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THE USE OF ALTERNATIVE ENERGY SOURCES FOR THE OPERATION OF ENGINEERING SYSTEMS OF DETACHED CONSUMERS

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The operation of many of the engineering systems that are necessary for the functioning of a detached residential building depends on specific sources of alternative energy, the use of which can significantly reduce the consumption of traditional fossil energy resources. A review of scientific works devoted to the operation of engineering systems using alternative energy sources is given. Several schemes of power equipment have been developed to obtain thermal and electrical energy supplied to isolated consumers. When designing a fixed technical solar system using solar radiation for operation, the locations of all power equipment, the solar receiver pitch on the roof of the building and the values of its optimal angle of inclination to the horizon were determined. A scheme of a small transportable hydroelectric power plant has been developed, which generates electric energy using the pressure created by the flow of water. A thermal refrigeration unit is designed, which uses the heat of the air removed from the animal stall to heat the heated medium.

Keywords: alternative energy sources, hydropower, heat, thermal refrigeration unit, temperature, heated medium

Introduction

The growth of energy capacities for industrial needs is increasingly raising the issue of saving energy resources, finding reliable alternative energy sources and creating energy saving, environmentally friendly technologies. Alternative energy sources can substitute traditional energy sources. Among the alternative energy sources, the most promising ones are solar energy and water energy.

The sun emits energy as radiation and about 30 % of its total amount is reflected back into space, and about 70 % reaches the Earth's surface [1,2]. This energy can be captured and converted into electricity or heat. That is why the issue of the efficient use of solar energy is receiving more and more attention.

The density of monochromatic radiation flux propagation in the form of solar radiation light depends on a number of factors, including geographic location, season and time of day. When the Sun is low, the rays go through a longer path in the atmosphere and they become more and more scattered, which results in a higher percentage of scattered radiation. The seasons determine the amount of sunshine on any given day: up to 18 hours in the summer and only 8 hours in the winter. According to [3,4], a string of regions of the Russian Federation with the number of sunny hours in the range from 2000 to 3000 per year can be determined.

There are technical systems that can be: 1) stationary devices oriented at a certain angle to the horizon; 2) devices that are able to change their position throughout the day and be under the constant influence of solar radiation. Mobile technical solar systems are environmentally friendly power plants designed to heat water and air, where a working medium is pumped through a circulation pump to a predetermined temperature. These devices can work at both low and medium ambient temperatures.

In [5], a numerical study was carried out to determine the amount of daily solar energy consumed by a mobile technical solar system with an evacuated "water in glass" tube collector for various angles of inclination, azimuthal angles of the collector, and geometric parameters under changing mass flow rate of the heated medium. The optimal inclination angles were obtained, at which the power plant works most efficiently.

The authors of [6] compared the efficiency and performance characteristics of stationary technical solar systems with tubes made of unglazed transparent material and ordinary glass under local conditions. The controlled parameters were the inlet and outlet temperatures of the tubes, solar radiation intensity, ambient temperature, wind speed and ambient relative humidity. In [7], a design of a stationary technical solar system with tubes made of stainless steel was developed, which is a tube with a closed stainless steel thermosyphon, which consists of evaporative and condensing parts. The developed parabolic grooved design of a stationary technical solar system, consisting of evaporative and condensing parts provides higher thermal efficiency compared to other existing technical systems.

The authors of [8] examined the influence of various nanomaterials and nanofluids on the efficiency of various types of technical solar systems. In the paper [9] a comparison was made between the technical solar systems made of metal and polymer materials with free convection under environmental conditions. A number of advantages of using polymeric materials in the manufacture of solar technical systems was discovered in comparison with metal structures. The thermal refrigeration plant takes energy in the form of heat from a low temperature source, increases the thermal potential of the taken energy and transfers the heat to a consumer.

The implementation of the thermodynamic cycle of a thermal refrigeration plant assumes that in order to increase the temperature of the heated medium, it is necessary to take heat from a low temperature source. As a source of low temperature, the following can be used: humid air, soil, sewage, heat of the air removed from the stall of animals, heat removed from cooled bodies in refrigeration units, etc. In a thermal refrigeration plant, a condenser is a heat exchanger that pumps heat to a heated medium with the purpose of its subsequent beneficial use in various engineering systems, and an evaporator is a heat exchanger that takes heat from a low temperature source. Thermal refrigeration units are used to heat humid air.

The authors of [10] carried out a comparative analysis of the economic costs of converting the heating system of private houses from oil boiler units to thermal refrigeration units. The authors of [11] conducted a numerical experiment and formulated recommendations for the selection of heat pumps in relation to various production processes. It was found that due to the recovery and modernization of removed heat, thermal refrigeration units can save 15-78 % of the consumed hot water, depending on the specific process. In [12], recommendations are given for choosing a specific type of thermal refrigeration units from several suitable combinations. In [13], based on the developed simulation model, energy and economic characteristics were analyzed and compared for four types of thermal refrigeration units operating at low-temperature waste heat recovery. Recommendations are given on the choice of a thermal refrigeration unit depending on the specific conditions of their operation. The authors of [14] described the operation of a refrigeration unit for cooling milk with simultaneous heating of water (Fig. 1).

