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Efficiency of Hybrid Solar Collectors Application in Building Heating Systems

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Abstract

The article focuses on the use of hybrid solar collectors as one of the ways to increase the efficiency of solar systems in general. The authors consider the design of a solar collector with the arrangement of circulation pipes above the heat-absorbing surface with a transparent coating. A solar system with natural circulation of the heat carrier (water) has been investigated. Based on the research results, a nomogram has been developed to define the relationship between the thermal efficiency coefficient of the solar cover with a transparent coating and the arrangement of pipes of the heat carrier circulation loop above the heat absorber depending on the angles and the intensity of the radiation flux. As a result, a functional dependence is obtained, which allows accurately determining the coefficient of thermal efficiency for specific parameters and input data. This research indicates the need for the use of hybrid solar collectors to ensure efficient collection of solar energy and emphasizes the importance of further research and improvement of the design of elements of such systems to reduce environmental pollution and increase the stability of heating systems.

Keywords: hybrid solar collector; heat absorber; solar system; coefficient of thermal efficiency.

1. Statement of scientific problem

Nowadays, there are many advanced technologies that provide and ensure the possibility of using nuclear and fossil fuel energy for many years to come. Despite the efforts of the world community to implement the decarbonization policy of production, the level of atmospheric pollution continues to increase, which leads to negative consequences for the biosphere. Other issues to be concerned about are thermal and radiation pollution, waste storage and consequences of accidents.

Introduction of new technologies in construction and the improvement of energy-saving properties of materials give impetus to the development of effective methods for collecting solar energy, with its further use in heat supply systems of buildings for various purposes. However collection and accumulation of the received heat is accompanied by constant losses, which are connected with climatic conditions, geographical location, structural features of the elements of solar systems, and the correct choice of the type of solar collector. These issues are among the main ones in the field of solar energy. They are possible to be solved by using innovative complex methods, which are based on the introduction of new elements into the design of solar converters.

2. Recent publications and studies related to the research problem analysis

Nowadays, the development of energy equipment requires new solutions. Along with efficient centralized systems [1], one of the most promising areas is solar energy [2]. Additional attention should be paid to the heat supply systems of

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buildings using solar collectors of various configurations [3], [4], [5]. This field is constantly developing, therefore, solutions for the introduction of new efficient hybrid solar collectors [6] are promising. Their peculiarity is that they are integrated into the external protection of the building [7]. Some of these solar collectors can perform a double function, serving not only as a source of energy, but also as elements of thermal insulation [8]. Others are built into the glass structures of buildings [9], [10], [11], thereby increasing the energy efficiency of the building as a whole.

In order to achieve a high efficiency of the hybrid solar collectors application, the potential of solar energy at the place of their installation needs to be taken into account [12], [13]. For this reason, further improvements to the design and research into the thermal characteristics of elements of such solar systems are needed [14], [15]. These elements can be made of both metal and polymer materials [16], which helps them to be effectively integrated into the architecture of buildings [17], [18].

3. The goal of the article

The main goal of this work is to investigate a hybrid solar collector and determine its thermal efficiency coefficient with an existing transparent cover, placing the tubes of the heat transfer circuit above the absorber in a solar heating system with natural circulation, depending on the angles of incidence and intensity of the radiation flux.

4. Research results presentation and discussion

The design of a hybrid solar collector, which requires further research, was created based on the review of existing combined and hybrid solar heating systems. The design of a hybrid solar collector with a transparent coating is proposed where the circulation tubes are placed above the heat absorber. These measures are taken to increase the area of heat absorption of solar radiation. This design of the solar collector can be used, for example, in the case of reconstruction of the building covering. The scheme of the experimental installation is presented in Figure 1.

