Analysis of thermal characteristics of a solar heat supply system with thermosiphon circulation

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Abstract-In this paper, the characteristics of the vertical distribution of the thermosiphon in the conditions of the southern region of Kazakhstan are experimentally studied. The design was equipped with several thermocouples for measuring and collecting the provided data using a data logger. The collector temperature has reached 75 °C, and the time to reach the highest temperature is approximately 1.5 hours after the point of limiting the flow of solar radiation. During the sunny period, the temperature of the upper layer of water in the storage tank was 60 °C. This system was demonstrated during the winter days. The measured thermal characteristics of the alignment are in good agreement. At the maximum values of the temperature systems, the average daily efficiency of the system was 52% with the difference between the collector temperature and the ambient temperature. While on other days, the average daily performance of the system is about 50%. The initial temperature in the tank has an impressive effect on the daily return of the system. An increase in the temperature difference between the water temperature and the collector temperature will lead to an increase in the thermal power of the collectors. Compared to other days, the daily efficiency of the system can reach 60% at an initial temperature of 7°.

Keywords-Solar energy; flat solar collector; solar installation; thermosiphone, exergy

I. INTRODUCTION

In, [1], two versions of the solar heater were investigated, which were developed based on the configurations of collector risers modeled in accordance with the conditions of clear and cloudy skies. In, [2], the characteristics of combined solar collectors with vacuum tubes (ETHPSC) were investigated. The central hypothesis is that energy accumulates in a larger volume than in the previous variety. The article, [3], presents storage facilities created for household needs, allowing you to choose the method of heating. In, [4], a new integrated installation with a flat collector was developed - a saline solution evaporator. Comprehensive studies of performance and operational characteristics are carried out by building an experimental system and creating a model of a multiprocessor connection. Studies show that the installation of a coolant by itself reduces the level of radiation in cloudy weather. In, [5], the solar heat supply system was analyzed in order to obtain parameters affecting the accumulation of heat in the environment. The accumulation of radiation is an important accumulation by the coolant of the coolant, the environment, which is crucial for the correct distribution of certain thermal energy required for use in the system In, [6], it was developed to improve the solar heat supply system. Various colors have been developed for vacuum devices with high purification. Several adsorption studies have been conducted. In, [7], thermophysical solutions were developed using various absorbing surfaces, and a study of absorbing panels was presented in order to provide the best heat transfer surfaces. A basic air-protruding plate is also presented. Efficiency indicators for collectors were

