Rural house heat supply system based on solar energy

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Abstract. The article examines the solar energy-based heat supply system of individual rural houses as the object of research. Currently, the volume of construction of standard houses in rural areas of the Republic of Uzbekistan is growing, which in turn leads to the problem of saving traditional energy resources and uninterrupted heat supply in their heating system. The authors proposed a scheme of a combined heat supply system with a flat solar collector and a water heating boiler in order to save fuel energy resources in the heating system of rural houses. In the article, experiments and measurements were carried out on the basis of experimental calculation methods in a solar heating system installed in an experimental solar house. Based on the conducted experiments, the thermal-technical characteristics of the proposed system, the thermal efficiency of the collector and the temperature regime were analyzed. The results of the study show that the maximum heat output of the flat solar collector was 8.7 kW, and the temperature of the hot water at the entrance to the heating system was 45-50°C. As a result of the application of the proposed combined heat supply system, 50% of the heat load in the daytime mode on sunny days was covered by solar energy.

1. Introduction

Consistent reforms are being carried out in the Republic of Uzbekistan on the rational use of natural energy resources, the introduction of energy-saving technologies in production, the introduction of new, modern technologies through radical modernization of enterprises. Decree of the President of the Republic of Uzbekistan dated February 7, 2017 PF-4947 "On the Strategy for further development of the Republic of Uzbekistan", May 26, 2017 "Measures for further development of renewable energy in 2017-2021, energy efficiency in economic and social spheres" PQ-3012 and November 8, 2017 PQ-3379 "On measures to ensure the rational use of energy resources" to reduce energy and resource consumption, the widespread introduction of energy-saving technologies in production, renewable energy Expanding the use of natural resources, increasing energy efficiency in various sectors of the economy have been identified as priorities [1,2]. In some European countries, heat consumption for the heating season in multi-storey houses, on average - 350 - 600 kW·h/(m²·year), and in single-storey houses - 600 - 800 kW·h/(m²·year), water per capita consumption is 250 - 500 l through the plumbing network, including for houses connected to the central heating system - 150 - 200 l. Research on the creation of autonomous heat supply systems shows that the use of autonomous system equipment instead of a central heating system can save up to 70% of energy [3,4,5,6].

The analysis shows that 40% of the primary energy produced in Uzbekistan is used for heating and lighting. According to industry experts, an average of 400 kWh of energy is used in Uzbekistan to heat 1 m², and 170 kWh in developed countries. In order to create a GDP of one thousand dollars in our
country, 2-3 times more energy is used than in developed countries. Therefore, the task is to reduce energy consumption by 2-2.5 times in the coming years. Electricity consumption in our country is growing from year to year. In 2000, the monthly consumption of a family was 114 kWh, but now it is 175 kWh [7]. Scientists around the world have conducted research to improve the efficiency of solar energy in heat supply systems and obtained significant results [8,9,10,11,12,13,14]. An analysis of research by industry scientists shows that combined schemes of solar and traditional heating systems have been relatively little studied. In order to develop autonomous energy systems based on the use of energy and resource-efficient, renewable energy sources, especially solar, in rural areas, especially in settlements far from traditional energy supply sources, a heating scheme of combined heat supply with solar and traditional heating system has been developed. An overview of the experimental solar house is shown in Figure 1 and a schematic of the combined heating system is shown in Figure 2.

![Figure 1. The experience is an overview of the solar house.](image)
Figure 2. The scheme of the system of rural heating in the home on the basis of solar energy: 1-solar collector; 2.4-expander; 3-water heating boiler; 5,6,7 - shut-off valve; 8-water heated floor; 9-heating batteries; 10-pump; 11-heated house; 12-solar panels (SP); Accumulator; In-inverter-converter.

The purpose of the research is to develop a systemic scheme of combined heating of rural houses with solar and traditional water heating boilers and to analyze the thermal-technical characteristics.

