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MODELLING OF THERMAL PROCESSES IN A HYBRID SOLAR COLLECTOR

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Abstract. One of the main tasks of the modern energy sector is to provide heat supply to energy-efficient buildings through the use of renewable energy sources, including solar energy. Since modern buildings have limited space for installing solar collectors, the integration of solar heaters into the structures of external walls and facades of buildings is a promising direction.

The article presents the results of studies of thermal processes in a heat supply system with a hybrid solar collector, in which a liquid coolant circulates. The system consists of a finned heat exchanger and a storage tank. In order to determine the feasibility of the practical application of such a design, a hybrid solar collector has been developed, which can be used to effectively model and solve the tasks before starting full-scale research.

Computer modelling of thermal processes in the SolidWorks environment was carried out, with the help of which a series of sequential experiments were created to determine temperature changes at the outlet of the heat exchanger and in the battery tank under different operating conditions. Based on the data obtained, graphs of temperature distribution, amount of thermal energy and changes in efficiency during the study were constructed.

Based on the results, conclusions have been drawn about improving the efficiency of the system with a hybrid solar collector and the possibilities of its further use in solar heating systems for energy-efficient buildings. These solutions make it possible to integrate such a solar collector into the external protection of the building.

The authors provide data indicating that the efficiency of a system with a hybrid solar collector is influenced by its design features, meteorological factors, pollution and the angle of the collector.

However, to fully confirm the results, further field experimental studies are needed to compare theoretical and experimental data. This work lays the groundwork for further optimisation of hybrid solar collector designs and their widespread implementation in solar heating systems.

Keywords: thermal processes, hybrid solar collector, solar heat supply systems, finned heat exchanger, modelling of thermal processes, efficiency.

Introduction. Nowadays the increasing demand for energy-efficient technologies and renewable energy sources makes the use of solar collectors increasingly relevant. Hybrid solar collectors, which combine the functions of generating thermal and electrical energy, represent one of the most promising solutions for enhancing the efficiency of energy systems. A key aspect of developing such systems is ensuring their stable and efficient operation, which requires a detailed analysis of thermal processes within the collector.

Thermal process modeling enables the study of interactions among various components of a hybrid solar collector, such as the absorber, heat carrier, and cooling elements, contributing to the optimization of design and an increase in the system's efficiency. It is also essential to consider the influence of external factors, such as solar radiation intensity, ambient temperature fluctuations, and thermal losses. All these factors significantly affect the performance of the collector and require thorough investigation to develop effective engineering solutions.

Analysis of recent research and publications. The analysis of recent publications covers various aspects of hybrid solar collector utilization and the study of thermal process modeling in heliosystems incorporating such collectors. Particular attention is devoted to mathematical modeling, which enables precise analysis of the energy efficiency and performance of solar thermal systems.

One of the primary directions in solar energy utilization is the integration of solar collector elements into building architectural forms [1] and the exploration of passive solar energy use in construction, particularly through the application of hybrid solar collectors in building structures [2, 3]. These systems enable the efficient use of solar energy for space heating, hot water production, and backup power supply, which are essential for hybrid systems [4, 5].

Energy supply systems where hybrid solar collectors serve as the main components are also being studied separately. These studies highlight the key advantages and disadvantages of using such collectors in energy-efficient buildings [6, 7].

At present, to enhance heat transfer efficiency in hybrid systems, researchers are focusing on the design features and key thermal parameters of solar collectors, which include aluminum grooved tubes [8].

The rise in the number of buildings with glass facades has spurred the combination of large transparent structures with solar collectors. Additionally, such hybrid solar collectors are equipped with photovoltaic panels, and a finned heat exchanger is installed in the housing, where a heat carrier circulates [9]. Researchers are also actively studying solar collectors integrated with building coverings and roofs, where absorber tubes are attached to the roofing material [10, 11].