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determined, as well as the efficiency coefficient when changing the shape of the surface of the absorbers. A new water heater was introduced in, [8]. Used engine oil is used simultaneously as an absorber and coolant for maximum absorption of solar radiation. The results were very satisfactory, as the design reaches the optimum heating temperature in less than three hours; the average efficiency is 65%, while the maximum reaches 80%. In addition, the design will be able to work from home electricity as an additional power key in case of a shortage of sunlight with the support of a mechanical control device. In the article, [9], contactless thermosiphon solar water heating systems (LT-SW) operating in models of passive and active cycles were designed and experimentally installed, and a comparative study was conducted. The pump led to an overload of the active cycle system, and most of the time there was a slight hydraulic pressure; because of this, the photothermal characteristics in the active cycle mode were worse, regardless of the photothermal linear adjustment, the worst exothermicity was observed. In this article, [10], the design of a thermosiphon consisting of an absorber, a reservoir, and the studied fraction of energy in the reservoir is considered. The study was modeled in various European control points (Athens, Davos, Würzburg, and Stockholm) in accordance with the standard. By reducing the noticeable effect of energy characteristics exceeding 0.8, the design has a great influence on behavior On the contrary, with a reduced volume, fewer values behave the same way in the same place. The results obtained during the work were selected depending on the load. Development research has attracted a lot of attention since the 1970s. Experimental studies of the thermal characteristics of a water thermosiphon were carried out and presented in, [11]. The experimental initial ones for a solar water heater are equal with detailed equations, and there is a discrepancy for the Nusselt criterion and the coefficient, respectively. The results show that the collector guarantees optimal thermal characteristics compared to the PFP collector. This is due to an increase in the concentration of sunlight due to the use of additional mapping planes in the solar collector. In addition, the extraction of the spirally twisted tape forms a disorderly flow inside the riser, which, in turn, increases the thermal characteristics and pressure drop. In, [12], the effect of pipe inserts, economically placed with a rod and gasket, on the heat transfer characteristics and the disagreement indicator in a thermosiphon solar water heater was analyzed. The results showed that the modified helicoidal structures significantly reduce the pressure difference compared to the drop provided by a full-size spiral and increase the joint instant thermal efficiency compared to a normal cylindrical collector. In this article, [13], the decrease in the operational characteristics of thermosiphon solar water heaters with flat plates due to deposits on the water surface is investigated. The study presents an analytical and experimental variety of mass water consumption depending on the thickness of scale in the risers of a normal solar thin water heater for all kinds of galvanic capacities used. In, [14], a combination of a thermosiphon collector and a separate section with corresponding parts was created; a thermosiphon design in which an absolute combination with an isolated circuit is used. In, [15], the composition of field research, literature review, and case study was used. The types of systems, types of collectors, installation technologies, types of additional heat sources, national economic indicators, and various key principles were summarized. Flat solar collectors were most often used, while electric heating elements were mainly known as additional heat sources for SWH systems. The characteristics of the equipped condensed device are illustrated in, [16]. The study examines ways to improve the efficiency of the existing system. In, [17], the energy characteristics of solar air collectors with two unequal plate absorbers, namely flat and trapezoidal plates, where the outlet is reduced and the removal rate increases, were presented. In, [18], exergetic characteristics of various absorbent ribbed collectors were carried out. Exergetic analysis is used to evaluate the energy characteristics of heaters. With a decrease in energy and air flow velocity, it looks like this, [19], consisting of heat pumps connected to a refrigerant. Temperature condenser dryers with heat pump increase productivity. Pressure switches regulate, and thermostats regulate, the temperature of hot water. with a circulation area of 300 liters in Almaty (43.25° latitude, 76.91° longitude) in Kazakhstan. In, [20], a solar heating system is presented, in which devices for heating rooms are developed, and thermodynamic equations with initial and boundary conditions are solved. In, [21], the history of the creation and research of solar energy is shown, and mathematical models of a collector with a system were solved.

The purpose of this work is an experimental study of the thermal characteristics of a thermosiphon solar water heater equipped with a vertical distribution tank in a mild winter in the southern region of Kazakhstan.

II. MATERIALS AND METHODS

Figure 1 illustrates the solar heat supply system.

Fig. 1 Principal diagram of solar-heat supply system 1—heat insulated body; 2—translucent cover; 3—tank absorber; 4-circulating pump; 5—thermal pump; 6—pipeline; 7—THE; 8, 9—thermometers for temperature measuring at inlet and outlet from the tank-absorber and environment; 10—kit of electric measuring devices K 501; 11—autotransformer; 12—tank-accumulator; 13-controller.

The innovation of the provided survey is contained in the fact that there is a direct solar collector, which acts as a heat-insulating clean double-glazed window with reduced pressure, and the coolant is made of stainless thin-walled wavy pipe. The heat received from the solar flux heats the solution in the coils, which is prevented from the collector, and cool liquid from the siphon of the sorting tank acts on its space, and systematic heat circulation occurs. The

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system allows you to track the dependence of the expiration time through the siphon depending on the size of the siphon head and its geometric parameter (the cross-sectional area of the siphon). With increasing water pressure, the hydraulic resistance (friction and local resistance) of the siphon increases, and the fluid velocity increases. Natural convection begins when heat transfer to the heat carrier leads to a temperature difference in the circuits of the thermosiphon solar system. Convection moves the heated liquid up the structure and simultaneously replaces it with a less heated one.

Figure 2 and Figure 3 show diagrams of a new solar heating system. The novelty of this study is also a new design of a flat solar collector. Glazed with a square of 2,03 sq.m (2x1 m) is used as an evaporator (heat source) for coolants R407C and R134a. Inside the solar collector, there is an aluminum sheet absorber with an aperture of 1,78 sq.m. This is attached to the cooler's copper tube with a cross-section of 18 mm filled with either circulating propylene glycol antifreeze substance (volume of 1,6 l) or freon under pressure. The solar collector evaporator is coated with a selective black coating for maximum reception of solar radiation with a minimum reflection coefficient. The absorber plate is located behind the glassed transparent surface with a width of 4 mm, and enclosed airspace (Figure 1). The solar collector's lower part is insulated with a 50 mm width mineral heat shield to prevent heat losses. The solar collector has been designed to gain the maximum heat from the solar radiation which constitutes 2,0 to 2,8 kWh annually per area of the collector, at the latitudes of Kazakhstan.