According to the proposed experimental scheme, the heat supply system of a country house consists of solar collectors 1 and water heating boiler 3 devices. In this case, the solar collector heats the water needed for heating to 55-60 °C. On cloudy days and cold days of the year, it will be possible to use 3 water heaters to heat the water. The heating system in the interior of the house combines two different styles. Firstly, the heating floor 8 is installed, which serves to distribute the heat evenly throughout the heating area of the room, and secondly, the traditional heating coils 9 are installed, which improves the convective heat exchange for volumetric heating of the room. The water returning from the heating system is sucked out by pump 10 and pumped to the heating source. Separation valves are used to carry out water circulation through the floor or heating coil, to change the flow of water coming through the solar collector or water heater 5,6,7. The power supply of the pump is made from the inverter of the energy converter Ac coming from the battery 12 of the solar photovoltaic panel.

2. Method
In determining the thermal and technical parameters of buildings, it is necessary to calculate the heating surface and the corresponding heat load on this surface, to determine the specific thermal characteristics of the building surface. Taking into account the difference between the internal and external temperatures of the building, the total heat load is determined [15,16,17].

\[
Q = q \cdot V_{build} \cdot (t_{i,t} - t_{c,t})
\]

(1)

where \(V_{build}\) is the total volume of the building, m³; \(q\) is the specific heat characteristic of surface areas, W/m², \(q = 0.78\) W/m² for modern buildings; \(t_{i,t}\) - required indoor air temperature of the house, °C; \(t_{c,t}\) is the calculated temperature of the outside air (selected for the coldest day), °C.
Solar collectors used for heating systems can have different operating efficiencies. To correctly calculate the capacity of a solar collector, it is necessary to know the area of the light receiving surface, the size of the insulation for the area to be installed, and the collector efficiency.

The heat flux through the solar collector is calculated from the following formula [18].

\[ Q = G_m \cdot c_p \cdot (t_2 - t_1), \]  

where \( G_m \) is the mass consumption of the heated medium, kg/sec; \( c_p \) - isobaric heat capacity of the medium, kJ/kg·°C; \( t_1 \) and \( t_2 \) - the temperature at the inlet and outlet of the solar collector, °C.

The calculated surface area of the solar collector is determined as follows.

\[ F = \frac{Q}{\alpha \Delta t}, \]  

where \( \Delta t = t_{air} - t_{envir} \), the difference between the light-receiving surface and the average air temperature, °C; \( \alpha \) - heat transfer coefficient, Watt/(m²·°C).

The useful heat energy obtained from a solar collector is determined from the Wheeler-Hottel-Bliss equation, which is convenient for calculating flat collectors [18,19].

\[ Q_{ef} = k_r \cdot F \left[ q_p^s (\tau \cdot \alpha) - u_L (t_1 - t_{envir}) \right], \]  

where, \( k_r \) - is the coefficient of heat extraction from the collector; \( q_p^s \) - the current density of total solar radiation on the flat surface of the collector, Vt/m²; \( \tau \) - transmittance of the transparent coating to sunlight; \( \alpha \) - absorption properties of the collector plate in relation to sunlight; \( u_L \) - total coefficient of heat loss in the collector, Watt/(m²·°C); \( t_{envir} \) - environmental temperature, °C.

To test a solar collector, the flux density of solar radiation incident on the collector surface, the outside air temperature, the ambient consumption and temperatures at the inlet and outlet of the collector are measured. In this case, the useful energy of the collector is determined by the following expression [18,19].

\[ Q_{ef} = G_v \cdot \rho_a \cdot c_p \cdot \left( t_{exit} - t_{enter} \right), \]  

where, \( G_v \) - volumetric consumption of the environment, m³/c; \( t_{exit} \) - ambient temperature at the outlet of the collector, °C.

The volumetric consumption of the medium through the solar collector \( G_v \), m³/s, is determined as follows.

\[ G_v = w \cdot F_o, \]  

where \( F_o \) - is the cross section of the collector, m².

