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To one of the tasks of modernization of boiler houses using flat plate solar collectors

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ABSTRACT

The article discusses the research and development of solar heating systems for application in traditional boiler houses. The rationale for the selection of the principal scheme of a solar installation was conducted. Issues of collector field strapping schemes, tank-accumulators strapping and connection to the boiler house piping were worked out. Thermomechanical calculations on assessing the intensity of solar radiation, the choice of radiation angle of inclination of solar collectors, inter-row distance of collectors were carried out. The issues of power supply, automation and ecology are considered.

Keywords:
Solar Collector; Collector Field; Storage Tank; Boiler House; Heat Exchanger; Solar Hot Water Supply System

1. Introduction

Currently, in the field of heat power, new innovative technologies are taking place more and more, associated with the use of environmentally friendly, alternative renewable energy sources of the solar, wind, small rivers, geothermal energy, etc. [1-4]. The most widely are the systems of solar heat supply, providing consumers with hot water and heating [5-7]. The use of solar energy provides not only the savings of traditional hydrocarbon fuels like coal, gas, oil, etc., but also seriously affects environmental issues [8-9].

The Kyrgyz Republic is a very promising country in terms of its geographical position and level of intensity of solar radiation. Thus, the average annual density of solar radiation is in the range of 700-1100 W/m^2, and the duration of sunshine is 2600-2800 hours per year [6]. In addition, it should be taken into account that the Republic is experiencing a huge deficit in traditional fuels like coal, liquid crude oil, gas, etc., which it is forced to purchase from neighboring countries like Kazakhstan, Russia, and Uzbekistan for currency. In particular, one should note the work of 2 of our THPs in Bishkek and Osh, which annually import coal for their work, including many rural, district, regional and departmental boiler houses that today use coal. This work is related to the growth and design of a solar hot water system for the district boiler house "Rotor" in the Djal microdistrict in Bishkek. In

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2005-2009, a joint group of scientists from Germany led by Professor Fain and from Kyrgyzstan under the leadership of Professor Obozov conducted research and the results of experimental data obtained directly at the installation located on the boiler house showed the economic feasibility and promise of such a solution [11]. In the work we will consider the issues of choosing a schematic diagram of a solar hot water supply system, consider and solve schemes for connecting to a common collector field, provide schemes for connecting the collector field with storage tanks and existing heating networks of the boiler house.

2. Rationale and Selection of a Principal Scheme

2.1 Schematic Diagram of a Solar Installation

The Rotor boiler house operates according to the combined heat supply scheme, when hot water is supplied simultaneously for both heating and hot water supply, therefore, periodically it is necessary to supply additional water to the system to compensate for its consumable part by consumers. Before installing the solar system, this was done by filling a certain amount of prepared water (from the chemical water treatment workshop) in storage tanks with a total volume of 800 m^3, followed by its supply to the network. In addition to chemical water treatment, no heating of the water is performed. That is, cold water is almost reversed. The aim of the work is to research and create a solar installation that would heat this cold water to a certain temperature and then feed it into the "return" network.

For systems designed to work year-round, both in the spring-autumn and winter periods, as a rule, multi-circuit systems are used. In practice, their rather large variety. In Figure 1 shows some of the most common [6-7].

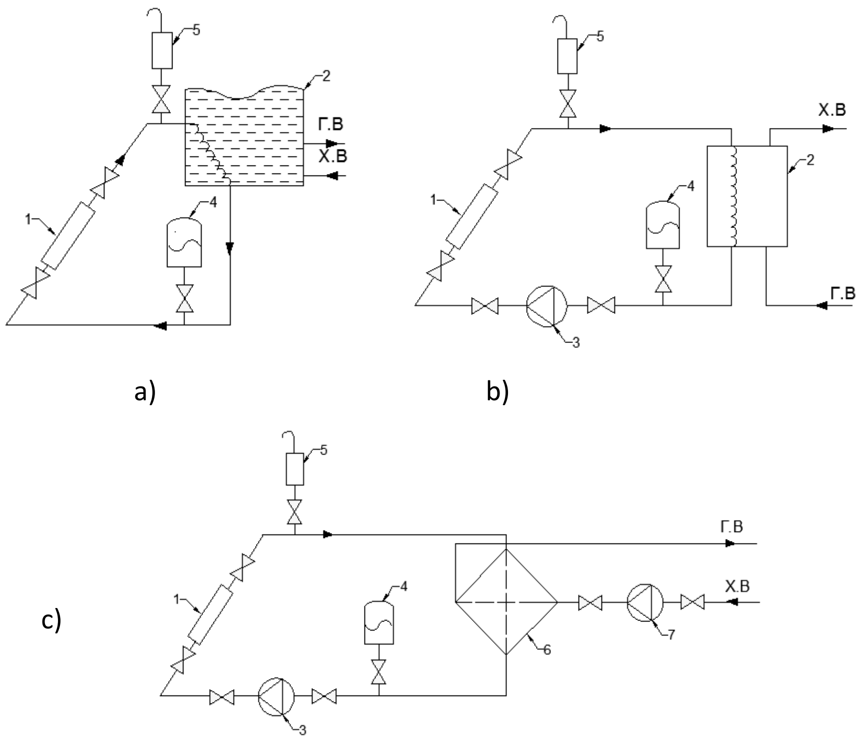

Fig. 1. Multi-circuit schemes for solar hot water a) with natural circulation, c) with forced circulation, c) with a high-speed heat exchanger. 1 - solar collector; 2 – tank-accumulator; 3 - solar circulation pump; 4 - expansion tank; 5 - air vent; 6 - high-speed heat exchanger; 7 - feed pump

A comparative analysis of various possible solar installations, taking into account the peculiarities of the operation of the Rotor boiler house and its water heating technology, made it possible to determine the circuit diagram presented in Fig. 2.

