, is designed to generate thermal energy, electricity, and provides significant energy savings during energy supply. Due to the speed of the electric regulator with solid filler and electric heater, the

Resumen

Este artículo describe la estructura y el funcionamiento de los sistemas de ahorro de energía basados en una bomba de calor con el uso de fuentes de energía renovables. Utilizando el método de un experimento de planificación activa de tres factores, las superficies de respuesta y sus secciones transversales bidimensionales se construyeron en las isolinas de la duración del proceso de transición y la cantidad de calor del portador de energía de la potencia del calentador eléctrico. Los sistemas de ahorro de energía desarrollados apoyan el régimen de temperatura de un objeto agrícola mediante el uso de energía solar, potencial bajo y fuentes de energía artificial durante todo el año. El sistema desarrollado (opción uno), instalado en lugares de difícil acceso en las instalaciones agrícolas, está diseñado para generar energía térmica, electricidad y proporciona ahorros de

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efficiency of the heat pump is increased, which maintains the microclimate parameters of the agricultural object.

Keywords: Heat pump, solar energy, low potential source of ground energy, energy saving, agricultural object, response surface

energía significativos durante el suministro de energía. Debido a la velocidad del regulador eléctrico con relleno sólido y calentador eléctrico, se incrementa la eficiencia de la bomba de calor, lo que mantiene los parámetros de microclima del objeto agrícola.

Palabras claves: Bomba de calor, energía solar, bajo potencial de energía del suelo, ahorro de energía, objeto agrícola, superficie de respuesta.

Resumo

Este artigo descreve a estrutura e a operação de sistemas de economia de energia baseados em uma bomba de calor com o uso de fontes de energia renováveis. Utilizando o método de um planejamento ativo de três fatores experimentais, as superfícies de resposta e suas seções transversais bidimensionais foram construídas nas isolinhas da duração do processo de transição e na quantidade de calor do portador de energia a partir da potência do aquecedor elétrico. Os sistemas de economia de energia desenvolvidos suportam o regime de temperatura de um objeto agrícola usando energia solar, fontes de energia artificiais e com baixo potencial ao longo do ano. O sistema desenvolvido (opção 1), instalado em locais de difícil acesso em instalações agrícolas, é projetado para gerar energia térmica, eletricidade e proporcionar economias de energia significativas durante o fornecimento de energia. Devido à velocidade do regulador elétrico com enchimento sólido e aquecedor elétrico, a eficiência da bomba de calor é aumentada, o que mantém os parâmetros microclima do objeto agrícola.

Palavras-chave: Bomba de calor, energia solar, baixa fonte potencial de energia do solo, economia de energia, objeto agrícola, superfície de resposta.

Introduction

One of the ways of energy saving problem solution is the use of a renewable low-potential energy source with heat pumps (HP) application (Kireev et al, 2003). HP also allows to solve the problems of object power supply remote from power supply systems (Vasilyev, 2007). Therefore, the development of an energy-saving system, which allows to reduce energy costs while maintaining the quality of agricultural products, is an important scientific task. The aim of the work is to justify the operating modes of the energy-saving system based on the heat pump in microclimate support system for agricultural facilities.

Materials and Methods

They carried out the theoretical studies using the theory of heat and mass transfer, the theory of machines and mechanisms, differential and integral calculus, as well as the analytical methods.
They applied the basics of the automatic control system in theoretical studies, including the regulation theory of monitored parameters. The experimental studies in laboratory and production conditions were conducted in accordance with the developed private methods, as well as by the methods of three-factor active planning of the experiment of the type 23 and the program "StatisticV5.0". The basic calculations and the processing of experimental study results were performed using the methods of mathematical statistics.

Results and Discussions

The basis of this study is made by the works of the most significant works of famous scientists in theory and practice (Novikova et al, 2015).

