Methods to increase heat and energy efficiency using energy saving technologies in buildings

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Abstract. In this article, a connection scheme of the heating system was proposed based on the use of solar collectors and heaters as assistants to local boilers used in the heating system of the enterprise on the basis of energy-saving technologies, the construction of the solar heater collector was developed, experimental results were obtained, including the tank accumulator for the selected object, heat in the room loss, calculation of the total amount of heat was determined. These devices can be used to save energy in the heating system of buildings. 21 solar collectors (1.2 kW each) are installed from the Thermotech FP202 solar collector to heat the building, their transmitters consume 0.6 kWh of electricity. The amount of electricity consumed during the heating season (182 days) was calculated to be 2620,8 kWh. The annual energy efficiency of the installed solar collector was determined to be 122304 kWh.

1 Introduction

Currently, the energy system of Uzbekistan provides energy to 19,000 industrial, 80,000 agricultural, 19,000 communal and 3.5 million household consumers. The sun's rays bring enormous energy to the earth every year, i.e. energy equal to 62•1016 kWh. 60% of this energy is spent on heating the earth's atmosphere, 25.5% on the ocean and sea, and 14.5% on the land. Of this, 2.5 percent is converted into mechanical energy of wind, 0.14 percent into mechanical energy of river movement, 0.12 percent into chemical energy of various fuels, wood, peat, coal, oil, and combustible shale [1-5].

Countries leading in solar water heating technology include Spain, France, Italy, Germany, Australia, the United States, China, and South Korea. Solar water heaters play a crucial role in reducing dependency on conventional power sources by harnessing solar energy to heat water. These systems utilize solar radiation to power flat plate collectors, which heat the water efficiently. The ability to absorb and transfer energy from solar radiation makes solar water heaters a reliable and sustainable option for various applications. Solar-powered water heaters are used for a diverse range of functions in residential, industrial, and modern settings. They are particularly effective for high-temperature water applications, such as those needed for domestic use, industrial processes, and even in resorts and hotel rooms for drying and cleaning purposes. Their simplicity and reliability make them an attractive

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solution for utilizing solar energy to meet water heating needs, offering an eco-friendly alternative to traditional fuel, gas, and oil-based systems [6-7-8-9].

In solar engineering, the accurate calculation of flux distribution density in the focal area of Mirror Concentrating Systems (MCS) is crucial for optimizing energy concentration and efficiency. Various methods have been developed to estimate MCS characteristics, focusing primarily on the geometric aspects that influence concentration characteristics. However, these methods often overlook the manufacturing imperfections and practical limitations inherent in MCS technology [10-11]. The effectiveness of a Mirror Concentrating System (MCS) largely depends on the precision of its reflecting or refracting surface. For facet mirror concentrators and heliostats, the accuracy of facet adjustment is crucial for optimal performance. Several adjustment methods exist to ensure the facets of these systems are correctly aligned and functional [12]. A model and a program for calculating the parameters and concentration of LFMs with flat facets have been developed. It is shown that LFMs can provide in increased concentration by up to 30 times at a number of facets of about 50 while ensuring the high uniformity of the concentrated radiation at the receiver [13]. Numerous studies in the literature have leveraged CFD analysis to investigate various aspects of linear Fresnel concentrator receivers. For instance, Ozalp and Hepbasli (2016) conducted a comprehensive CFD study to analyze the thermal performance of a linear Fresnel receiver under diverse operating conditions, highlighting the critical role of receiver design parameters in optimizing thermal efficiency [14]. Similarly, Wang et al. (2018) employed CFD simulations to explore the impact of receiver geometry and operating parameters on energy absorption and thermal losses [15]. A fundamental component of a linear Fresnel concentrator system is the receiver, tasked with absorbing concentrated sunlight and converting it into thermal energy. Maximizing the efficiency and minimizing the thermal losses of the receiver are paramount to enhancing the overall performance of the CSP system. Computational Fluid Dynamics (CFD) has emerged as an invaluable tool for simulating and analyzing the intricate fluid flow and heat transfer processes within the receiver [16].

If we take into account that the surface of the cross section of the earth is 127,6•106 km^2, the energy of sunlight falling on the earth is 176,6•1012 kW, which means that 1,56•1018 kWh ≈ 1,6•1018 kWh of solar energy falls on the earth in a year. The golden rays of the sun bring to our earth 150,000 billion kWh of wind energy and 33,000 billion kWh of water energy per year. In forests, 220,000 billion kilowatt hours of energy are collected annually due to sunlight. In addition, thanks to solar energy, huge energy reserves have been accumulated in the earth's crust for thousands of years. For example, there are 3,580,000 billion kWh of energy in coal, 480,000 billion kWh in peat, 700,000 billion kWh in combustible shale, and 80,000 billion kWh in natural gas. At present, humanity uses less than one thousandth of these huge reserves per year. Today, it is known that the sun is like a giant nuclear reactor, where nuclear reactions take place at high pressure and temperature. Due to this reaction, during the process of turning hydrogen into a helium nucleus, the temperature in the active zone of the solar reactor exceeds 10 million degrees [17-18].