During this experiment, a piston-type sealed compressor filled with freon R407C was used. To avoid overloading and internal overheating, the compressor has been equipped with an automatic safety shutoff relay. A plate-soldered heat exchanger (condenser) with a thermal load of 6,9965 kW was used. The coolant receiver and sight glass have been installed subsequent to the condenser, dryer, and flow meter filter, which is used for removing moisture content from the coolant. A thermal expansion valve regulates the coolant flow through the solar collector-evaporator. Upon conducting the experiments, the solar collector has been directed to the south at an angle of 45 ^{0}C (latitude 54,1 0N, longitude 71,3 0E, Astana, Kazakhstan) to the horizon.

Thermosyphons and thermal tubes reveal extensive abilities in the creation of inert heat and mass transfer systems. Recuperation of thermosyphon (heat pipes) simplifies the production of the installation and guarantees its highest modularity, maintainability, and reliability. During the studies, the authors created and argued for the installation of a solar collector based on thermosiphons mounted on panels that absorb solar rays.

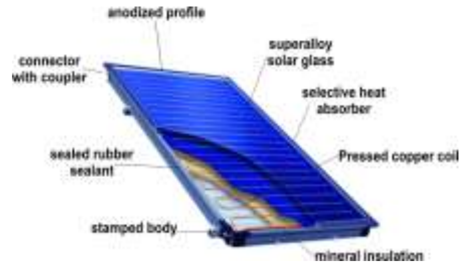


Fig. 2 Solar collector

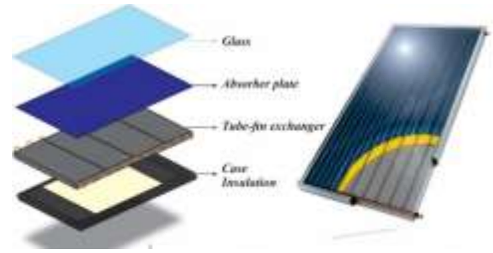
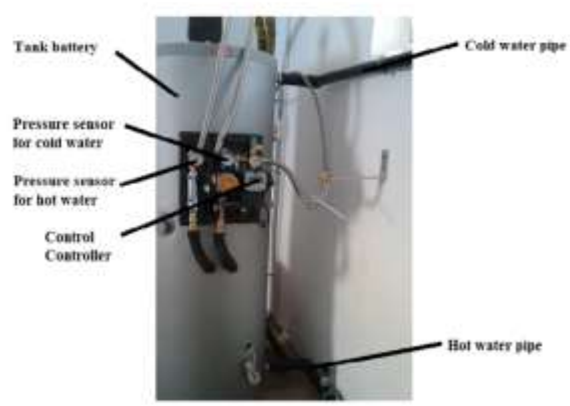


Fig. 3 Sheme solar collector

Fig. 4 Solar heating system.

Figure 4 shows a new single-circuit solar heat supply system with a thermosiphon.



(**a**)

(b)
Fig. 5 a,b. Solar heating system with thermosiphone

Figure 5 a,b shows a solar heating system with a thermosiphon. In a flat solar collector in accordance with the invention: made of fiberboard, instead of a flat pipe, a flexible thin-walled aluminum pipe, a siphon is laid. There is a siphon, as well as a dosing tank. The distribution tank with the solar collector is connected using a metal-plastic pipe. The installation is equipped with an automatically controlled circulation pump. There is also a battery water tank made of galvanized iron, which has a 15 cm thick glass wool insulation, as well as a cover for weather protection.

In the course of the study, it was found that the reduction in efficiency compared with the increase in energy efficiency due to the use of unpainted material minimized. The heat of cool water acts into the resulting flow, heat transfer increases, and the walls of the perineum heat up. in addition, it was investigated that the heat capacity of the solar collector depends on the thickness of the absorbent layer. Having conducted a real experimental study, we were convinced that it is fundamental for the northern regions of Kazakhstan. As a result of experimental training using 50 liters of water, it became likely to heat water from 200 °C to 450 °C in 60 minutes, and the efficiency of a thin plate-shaped collector collected from 40% to 50% if the tubes were placed under the absorbent plate. The results of research on the study of seasonality in winter criteria with thick clouds and cloudless weather were presented.