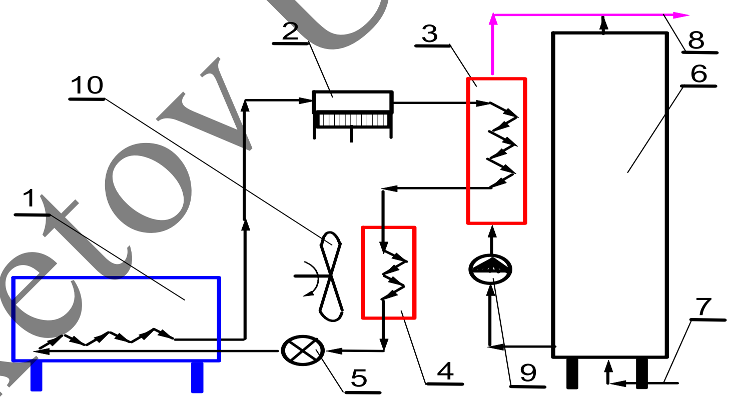

Fig.1. Layout of the refrigeration unit [14]: an evaporator in the milk tank; 2 - a compressor; 3 - condenser for water heating; 4 - an air condenser; 5 - a throttle; 6 is a water tank; 7 - the cold water inlet; 8 the hot water outlet; 9 is a centrifugal pump; 10 - a fan

Freon R12 is used as a working fluid circulating in the refrigeration un it. The pressure in condenser 3 is 1.73 MPa, and the temperature is 45 °C. The pressure in the evaporator 1 is 0.34 MPa, and the temperature is -3 °C. The refrigerant circulation circuit has an additional heat exchanger-condenser 4, which makes it possible to increase the temperature of a small part of hot water from 40 °C to 70 °C due to the superheat of the Freon in the reverse thermodynamic cycle. The total power of electric drives is 35 kW. The condenser 4 can be placed directly in the water heat storage tank 6.

The heat that is removed by fresh milk during its cooling, and the "waste" heat from the compressor 2 can be taken using the evaporator 1 and transferred to the heated medium by the condensers 3 and 4 of the refrigeration unit. Figure 2 shows a diagram of the operation of a refrigeration unit on a dairy farm [15]. Fresh milk with an initial temperature of 37 °C enters the plate heat exchanger 7. A pipeline is installed in the first section of the heat exchanger, through which tap water with a temperature of 10 ° C is supplied, moving in the opposite direction (countercurrent).

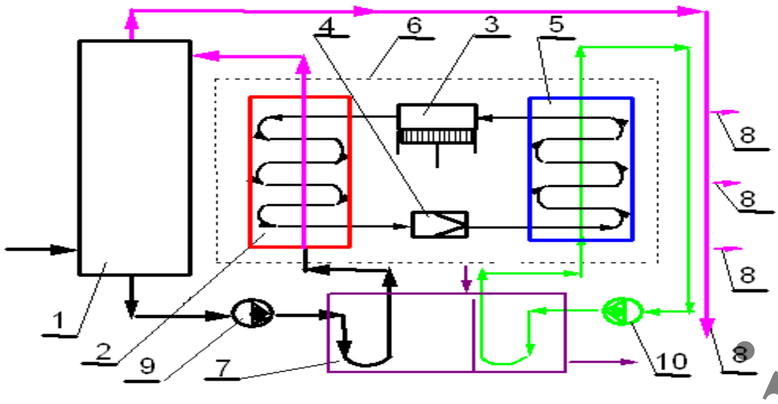

Fig.2. Layout of a refrigeration unit on a dairy farm [15]: 1 is a hydraulic accumulator; 2 is a condenser; 3 is a compressor; 4 is a pressure reducing valve; 5 is an evaporator in a tank with "ice" water; 6 is a body of the refrigeration unit; 7 is a plate heat exchanger; 8 is a consumer of hot water; 9 is a centrifugal pump for forced circulation of cold water; 10 is a centrifugal pump for forced circulation of "ice" water

At the same time, the temperature of the water rises to 28 °C, and the temperature of the milk drops to about 20 °C. Then the heated water through the pipeline enters the condenser 2 of the refrigeration unit, where the freon vapor (Freon R22), condensing, heats the water up to 55 °C. Warm water enters the upper part of the accumulator 1, from which it is used as needed for household needs. Milk from the first section of the plate heat exchanger 7 with a temperature of about 20 °C enters the second section, where "ice" water with a temperature of 1 °C is supplied in a countercurrent from the refrigeration unit through the built-in pipeline. Cooled to 4 °C, milk is pumped into vehicles or into storage containers.

Water, having heated up to 7 °C, enters the tank 5 with the "ice" water of the refrigeration unit, where the boiling freon passing through the evaporator takes heat from the water and reduces its temperature to 1 °C.

Thus, by recuperating the "waste" heat of milk and the compressor unit of the refrigeration unit, without additional energy costs, heated water is obtained for household purposes with a temperature of 55 ° C in the amount of 1.1 liters per liter of cooled milk. The scheme of operation of the thermal refrigeration unit TRU-14 for a dairy farm [16] is shown in fig. 3.