A formula is proposed for calculating the determination of the transmitted amount of the radiant flux of the sun to the unit of the frontal surface through the shape of the metal shavings from the value of the opening step angle in different thicknesses of the metal shavings. It has been confirmed that the solar radiant flux passing to the unit of the frontal surface through the metal chip shape reaches its maximum value in the following cases: when the chips are 0,002 m thick, they have an optimal angle $\varphi = 58°$, the transmitted energy of the radiant flux through the chip shape is $E = 31\%$; with a chip thickness of 0,0005 m, the optimal angle is $\varphi = 42°$, the transmitted energy of the radiant flux through the chip shape is $E = 41\%$; with a thickness of 0,001 m, the optimal angle is $\varphi = 50°$, the transmitted energy of the radiant flux through the chip shape is [19]. It is proposed that a novel solution to improve solar lighting in buildings by employing a system of mirrors, with one mirror tracking the Sun's motion and the others remaining stationary. This approach addresses the inefficiencies of previous systems by incorporating solar tracking to maximize light transmission. The proposed system consists of a solar concentrator based on a focusing heliostat with an area of 6.72 m², positioned at a height of 10 meters above ground level. This heliostat automatically follows the Sun's trajectory from morning to evening, directing solar beams into an underground room. The system is designed with four mirrors: the first mirror, with an area of 2.25 m², is installed at a 45° angle and reflects light to the second mirror, which is positioned at a depth of a hole at a 45° angle. The second and third mirrors, each with an area of 1 m², are located in the hole, which has an area of 1.20 m² and a depth of 5 meters. These mirrors further direct the concentrated solar beams to the room's ceiling [20]. In ideal scenarios, the radiant flux density remains constant as it reflects off the mirror surface without spreading. However, real-world fabrication inaccuracies introduce deviations in the mirror's reflective surface, which can lead to a decrease in flux density. These deviations, quantified by the average spatial deviation of the mirror's normals from their theoretical directions, impact the focusing ability of the system and the size of the reflected beam cone [21].

2 Materials and methods

In order to use its natural and climatic conditions for the development of Uzbekistan's energy industry, extensive research has been conducted on the use of renewable energy sources, in particular, solar energy, and small solar power plants. At the same time, scientific research works are being carried out in our Republic for the economical use of solar energy and the effective use of its potential. It is known that on clear days, 600-1200 kW of solar heat energy falls on each square meter of the surface of the solar collector, depending on the different seasons of the ear, based on this, we can get an average of 900 kW. The atmosphere is not always transparent, and the surface of the collector is not always perfectly clean, so if we consider that the heat loss is 100 W, we can assume that 700 W/m^2 of heat is transferred from the surface of the collector [22].

Heat capacity of water

$$4200\ \text{J/kg}\cdot{}^{\circ}\text{C},$$

relationship between power units:

$$1\ \text{W}\cdot\text{hour} = 3600\ \text{Joule},$$

that is, 1,16 W is needed to heat 1 kg of water by 1 °C. Based on these dimensions, it is possible to derive a conditional power value for a solar collector with an area of 2 m^2.

$$Q_k = 2\cdot 700/1{,}16 = 1206{,}9\ \text{W}$$

For convenience, it can be taken as Qk = 1200/kg•grad. It should be noted that 1200 is suitable only when the water temperature is 10-70 °C. In general, this ratio shows how many kilograms of water can be heated by one degree per hour by the solar collector. That is, the collector heats the temperature of 100 liters of water to 12 °C and 25 liters of water to 48 °C per hour.

We choose the Thermotech FP202 solar collector, its technical characteristics: total area 2.02 m^2, absorber surface 1.84 m^2, volume 1.56 l, maximum operating pressure 10 bar, stagnation temperature 234 °C, flow 0.25-0.5 l/min•m^2, forced circulation in the collector power of 50 W. Let's calculate how many collectors with a surface of 2 m^2 each are needed to heat the building. For this, we calculate the power needed to heat the building:

$$Q_b = V * T * K, kkal/hour \tag{1}$$

here, V – the volume of the heated room, m^3, T – difference between outside air and inside air, K – diffusion coefficient (the type of building depends on the insulation condition of the room).

The value of coefficient K is chosen as follows:

- K = 3.0-4.0 in the absence of thermal insulation for simplified wooden structures or corrugated metal sheets;
- K = 2.0-2.9 when thermal insulation for a brick wall is partial;
- When thermal insulation is average for a standard wall with a thickness of two bricks, K = 1.0-1.9;
- K = 0.6-0.9, when thermal insulation is high for a high-quality double-insulated wall.