It is important to control the quality of agricultural machinery products supplied by the agro-industrial complex, so it is necessary to pay attention to the reliability of systems and devices during operation (Dorokhov, 2010; Qazani, et al., 2018).
They developed the converter of a low-potential energy source (LPES) with the basic elements: HP, heat exchanger, active fan, air humidifier and

distributors, presented in the form of electric regulators 2, 6, 7 (Figure 1).
LPES in the form of a salt solution with the temperature of 6 ... 8 °C is extracted with a heat exchanger and enters the regulator (Ershova et al, 2017).

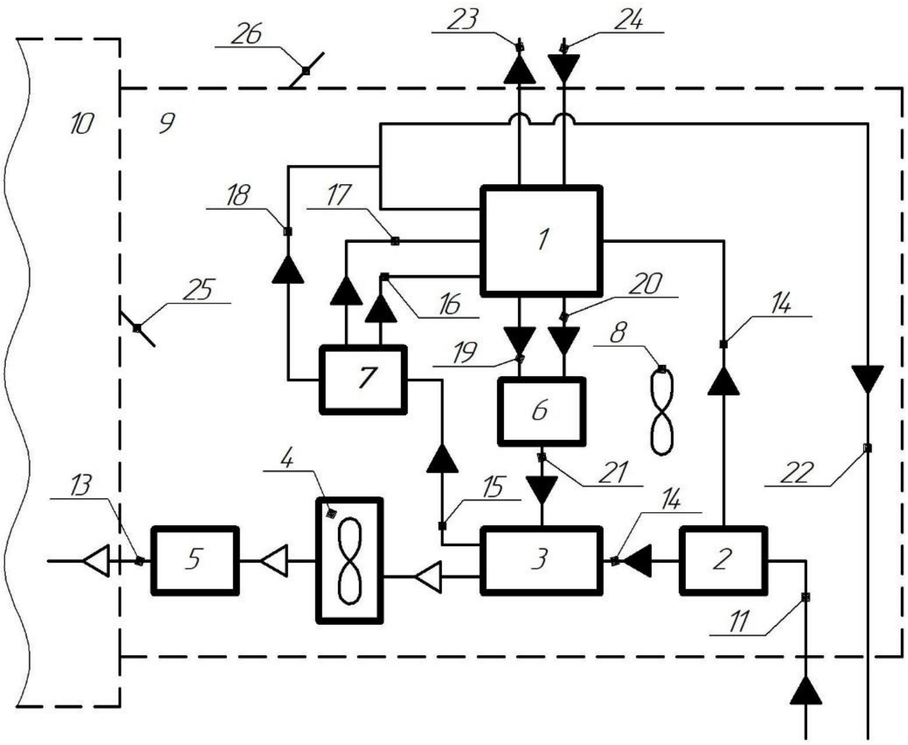

Figure 1 - Block diagram of LPES converter:

1 - HP; 2 - LPES distributor; 3 - heat exchanger; 4 - electric fan; 5 - air humidifier; 6 - heat and cold distributor; 7 - waste energy distributor; 8 - the fan of the power converter room; 9 - the room of the energy converter; 10 - agricultural object (vegetable storage); 11,12,14 - LPES channels; 13 - the duct for an object ventilation; 15 - the channel of spent LPES and heat carrier; 16,17,18 - the channels of the used coolant, heat carrier and LPES, respectively; 19 - coolant channel; 20 - heat carrier channel; 21 - heat carrier channel; 22 - spent LPES channel; 23 - coolant (heat carrier) channel for other consumers; 24 - the channel of the spent heat carrier (coolant); 25 - the damper for air receiving from the object; 26 - the damper for outside air receiving.

The following problems are solved in the regulator:

1. the maintaining of the temperature regime, for example, 6 °C, then LPES in the form of a coolant enters the heat exchanger, where heat exchange takes place with the air of the energy converter room (Bolotov, 2010);

2. The temperature rises, when LPES enters the heat pump, and high-temperature heat energy in the form of salt brine is fed to the regulator, the heat exchanger, where the air is heated, which, like the first item, is fed to the object. The resulting heat energy is also used to maintain the required temperature, for example, during the medicinal period of potato storage (Abdo, 2013);

3. the temperature decrease, then the HP switches to the cooling mode and the coolant with the temperature of 0 ... - 20 °C in the form of a saline solution enters the heat exchanger, where the air is cooled and supplied to the storage facility. The main work on the distribution of energy and LPES is performed by regulators.