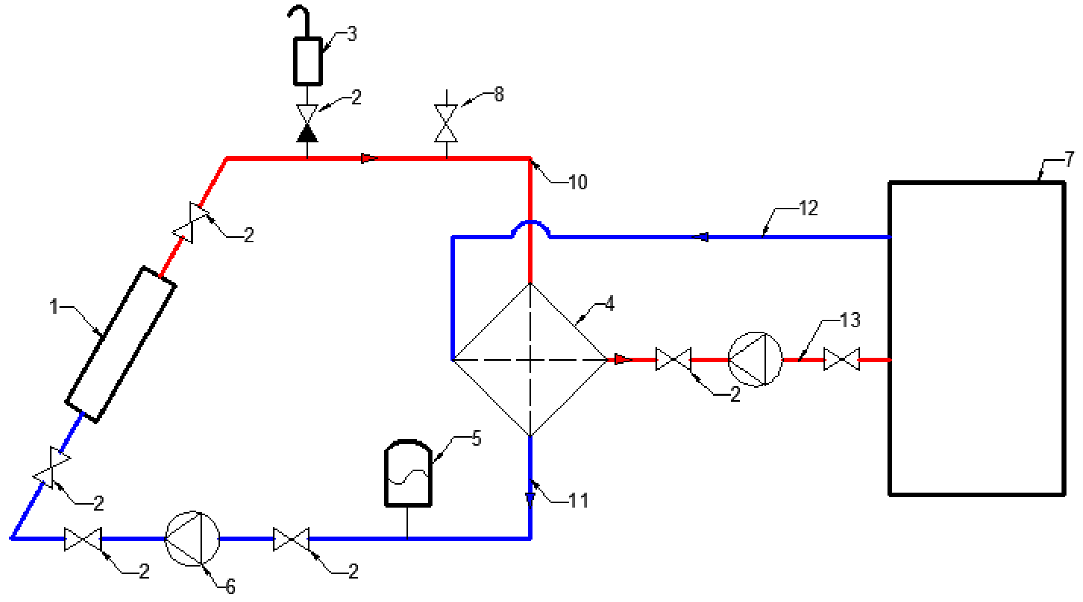

Fig. 2. Schematic diagram of a solar installation. 1 - solar collector field; 2 - valves; 3 - air vent; 4 - high-speed heat exchanger; 5 - membrane expansion tank; 6 - solar circulation pump; 7 - consumer (boiler house); 8 - safety valve; 9 - pump for supplying water to the boiler network; 10 - solar hot water pipeline; 11 - cold water pipeline of the solar circuit; 12 - cold water pipeline; 13 - hot water pipe

The installation works as follows. Initially, the solar circuit is filled with non-freezing liquid (the fuel tank is not shown in this diagram). When it is filled, the valve 2 of the air inlet 3 is open. As it fills, the air in it is etched through it. After filling is complete, the air vent valves are closed and the circuit is ready for operation. Under the influence of solar radiation, the heat carrier in the solar collector heats up and enters the high-speed heat exchanger 4 through pipeline 10. In the heat exchanger, the heat carrier transfers its heat to the second circuit in which cold heated water flows and returns via the pipe 11 to the solar collector. Thus, the conversion and transmission of solar energy to the consumer occurs. The pump 6 circulates the coolant in the circuit. Shut-off valves 2 installed in front of the entrance and exit of the solar collector are necessary for technological ways of repairing the collector field and ensuring equal hydraulic resistance in the branches of the solar field by adjusting the flow rate of the coolant. The expansion tank 5 of the membrane type provides compensation for excess pressure in the solar circuit resulting from volumetric thermal expansion of the coolant. Valves 2 before and after the circulation pump are technological (necessary for installation and repair work). The safety valve 8 is designed to relieve high pressure arising in an emergency. As you can see from the circuit, the heated process water in a high-speed heat exchanger is pumped to a boiler room using a pump 9 for connection to a heating network.

2.2 General Schematic Diagram of a Solar Installation

To ensure the efficiency of the solar installation, taking into account the possibilities of placing solar collectors on its territory and the operating experience of previously constructed plants, it was decided to place 396 solar simple collectors on the roof of a boiler house with a total area of 1000 m^2.

It was proposed to divide all the equipment into 2 groups, each of which can independently work and then combine them into a single system by means of a parallel connection, which ensures joint operation in the boiler room network. Based on this concept, we have implemented a scheme that ensures this principle of operation, as shown in Fig. 3.

