Vol. 3, No. 1, 2021

https://doi.org/10.23939/jtbp2021.01.137

Vasyl Zhelykh[1], Mariana Kasynets[1], Khrystyna Myroniuk[1], Uliana Marushchak[2], Bogdan Gulai[1]

ENERGY EFFICIENT SOLAR HEAT SUPPLY SYSTEMS FOR BUILDINGS AND STRUCTURES

Lviv Politechnic National University,
[1] Department of Heat and Gas Supply and Ventilation,
[2] Department of Building Production
mariana.y.kasynets@lpnu.ua

Today, the energy sector of Ukraine requires significant consumption of traditional energy sources (oil, gas, coal, nuclear energy). However, their use is associated with a number of difficulties, including thermal, chemical, and radioactive contamination of the environment and the exhaustion of their reserves. The paper is devoted to solving the actual problem of improving the efficiency of solar heat supply systems with solar collectors. An analysis of the potential of solar energy and existing solar heat supply systems is presented. The advantages and disadvantages of various solar collector designs and methods of their research are analyzed. The analysis of the main directions for improving the efficiency of solar collectors and solar heat supply systems, in general, is presented. An improved solar heat supply system with the proposed design of a solar collector is obtained and its temperature characteristics are established depending on the intensity of solar energy intake.

Key words: non-traditional energy sources, solar energy, solar collector, solar heat supply system, heat carrier temperature, solar energy intensity

Introduction

Energy sources are divided into two groups: renewable (non-traditional) and non-renewable (traditional). Reducing sources are sources based on constantly existing or periodically occurring energy flows in the environment. Non-renewable substances are natural reserves of substances and materials that can be used by humans for energy production (Shapoval, 2019).

Today, more and more authors devote their works to the systematization and improvement of non-traditional energy sources and the comprehensive calculation of installations that allow obtaining energy on their basis (Solovei, 2007).

Non-renewable energy sources have a sufficiently large potential to provide the necessary standard of living for people. It is calculated that in order to obtain the necessary amount of unconventional energy for the energy supply of urban residents, it is necessary to use only 5 % of the area occupied by them (Dudyuk, 2004).

The advantages of solar energy over traditional fuels are:

– inexhaustible energy source;
– use of solar energy on almost all parts of the Earth's surface;
– direct conversion of solar energy into thermal or electrical energy;
– possibility of obtaining high-temperature heat carriers.

Solar energy conversion is carried out in three main directions: thermal, thermodynamic, and photovoltaic (Babych, 2019, Kudrya, 2005).

Today, it is important to improve existing solar collectors and solar heat supply systems (SHSS) for their maximum integration into traditional heat supply systems and wide application in practice.

Passive solar energy conversion systems are systems whose designs are based on the principle of free convection. In other words, no machines or mechanisms are used to transfer heat. In a passive solar heat supply system, the building structure itself acts as a solar collector. Solar radiation falling on walls, windows, roofs, and other surfaces is absorbed by the building and stored as accumulated heat.

Systems with active use of solar energy are systems that are based on devices and mechanisms for transporting heat carrier. Active systems with mechanical circulation are effective because they use existing water heating systems by connecting a solar radiation receiver and a pump to them.

Problem statement

The amount of solar energy that falls on each square meter of the Earth's surface depends on the angle of inclination and latitude of the area, the time of year, and cloud cover (Zhelykh, 2015). Due to the low density of incident solar radiation and its change during the day and year, its use is difficult, but it is quite promising and economically profitable.

Currently, there are a significant number of circuit solutions for solar heat supply systems, as well as elements of such a system. A number of solar collector designs have been developed, but each of them will work most efficiently only in certain conditions.

Analysis of recent research and publications

The necessary data on solar energy is not available, and for this purpose you can use analytical dependencies that allow you to solve the tasks set with sufficient accuracy. Many works have been devoted to finding and describing such dependencies (Malkin, 2002, Havrus, 2008).