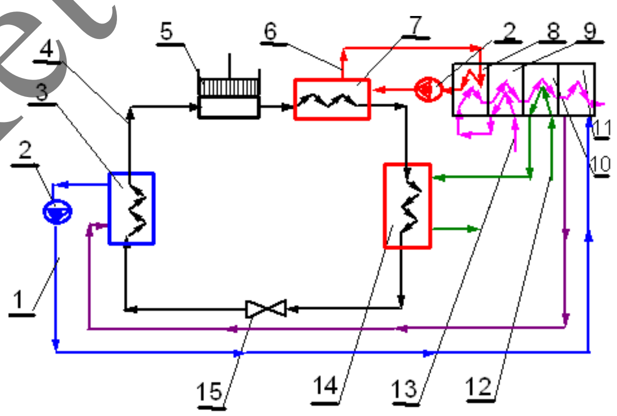

Fig.3. Layout of thermal refrigeration unit TRU-14 for a dairy farm [16]: 1 is an "ice" water line; 2 is centrifugal pumps; 3 is an evaporator; 4 is a freon line; 5 is a compressor; 6 is a hot water line; 7 is a heat exchanger; 8 is a pasteurization section; 9 is a regeneration section; 10 is a pre-cooling section; 11 is a final cooling section; 12 is a tap water line; 13 is a milk line; 14 is a condenser; 15 is a thermostatic expansion valve TEV

The thermal refrigeration unit is designed to cool water used as an intermediate coolant in tanks, and simultaneously heat it to meet sanitary and technological needs on livestock farms.

The freon (Freon R22) boiling in the evaporator 3 removes heat from the water in line 1 and lowers the water temperature to 0 °C. Then the freon vapor is compressed by the compressor 5 and fed into the heat exchanger 7, where R22 freon is condensed due to heat exchange with water. Further, water, heated to 85...90 °C, from the heat exchanger 7 enters the milk pasteurization section 8.

In the condenser 14, freon R22 transfers all the heat obtained by compressing freon vapor in the compressor 5 to running water, which is heated to 50 °C and used on a dairy farm for sanitary and hygienic purposes. As shown by theoretical calculations, the use of a 75kW thermal refrigeration unit TRU-14 on a dairy farm for 1,000 heads saves up to 100 tons of liquid fuel and 350,000 kW· h electricity per year on the farm. The technological scheme of operation of the thermal refrigeration unit TRU-14 for a dairy farm is shown in Fig. 4.

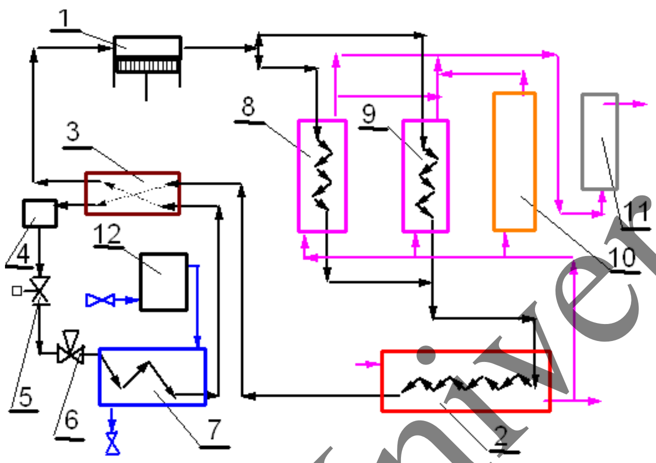

Fig.4. Technological scheme of thermal refrigeration unit TRU-14 for a dairy farm [16]: 1 is a compressor; 2 is a condenser; 3 is a regenerative heat exchanger; 4 is a filter-drier; 5 is a membrane solenoid valve; 6 is a thermostatic expansion valve; 7 is an evaporator; 8 is a heat exchanger; 9 is a heat exchanger; 10 is a capacitive water heater; 11 is an electric heater; 12 is a cold water tank

Freon R22 vapors are compressed by the compressor 1 and fed into the condenser 2, where they are cooled and condensed, giving off the heat to running water. From the condenser 2, liquid freon enters the regenerative heat exchanger 3, and then moves into the filter-drier 4, where it gets dried and cleaned from impurities. Further, passing through the solenoid valve 5, freon R22 is fed into the thermostatic valve 6, where the freon is throttled to the boiling pressure, and enters the evaporator 7. In the evaporator 7, the freon boils, absorbing heat and cooling the coolant (water). Vapors of freon R22 are pumped out by the compressor 1 from the evaporator 7 through the regenerative heat exchanger 3, and then the refrigeration cycle is repeated. Cold water (refrigerant) makes a closed cycle in the milk cooling system. Warm water at the outlet of the condenser 2 is divided into two streams. Part of it enters the heat exchangers 8, 9 and 10 for further heating, and its amount is set using a water control valve.

The water in the heat exchangers is heated by heat exchange with hot freon vapor moving in countercurrent. The flow heat exchanger provides heating of water to a temperature of 40 °C in 10…15 minutes after turning on the refrigerating unit. The heat exchanger of the convective circuit heats water in the amount of 150 liters to a temperature of 60 ... 65 °C in a cycle of 3.25 hours. If it is necessary to withdraw hot water before the completion of the full cycle of the thermal refrigeration unit, the water temperature can be brought to a predetermined level using the electric water heater 11.