The developed energy-saving system (the first version) consists conventionally of the following closed circuits (Fig. 2) (Jarreau and Poncet, 2012).

A coolant (for example, a silicate fluid) circulates in the solar collector along the first circuit; after the heat exchange of the coolant with the sun rays, the coolant is heated, and the heat exchanger heat is transferred to the coolant II of the closed circuit.

The heat accumulator maintains the temperature of the liquid during the operation of the circuit I, which is monitored by the temperature sensor (Wonglimpiyarat, 2010).

In the IInd circuit (warm one) the coolant (water) is heated in the heat exchanger after the heat exchange with the circuit I coolant, for example, to the temperature of 90 ... 95 °C.

At that, an electric actuator distributes the coolant flows to the evaporator, to the absorption refrigerating machine (ABRM), and to the object of heating.

The IIIrd circuit consists of an evaporator; a turbine; a capacitor; an electric pump and the channels of low-boiling substance circulation. In the IIIrd circuit, the pump drives the working substance, creating a certain pressure to generate the necessary electricity.

Salt solution circulates along the IVth circuit, the temperature of which makes 6 ... 8 oC in the heat exchanger as the result of heat exchange with the soil surface. In the condenser, the coolant absorbs heat from the exhaust vapor of the working substance, turning it into a liquid. The generator produces electricity, which is supplied to the consumer.

The energy-saving system works as follows. The coolant I of the circuit circulates with a pump. In case of an error signal, this signal is fed to the control unit, which supplies electric current to the electric regulator. At that the channel opens, and the coolant, passing through the heat accumulator, transfers heat to the storage tank. Then the coolant is returned to the channel 29 for further circulation in the Ist circuit.

During the accumulation of the necessary heat, the temperature sensor eliminates the error signal in the comparator by a signal supply, while the electrical controller closes the channel.

The second circuit design was developed, including an artificial energy source (Sayfudinova, 2016), for additional reliability provision maintaining the temperature parameters of the system.