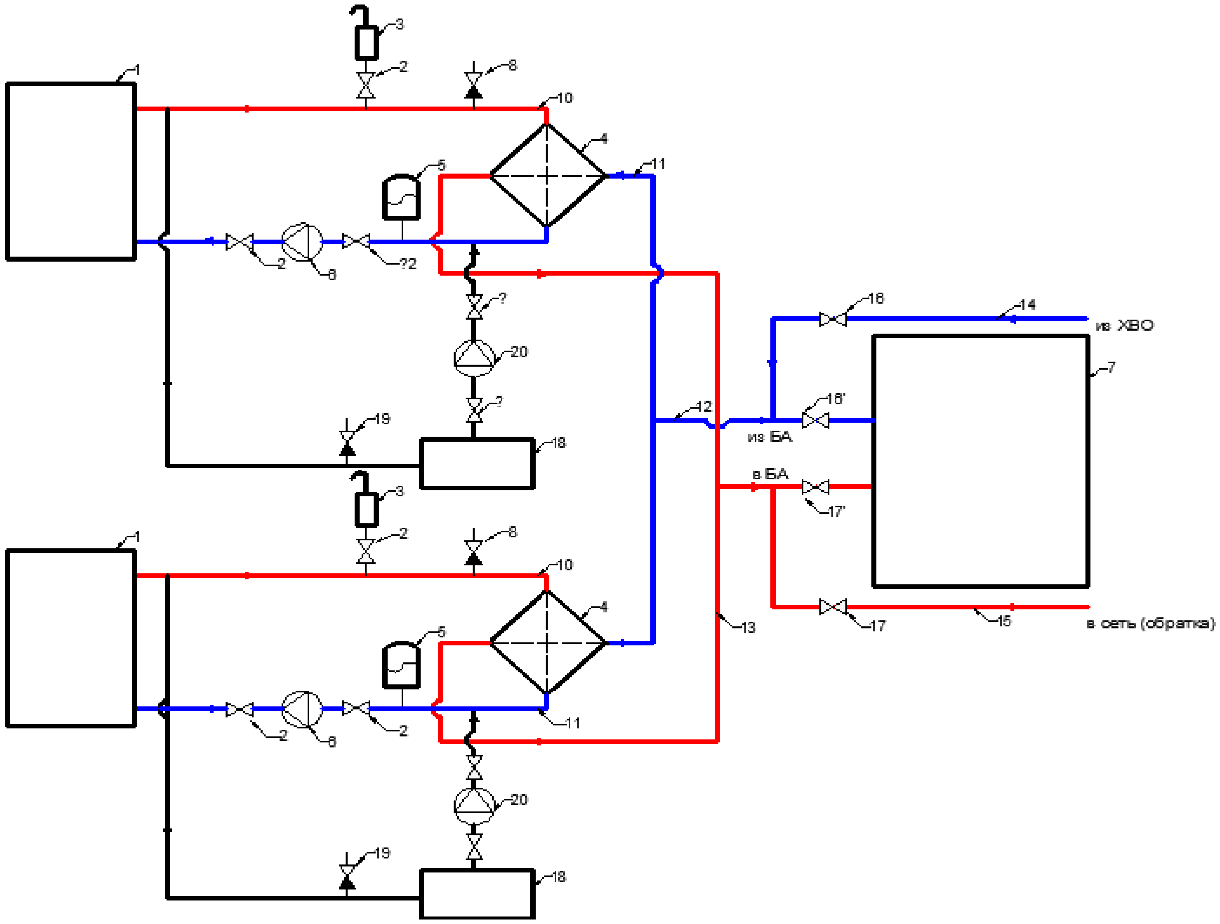

Fig. 3. General schematic diagram of the rotor solar hot water supply system. 1 - Solar collector field of 200 collectors with a total area of 500 m2; 2 - shutoff valves; 3 - air vent; 4 - high-speed heat exchanger; 5 - membrane expansion tank in each block of 4 pcs.; 6 - circulation pumps of the solar circuit; 7 - valve; 8 - safety valve; 9 - valves of the make-up circuit; 10 - solar hot water pipeline; 11 - cold water pipeline from the boiler room network; 12 - hot water pipeline to the boiler room network; 13 - cold water pipeline from the boiler storage tank; 14 - hot water pipeline to the boiler storage tank; 15 - valves of the corresponding pipelines; 16 - make-up tanks; 17 - safety valves; 18 - make-up pump

As you can see the general scheme consists of 2 independent units that work autonomously independently. The operation of each of them is identical to the description of the operation of the circuit given by us in the previous section of the work. The general scheme under consideration shows the possibility of combined joint work of these units directly to a single boiler house.

When the amount of coolant in the solar circuit decreases, the make-up pump 2 is turned on which supplies the coolant to the circuit from the make-up tank 18. In the event of an emergency, when for some reason the system stops working in the hot season, additional pressure appears in the solar circuit due to increased coolant temperatures and as a result of its volume expansion. A safety valve 19 is provided for this.

The presented circuit in Fig. 3 provides for the operation of the system in 2 modes. The first is the main and the second emergency. When operating in the main mode, the heated process water in a high-speed heat exchanger is immediately fed through the pipeline 15 to the network (return) of the Rotor boiler house, cold water from the chemical water treatment plant goes directly to the high-speed heat exchanger. In this case, the valves 16 and 17 are closed, and the valves 16 'and 17' are open.

In an emergency situation, when, for example, the electricity is turned off and the main pumps of the boiler house, the water supply to the return network are stopped, the supply of hot water to the consumer naturally stops. At this time, in order to avoid overheating of the coolant in the solar circuit, the circulation pumps 6 are powered by a stand-alone power supply, and the heated water passing through the high-speed heat exchanger is not supplied directly to the return network, but to the reserve capacity of the storage tank, which is 800 m3. Accordingly, the heated cold water also enters the high-speed heat exchanger from the storage tank (this storage tank is not shown in the diagram) through pipeline 16.