At present, the use of alternative energy sources in the energy industry, which includes the energy of water resources of rivers (hydropower), is becoming an urgent task. This type of energy owes its origin to solar energy. The sun evaporates the water of rivers, seas and oceans, and then it rains over the entire territory of the globe.

It has been estimated that the planet Earth has 10^{18} tons of water reserves, and only 1/2000 of it is annually involved in the cycle. Hydropower provides around 2,600 TW· h of the world's electricity generation per year, which is about 20 % of the world's total electricity demand, making it one of the most reliable and cost-effective renewable energy sources. In 2001, the largest hydropower producing countries were Canada (333.0 TW· h), the US (201.2 TW· h) and Norway (120.4 TW· h). Hydropower consumption in the EU countries grew by almost 27 % between 1991 and 2001. In 2001, hydropower accounted for approximately 5 % of total electricity consumption in the EU countries. France is the largest producer of hydropower in the EU. In 2001, the generating capacity of hydropower plants in France was about 25,000 MW [17].

As of 2015, over 47,000 small hydropower plants under 50,000 kW have been built in China. Most hydropower plants are located in the mountainous regions of southern China, where there are large reserves of water resources (rivers) [18]. According to [1], the average capacity of one small hydropower station was 143 kW. These small-scale hydropower plants (SHPPs) generated up to 0.01 % of the entire produced electricity.

Lately, scientists and researchers have been looking for progressive and economically sound technical solutions for small hydropower plants (SHPPs). HPPs and SHPPs can serve as a reliable reserve of electricity for remote consumers. The authors of [19] describe the operation of the HPP as a power plant for generating electricity from renewable energy sources and evaluate the possibility of building a HPP in the Republic of Macedonia. The paper describes the possibility of using HPPs of low power (up to 10 MW).

In [20], the possibility of extracting energy from water resources is estimated using the example of the Alviela River in Portugal using three types of turbines: two propeller turbines (with and without adjustable blades) and an Archimedes screw turbine. The results showed that with an available head of 2.5 m, the most acceptable solution is to use an Archimedes screw turbine with a nominal flow of 3 m^3/s and a nominal power of 55 kW. The further development of the world energy industry is connected with a more rational use of energy.

Thus, it can be stated that:

- modernization of the existing structures of stationary and mobile technical solar systems, hydroelectric power plants and refrigeration unit is required;

- there is a strong need for new information that will make it possible to study the issue of the development and design of the simplest structures of technical solar systems, transportable small-scale hydropower plants and thermal refrigeration units.

The purpose of the study is to develop specific recommendations and select design solutions for power equipment for remote consumers, which will allow converting the energy potential of alternative sources into other types of energy for their subsequent beneficial use.

1 Experimental technique

To assess the possible use of three experimental power plants by remote consumers, the design calculation of power plants based on algebraic equations describing their operation was chosen as a research method. As experimental power plant No. 1, the authors propose a layout of a stationary technical solar system that can be used to ensure the operation of engineering systems for a residential building of a detached consumer. The layout of the power plant is shown in fig. 5.

Experimental power plant No. 1 consists of a solar receiver, which is an aluminum corrugated pipeline with a diameter of d = 0.08 m and a length of l = 10 m, which receives the energy of solar rays, a centrifugal fan and an accumulator. Humid air with a temperature of $t_{f_1} =$ 17 °C is taken from the environment through the air intake grille and fed into the pipeline by a fan. Aluminum corrugated pipeline is mounted on the south side of the roof of the building, which is inclined to the horizon at an angle of 30 °.

Owing to the centrifugal fan 2, air moves through the pipeline with a mass flow rate varying in the range of G = 0.05 ... 0.054 kg/s and a corresponding volumetric flow rate of Q = 0.0417 ... 0.045 m^3/s, and at the same time at the outlet its temperature becomes turns t_{f_2} = 39…41 °C. Heated air is supplied either to the room or to the accumulator 3, which is located under the building. The design of the stationary technical solar system provides for the use of recirculated air from the room and the supply of outside air directly to the accumulator 3 in the case when the solar receiver 1 is not working (at night or in cold weather).

The design calculation of the power plant is performed in the following sequence.

1. Initial and final parameters of coolants are set.

2. Using the literature recommendations, the speeds of the coolant moving through the pipeline are set.

3. The values of the volumetric and mass flow rates of the coolant are determined by the value of the velocity.

4. The power of the heat flow is determined, which is transmitted with the help of solar radiation to the cold coolant (air).

5. The efficiency of a stationary technical solar system is calculated.

Useful heat flow, which is transferred to the coolant through the pipeline wall, W

$$\Phi_e = Gc_p(t_{f_2} - t_{f_1}), \quad (1)$$

where G is the mass flow rate of the coolant, kg/s;

c_p is the specific isobaric heat capacity of air, which in this case does not depend on temperature, c_p = = 1004 J/(kg · K);

t_{f1} is the humid air temperature at the inlet of the pipeline, t_{f_1} = 17 °C;

t_{f2} is the humid air temperature at the outlet of the pipeline, t_{f_2} = 39…41 °C.

It was determined that the values of the useful heat flux vary in the range of Φ_e = 1104 … 1301 W.

The efficiency of a stationary technical solar system is the following:

$$\eta = \frac{\Phi_e}{\pi dl \cdot J_C}, \quad (2)$$

where πdl is the pipeline side surface area, m^2;

J_C is the total flux density of solar radiation incident on the surface of the pipeline, J_C = 600 W/m^2.