Despite the large number of traditional systems, there are solutions where the material of the sun-receiving surface is corrugated carbon-graphite canvas. The main advantage is the lightness of the structure, with a fairly large area of the adsorber [12].

To assess the feasibility of using specific elements in a solar thermal system, computer modeling is employed. Such solutions lead to optimization, which, in turn, significantly enhances the efficiency of these systems and reduces energy consumption costs [13, 14].

Hybrid solar thermal collectors can also be utilized for preparing drying agents. The analysis of such thermal processes employs 3D modeling within the collector, allowing improvements in drying processes for agricultural systems [15].

A review of publications has shown that modeling thermal processes in systems with hybrid solar collectors holds great potential, particularly regarding their integration into energy-efficient buildings. However, further field experimental studies are needed to fully confirm the results, allowing for a comparison of theoretical and experimental data.

The aim of the article is to improve the design of a hybrid solar collector, develop and implement a computer model to study thermal processes using SolidWorks software for further analysis and optimization of its design. The article focuses on exploring the capabilities of computational modeling for detailed studies of heat transfer, reduction of thermal losses, and enhancement of the solar collector's efficiency. Additionally, it aims to provide recommendations for engineers in the field of renewable energy.

Research Methodology. To address the tasks set, computer modeling was applied using SolidWorks software. A detailed model of the heat supply system was created, featuring a fine mesh breakdown to analyze the temperature distribution.

Presentation of Main Material. To address the task in the field of energy-efficient construction, a design for a hybrid solar collector has been proposed. This design integrates elements of a solar collector and a window (Fig. 1).

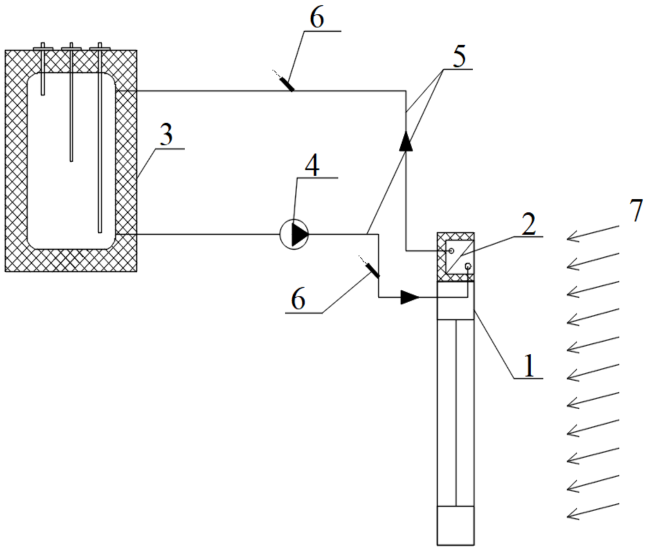
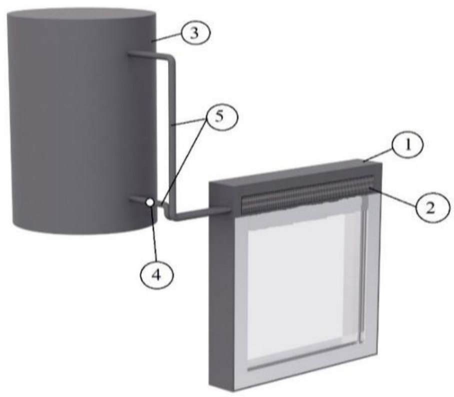


Fig. 1. Installation diagram:
1 – hybrid solar collector housing; 2 – finned heat exchanger; 3 – heat accumulator;
4 – pump installation location; 5 – pipelines; 6 – temperature sensors; 7 – solar radiation direction

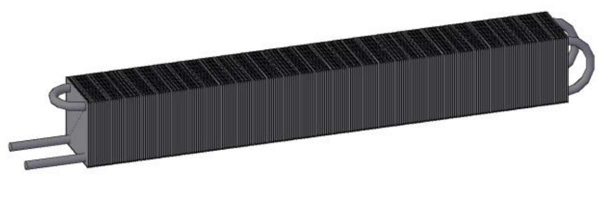
A computer model of this solar collector was developed to investigate its thermal characteristics, featuring a ribbed heat exchanger integrated into the upper part that operates alongside a heat accumulator (Fig. 2). This model, at the stage of theoretical research, facilitates the efficient resolution of several tasks before practical application.