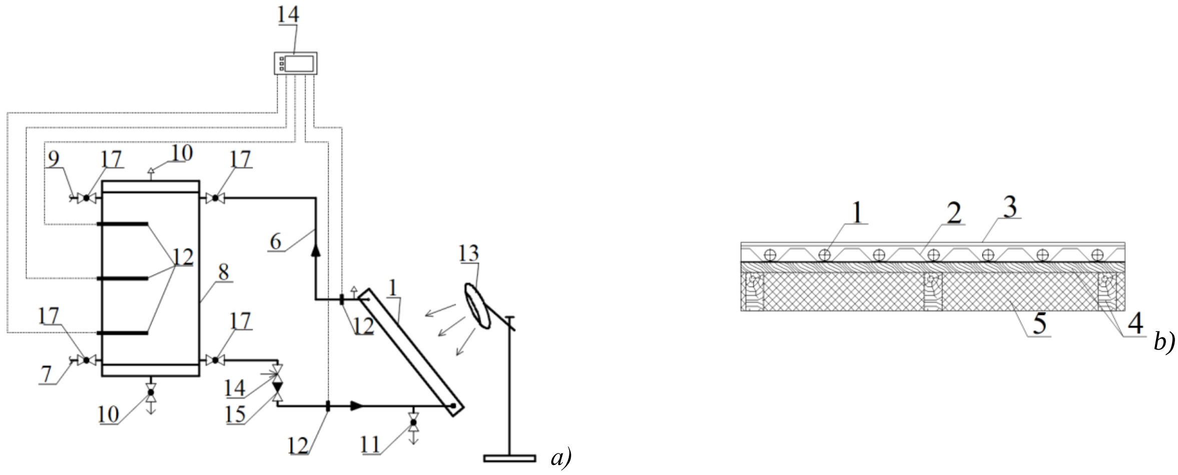

Fig.1. The scheme of the experimental installation (*a*) and hybrid solar collector (*b*): 1 – circulation tube for the heat transfer fluid; 2 – roofing material of the building; 3 – transparent coating; 4 – roof structures; 5 – thermal insulation; 6 – supply pipeline; 7 – return pipeline; 8 – heat accumulator; 9 – coolant selection nozzle; 10 – air outlet valve; 11 – faucet for draining the coolant; 12 – resistance thermometers; 13 – radiation source; 14 – display; 15 – balancing valve; 16 – return valve; 17 - shut-off valves.

In the proposed design of the hybrid solar collector, ordinary window glass with a solar transmittance coefficient of 95% is used as the transparent covering. The response function chosen is the thermal efficiency coefficient of the solar covering, K_{ef}, which indicates the influence of changes in the angles of incidence and the density of the radiation flux on the thermal characteristics of the solar covering.

$$K_{ef} = \frac{q_{hs,i}}{q_{hs}}, \tag{1}$$

where q_{hs} is the amount of heat accumulated in the heat storage tank at incidence angles of radiation flux $\alpha = 90°$ and $\beta = 90°$ and its radiation flux density $I_v = 900$ W/m²; $q_{hs,i}$ is the amount of heat accumulated in the thermal accumulator tank for different angles of incidence and the radiation flux density I_v.

Based on the conducted research of the helio-covering thermal characteristics, it has been determined that the thermal efficiency coefficient of the helio-covering K_{ef} for the radiation flux density I_v = 300 W/m^2 varies from 0.47 to 0.77 for changes in the angles of its incidence from 30 degrees to 90 degrees (Fig.2 – Fig.4). The thermal efficiency coefficient of the solar collector with a transparent covering and tubes of the circulation circuit located above the heat absorber decreases with changes in the angles of incidence of the radiation flux from 90 to 30 degrees.