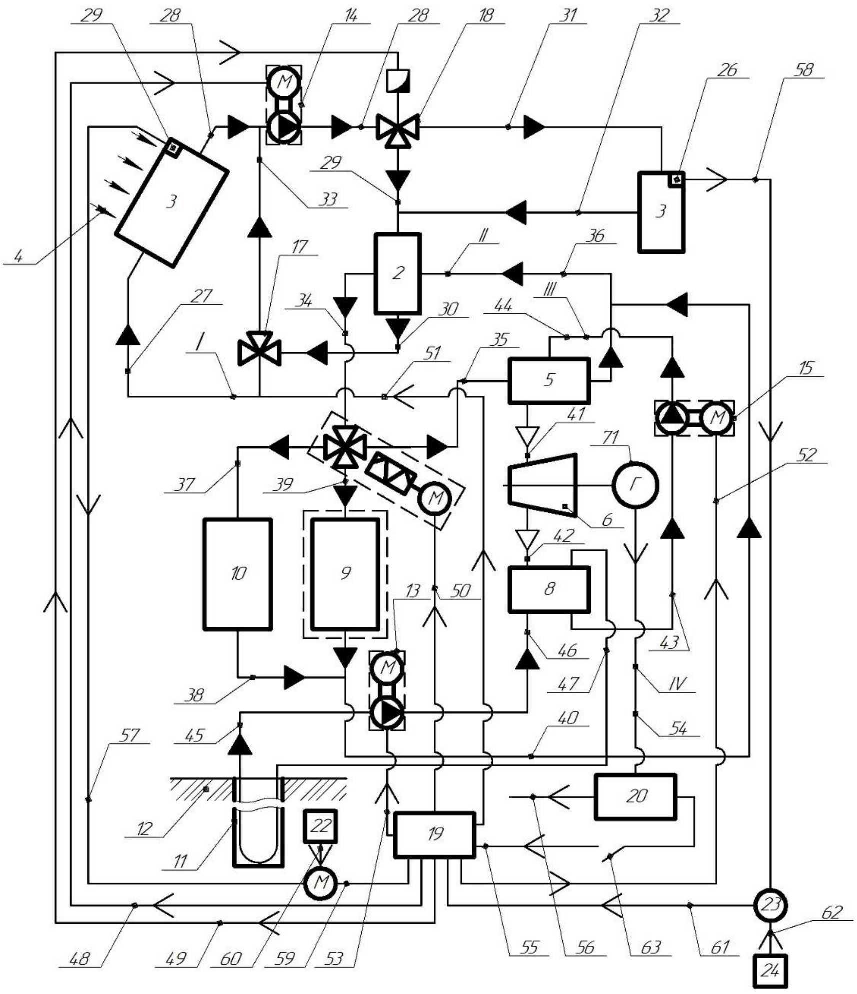

Figure 2 - Schematic diagram of the energy-saving system (the first option):

1 - solar collector; 2 - heat exchanger; 3 - heat accumulator; 4 - sun rays; 5 - evaporator; 6 - turbine; 7 - generator; 8 - capacitor; 9 - ABRM; 10 - heating facility; 11 - low-potential ground heat exchanger; 12 - ground; 13, 14, 15 - electric pumps; 16 - relay-pulse controller; 17 - electric regulator with a solid filler and TM, 18 - electric regulator with a solid filler and EN; 19 - control unit; 20 - power supply; 21,23 - comparison units; 22, 24 - setting devices; 25, 26 - temperature sensors;
27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40 — coolant supply channels; 41, 42, 43, 44 - low-boiling substance supply channels; 45, 46, 47 — low-potential coolant channels; 48, 49, 50, 51, 52, 53, 54, 55 — power supply channels; 56 - the channel of power supply to the consumer; 57, 58, 59, 60, 61, 62 - the channels for electrical signal supply; 63 - closing contact
The main sources of energy in an energy-saving unit are the following ones: renewable energy source (RES), which includes a solar source of thermal energy, LPES, and an artificial energy source (AES) (gas boiler) (Fig. 3).

The heat carrier is heated to 90 °C in the solar energy source.

Another part of the low-potential thermal energy enters the condenser, where turns it into a liquid after the heat exchange with the spent vapor of the low-boiling substance and returns back to LPES.

The system operation on renewable energy source.
If the sensor 20 demonstrates the coolant temperature equal to 90 °C, then there is no error signal in the comparator unit and signal is not supplied and the power is not supplied to the electric regulator. In this case, the control unit supplies the current to the electric regulator, and low-grade energy with coolant begins to flow through the channel 52 and 54.

In a heat pump the temperature of the coolant rises to 80 °C, and the spent low potential energy is returned back to LPES.

The heat carrier, heated to the temperature of 80 °C, enters the electric regulator with an increased pressure, the evaporator, where the low-boiling working substance (liquid) arrives simultaneously. In the evaporator, the low-boiling working substance draws heat from the hot coolant, while the low-boiling working substance evaporates and turns into steam. Then, the working steam enters the turbine, where the part of the working substance energy is converted into electricity. The exhaust steam enters the condenser, then into the evaporator in the form of a liquid, and the low-potential energy coolant enters LPES. The spent coolant enters the electric regulator after the heating object and ABRM, and then in the heat pump.

When the temperature of the coolant rises above 90 °C, a mismatch signal is generated in the comparison unit, which is fed to the control unit, the power supply to the regulator is cut off, and the supply of LPES to the HP is stopped. The coolant is supplied from the solar energy source to the evaporator, to the heating object and to the ABRM. The spent coolant is fed through an electric regulator after the object of heating and ABRM. The cycle is repeated.