This model contains an experimental conclusion for the flow velocity satisfying the above equation. The density of water is estimated by the friction pressure shown on a flat solar collector. The intake and exhaust pipes of the collector are calculated by separate nodes with a negligible heat capacity, [1]

$$T_{po} = T_a + (T_{pi} - T_a)\exp[-\frac{(UA)_p}{mC_p}] \quad (1)$$

In the article, [22], a numerical simulation model of thermosyphon solar water heaters was developed, which was compared with test data in two places. The model was used to study the data of vertical and horizontal tank thermosiphon systems. The results show that thermosiphon systems have suitable capacities when the daily volume consumption of the collector is presumably equal to the daily volume of loading. It was found that the thermal conductivity in the horizontal system of one tank significantly reduces the contribution of solar energy.

Equation represents the temperature at the midpoint of any collector node, k

$$T_{ck} = T_a + \frac{I_T F_R(\tau\alpha)}{F_R U_L} + (-T_a - \frac{I_T F_R(\tau\alpha)}{F_R U_L})*\exp[\frac{F' U_L}{G*C_p} * \frac{(k-\frac{1}{2})}{N_x}] \quad (2)$$

The collector parameter F'UL is calculated from

$$G_{test} * C_p \ln(1 - \frac{F_R U_L}{G_{test} C_p}) \quad (3)$$

The total amount of heat in the system is:

$$Q_u = r_c A(F_R(\tau\alpha)I_T - F_R U_L(T_{CI} - T_a)) \quad (4)$$

Specific exergy (ex in kJ/kg) and total exergy factor (Ex in kW) are computed by applying the following equations (1-2):

$$\psi = (h - h_0) - T_0(s - s_0) \quad (5)$$

$$\dot{E}x = \dot{m}\psi \quad (6)$$

The exergy efficiency ($\varepsilon_{(s.collector)}$) of the solar collector is defined according to the formula (7):

$$\varepsilon_{s.collector} = \frac{\dot{m}_r c[(T_2 - T_1) - T_0 \ln(\frac{T_2}{T_1})]}{A\dot{I}\left[1 + \frac{1}{3}\left(\frac{T_0}{T_s}\right)^4 - \frac{4}{3}\left(\frac{T_0}{T_s}\right)\right] + W_p} \quad (7)$$

For experimental studies, a self-recording potentiometer of the brand KSP-4 manufactured in Russia was used. Designed for measuring DC power and voltage, as well as non-electrical quantities converted into electrical signals and active resistance. They work with primary converters whose resistance, including the resistance of the communication line, does not exceed 200 ohms. The maximum supply voltage is 10V. Designed for switching DC and AC 1A electrical circuits with a voltage of 220V. If the current exceeds 1A, an intermediate relay must be used.

The M80 pyranometer with GSA galvanometer is used to measure solar radiation falling on the surface. The M80 pyranometer with GSA galvanometer has a spectral characteristic from 400 to 1100 nm. The pyranometer can operate at ambient temperatures from -50 to +50°C and a relative humidity of 100% at +25 °C. The measurement range of solar illumination is from 1 W/m^2 to 1300 W/m^2, as well as the measurement range of energy effects: from 1 W/m^2 to 500 kW/h/m^2.

The laser thermometer "Center-350" is designed to measure the surface temperature of an object, it applies to various hot, dangerous, or hard-to-reach objects, quickly and safely contactless. The laser thermometer has a temperature range from -20 to 500 ^{0}C. The radiation coefficient for various objects is 0.95. The maximum supply voltage is 9V. The laser thermometer is configured to measure objects in 500 ms, it also has an optical resolution of 8:1.

III. RESULTS

Figure 6 shows the location of the pump. As you can see in this picture, as soon as they started to turn on (at about 8:45) and supply heated water to the house. In this regard, the temperature in the city began to fall, but at 10:25 the temperature began to rise constantly due to weather conditions. The temperature in the tank reaches the limit values after 15:00, during this period the pump in the tank is turned on and cold water is supplied (temperature 15 ° C), so the temperature has a jumpy appearance.

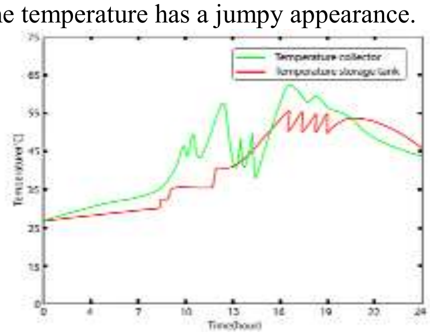


Fig. 6 Temperature dependence on time in the collector and tank with heat pump regulation in the liquid flow.