The studied system shown in Fig. 2a consists of a solar window housing, which incorporates a ribbed heat exchanger, as well as an accumulator tank designed for storing the collected thermal energy. The ribbed structure of the heat exchanger increases the heat exchange surface area, enhancing the efficiency of heat transfer from the absorber to the liquid heat carrier circulating in the system. The accumulator tank is equipped with thermosensors to record temperature changes during the experiment.

During the simulation in the SolidWorks environment, the thermal properties of the materials, the liquid heat carrier flow rate, and the intensity of solar radiation were taken into account. The obtained results were recorded and entered into a table depending on the specified radiation intensity. Temperature change graphs in the heliocollector and accumulator tank were also plotted.



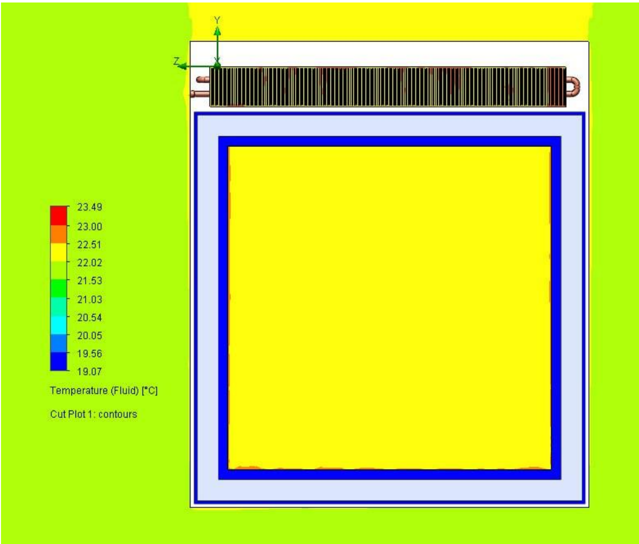
a)



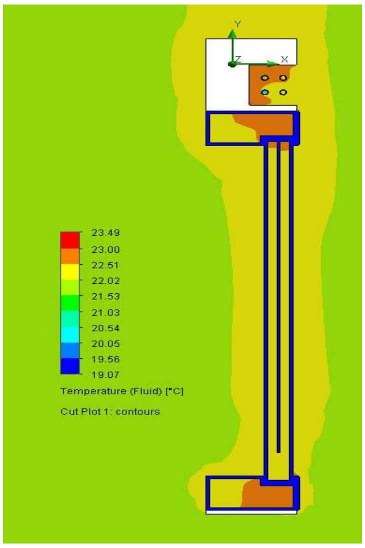
b)

Fig. 2. Computer model of a solar collector:
a – model of the hybrid solar collector; b – finned heat exchanger; 1 – housing of the hybrid solar collector; 2 – finned heat exchanger; 3 – heat accumulator; 4 – location of the pump;
5 – pipelines

In Fig. 3, a temperature increase to 22.5 °C can be observed in the lower part of the frame. Additionally, convective flows around the window structure are visible, with an average temperature of approximately 22 °C. Heat accumulation in the housing is also evident, with the temperature rising to 23 °C. The upper part of the open absorber reached a temperature of over 23 °C, while the lower part heated up to 22 °C.



a)



b)

Fig. 3. Temperature distribution:
a – in front of the solar window; b – in section

Fig. 4 showed that the lack of transparent protection in front of the heat sink causes significant convective heat loss, which generally reduces the efficiency of the solar collector and reduces the temperature of the coolant at the outlet. This encourages further technical improvements to this design.