Similarly, the evaporation of a low-boiling substance occurs and its transformation into steam takes place in the evaporator. Then the working steam goes to the turbine, where the part of the working steam energy is converted into electrical energy by the generator. Then the electric energy is supplied to the consumer.
The result of these processes is a high drop of the working substance evaporation and condensation and, consequently, there is a rather high efficiency of solar energy conversion into electrical energy.

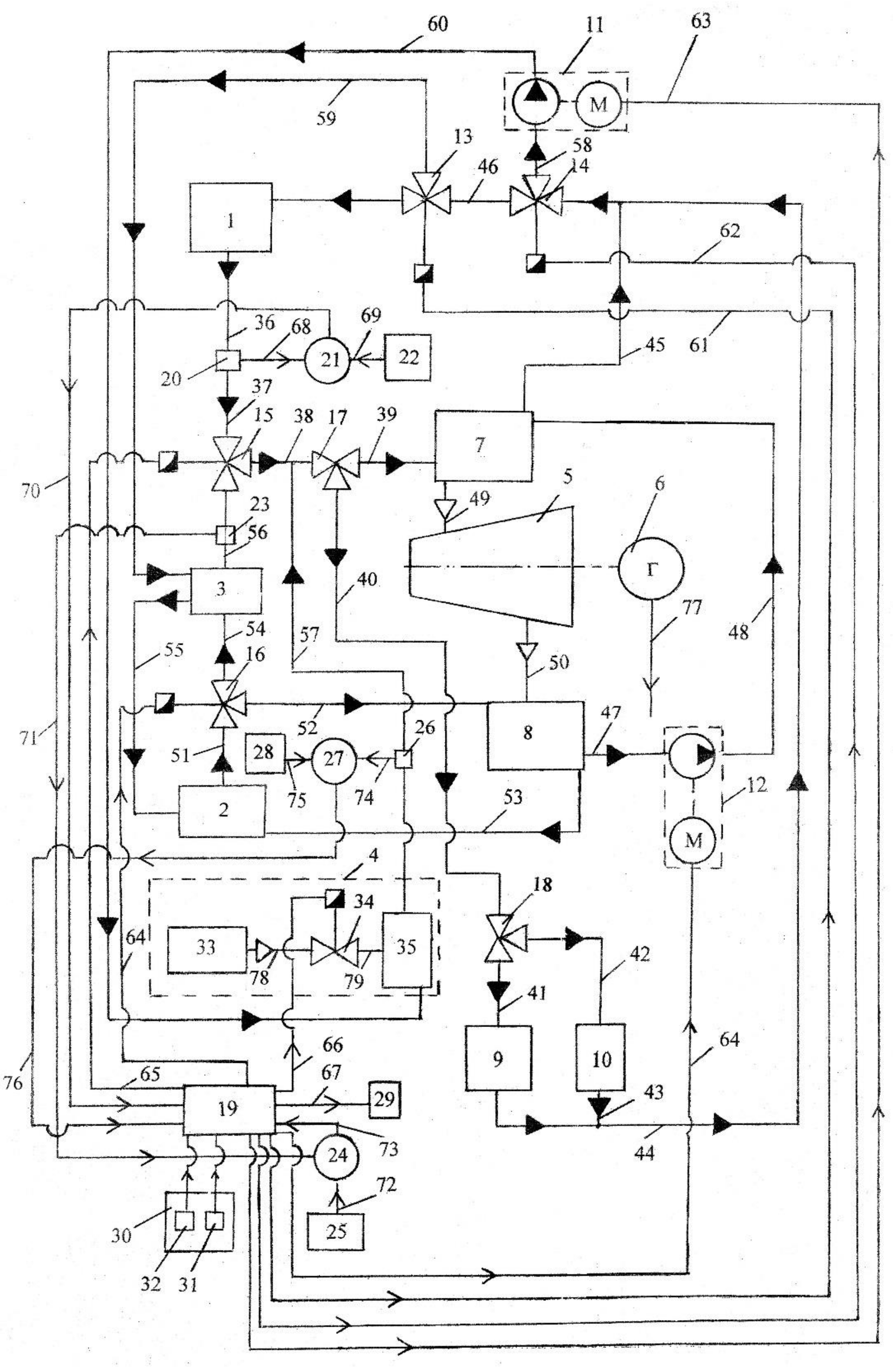

Figure 3 – Schematic diagram of the energy-saving system (second version):