If there is no data on solar energy, you can use the formula (Zakhidov, 1977):

$$Q = I_0 \left(0.29 \cdot \cos\varphi + 0.52 \cdot \frac{n_r}{n_p} \right), \tag{1}$$

where Q – daily sum of solar energy in the horizontal plane, (W·h) per (m^2·day); I_0 – solar constant, (W·h) per (m^2·day); φ – geographical latitude, deg.; n_r, n_p – valid and possible number of hours of sunshine per day, h.

To estimate the solar energy that enters the solar collector during the day, you can use the following dependence: (Malevsky, 1977):

$$\begin{aligned}\cos\theta &= \sin\delta \cdot \sin\varphi \cdot \cos\beta - \sin\delta \cdot \cos\varphi \cdot \sin\beta \cdot \cos\gamma + \cos\delta \cdot \cos\varphi \cdot \cos\beta \cdot \cos\omega + \\ &+ \cos\delta \cdot \sin\varphi \cdot \sin\beta \cdot \cos\gamma \cdot \cos\omega + \cos\delta \cdot \sin\beta \cdot \sin\gamma \cdot \sin\omega\end{aligned} \tag{2}$$

where θ – angle of incidence of direct solar energy, measured between the direction of radiation and the normal to the surface; δ – declination of the sun; φ – latitude of the area; β – angle of inclination to the horizon; γ – azimuthal angle, deviation of the normal to the solar collector from the local meridian (deviation to the East is considered positive, to the West-negative).

The declination of the Sun can be obtained by the formula:

$$\delta = 23.45 \cdot \sin \cdot \left[360 \frac{284 + N}{365} \right], \tag{3}$$

where N – serial number of the day of the year.

In solar heat supply systems, the main elements are solar collectors. Today there are many works devoted to the study of solar collectors (Akimenko, 2020, Moiseenko, 1992, Doroshenko, 2018). They convert solar energy into heat, which can be accumulated and transferred to the consumer (Pukhovyj, 2007, Cristofari, 2002, Raman, 2000). In systems of direct conversion of solar energy into electrical energy the main components are solar cells (Fahrenbruch, 1987, Fortuin, 2014, Chen, 2015).

To increase the efficiency of a solar collector, it is important to find such optimal installation angles at which the maximum possible amount of absorbed solar energy will be obtained (Misak, 2014, Odintsov, 2009, Gladen, 2014). Azimuth change $\gamma_в$ or the angle of inclination of the working surface of the collector $\beta_в$ around ± 30º slightly affects the total amount of energy collected (Chorna, 2011). The simultaneous change in the angles of inclination and azimuth of the collector relative to the incident heat flow has a much greater impact on the amount of energy absorbed, which affects the efficiency of both the collector and the solar installation as a whole (Fig. 1). (Shapoval, 2010, Misak, 2014, Gershkovych, 2009)

There is a well-known analysis of the results of studies that show that the use of delta systems, instead of traditional ones, makes it possible to extend the efficient use of solar heat supply systems by an average of 1.5 hours per day (Novakivskyj, 2004, Novakovsky, 2003).