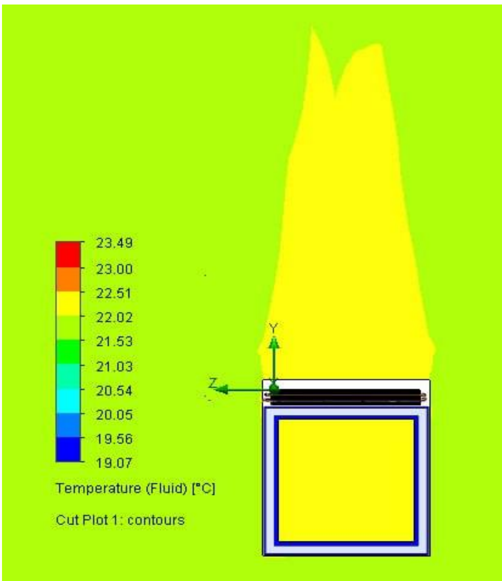


Fig. 4. Convective flows around the studied model

From Fig. 5, it is evident that the outlet temperature of the heliocollector increased from 19°C to 22.3°C between the 5th and 40th minutes, with minimal temperature changes thereafter.

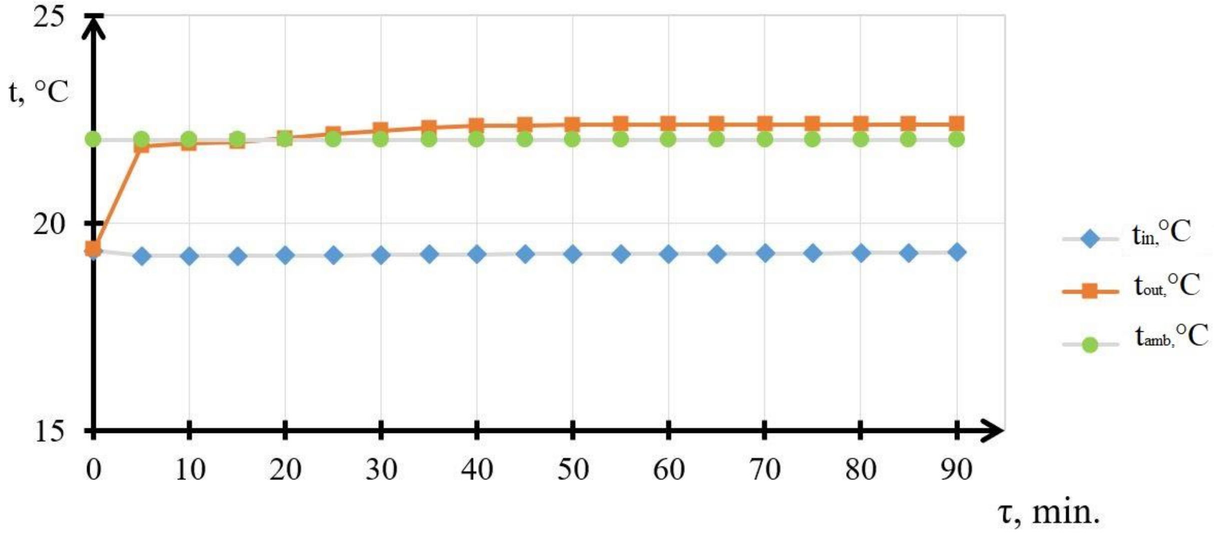


Fig. 5. Heat carrier temperatures at the inlet and outlet of the heliocollector and ambient temperature throughout the experiment

Fig. 6 shows that during the modeling, the temperature in the accumulator tank remained steady at 19°C up to the 40th minute, after which it gradually increased to 21°C. The graph illustrates the temperature distribution within the tank based on the positions of the installed sensors.