1 - the solar source of heat energy; 2 - LPES; 3 - HP; 4 - an artificial source of thermal energy; 5 - turbine; 6 - generator; 7 - evaporator; 8 - capacitor; 9 - heating object; 10 - ABRM; 11, 12 - electric pumps; 13, 14, 15, 16; 17, 18 - electric regulators; 19 - control unit; 20, 23, 26 - temperature sensors; 21, 24, 27 - comparison unit; 22, 25, 28 - adjusters; 29 - warning device; 30 - operational control panel; 31 - RES switch; 32 - AES switch; 33 - gas cylinder; 34 - solenoid valve; 35 - gas boiler; 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60 — coolant channels; 47, 48, 49, 50 - the channels of low-boiling substance; 61, 62, 63, 64, 65, 66, 67 — power supply channels; 68, 69, 70, 71, 72, 73, 74, 75, 76 - the channels for electrical

signal supply; 77 - the channel of electric energy transfer to the consumer; 78, 79 - the channels of gas supply to the boiler

Using the method of three-factor active planning of type 23 experiment and the program "Statistic V5.0", they developed the following response surfaces and their two-dimensional sections in isolines: the duration of the transient process and the amount of heat carrier energy from the ES power (Fig. 4, 5).

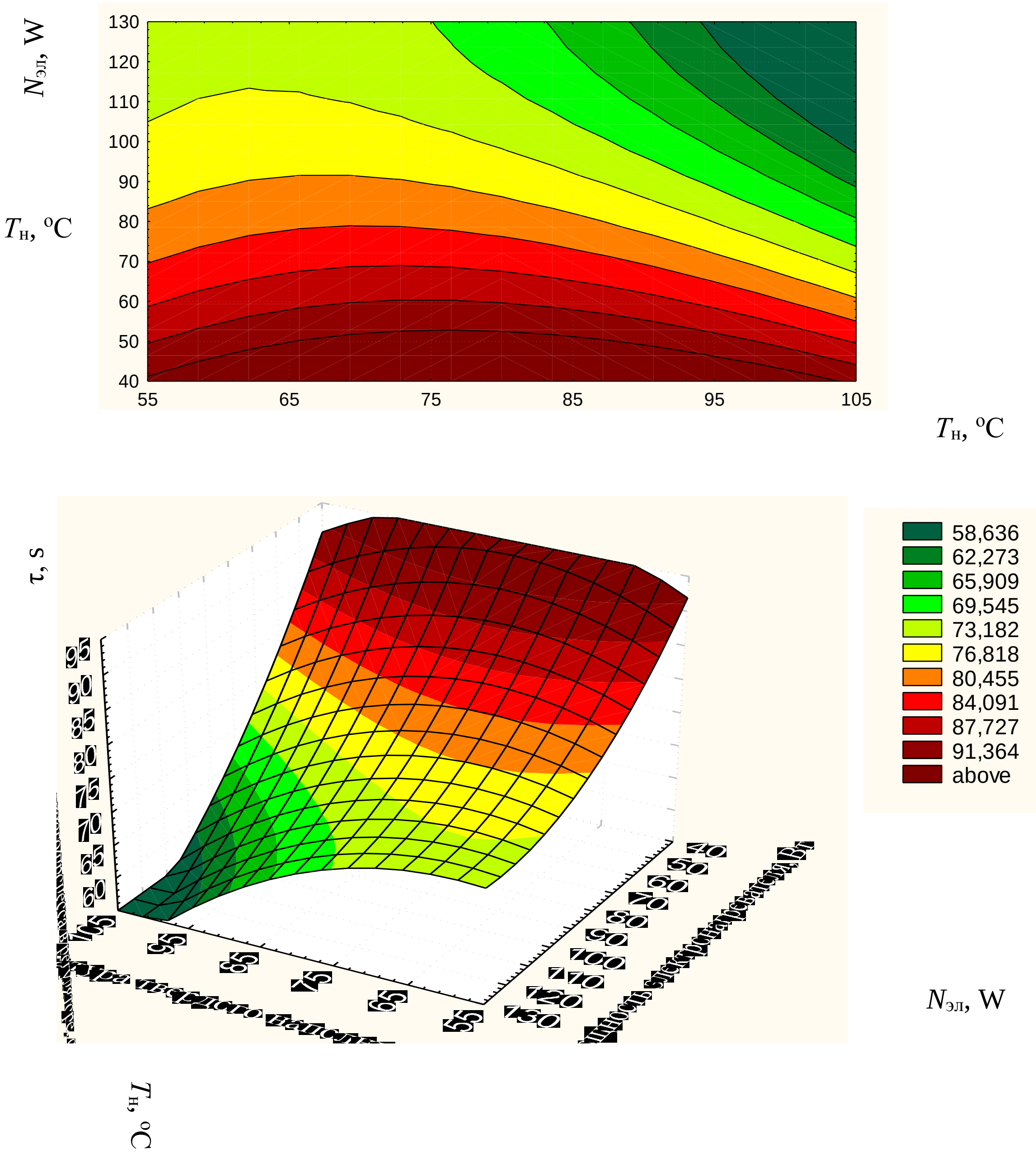

Figure 4 - Two-dimensional sections in the isolines and the response surface of the three-factor model for transient process duration of the electric regulator depending on the power of the ES and the temperature of the solid filler at a constant temperature of the energy source equal to 60 °C

The empirical expression of the transition process duration model of the electric regulator depending on the power of the ES and the temperature of the solid filler at the constant temperature of the energy carrier equal to 60 °C:

$$t = 40{,}42 + 1{,}986 \cdot T_{н} - 0{,}425 \cdot N_{эл} - 0{,}011 \cdot T_{н}^{2} - 0{,}005 \cdot T_{н} \cdot N_{эл} - 0{,}003 \cdot N_{эл}^{2}, \; c \quad (1)$$

Q - the amount of heat carrier heat, J;
$T_{н}$ - the temperature of the solid filler, oC;
$N_{эл}$ - electric heater power, W;
τ - transient process duration of the electric regulator, s.