To determine the amount of heat capacity, we take the following as preliminary data: Heated building, administration building of Fergana oil products LLC, area - 193 m^2;

- Room height – 3 m;
- Outside temperature in winter -20 °C;
- Required temperature inside the room 18 °C;
- The difference between indoor and outdoor temperatures in winter t=38 °C;

K – diffusion coefficient (the type of building depends on the insulation condition of the room), K=1.0.

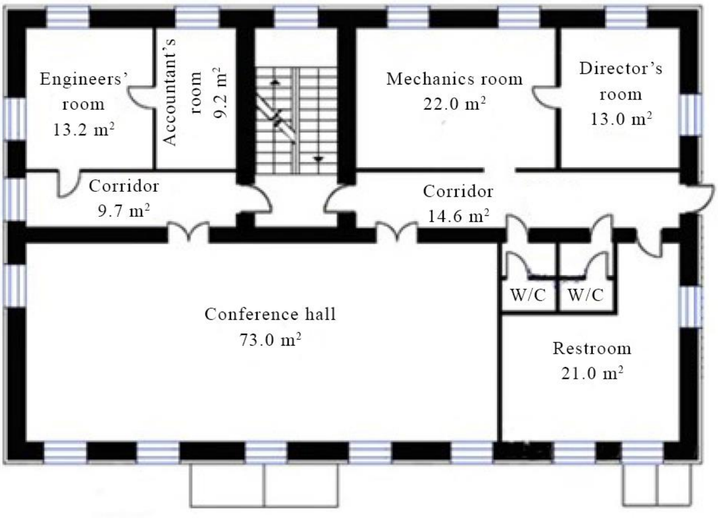

Fig.1. Drawing of the administration building.

3 Results and discussion

Let's put these data in formula (1),

$$Q_{mn} = V * T * K, \frac{kkal}{hour} = 193 * 3 * 38 * 1 = 22002 \frac{kkal}{hour} \qquad (2)$$

If,

$$1\ \text{kW} = 860\ \text{kcal/hour}$$

From the given relationship, we find the amount of heat in kW:

$$Q_b = \frac{22002}{860} = 25{,}58\ kW \tag{3}$$

The number of collectors needed to heat the building

$$N_k = \frac{Q_{mn}}{Q_k} = 25{,}58\ kW * \frac{10^3}{1200} = 21\ pieces \tag{4}$$

Evaluation of the economic efficiency of the combined heating system for heating the building. If the building is heated only by solar collectors, the current cost value will be the power consumption of the electric drive (one 50 W) used to ensure the forced circulation of the forced heat carrier in the system.

If 21 solar collectors (1.2 kW each) are installed from the Thermotech FP202 solar collector to heat the building, their transmitters consume 0.6 kWh of electricity. The amount of electricity consumed during the heating season (182 days) is found as follows:

$$P_{elect} = (24 * 182) \cdot 0.6 = 2620.8\ kW \cdot hour \tag{5}$$

Electricity consumed during the heating season when the building is heated by an electric heater,

$$Q = Q_b \cdot (24 \cdot 182) = 28{,}6 \cdot 24 \cdot 182 = 124924{,}8\ kW \cdot hour \tag{6}$$

Annual energy efficiency of an installed solar collector:

$$C_{col} = Q - P_{elect} = 124924{,}8 - 2620{,}8 = 122304\ kW \cdot hour \tag{7}$$

If we multiply the found amount by the tariff for 1 kWh of electricity - 900 soums for the legal entities, the financial value of energy efficiency will be - 122304·900 = 110073600 soums. If the building is heated only with a heat pump, the amount of electricity consumed during the heating season (182 days) is found as follows:

$$P_{pump} = (24 \cdot 182) \cdot 3{,}18 = 13890{,}24\ kW \cdot hour \tag{8}$$

Energy efficiency of the heat pump during the heating season:

$$C_{pump} = Q - P_{pump} = 124924{,}8 - 13890{,}24 = 111034{,}56\ kW \tag{9}$$

If we multiply the found amount by the tariff for 1 kWh of electricity - 900 soums, the financial value of energy efficiency - 111034.56·900 = 99931104 soums.

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5 Conclusion

A Thermotech FP202 solar collector was chosen to provide the administration building with a primary source of thermal energy for the heating season. Its technical characteristics: total area 2.02 m^2, absorber surface 1.84 m^2, volume 1.56 l, maximum working pressure 10 bar, stagnation temperature 234 °C, flow 0.25-0.5 l/min•m^2, forced circulation in the collector electric drive power 50 W. 21 collectors with a surface area of 2 m^2 each were selected to heat the building. The amount of electricity consumed during the heating season (182 days) was calculated to be 2620,8 kWh. The annual energy efficiency of the installed solar collector was determined to be 122304 kWh.

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