3. General Diagram for Lining the Collector Field and Heat Networks

One of the most important elements in the design of solar heat supply systems is the assembly of individual thermal solar converters (collectors) in a common helio-field. In practice, there are three types of compounds - parallel, serial and mixed. Series connection, as a rule, is used in cases when the consumer needs a high temperature of hot water for technological needs. This connection scheme is used for small-capacity consumers (private homes, small campsites, camps, etc.). Parallel connection is mainly used for large enough circuits and where there is a need to regulate and control the temperature of the heated water. For such compounds, efficiency significantly higher than with a serial connection (less heat loss).

3.1 Collector Field Piping

In our case, the system provides for the regulation of the temperature of the heated water, secondly, the parallel operation schemes of 2 blocks of the solar installation are determined, and finally, our system is quite powerful, where 396 collectors with a total area of 1000 m2 work simultaneously. In this embodiment, preference should be given to parallel connection, according to the so-called associated circuit.

When forming a helio-field, we will adhere to the principles of modularity of a standard block of solar collectors, that is, a helio-field created is based on a modular block. The size of this block and the number of installed collectors in it, we took into account the possibility of placing the entire helio-field on the roof of the boiler house, taking into account the area of the supporting truss on which they are attached. Scheme of adopted module with strapping 8 collectors in a single block is shown in Fig. 4.

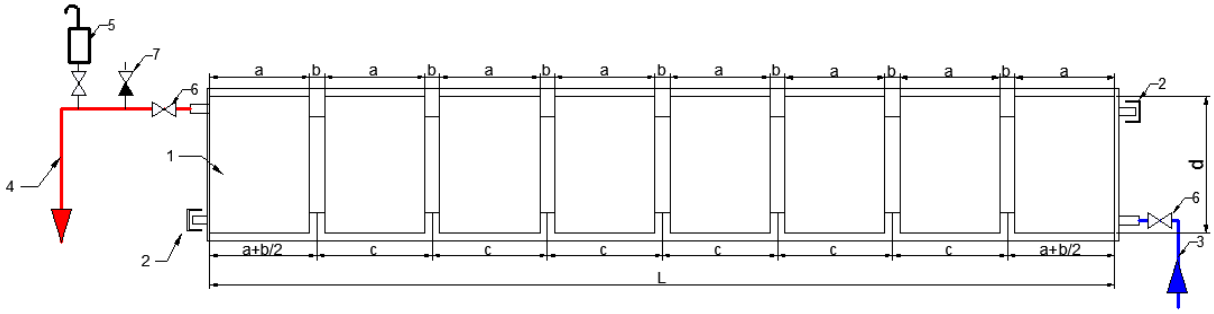

Fig. 4. Scheme for piping a standard module of the solar field of collectors. *1 - solar collector; 2 - stubs; 3 - cold water pipeline (glycol return); 4 - hot water pipeline (glycol supply); 5 - air vent; 7 - safety valve; 6 - adjustable valves*

As can be seen from the circuit, 8 collectors are interconnected in parallel. Connecting the module to the main pipelines is carried out according to the associated scheme. That is, the cold water pipeline is connected to the first collector to the lower pipe, and the hot water pipe to the output upper pipe of the last collector. Such a scheme makes it possible to provide, under equal conditions, each collector located in the module. This means that the flow rate of the coolant in all collectors is the same, as a result of which the temperature difference of the coolant is only one, and therefore, with proper adjustment, the efficiency of all collectors will be the same and the system as a whole will work with the maximum efficiency. To eliminate the possibility of air jams, the entire module should be installed at a certain angle, at which the lowest point will be at the place of supply of the cold water pipeline, and the highest at the place of supply of the hot water pipeline. The slope must be at least 0.01. Such an installation allows, during the initial period of filling the solar circuit with the coolant, to etch all the air in the system through the air vent 5. Upon completion of filling the circuit with the coolant, the air vent valve closes. As can be seen from the diagram between the collectors there is some space. This is done in order to reduce the windage of the installation and thereby reduce the wind load. Secondly, it is necessary for the technological needs of the assembly and installation of the module. Valves 6 are provided for equalizing hydraulic resistance in all collectors of the entire heliofield by regulating the flow of coolant. The numerical values of the geometric dimensions of the module are given in Table. 1.

Table 1
Geometrical dimensions of the module

Unit	AND	b	C	d	e
mm	1230	100	1330	2030	10540

A complete connection diagram of all 396 collectors into a single helio-field based on the presented module is shown in Fig. 5.

A mixed parallel-serial connection scheme is used here. That is, the collectors in the module are connected in series. The modules are interconnected in parallel, while the principle of the associated circuit is maintained. Based on the calculation of the area of the supporting structure, it was decided to place all the collectors in 11 rows of four modules in a row. That is a total of 396 pcs.

$$(11x10)\ x2 + (11x8)\ x2 = 396 \text{ pcs. collectors.} \quad (1)$$

Moreover, the system, as we showed earlier, consists of 2 independent blocks. In the general presented scheme, it can be seen that 2 blocks of solar collectors consist of 198 pcs. in each block.