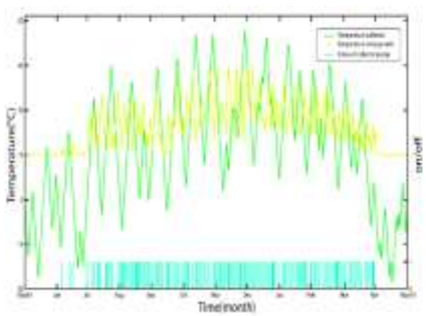


Fig. 7 Comparison of ambient temperature versus time.

Figure 7 shows a comparison of ambient temperature with time. The water supply in the storages increases from May to December since favorable weather is observed in the south of Kazakhstan at this time, and from January to February the temperature decreases. The temperature of the collector pump from June to November works normally, the collector works under the influence of electrical energy.

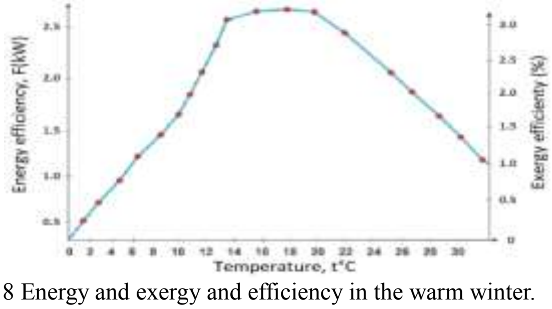


Fig. 8 Energy and exergy and efficiency in the warm winter.

Figure 8 shows energy efficiency and exergy in a warm winter. As mentioned above, the experimental work was carried out in the warm winter of Southern Kazakhstan, it was found that energy efficiency has a maximum value in the summer months and is 2.5 kW, while the exergy efficiency reaches its maximum value in the winter months of 3%. In winter, the increase in the temperature of the liquid in the collector is insignificant, so the collected exergy decreases. The useful energy and thermal efficiency of the system increases with increasing solar radiation, as well as the share of solar energy, mainly due to the fact that the thermal efficiency of collectors depends on the ambient temperature, the operating temperature of collectors, and solar radiation. Since the operating temperature of the collectors corresponds well to the transformation temperature of materials for energy storage with a phase transition, and the fluctuations in the ambient temperature are small and negligible, the efficiency of the collectors increases with increasing irradiation is based on the assumption that the ambient temperature and the operating temperature of the collectors are unchanged. These values of energetic efficiency are related to three main factors: ambient temperature, the need for chilled water, and direct solar radiation since they determine the operating mode of the system itself. The winter months represent the lowest ambient temperature values and therefore the lowest need for cold during the day. This directly affects the operating conditions of the system, since it hardly works in optimal conditions, which leads to a low overall efficiency (0.99%). On the other hand, in winter it represents the maximum value reached by the system (3%), which is consistent with the maximum recorded temperatures, the maximum solar radiation reached, and the greater need for cooling.

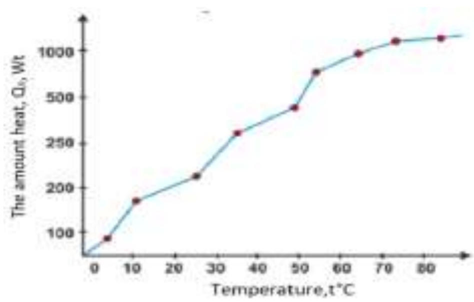


Fig. 9 The amount of heat coming from the collector into the battery tank.

Figure 9 shows the dependence of the amount of heat coming to the battery tank heating temperature. In temperature criteria, the greatest property of the average daily system performance is 52% with difference between the collector temperature and the ambient temperature. While on other days, the average daily performance of the system collects approximately 50%. Compared to other days, the daily efficiency of the system is perhaps 60% at the initial temperature of 7 °.