Specific heat capacity of the collector, Watt/m²:

\[ q_{s.h.e} = \frac{Q_{ef}}{F}. \]  

Based on the conducted experimental tests, the efficiency of the solar collector is determined by the following formula:

\[ \eta = \frac{Q_{ef}}{q_p \cdot F}. \]  

If we consider the heat balance equation:

\[ G_v \cdot \rho_a \cdot c_p \cdot \Delta t = \alpha \cdot F \cdot \Delta t_{cp}, \]  

in that case,
Based on the above methodology, computational and experimental studies were conducted to determine the thermal efficiency of the solar collector - heat efficiency and efficiency.

3. Results and Discussions

For the southern regions of the country, especially in the city of Karshi, the thermal and technical characteristics of a solar house with a combined autonomous power supply were studied. The results of the study are presented in Table 1.

Table 1. Thermal and technical characteristics of the solar heat supply system

| Measurement time, hours | Solar radiation, \( q_p \) Watt/m² | Solar radiation falling on the collector surface, \( Q_p \) W | Thermal efficiency of the collector, \( Q_{heat} \) kW | Outdoor air temperature, \( t_{out} \), °C | Room temperature, \( t_{in} \), °C | Outlet water temperature, \( t_{out} \), °C | Inlet water temperature, \( t_{inlet} \), °C |
|------------------------|-------------------------------|---------------------------------|-----------------|---------------------|---------------------|----------------------|---------------------|
| 9-00                   | 323                           | 1130                            | 2.1             | 22.5                | 27.0                | 31                   | 32                  |
| 10-00                  | 655                           | 2292                            | 4.3             | 23.4                | 29.0                | 32                   | 34                  |
| 11-00                  | 845                           | 2975                            | 4.3             | 26.2                | 31.0                | 38                   | 40                  |
| 12-00                  | 963                           | 3370                            | 8.7             | 27.9                | 32.0                | 39                   | 43                  |
| 13-00                  | 962                           | 3367                            | 8.7             | 28.8                | 33.0                | 40                   | 44                  |
| 14-00                  | 858                           | 3003                            | 8.7             | 31.9                | 34.0                | 42                   | 46                  |
| 15-00                  | 763                           | 2670                            | 8.7             | 32.7                | 34.1                | 41                   | 45                  |
| 16-00                  | 596                           | 2086                            | 4.3             | 31.4                | 33.3                | 40                   | 42                  |
| 17-00                  | 282                           | 987                             | 2.1             | 29.2                | 32.1                | 33                   | 34                  |

The heat capacity of the collector is shown in Figure 3, the graph of indoor and outdoor air temperatures in Figure 4, and the graph of the inlet and outlet temperatures of the water heated in the collector in Figure 5.
Figure 3. Thermal efficiency of a flat solar collector. (October 15, 2019)

Figure 4. Graph of outdoor and indoor air temperatures of a house heated using solar collectors.
Figure 5. Graph of inlet and outlet temperatures of heated water in the collector.

It is advisable to use solar collectors in order to reduce fuel costs in heating systems and prevent environmental damage. The working principle of solar collectors is based on the collection of solar energy and the use of this energy to heat the water circulating inside the pipes. The more energy is supplied to the heat carrier, the higher the efficiency of the device. The cold water in the collector reservoir flows towards the bottom of the collector and at this time the heated water flows out into the reservoir. Cold water enters instead of the empty medium in the collector pipe, where it is heated. In practice, the water collected in the reservoir is stored in a boiling state, and on sunny winter days the water temperature can reach 55-60 °C.

4. Conclusions
Experiments and measurements were carried out on the basis of experimental calculation methods in a solar heating system installed in a solar house. Based on the conducted experiments, the thermal-technical characteristics of the proposed system, the thermal efficiency of the collector and the temperature regime were analyzed.

The results of the research show that the maximum heat output of the flat solar collector was 8.7 kW, and the temperature of the hot water at the entrance to the heating system was 45-50 °C.

As a result of the use of a combined heat supply system, it is justified to cover 50% of the heat load in the daytime heating mode on sunny days at the expense of solar energy.

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