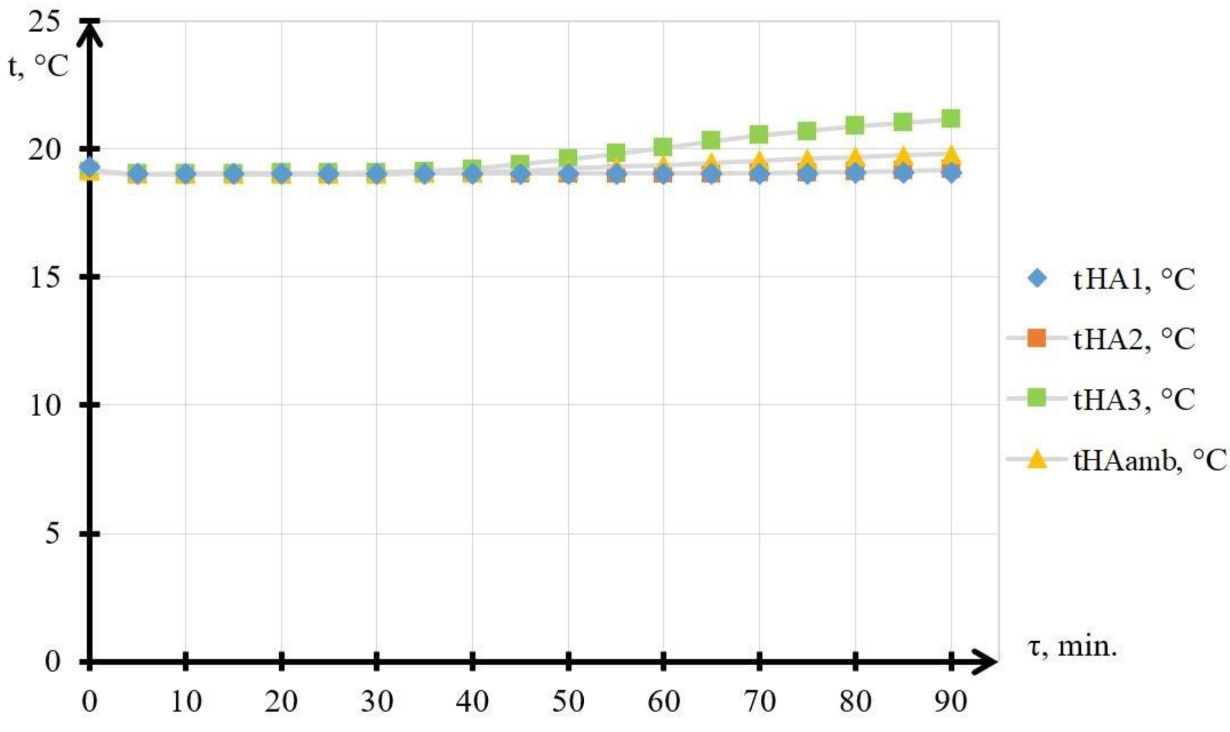


Fig. 6. Temperature change in the heat accumulator depending on the heating time

During the simulation, the instantaneous power of the solar collector Qsk increased during the first half of the experiment (Fig. 7), and then stabilized.

On Figure 8, it can be observed that the efficiency coefficient of the hybrid solar window increased from 72% at the 5th minute to 85% at the 50th minute, and then changed insignificantly. Overall, the average efficiency coefficient of the studied solar collector was 0.82.