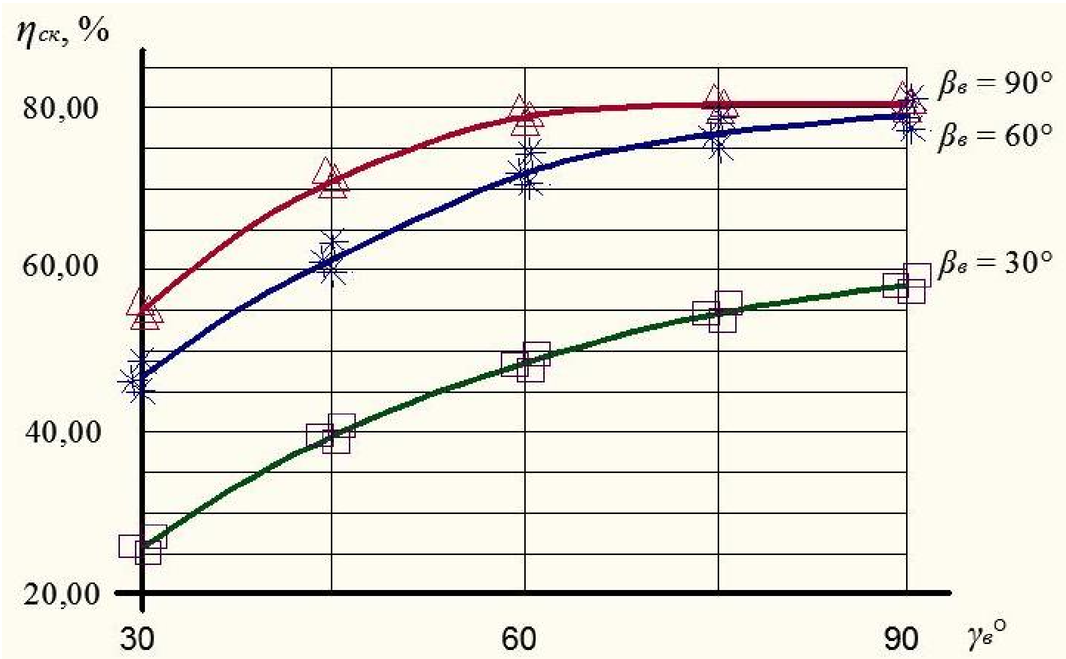

Fig. 1. Efficiency of the flat solar collector η_{SC} depending on the angles of incidence of the heat flow $\gamma_в$, $\beta_в$ and radiation intensity $I_в$ = 900 W/m^2 (Shapoval, 2010)

Triple-oriented solar collectors capture solar energy more efficiently (Мисак, 2014). They allow you to additionally receive solar energy in the morning hours and accumulate more of it before lunch.

Purpose of the study

Improve the solar heat supply system with the proposed solar collector design and establish the temperature characteristics of the structure depending on the intensity of solar energy intake.

Presentation of the main material

In conditions of medium cloud cover, field studies were carried out, in which the following measurements were carried out: the water temperature at the entrance to the installation, the water temperature at the exit from the installation, the water temperature in the storage tank of the solar collector.

It was found that the water temperature at the outlet of the experimental solar collector by lunchtime was ≈4–5 % higher than the water temperature at the entrance to the solar installation and the water temperature in the storage tank of the solar collector combined with the roof of the house (Fig. 2).

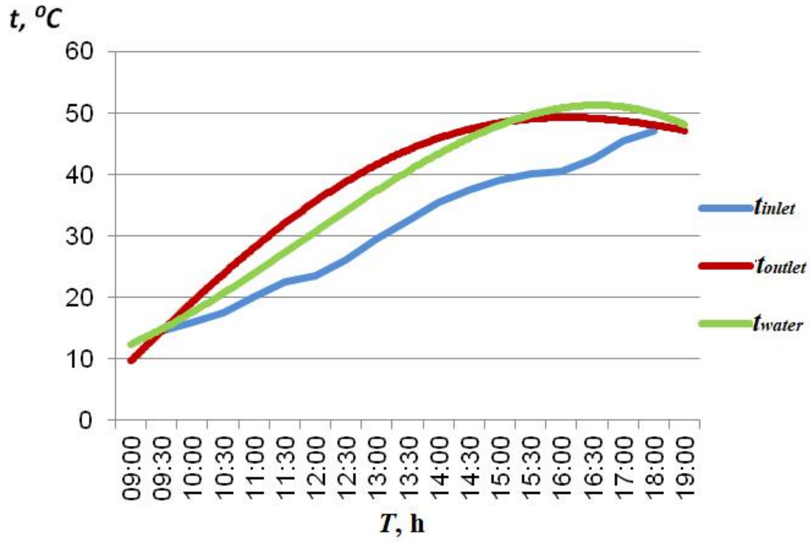

Fig. 2. Changes in the temperature of the heat carrier in the solar installation during the experiment

It was found that the change in the heating temperature of the coolant depending on the intensity of solar radiation ***I*** and the time of irradiation ***T*** reaches its maximum in the afternoon (Fig. 3). This indicates the effectiveness of this solution and the prospects for using a solar collector combined with the roof of a house in Lviv.