It was found that the values of the efficiency of a stationary technical solar system varied in the range of η = 0.59 … 0.7. As an experimental power plant No. 2, the authors propose a layout for a transportable small hydroelectric power station, which can be used to produce electrical energy. The layout of the power plant is shown in fig. 6. Experimental power plant No. 2 consists of a water intake device, a pressure hose, which is a polyethylene pipe with a diameter of d = 0.025 m and a length of l = 5 m, a hydraulic turbine and an electric current generator.

Water enters the intake device 1 and then, moving along the pressure hose 2, through the inlet pipe enters the spiral chamber 3 of the hydraulic turbine. The flow of water inside the chamber spins the turbine impeller and transmits torque to the electric current generator 4, which, during rotation, generates electrical energy used for the needs of consumers.

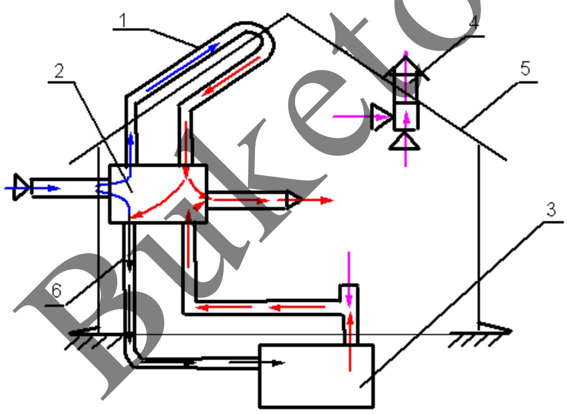

Fig. 5. Layout of a stationary technical solar system in a residential building: 1 is a solar receiver for solar rays; 2 is a centrifugal fan; 3 is an accumulator (water, granite, pebbles); 4 is an exhaust hood; 5 is a gable roof of the building; 6 is an air duct.

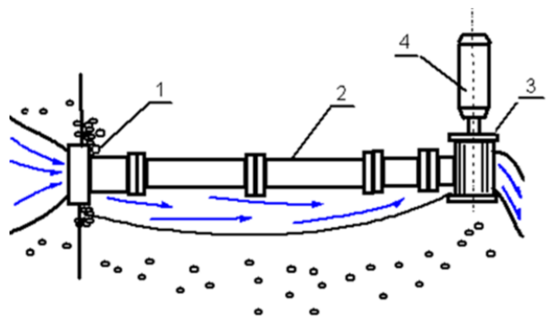

Fig. 6. Layout of a transportable hydropower station: 1 is a water intake device; 2 is a pressure hose; 3 is a spiral chamber of the hydraulic turbine; 4 is an electric current generator

Water moves along the pressure hose with a volumetric flow rate, which varies in the range of Q = =0.01…0.03 m^3/s. We assume the available water head to be constant at H = 3 m, the efficiency of the turbine is η_{turb} = 0.55…0.95 and the efficiency of the generator is η_{gen} = 0.96…0.97. A small hydroelectric power station is operated for 6 months a year due to the freezing of the reservoir in the autumn-winter period, that is, the time is t = 4320 h.

The design calculation of the power plant is performed in the following sequence:

1. The variety range of the volumetric flow rate Q is set.
2. The available head H is taken as a constant value.
3. Using the literature recommendations for small hydroelectric power plants, the efficiency of the turbine η_{turb} and the efficiency of the generator η_{gen} are determined.
4. The operating time is determined for a small hydroelectric power station (in hours) during the year.
5. Calculate the power of a transportable HPP N at a specific point in time, W.
6. The maximum power is calculated for a transportable hydroelectric power station N_{max}, called installed power, W.
7. The amount of electricity E generated by a transportable hydroelectric power station for the entire time of operation is determined, kW·h.

It was determined that the amount of electricity generated by the transportable hydroelectric power station for a fixed period of time varied in the range of E = 740…2220 kW·h. As an experimental power plant No. 3, the authors propose a layout of a stall thermal refrigeration unit, which allows preparing and supplying hot water and heated air to a residential building of a detached consumer. A diagram of the thermal refrigeration unit that uses the heat of the air removed from the animal stall to heat the coolant is shown in fig. 7.

The experimental power plant No.3 consists of an evaporator 1, which is located in the animal stall (room No. 1), a primary heat exchanger 5, a condenser 3, located in a residential building (room No. 2), a compressor 2 and a throttle 4. A primary recuperative heat exchanger 5 is mounted in the animal stall, which transfers heat from the air to an intermediate heat carrier (water), which is sent through the pipes to the evaporator 1 and gives off its heat to freon R12. In the evaporator, freon R12 circulating in the refrigeration unit boils and enters compressor 2 in the state of dry saturated steam. In the compressor, freon R12 is compressed and enters condenser 3 in the form of superheated steam.

As a result of the condensation process, freon flows in the form of a liquid into throttle 4 and then it enters the evaporator 1, and the processes occurring in the thermal refrigeration unit are repeated. The condensation process is accompanied by the release of heat, which, with the help of an intermediate coolant, can be used to ensure the operation of an engineering system that replenishes the heat losses of a residential building. If an engineering system with a working medium “dry air – saturated water vapor” is used in a residential building, the air must be heated to the specified parameters in a water heater before being supplied to the working area and then delivered to the room using the air distribution grille 6.