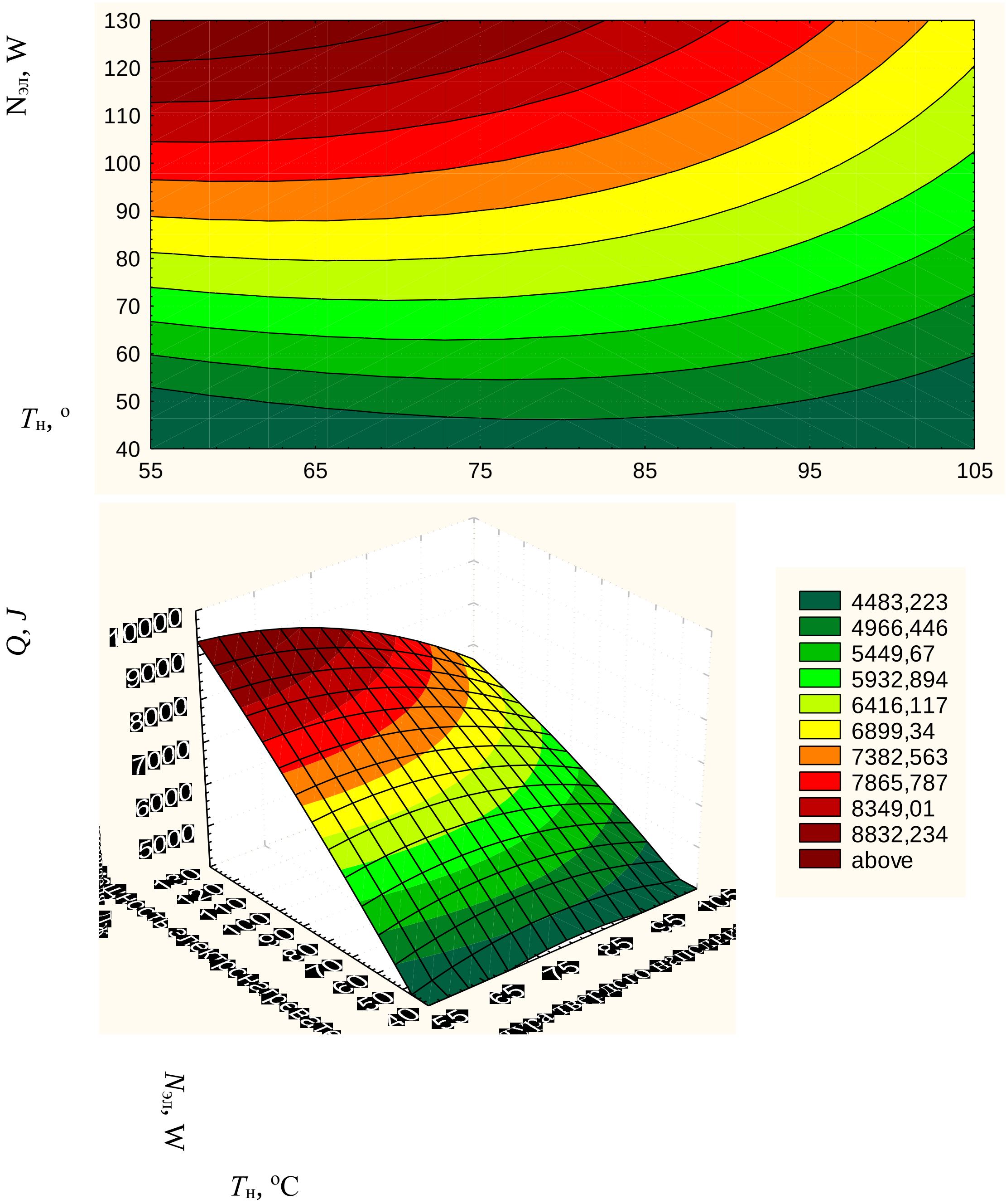

Figure 5 - Two-dimensional cross-sections in isolines and the response surface of three-factor model for the amount of heat carrier energy depending on the power of an electric heater and the temperature of the solid filler at the constant temperature of the energy carrier equal to 60 °C

The empirical expression of the model for the amount of energy carrier heat depending on the power of ES and the temperature of the solid filler at the constant temperature of the energy carrier equal to 60 °C:

$$Q = -5901{,}256 + 159{,}581 \cdot T_н + 117{,}6879 \cdot N_{эл} - 0{,}824 \cdot T_н{}^2 - 0{,}625 \cdot T_н \cdot N_{эл} - 0{,}114 \cdot N_{эл}{}^2, \text{Wt} \quad (2)$$

Conclusions

We developed the scheme of low-potential energy source (6 ... 8 °C) conversion into the source of heat (50 °C) and cold (–2 °C) by modernized electric regulators of HP.

The developed energy-saving systems support the temperature regime of an agricultural object by using solar energy, low-potential and artificial energy sources throughout the year.

The developed system (option one), installed in hard-to-reach places at agricultural facilities, is designed to generate thermal energy, electricity, and provides significant energy savings during energy supply.

The energy-saving system (option two) meets the need for electricity and cold for agricultural facilities located in remote areas, remote from power lines throughout the year by using renewable energy sources and energy sources. The developed system replaces diesel electrical installations, generators and boiler rooms, the energy cost of which is very high. In addition, the plants operating on traditional hydrocarbon raw materials pollute the atmosphere and soil. The use of ABRM allows to preserve the quality of agricultural raw materials and increase their shelf life. At the same time, ABRM is characterized by significantly lower power consumption and its use by agricultural producers allows to reduce operating and construction costs.

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