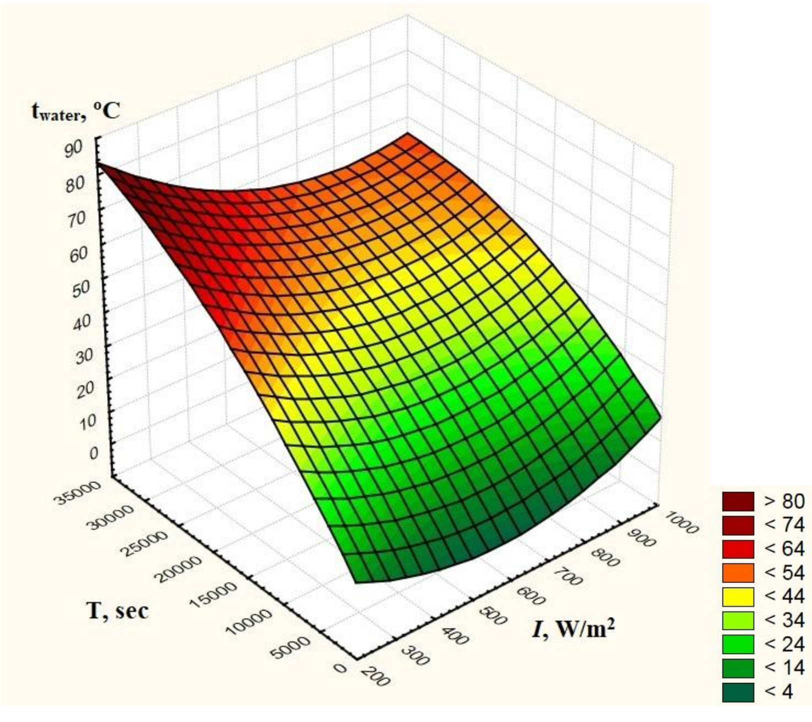

Fig. 3. Dependence of changes in the heating temperature of the heat carrier on the intensity of solar energy I and the irradiation time T

The conducted studies of the solar collector combined with the building surface allow us to speak about its possibility of wide use in solar heat supply systems. The solar radiation flux density of 950 W/m^2 confirms the possibility of using solar energy in Lviv. t_{water}, °C.

Conclusion

An improved solar heating system with the proposed solar collector design was tested during field studies. The temperature characteristics of the structure, depending on the intensity of solar energy intake, are among the low-potential characteristics of solar collectors. Therefore, the proposed design can be offered to the consumer during the design of swimming pools, in systems with a duplicate energy source, etc.

A promising area of further research remains the establishment of the thermal efficiency of the developed solar collector with changes in the intensity of simulated solar radiation and different modes of movement of the coolant through the heat exchanger of the solar collector in the solar heat supply system.

References

Shapoval, S., Zhelykh, V., Spodyniuk, N., Dzeryn, O., Gulai, B. (2019). The effectiveness to use the distribution manifold in the construction of the solar wall for the conditions of circulation. *Pollack Periodica*, 14(2), 143–154. doi:10.1556/606.2019.14.2.13 (in English)

Solovei, O. I., Lega, Yu. G., Rosen, V. P., Sitnik, O. O., Chernyavsky, A. V., Kurbak, G. V. (2007). *Nontraditional and Renewable Energy Sources: Teaching. Manual.* Cherkasy: ChTTU. (in Ukrainian)

Dudyuk, D. L., Mazepa, S. S. (2004). *Unconventional (renewable) energy sources.* Lviv: RVV Ukr DLTU. (in Ukrainian)