The design calculation of the power plant is performed in the following sequence:

1. The variation range of the volumetric flow rate of R12 freon circulating in the thermal refrigeration unit is set to be M = 0.1…0.3 kg/s.
2. Using the thermal Ts - diagrams of the refrigeration unit for difluoro-dichloro-methane (freon R12) the thermodynamic parameters of the state at the characteristic points of the cycle are determined.
3. Values of the specific removed q_1 and supplied q_2 heat are determined.
4. The specific work of the refrigeration cycle l_c is calculated.
5. The adiabatic power of the compressor drive N is determined.
6. The cooling ε and heating φ coefficients are calculated.
7. The theoretical volume V, described by the compressor piston in 1 s, is determined.

The stall thermal refrigeration unit operates on a throttling cycle. The boiling point of freon R12 in the evaporator is t_0, the condensation temperature is t_c. Freon R12 enters the compressor in the form of dry saturated steam with a temperature t_0. Before entering the throttle, the working fluid is supercooled to a temperature of $t_H = t_c - 10°C$. Freon R12mass flow rate is M = 0.1 kg/s. Let us build a cycle of operation of a stall thermal refrigeration unit in a thermal Ts - diagram for difluoro-dichloromethane (Fig. 8). The presented thermal *Ts* - diagram for freon R12 allows you to determine the thermodynamic parameters of the state at the characteristic points of the cycle of a thermal refrigeration unit. The results of the *Ts* - diagram are summarized in Table 1.

It was found that the heating coefficient remained unchanged at φ = 5.25. To implement the reverse thermodynamic cycle, it is necessary to expend work on the compressor drive. The compressor is driven by an electric motor. The main task in this case is the selection of an electric motor with the smallest power to ensure the economical operation of a thermal refrigeration unit.

To ensure the circulation of freon R12 with a mass flow rate of $M = 0.1$ kg/s, a piston compressor with a 2.8 kW drive is required. To analyze the possible use of a stall thermal refrigeration unit the compressor for a throttling cycle was calculated, results are summarized in the Table 2.

Table 1. State parameters of a cycle of a thermal refrigeration unit

Point number	Working fluid parameters				
	t_i, °C	p_i, MPa	v_i, m^3/kg	h_i, kJ/kg	s_i, kJ/(kg · K)
1	-30	0.1	0.149	559	4.77
2	45	0.75	0.025	596	4.77
3	30	0.75	0.025	587	4.75
4	30	0.75	0.0025	449	4.28
5	20	0.58	0.0025	440	4.25
6	-30	0.1	0.05	440	4.29

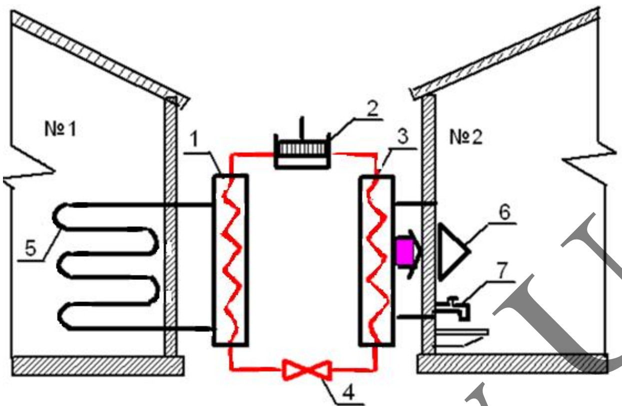

Fig. 7. Layout of a house with a thermal refrigeration unit and an animal stall: 1 - an evaporator; 2 - a compressor; 3 - a condenser; 4 - a throttle; 5- a primary heat exchanger; 6 - a supply grille for supplying heated air to the room; 7 - a hot water mixer.

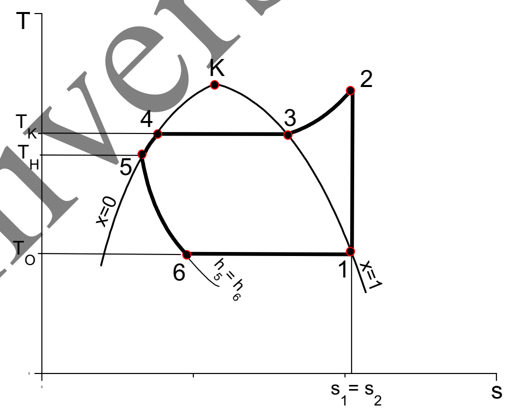

Fig. 8. Operation cycle of a thermal refrigeration unit in thermal *Ts* - diagram for difluoro-dichloro-methane (freon R12)

Table 2. Compressor characteristics of a thermal refrigeration unit

No.	Throttled cycle characteristics	Values	No.	Throttled cycle characteristics	Values
1	G, kg/h	360	8	N'_a, kW	5.46
2	V_D, m^3/h	53.64	9	η	0.725
3	G'	7.5	10	N'_i, kW	7.53
4	λ_i	0.66	11	N_{fr}, kW	2.45
5	λ_W	0.8	12	N_e, kW	9.98
6	λ	0.528	13	q_v, kW/m^3	798.65
7	V_h, m^3/h	101.59	14	K_e	1.19

2 Results and discussions

For the experimental power plant No. 1, which consists of an aluminum corrugated pipeline with a diameter of $d = 0.08$ m and a length of $l = 10$ m, which is placed on the roof of a building to receive the energy of solar rays, a centrifugal fan and an accumulator, a design calculation was carried out based on algebraic equations. It was assumed that the temperature of humid air at the inlet to the pipeline was $t_{f_1} =$ =17 °C, and the temperature of humid air at the outlet of the pipeline varied in the range of $t_{f_2} = 39 \ldots 41$ °C.