The main contribution to this study is the characteristics of a thermosiphon heater equipped with a vertical distribution tank in a mild winter in the southern region of Kazakhstan. The solar collector was designed in such a way as to receive the greatest amount of heat from solar radiation, which accumulates from 2.0 to 2.8 kWh per year per collector area in the latitudes of Kazakhstan. During this experiment, a sealed piston compressor filled with R407C freon was used. A solar structure with thermosiphon circulation was also created, which is a glazed gap with a reduced coolant content made of aluminum. The solar station has a metering tank, which is connected to a flat solar collector using a metal-plastic pipe. In addition, there is a water storage tank made of galvanized iron, which has a 15 cm thick glass wool insulation, as well as a cover for weather protection. During the pilot operation, the collector temperature reached 75 ° C, and the time to reach the highest temperature is about 1.5 hours after the point of the greatest flow of solar radiation. During the sunny period, the temperature of the upper layer of water in the reservoir for the sake of preservation was 60 °C. The results showed that the increases with an increase in the temperature of the heat pump evaporator within the range considered in this paper. Thus, flat solar collectors are better suited for operation in winter. The condenser in the thermal pump functions for heat transfer from the working body to the water, since it is heated. As a result, the working body transforms from a steamy state into a liquid, i.e., it condenses. To the thermal pump condenser, a jacket-tube construction is most frequently applied. The water being heated then passes inside the tubes, and a working body condenses at the pipes outer side in annular space. This confirms that a major part of steam (above 99%) condenses in the zone of mass condensation, where it permeates a comparably small amount of air. The temperature of the saturated steam does not usually exceed 50–60 °C. In the cooling zone, the partial steam pressure is less, and the steam-air mixture temperature is lower. In that zone, it is possible the condensate is subject to overcooling, which is not favorable for the installation’s efficiency on the whole. Proceeding from graph experimental data, it is seen that the higher the cycle’s cooling capacity in the cycle, the bigger the amount of the process cycle’s internal energy in the thermal pump that is released, which is confirmed with the first law of thermodynamics.

IV. CONCLUSIONS

In this paper, the characteristics of a thermosiphon solar water heater equipped with a vertical distribution tank are experimentally investigated in conditions of mild winter in the southern region of Kazakhstan. The system was equipped with several thermocouples for measuring and collecting data using a data logger. With the help of a pyranometer and a thermometer, the temperatures of the solar collector on a clear day and in the tank were recorded. On a sunny day, the temperature of the upper water layer in the storage tank was 60 °C. During the study, it was recorded that a sudden drop in solar insolation at about 13:30 was detected on the absorber plate with a delay of one hour. The maximum temperature on the absorber plate is reached at 15:00 when it reaches 85 °C. On this day, the maximum energy falling on the absorber plane is 1000 W/m^2. It has been experimentally proved that in the southern region of Kazakhstan, under the influence of high solar radiation, it is possible to introduce such installations for heating a building and a room. In our opinion, the results have been achieved. They have scientific significance for this study. The main points of the achieved goal are a new design of a flat solar collector, a new design of a solar heat supply system, as well as the use of devices for experimental research of the characteristics of a thermosiphon solar water heater equipped with a vertical distribution tank was carried out in a mild winter in the southern region of Kazakhstan. In the course of the experiment, the most noticeable root cause of this action seems to be an impressive decrease in the properties of energy. The highest value of the average daily performance of the system was 52% with a difference in ambient temperatures. The temperature of the collector will lead to an increase in power on other days, the daily efficiency of the system can reach 60% at an initial temperature of 7 °. This study was conducted for flat plate collectors in the colder climate of Kazakhstan, with the experiment being conducted during the winter months. In this study, the method of the thermal characteristics of a glazed flat collector was used, which contains a brief and accurate interpretation. As a result of experimental work using 50 L, water can be heated from 200 °C to 450 °C in 60 min, and the efficiency of a flat plate collector varied from between 40% to 50% when the tubes were located under the absorbing plate. The results of experiments on seasonality in winter conditions with dense clouds and sunny weather are presented. It has been experimentally established that the power generated by a flat solar collector ranges from between 1.6 to 2.2 and from between 2.3 to 3 kW/m^2. The increase in power is explained by the absence of optical losses during the passage of solar energy through the glazing as well as the significant decrease in resistance to heat flow. This study confirmed that the solar-heat supply system in the future will produce new neural networks and predictive machine learning as well as learning.

The direction of future research is related to the numerical analysis of the solar heat supply system using TRNSYS.

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Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Temirbaeva Nazgul, Andaeva Zamira, and Osmonov Ysman carried out the simulation and the optimization.

Toktassyn Ayaulym, Tolepberdinova Ardak has implemented the Algorithm

Telgozhayeva Farida, Kunelbayev Murat has organized and executed the experiments of Section 4.

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