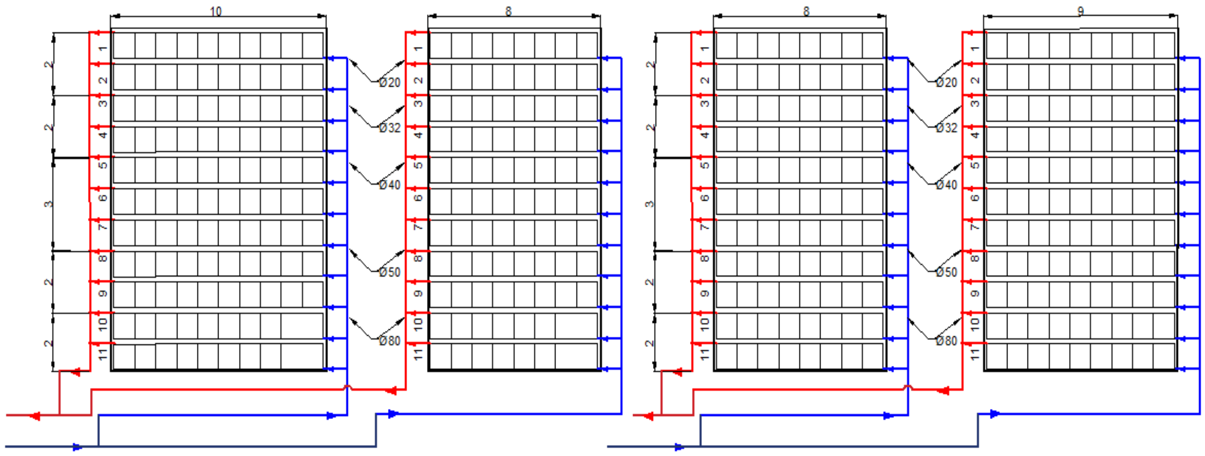

Fig. 5. General scheme for connecting solar collectors in the solar plane. Note: a - distances are presented in the constructive part; pipe diameters are given for a block of modules of 5 pcs

3.2 Diagram of the binding of tank-accumulators and connection to the boiler house networks

The general layout of the binding of the tank-accumulators and the connection of the main pipelines of the solar installation to the boiler house networks are shown in Fig. 6.

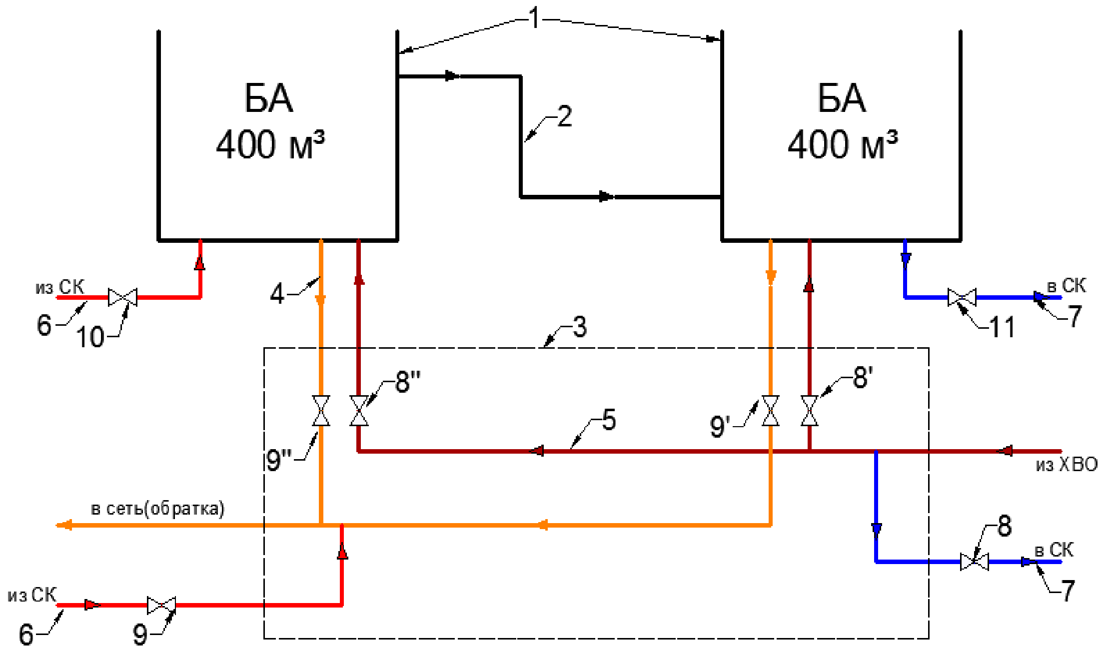

Fig. 6. The layout of the binding of the tank-accumulators and connection to the boiler house networks. *1 – tank-accumulators; 2 - connecting pipeline; 3 - distribution chamber; 4-5 - existing pipelines, boiler house networks; 6 - cold water pipeline from a solar installation; 7 - cold water pipeline of a solar installation; 8.8 ', 8 ”9.9'9” 10-11 shut-off valves*

As previously noted, the system provides for the operation of the installation in two modes. The first main operating mode, in which the solar installation heats the water and supplies it directly to the boiler return network. In this case, the system operates as follows. Pre-treated water from the chemical shop. Pipeline water treatment is supplied to the solar circuit through pipeline 7. At this time, valve 8 is open, and valves 8' and 8” are closed. Cold water passing through the solar installation heats up and returns to the return network, respectively, in this case, valve 9 is open, and valves 9' and 9” are closed. That is, in this operating mode, water bypassing the battery tanks immediately goes directly to the solar circuit of the installation and then is fed into the return network for supply to the consumer.