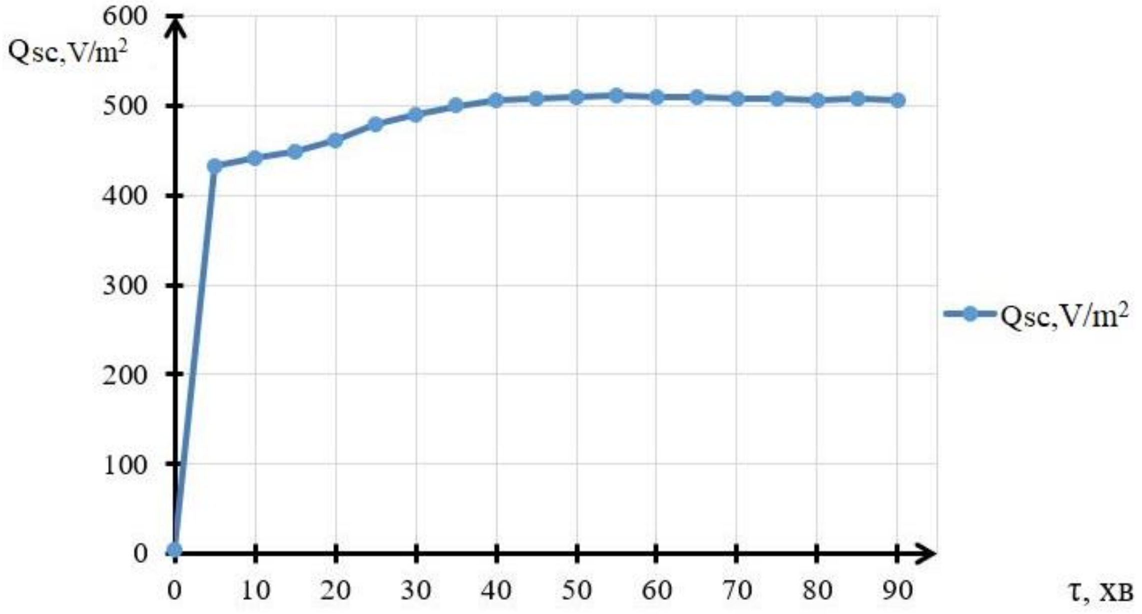


Fig. 7. Instantaneous power of the solar collector

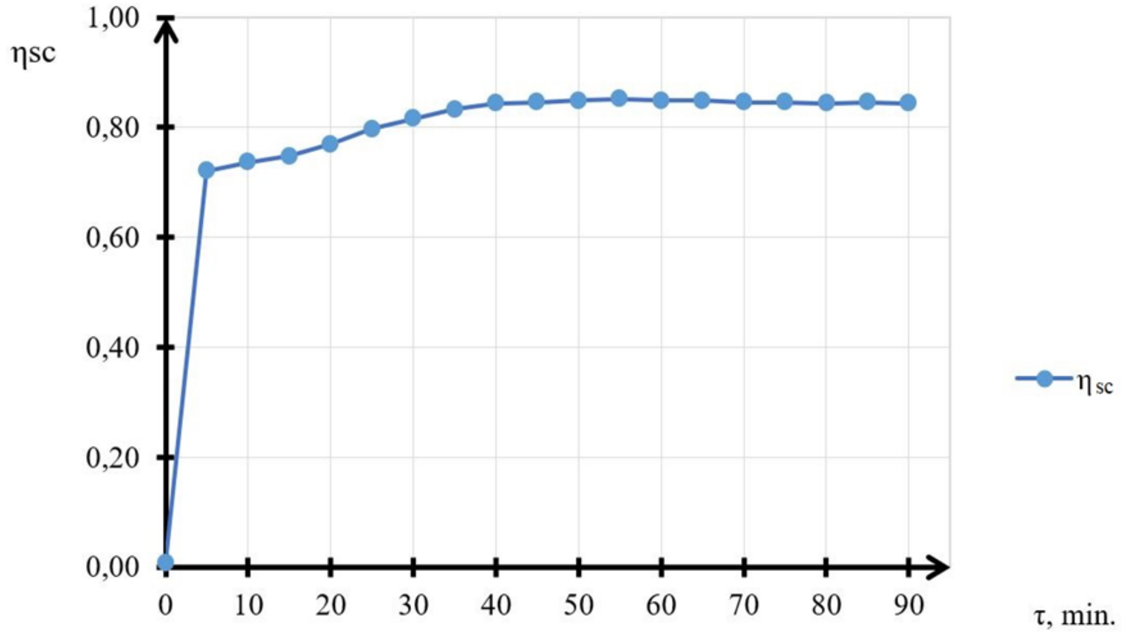


Fig. 8. Change in solar collector efficiency during the experiment

Conclusions:

This article presents the results of modeling thermal processes in a hybrid solar collector. The main attention was paid to theoretical approaches and computer modeling, which allowed to evaluate the operation of the hybrid solar collector under various operating conditions.

Based on the measures taken, it was shown that the efficiency of using a solar window with a built-in finned heat exchanger for collecting solar energy increased. The use of an accumulator tank allows for the effective storage of thermal energy for further use in heat supply systems. The analysis of temperature fluctuations in the heat accumulator proved that the use of a finned heat exchanger provides more uniform heating of the coolant in the system. The simulations also showed that the average coolant temperature at the outlet of the hybrid solar collector was about 22°C, and the maximum was 22.37°C. In the heat accumulator, the average temperature was 19.31°C, and in the upper part - 21.15°C. As for the instantaneous power, it was 511 W/m2. The average efficiency was 0.82, and the maximum during the experiment was 0.85.

The research yielded results that can be aimed at optimizing the design of a hybrid solar collector with a finned heat exchanger and the possibility of integrating such a collector with other energy sources to increase the overall efficiency of the solar heating system.

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МОДЕЛЮВАННЯ ТЕПЛОВИХ ПРОЦЕСІВ У ГІБРИДНОМУ ГЕЛІОКОЛЕКТОРІ

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Анотація. Одним із головних завдань сучасної енергетики є забезпечення теплопостачання енергоефективних будівель за рахунок використання відновлюваних джерел енергії, зокрема і сонячної енергії. Оскільки на зовнішніх огородженнях сучасних будівель є обмежений простір для встановлення геліоколекторів, перспективним напрямком є інтеграція сонячних нагрівників у конструкції зовнішніх стін і фасадів будівель.

У статті наведено результати досліджень теплових процесів у системі теплопостачання з гібридним геліоколектором (ГГК), в якій циркулює рідинний теплоносій. У своїй конструкції дана система містить ребристий теплообмінник та бак-акумулятор. Для того, щоб визначити доцільність практичного застосування такої конструкції, розроблено гібридний геліоколектор, за допомогою якого можна ефективно змоделювати та вирішити поставлені задачі перед початком натурних досліджень.

Проведено комп'ютерне моделювання теплових процесів у середовищі SolidWorks, за допомогою якого створено серію послідовних експериментів з визначення температурних змін на виході з теплообмінника та в баку-акумуляторі за різних умов експлуатації. На основі отриманих даних побудовані графіки розподілу температур, кількості теплової енергії та зміни коефіцієнта корисної дії протягом дослідження.

На основі результатів зроблено висновки щодо підвищення ефективності системи з гібридним геліоколектором та можливостей її подальшого використання у системах сонячного теплопостачання енергоефективних будівель. Ці рішення дозволяють інтегрувати такий сонячний колектор у зовнішнє захищення будівлі.

Автори наводять дані, які вказують, що на ефективність роботи системи з гібридним сонячним колектором впливають його конструктивні особливості, метеорологічні фактори, забруднення та кут нахилу колектора.

Однак для повного підтвердження результатів необхідні подальші натурні експериментальні дослідження, які дозволять порівняти теоретичні та експериментальні дані. Ця робота закладає основи для подальшої оптимізації конструкцій гібридних сонячних колекторів та їх широкого впровадження у системи сонячного теплопостачання.

Ключові слова: теплові процеси, гібридний сонячний колектор, системи сонячного теплопостачання, ребристий теплообмінник, моделювання теплових процесів, коефіцієнт корисної дії.

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