According to the accepted value of the velocity in the pipeline, it was found that the volumetric flow rate per second varied in the range of $L = 0.0417…0.045$ m^3/s.

The influence of the volume flow (velocity) of air moving through the pipeline on the efficiency of a stationary technical solar system was studied. The dependence of the efficiency of a stationary technical solar system on the volume flow (velocity) of air is shown in fig. 9. An analysis of the presented graph allows us to establish that with an increase in the volume flow (velocity) of air, the efficiency of a stationary technical solar system increases. This is due to the fact that with an increase in the coolant velocity, the heat transfer coefficient of radiative-convective heat transfer increases and the intensity of heat and mass transfer processes increases.

For experimental power plant No. 2, which consists of a water intake device, a pressure hose, which is a polyethylene pipe with a diameter of $d = 0.025$ m and a length of $l = 5$ m, a hydraulic turbine and an electric current generator, a design calculation was carried out based on algebraic equations.

It was assumed that water moves along the pressure hose with a volumetric flow rate, which varies in the range of $Q = 0.01…0.03$ m^3/s. The available water head is assumed to be unchanged at $H = 3$ m, the efficiency of the turbine is $\eta_{turb} = 0.55…0.95$ and the efficiency of the generator is $\eta_{gen} = 0.96…0.97$. A small hydroelectric power station is operated for 6 months a year due to the freezing of the reservoir in the autumn-winter period, that is, the time is 4320 h. The influence of the volumetric flow rate of water Q supplied to a small hydroelectric power station on the amount of electricity generated by the generator was studied.

The dependence of the volume of electricity E generated by the generator on the volumetric flow rate of water Q is shown in fig. 10.

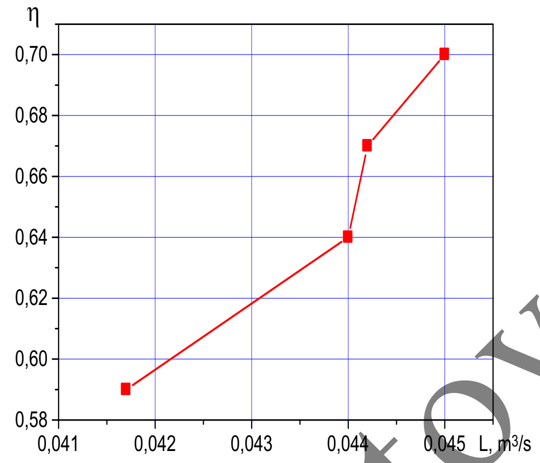

Fig. 9. Efficiency of a stationary technical solar system versus the volume flow (velocity) of air

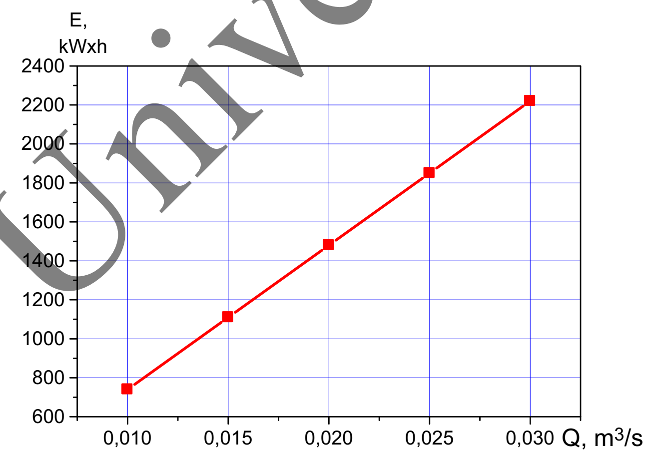

Fig. 10. Volume of electricity generated by the generator versus the volumetric flow rate of water

An analysis of the presented graph allows us to establish that with an increase in the volumetric flow of water entering the small hydroelectric power station, the generation of electric energy by the generator will increase. For the experimental power plant No. 3, consisting of an evaporator located in the animal stall, a primary heat exchanger, a condenser located in a residential building, a compressor and a throttle, a design calculation was carried out based on algebraic equations. It was accepted that the variation range in the volumetric flow rate of R12 freon circulating in the thermal refrigeration unit is $M = 0.1…0.3$ kg/s. Using the thermal Ts-diagram for freon R12, the thermodynamic parameters of the state at the characteristic points of the cycle of the thermal refrigeration unit are determined. It was found that the total cooling capacity varied in the range of $Q_0 = 11.9…35.7$ kW, and the specific work of the cycle remained unchanged at $l_c = 28$ kJ/kg. The theoretical power of the compressor drive of the thermal refrigerating unit varied in the range of $N = 2.8…8.4$ kW. It is established that the cooling coefficient is $\varepsilon = 4.25$, and the heating coefficient is $\varphi = 5.25$.

