EXPERIMENTAL PERFORMANCE ASSESSMENT OF A PCM-ASSISTED FLAT-PLATE SOLAR WATER HEATING COLLECTOR UNDER ARID CLIMATIC CONDITIONS

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Abstract. *The authors present a flat-plate solar water heating collector designed to improve the efficiency of hot water supply systems through the utilization of solar energy. An experimental solar water heating collector system was developed and equipped with a thermal energy storage unit based on a phase change material (PCM), as well as an additional hinged reflector installed parallel to the collector, serving as an auxiliary source of solar thermal energy. The results of experimental investigations carried out under the climatic conditions of Karshi city are presented. The experimental results demonstrated the high energy performance of the developed solar water heating collector. It was determined that the temperature of the heated water reached 65–70 °C during the summer period, while the application of the thermal storage unit ensured heat retention and maintained a stable temperature regime during evening hours.*

Keywords: *solar water heating collector, phase change material, thermal storage, solar thermal energy, thermal performance, energy efficiency, solar reflector, heat transfer enhancement, renewable energy systems, hot water supply.*

Аннотация. *Авторами представлен плоский солнечный водонагревательный коллектор, предназначенный для повышения эффективности систем горячего водоснабжения за счет использования солнечной энергии. Разработана экспериментальная установка солнечного водонагревательного коллектора, оснащенная теплоаккумулятором на основе фазопереходного материала (PCM), а также дополнительным* *шарнирным рефлектором, установленным параллельно коллектору и выполняющим функцию дополнительного источника солнечной тепловой энергии. Представлены результаты экспериментальных исследований, проведённых в природно-климатических условиях города Карши. Результаты экспериментов показали высокую энергетическую эффективность разработанного солнечного водонагревательного коллектора. Установлено, что температура нагреваемой воды в летний период достигает 65–70 °C, а применение теплоаккумулятора обеспечивает аккумулирование тепловой энергии и поддержание стабильного температурного режима в вечерние часы.*

Ключевые слова: *солнечный водонагревательный коллектор, фазоизменяющий материал (PCM), аккумулирование тепловой энергии, солнечная тепловая энергия, теплотехнические характеристики, энергетическая эффективность, солнечный рефлектор, интенсификация теплообмена, системы возобновляемой энергетики, горячее водоснабжение.*

Annotatsiya. Mazkur ishda quyosh energiyasidan foydalanish orqali issiq suv ta'minoti tizimlarining samaradorligini oshirishga mo'ljallangan yassi quyosh suv qizdirish kollektori taqdim etilgan. Fazaviy o'zgaruvchan material (PCM) asosidagi issiqlik akkumulyatori hamda kollektor bilan parallel joylashtirilgan va qo'shimcha quyosh issiqlik energiyasi manbai vazifasini bajaruvchi sharnirli reflektor bilan jihozlangan eksperimental quyosh suv qizdirish kollektori ishlab chiqilgan. Qarshi shahri iqlim sharoitida o'tkazilgan eksperimental tadqiqotlar natijalari keltirilgan. Tajriba natijalari ishlab chiqilgan quyosh suv qizdirish kollektorining yuqori energetik samaradorlikka ega ekanligini ko'rsatdi. Tadqiqotlar davomida yoz mavsumida qizdirilayotgan suv harorati 65–70 °C ga yetishi, issiqlik akkumulyatoridan foydalanish esa issiqlik energiyasini saqlash va kechki soatlarda barqaror harorat rejimini ta'minlash imkonini berishi aniqlandi.

Kalit so‘zlar: *quyosh suv qizdirish kollektori, fazaviy o‘zgaruvchan material (PCM), issiqlik energiyasini akkumulyatsiyalash, quyosh issiqlik energiyasi, issiqlik-texnik ko‘rsatkichlar, energetik samaradorlik, yassi reflektor, issiqlik almashinuvini jadallashtirish, qayta tiklanuvchi energiya tizimlari, issiq suv ta’minoti.*

Introduction

The combustion of fossil fuels leads to the emission of greenhouse gases (CO_2, SO_2, and NO_x), contributes to acid rain formation, air pollution, ozone layer depletion, and global warming. These environmental challenges are further intensified by the continuously increasing global demand for thermal and electrical energy. A significant portion of energy consumption is associated with domestic and industrial hot water production, making the development of energy-efficient water heating technologies an important research priority. Solar water heating collectors have been developed to reduce the consumption of conventional fossil fuels and to promote the utilization of renewable energy resources [1-4].

Currently, extensive research is being conducted worldwide and in Uzbekistan on the development of solar thermal energy systems based on low-temperature solar technologies for hot water supply applications. Particular attention is devoted to the optimization of heat transfer processes, the development of advanced collector designs, and the determination of optimal operational, technological, and design parameters that ensure stable hydraulic and thermal performance of solar water heating systems. The improvement of energy efficiency, enhancement of thermal performance, and development of modern flat-plate solar water heating collectors remain among the most important research challenges in this field [5].