Babych, M., Krygul, R., Shapoval, S., Tolstushko, N., Korobka, S., Tolstushko, M. (2019). Results of experimental researches into process of oak veneer drying in the solar dryer. *Eastern-European Journal of Enterprise Technologies*, 2 (8–98), 13–22. doi:10.15587/1729-4061.2019.162948 (in English)

Kudrya, S. O., Golovko, V. M. (2005). *Basics of designing power plants with renewable sources.* Nizhyn: Aspect-Polygraph Publishing House. (in Ukrainian)

Zhelykh, V., Pona, O., Eltman, A., Shapoval, S. (2015) *Perspectives of using heliosystems and their research in solar heating system, XV International Scientific Conference: Current issues of civil and environmental engineering and architecture, September 2015.* Rzeszów – Lviv – Kosice. (in English)

Malkin, Ye. S. (Ed.). (2002). *Method of presenting data on solar radiation for calculating the solar heating system.* Ventilation, lighting and heat and gas supply. K.: KNUBA. (in Ukrainian)

Havrus, V., Shelevytsky, I. (2008). Forgot the right to the sun or warmth in your home. *Electronic journal of the energy service company "Ecological Systems"*, 2. http://esco-ecosys.narod.ru/2008_2/art140.htm. (in English)

Zakhidov, R. A., Vainer, A. A., Umarov, G. Ya. (1977). *Theory and Calculation of Heliotechnical Concentrating Systems.* Tashkent: Fan. (in Russian)

Malevsky Yu. N. (Ed.). (1977). *Thermal processes based on solar energy utilization.* M*:* Mir. (in Russian)

Akimenko, O., Kostiuchenko, I. (2020). Prospects of the introduction of alternative energy sources as a step to the internation cooperation. Problems and Prospects of Economics and Management, 4 (24), 43–50. (in Ukrainian)

Moiseenko, V. V. (1992). *System development of a solar collector for decentralized heat supply.* (PhD dissertation). Odessa National Polytechnic University, Odessa. (in Ukrainian)

Doroshenko, A. V., Khalak, V. F. (2018). Solar polymer liquid collectors. Analysis of existing results, new solutions. *Refrigeration Engineering and Technology,* 54 (5), 44–52. https://doi.org/10.15673/ret.v54i5.1250 (in Ukrainian)

Pukhovyj, I. I., Bezrodny, M. K., Kudrya, T. S. (2007). Study of the passive solar heating system of the "glazed loggia" type in the absence of traditional heating. Renewable energy of the XXI century: materials of the VIII International conference, September 17–21, 2007. Crimea, 105–106. (in Ukrainian)

Cristofari, C., Notton, G., Poggi, P., Louche, A. (2002). Modelling and performance of a copolymer solar water heating collector. *Solar Energy*, 72, 2, 99–112. Режим доступу до журн. : https://doi.org/10.1016/s0038-092x(01)00092-5 (in English)

Raman, R., Mantell, S., Davidson, J., Wu, C., Jorgensen, G. (2000). A review of polymer materials for solar water heating systems. *Journal of Solar Energy Engineering*, 122, 2, 92-100. Doi: https://doi.org/10.1115/1.1288214 (in English)

Fahrenbruch, A., Byub, R. (1987). *Solar elements: theory and experiment.* M .: Energo-atomizdat. (in Russian)

Fortuin, S., Hermann, M., Stryi-Hipp, G., Nitz, P., Platzer, W. (2014). Hybrid PV-thermal collector development: concepts, experiences, results and research needs. *Energy Procedia,* 48, 37–47. doi: https://doi.org/10.1016/j.egypro.2014.02.006 (in English)

Chen, G., Doroshenko, A., Koltun, P., Shestopalov, K. (2015). Comparative field experimental investigations of different flat plate solar collectors. *Solar Energy*, 115, 577–588. https://doi.org/10.1016/j.solener.2015.03.021 (in English)

Misak, Y. S., Voznyak, O. T., Datsko, O. S., Shapoval, S. P. (2014). *Solar energy: theory and practice: monograph.* Lviv: Lviv Polytechnic Publishing House. (in Ukrainian)