The second mode involves the operation of the installation during a power outage in the network or some other emergency. Thus, for example, in the event of a power outage, the main boiler house pumps supplying water to the network may stop, then the water supply to the solar circuit of the installation will stop and the system may overheat, that is, it is possible that the coolant in the collectors boils and its destruction can occur. To avoid this, the system provides the option of switching the collector field to the backup tank-accumulators 1. In this case, when the main power supply is turned off, the boiler backup power supply (diesel generator) is turned on, which can provide the solar installation circulation pumps and backup circulation pumps connecting the solar system to storage tanks. And then cold water is not supplied to the solar installation from the chemical workshop water treatment, and from storage tanks. At this time, valve 8 is closed and valve 10 is open. Accordingly, hot water from the solar installation is supplied to the storage tank through line 6. At this time, valve 10 is open and valve 9 is closed. In this case, heat exchange occurs in the high-speed heat exchanger. In the collectors, the coolant does not overheat, and hot water accumulates in the tanks.

4. Thermo-Channel Part

4.1 Calculation and assessment of the intensity of solar radiation

To ensure the effective operation of the solar installation, it is necessary first of all to know the intensity of solar radiation at the installation site.

Table 2
Measurement data of solar radiation in Bishkek

Month	1	2	3	4	5	6	7	8	9	10	11	12
E_{Σ}, MJ/m^2	7.56	10.13	12.28	17.37	21.6	25.16	24.3	21.73	17.37	11.61	7.09	5.8
E_D	3.91	5.36	6.34	7.78	6.91	7.78	7.56	6.48	5.56	4.86	3.34	3.1
$t.°C$	-5.6	-3.2	3.8	11.4	16.9	21.3	24.1	22.6	17.3	10.1	2.2	-2.9

The data in Table 2 is the intensity of solar radiation according to meteorological data of Bishkek on a horizontal surface.

Based on the obtained initial data, we calculated the average monthly total density data of the level of solar radiation using the Meteonorm software product. The calculation results are summarized in Table 3.

Table 3
The total monthly average density of solar radiation

N_{n-n}	1	2	3	4	5	6	7	8	9	10	11	12
kW/m²	62.55	78.11	127.6	154.9	195.11	200.9	219, 3	187.5	157.99	108.9	69.2	47.3

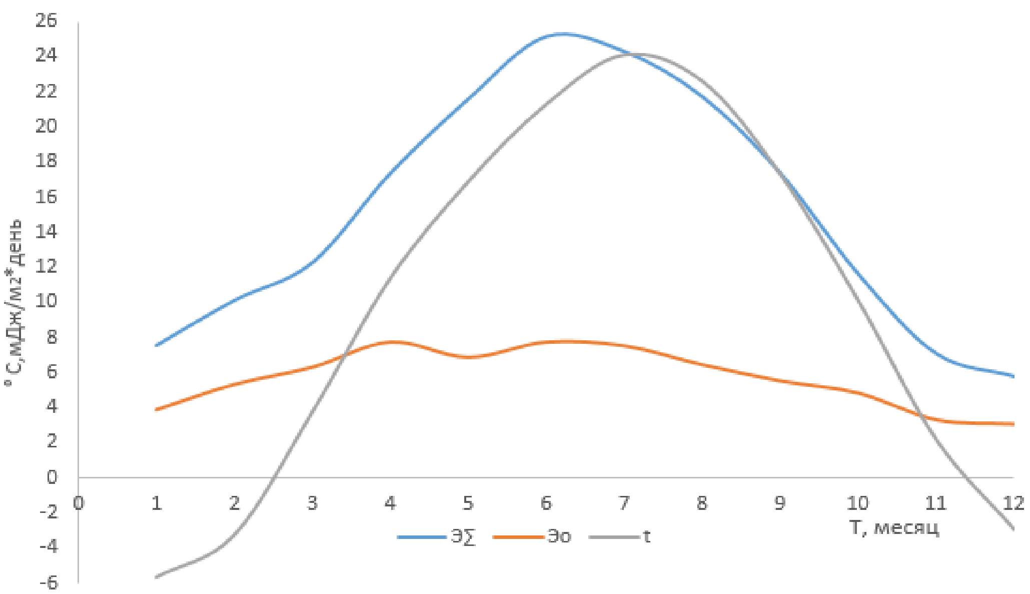

Fig. 7. Graphical dependence of the daily intake of total E∑ of diffuse (diffuse) solar radiation and temperature t by months E_0

4.2 Calculation of the Rational Angle of Inclination of Solar Collectors

In the operating mode of the Rotor boiler house, the most important period for producing hot water is the summer period, which is characterized by the highest water consumption by the consumer, therefore, we determine this period as the most preferable for the operation of the solar installation. Based on this, taking into account the calculation of the maximum and minimum angles of declination of the sun above the horizon, it was found that then, respectively, the angle of inclination of the solar collector to the horizon will be $\delta_{\text{cp}} = 12{,}5°$

$$\alpha = \varphi - |\delta_{\text{cp}}| = 42{,}8 - 12{,}5 = 30{,}3°. \quad (2)$$

4.3 Calculation of the Row Spacing of the Collectors

When installing solar system, it is necessary to choose the rational value of the row spacing. It is clear that if the solar collectors are stationary, the angle of incidence of solar radiation on its surface will change not only during the day, but throughout the year. Therefore, we calculated the rational angle of inclination of solar collectors, taking into account the annual average, a change in the declination angle.