At the same time, increasing the thermal efficiency of solar water heating collectors through the improvement of absorber designs, incorporation of thermal energy storage materials, application of solar reflectors, and intensification of heat transfer processes has become highly relevant. Despite significant progress achieved in recent years, challenges related to optimizing the heat exchange surface area of absorbers, improving thermal energy storage capacity, reducing system costs, and enhancing overall collector efficiency remain unresolved. Therefore, the development of advanced flat-plate solar water heating collectors with improved heat transfer characteristics and higher energy efficiency represents an important scientific and practical task for autonomous hot water supply and energy-saving systems. In the global practice, numerous studies have been conducted on the development and optimization of solar water heating collectors aimed at increasing the heat transfer coefficient and overall energy efficiency through the improvement of absorber designs and heat exchange surfaces. The performance of solar thermal systems largely depends on the effective utilization and storage of thermal energy, making thermal energy storage an essential component of modern solar water heating technologies [6].

One of the key challenges is to determine the efficiency of thermal energy storage units integrated into solar water heating systems. Their performance depends on the proper selection of thermal storage materials, optimization of storage capacity, geometric dimensions and arrangement of storage elements, heat transfer fluid flow rate, installation conditions, and the possibility of integrating the storage system into existing engineering structures [7-10].

The objective of this study is to experimentally investigate the operating modes of a flat-plate solar water heating collector equipped with a thermal energy storage unit and to evaluate its energy performance under the southern climatic conditions of Karshi, Republic of Uzbekistan [11,12].

Materials and Methods

A flat-plate solar water heating collector was developed for use in autonomous hot water supply systems. The experimental system incorporates a thermal energy storage unit based on a phase change material (PCM) and an additional solar reflector to enhance solar energy utilization. Experimental investigations were carried out at the “Alternative Energy Sources” educational and research test site of the Karshi State Technical University. The developed experimental solar water heating collector and its main structural components are shown in Figure 1.

Fig. 1. Flat-plate solar water heating collector.

The flat-plate solar water heating collector is additionally equipped with a thermally insulated storage tank incorporating a spiral-type heat exchanger for storing the collected thermal energy. Furthermore, the system includes an adjustable hinged reflector installed parallel to the solar collector, which serves as an additional source of solar thermal energy. The integration of the thermal storage unit and the reflector not only improves the overall thermal efficiency of the solar water heating collector but also increases the useful heat gain and enhances the collector's ability to meet hot water demand. In addition, the thermal storage system enables the accumulation of excess solar energy during periods of high solar radiation and its utilization during periods of low solar intensity, thereby improving the reliability and continuity of hot water supply [13-16].

Results and discussions

The highest solar radiation intensity during the entire experimental study period was observed in June 2026. The results of the theoretical and experimental investigations are presented in Table 1.

Table 1.

Experimental Results of the Flat-Plate Solar Water Heating Collector Operating in Water Heating Mode (June 2026).

Local Time	Water Inlet Temp., t_1 (°C)	Water Flow Rate, G_w (kg/s)	Water Outlet Temp., t_2 (°C)	PCM Thermal Storage Temp., t_{PCM} (°C)	Solar Radiation Intensity on Collector Surface, q_r (W/m²)
5:00	18	0,04	20	21	200
6:00	20	0,04	25	26	250
7:00	23	0,04	30	34	450
8:00	25	0,04	36	39	550
9:00	27	0,04	38	44	730
10:00	30	0,04	44	46	800
11:00	34	0,04	52	53	930
12:00	36	0,04	58	65	100
13:00	40	0,04	60	70	1100
14:00	44	0,04	65	70	1150
15:00	42	0,04	62	68	1100
16:00	38	0,04	60	64	950
17:00	32	0,04	51	55	750
18:00	27	0,04	45	47	450
19:00	22	0,04	40	43	150
20:00	20	0,04	28	30	100
21:00	18	0,04	24	24	20
22:00	16	0,04	22	22	15

Conclusions

Based on the experimental investigations conducted under the climatic conditions of Karshi, the operational performance and thermal characteristics of the developed flat-plate solar water heating collector were evaluated. The results demonstrated that the collector was capable of heating water up to 65–70 °C during periods of maximum solar radiation intensity. The integration of the thermal energy storage unit ensured stable thermal performance and enabled the retention of useful heat during periods of reduced solar irradiation.

The experimental data confirmed a strong correlation between solar radiation intensity and the outlet water temperature of the collector. The highest thermal performance was achieved during midday hours when solar radiation exceeded 1100 W/m^2. The obtained results indicate that the developed collector can effectively satisfy a significant portion of domestic hot water demand using renewable solar energy.

Furthermore, the thermal energy storage system improved the operational reliability of the collector by reducing temperature fluctuations and extending the availability of hot water beyond peak solar hours. The study confirms that the proposed flat-plate solar water heating collector is an energy-efficient, environmentally friendly, and economically viable solution for autonomous hot water supply systems in regions with high solar energy potential.

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