Odintsov, A. N. (2009). Feasibility of using vertical solar collectors for thermal regulation of premises. *Bulletin of SevDTU*, 97, 204–209. (in Russian)

Gladen, A. C., Davidson, J. H., Mantell, S. C. (2014). The effect of a thermotropic material on the optical efficiency and stagnation temperature of a polymer flat plate solar collector. *J. Sol. Energy Eng*, 137 (2), 021003-021003. https://doi.org/10.1115/1.4028366 (in English)

Chorna, N. O. (2011). Method of calculation of optical-geometric parameters of “zonal” focclines. *Lighting and Electronics*, 2, 43–49. (in Ukrainian)

Shapoval, S. P. (2010). The efficiency of the “delta system” of flat solar collectors at different angles of their installation. *Bulletin of the National University “Lviv Polytechnic”: Theory and Practice of Construction*, 664, 331-335. (in Ukrainian)

Gershkovych, V. F. (2009). Heat pump in a multi-storey residential building. Is it for the future or today? *Installation Market*, 1, 32–33. (in Ukrainian)

Novakivskyj, E. V. (2004). *Improving the efficiency of solar energy use in combined industrial heating systems.* (PhD dissertation). Odessa National Polytechnic University, Odessa. (in Ukrainian)

Novakovsky, E. V., Denisova, A. E., Mazurenko, A. S. (2003). Analysis of the efficiency of delta-system solar collectors for alternative heating systems. *Ecotechnology and resource conservation: scientific and technical journal,* 6, 14–17. (in Ukrainian)

В. М. Желих[1], М. Є. Касинець[1], Х. В. Миронюк[1], У. Д. Марущак[2], Б. І. Гулай[1]
Національний університет “Львівська політехнікаи”,
[1] кафедра теплогазопостачання та вентиляції,
[2] кафедра будівельного виробництва

ЕНЕРГОЕФЕКТИВНІ СИСТЕМИ СОНЯЧНОГО ТЕПЛОПОСТАЧАННЯ БУДІВЕЛЬ ТА СПОРУД

Сьогодні енергетика України потребує значного споживання традиційних джерел енергії (нафти, газу, вугілля, атомної енергії). Проте їх використання пов’язане із виникненням певних труднощів, серед яких теплове, хімічне, радіоактивне забруднення навколишнього середовища та вичерпність їх запасів. У праці вирішено актуальну проблему підвищення ефективності систем сонячного теплопостачання з плоскими сонячними колекторами. Проаналізовано потенціал сонячної енергетики та існуючих систем сонячного теплопостачання. Невідновні джерела енергії мають достатньо великий потенціал для забезпечення потрібного життєвого рівня людей. Встановлено, що для отримання необхідної кількості нетрадиційної енергії для енергозабезпечення жителів міст потрібно використати лише 5 % зайнятої ними площі. Проаналізовано переваги та недоліки різних конструкцій сонячних колекторів, методи їх досліджень. Актуальним дослідженням є вдосконалення наявних сонячних колекторів та систем сонячного теплопостачання для їх максимальної інтеграції в традиційні системи теплопостачання та широке застосування на практиці. Подано аналіз основних напрямів підвищення ефективності сонячних колекторів та систем сонячного теплопостачання загалом. Отримано удосконалену систему сонячного теплопостачання із запропонованою конструкцією сонячного колектора та встановлено його температурні характеристики залежно від інтенсивності надходження сонячної енергії. Встановлено, що температура води на виході з експериментального сонячного колектора до обідньої пори дня була на ≈4–5 % вища, ніж температура води на вході в сонячну установку та температура води в баку-акумуляторі сонячного колектора. Тому запропоновану конструкцію можна використовувати для споживачів під час проектування басейнів, у системах з джерелом енергії, яке дублюється

Ключові слова: нетрадиційні джерела енергії, сонячна енергія, сонячний колектор, система сонячного теплопостачання, температура теплоносія, інтенсивність сонячної енергії.