Given the angle of inclination $\alpha = 30°$, it is necessary to calculate the rational inter-row space. In the calculation, in addition to the angle α, the geometric parameters of the collector should be taken into account. The scheme for calculating the row spacing is shown in Fig. 8. It was taken into account that during the period of maximum intensity of solar radiation, its incidence on the collector surface would be perpendicular to the angle of inclination α.

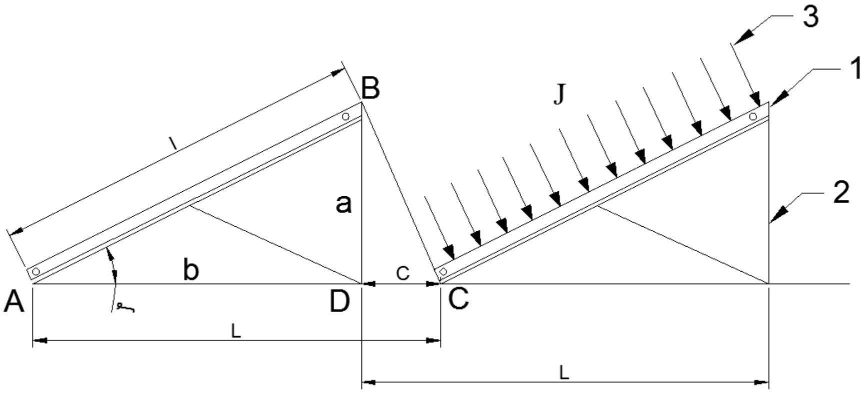

Fig. 8. Layout of the solar collector on the supporting farm. *1 - Solar collector; 2 - reference farm; 3 - solar radiation; L - row spacing*

The initial technical parameters of the used solar collector, the overall parameters, respectively, are 2030 mm long, 1230 mm wide and 93 mm thick.

Therefore, in our calculation scheme, in the rectangle, the triangle of the AVD AB, there is the hypotenuse AD and DB - respectively, legs. Therefore, the length AB = l is the length of the solar collector, i.e., l = 2030 mm

Then the value of AD = b = l·cosα

b = 2030· $cos30° = 1758$ mm. (3)

A ray of sunlight hits a collector that casts a shadow. The distance DC = c is the shading zone. Where the next row of collectors should not go. We determine this distance from the consideration of 2 rectangular triangles ABD and DBC. From the first triangle we determine the size of the leg BD equal to a. That is

$a = l \cdot sin\alpha = 2030 \cdot sin30° = 1015$ mm. (4)

The value of BC will accordingly be

$$cos30^0 = \frac{a}{BC}. \quad (5)$$

$$BC = \frac{a}{cos30^0} = \frac{l \cdot sin\alpha}{cos30^0}. \quad (6)$$

$$BC = \frac{2030 \cdot 0,5}{0,866} = \frac{1015}{0,866} = 1172 \text{ mm}. \quad (7)$$

Then $DC = \sqrt{(BC)^2 - a^2} = \sqrt{1,373 - 1,03} = 0,585$ mm.
Hence

L (8)= $1758 + 585 = 2343$ mm.

Thus, the minimum length between the rows of collectors can be taken equal to 2500 mm.

5. Power Supply

The power supply for the adopted circuit is an indoor switchgear with two transformers 1000/10/0.4, one of which is a backup. Power supply from the specified switchgear is carried out for the receivers of the boiler "Rotor". The number of power consumers, the installed and estimated power of power consumers is determined by the boiler house electrical equipment.

The main electrical equipment of the solar system installed on the Rotor boiler house is a controller for controlling the solar system - 1 pc., A pump for the solar system - 2 pcs., An electric control panel - 1 pc.

This electrical equipment provides the solar system, consisting of solar collectors with a total area of 1000 m2. The solar system is divided into two parallel working groups of 500 m2. In turn, each group consists of 25 subgroups of collectors of 8 pcs. collectors in each. Each pump provides a group of collectors. The controller provides control over the entire system.

5.1. Schematic diagram

Figure 9 shows a circuit diagram of a power supply of the main electrical equipment of the solar system. The circuit ensures the reliability of the system. This circuit allows electrical equipment to function reliably in specified operating modes. The simplicity and cost-effectiveness of the designed circuit is ensured by the use of standard equipment and standard (normalized) nodes.

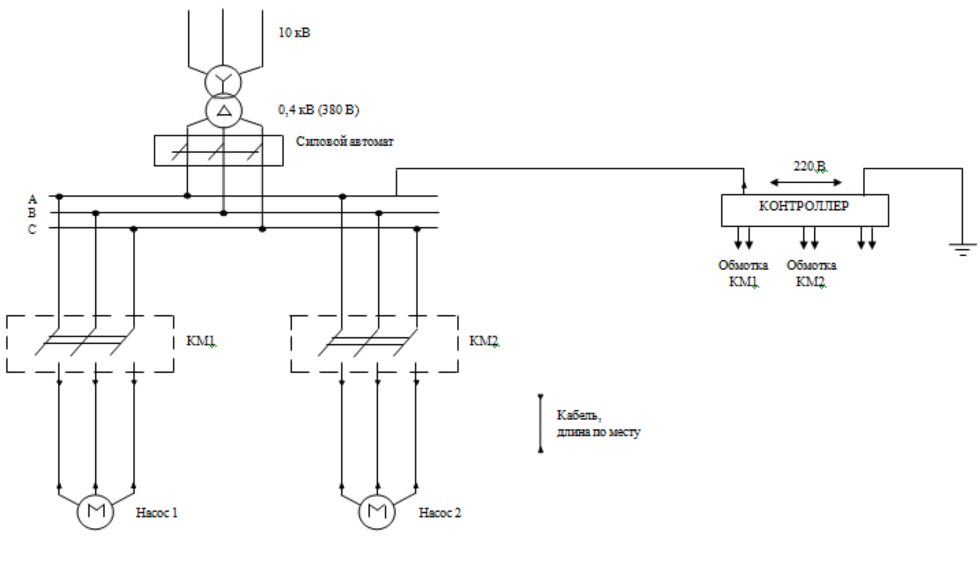

Fig. 9. Schematic diagram of the power supply of the main electrical equipment of the solar system