The effect of the volumetric flow rate of R12 freon circulating in a thermal refrigeration unit on the compressor drive power of a thermal refrigeration unit was studied. The dependence of the compressor drive power on the volume flow rate per second is shown in fig. 11. An analysis of the presented graph allows us to establish that with an increase in the volumetric second flow rate of freon R12, the power to drive the compressor increases. To ensure the circulation of freon R12 in a thermal refrigeration unit with a mass flow rate of $M = 0.1$ kg/s, it is most economical to use a piston compressor with a 2.8 kW drive, since the cost of electrical energy in this case will be minimal.

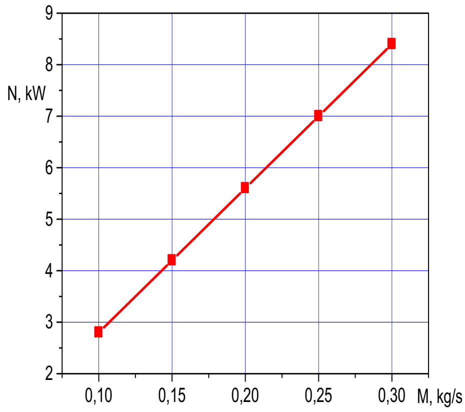

Fig. 11. The compressor drive power on the volume flow rate per second.

Conclusion

1. For the power plant No. 1, using the proposed research method, the variation ranges in the main operating parameters were determined, namely, the volumetric flow rate of the cold coolant is L = =0.0417...0.045 m^3/s, the mass flow rate of air is G = 0.05…0.054. It is recommended to operate a stationary technical solar system at these parameters in order to obtain a coolant temperature at the pipeline outlet of t_{f2}=39…41 °C.

2. The temperature range for the air obtained at the outlet of the pipeline is quite sufficient to ensure the operation of the engineering system that compensates for heat losses in the building.

3. The variation range of the efficiency of a stationary technical solar system for given operating conditions was determined to be η = 0.59 ... 0.7.

4. The temperature of the air at the outlet of the pipeline can be maintained around the clock by using an accumulator (water, granite, pebbles) during those periods of time when there is no solar radiation (at night or in cold weather).

5. The design calculation of the power plant made it possible to establish the operating ranges for changing the main operating parameters. When conducting full-scale experiments using experimental power plant No. 1, it is possible to expand the program of experiments by organizing a developed discretely rough outer surface of an aluminum corrugated pipeline using rings that must be installed on it at the same distance from each other. Periodic destruction of the boundary layer and turbulence of the flow in the region between the ridges is an additional way to increase the heat transfer coefficient, which can be used to increase the efficiency of the power plant No. 1.

6. For the power plant No. 2, using the proposed research method, the variation ranges in the main operating parameters of a small hydroelectric power station were determined, at which it is recommended to operate the power plant: the volumetric second flow rate varied in the range of Q = 0.01...0.03 m^3/s, the set power varied in the range of N_{max} = 171.3…513.9 W, the amount of electricity generated by a transportable hydropower plant for t = 4320 h varied in the range of E = 740…2220 kW·h.

7. A direct relationship was established between the volumetric flow of water entering a small hydroelectric power station and the generation of electrical energy by a generator.

8. The main advantages of a small hydropower plant are mobility, relatively low cost and ease of maintenance. In this regard, if necessary, the electric current generator can be upgraded into a power unit for converting hydraulic energy into mechanical energy, or this power plant can be used to supply water to remote consumers.

9. For the plant No. 3, using the proposed research method, the thermodynamic parameters of the state were determined at characteristic points of the cycle of the thermal refrigeration plant. It was found that the total cooling capacity varied in the range Q_0 = 11.9…35.7 kW, the specific work of the cycle remained unchanged l_c = 28 kJ/kg. The cooling coefficient ε = 4.25, and the heating coefficient φ = 5.25.

10. A direct relationship was established between the change in the volumetric second flow rate of freon R12 and the power to drive the compressor.

11. It was found that the change in the volumetric second flow of freon R12 does not affect the values of the cooling and heating coefficients.

12. The values of the cooling and heating coefficients depend only on the nature of the working fluid circulating in the thermal refrigeration plant.

13. The main advantage of a thermal refrigeration machine with an animal stall is that the use of physiological heat of animals as low-grade heat saves significant costs during construction and operation compared to power plants that use geothermal heat from the earth and the heat of rivers, lakes and rivers as a low-temperature source.

14. The results of the calculation showed that a thermal refrigeration unit with a 10 kW drive with a heating coefficient of φ = 5.25 can provide 52.5 kW of heat. If the animal stall contains 300 pigs or cows, it is recommended to operate the thermal refrigeration unit without an additional energy source.

15. A stall thermal refrigeration plant does not generate thermal energy, but "pumps" it from the environment. At the same time, less electrical energy is spent on the "pumping" of heat than on the generation of thermal energy. Thus, 1 kW of electrical energy gives 5.25 kW of thermal energy.

16. It has been established that for each paid 1 kW of electrical energy, we will receive 4.25 kW of free thermal energy.

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