Structurally, the circuit consists of a supply transformer T1 1000/10/0.4, which feeds three-phase pumps M1 and M2 with a power of 800 W each through a power machine, the voltage on the pumps is three-phase and equal to 380 V. The power machine serves to supply and disconnect power. The pumps are connected to the power circuit through magnetic contactors KM1 and KM2. The circuit provides an independent power supply for each pump. Pumps have built-in frequency converters.

The controller power is connected through phase A and has a voltage of 220 V. The controller has a protective earth. The solar system is controlled by the controller. The scheme is designed for frequent inclusion and continuous long-term operation, which is one of the basic requirements for the system. Protections and control over the operating modes of the system are collected on the controller. The controller is designed to control two parallel circuits of the solar system. The choice of cable is based on a current strength of 7-8 A per 1 mm^2 of the cross-section of the copper material. Based on the pump power of 800 W, each section of the copper wire can be selected 2.5 mm^2. Cable brand can be selected KVVG 4x2.5. However, the cable can be laid in rooms where dampness can occur. In this case, the use of a cable of the corresponding brand with double insulation of the brand should be considered. where dampness may occur. In this case, the use of a cable of the corresponding brand with double insulation of the brand should be considered. where dampness may occur. In this case, the use of a cable of the corresponding brand with double insulation of the brand should be considered.

The circuit diagram is designed so that its operation in production conditions is extremely simple, requires a minimum of costs and attention of the operating personnel, and provides the ability to carry out repair and adjustment work in compliance with the necessary safety measures.

6. Ecology

The total installed capacity of the solar heating system is estimated at 1,750 kW, and the annual energy production, taking into account the average annual indicators of sunshine for Bishkek, is 4,637.5 MWh per year.

The system allows to save a significant part of the energy generated by using solid fuel and, accordingly, reduce CO_2 emissions.

When calculating greenhouse gas emissions from energy activities related to fuel combustion, an inventory of emissions from energy (heat) production and for the company own needs is carried out, gas emissions with a direct greenhouse effect are estimated - carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

In the process of burning fuel, most of the carbon is emitted directly in the form of CO_2. Other gases (CH_4 and N_2O) are also evaluated. All released carbon is considered as CO_2 emissions. Non-oxidized carbon remaining in the form of particulate matter, soot or ash is excluded from the total greenhouse gas emissions by multiplying by the oxidation coefficient of carbon in the fuel (which shows the proportion of burnt carbon).

The annual energy output of the solar system is estimated at 16 695 000 MJ per year. The specific heat of combustion of coal used in the boiler room is 20 MJ per 1 kg of substance. Thus, the energy generated by the solar system is equivalent to 834 750 kg of coal.

Calculation of CO_2 emissions when recalculating energy production using the solar system to save coal replaced by the system is carried out according to the formula:

$$E = M \times K1 \times CV \times K2 \times 44/12; \quad (9)$$

where E - is the annual CO_2 emission in weight units (tons / year); M - actual fuel consumption per year (tons /year); K1 - is the coefficient of carbon oxidation in the fuel (shows the proportion of burnt carbon); CV - calorific value (J/t); K2 - carbon emission factor (tons/J); 44/12 is the conversion factor of carbon to carbon dioxide (molecular weights, respectively: carbon - 12 g/mol, O2 = 2 x 16 = 32 g/mol, CO2 = 44 g/mol).

In this way:

E = M x K1 x TNZ x K2 x 44/12 = 1351949 tons/year.

7. Conclusion

According to the results of research work carried out as part of the development of the solar system, the following results were obtained:

In order to justify and select the installation scheme, the initial data for the calculation and design are determined. A schematic diagram of a solar installation with the layout of its main elements has been selected. The general schematic diagram of the solar hot water system for the Rotor boiler house has been worked out. The scheme of the binding module of the solar field of the collectors for a solar installation is determined. A general scheme for connecting solar collectors in the helio-field with the determination of the necessary distances provided for the structural part of the installation was designed. The scheme of strapping the tank-accumulators and connecting the solar system to the boiler house networks has been worked out. The calculation and evaluation of the intensity of solar radiation attributable to the designed system.

In the framework of the practical implementation of the obtained scientific results, the following work was carried out:

A schematic diagram of the power supply of the main electrical consumers of the system has been developed. The description of the main elements of the electrical part, including the system controller, is responsible for the control functions and protection of the system, is given. An environmental assessment of the introduction of the solar system has been carried out and a calculation of the reduction of CO_2 emissions has been made. The architectural and planning solution for the construction of the solar system and its building part has been worked out. The issues of power supply and instrumentation and automation are also considered. Much attention is paid to the calculation of the supporting part of the design of the solar installation and its building part.

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