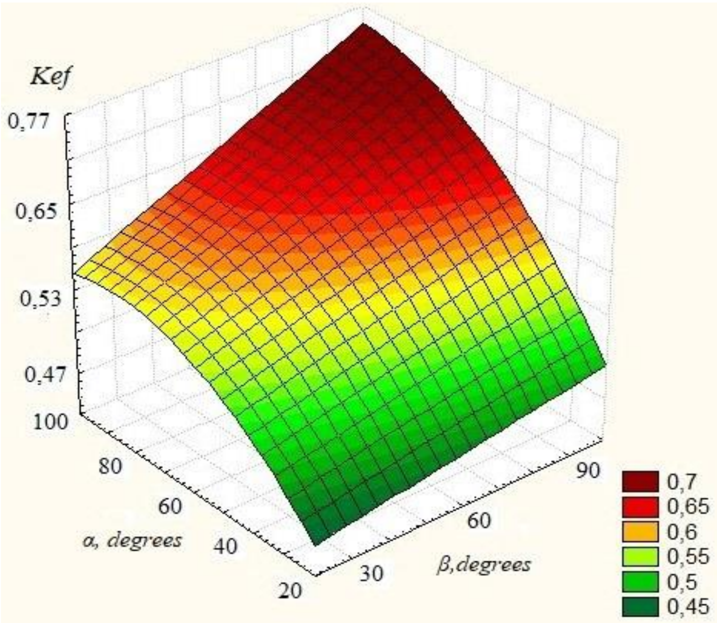

Fig.2. The dependence of the thermal efficiency coefficient of the solar cover with transparent tubes of the circulation circuit, located above the heat absorber, on the density of radiation flow I_v=300W/m^2.

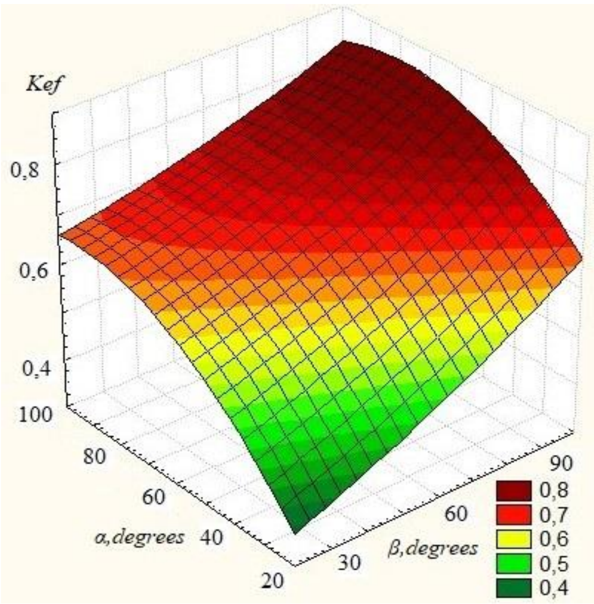

Fig.3. The dependence of the thermal efficiency coefficient of the solar cover with transparent tubes of the circulation circuit, located above the heat absorber, on the density of radiation flow I_v=600W/m^2.

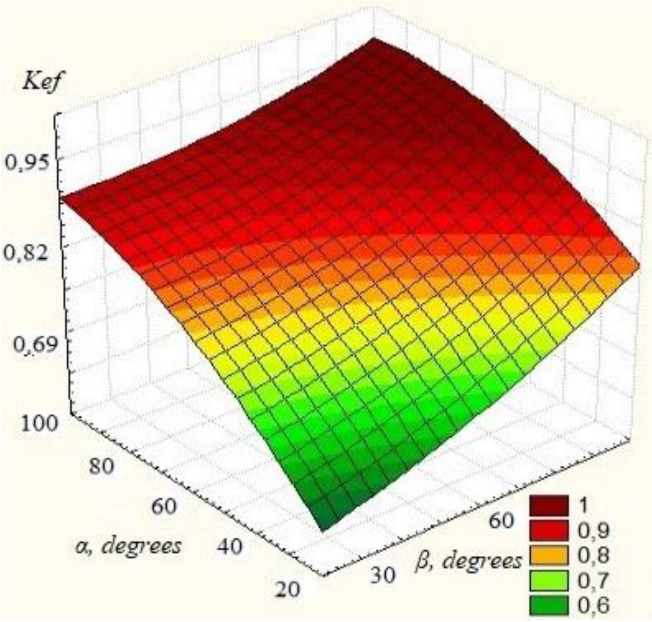

Fig.4. The dependence of the thermal efficiency coefficient of the solar cover with transparent tubes of the circulation circuit, located above the heat absorber, on the density of radiation flow I_v=900W/m^2.

Statistical processing of the research results has been carried out with application of the following relations:

$$F = \frac{0.001677}{0.000100} = 16.77 < F_{table.} = 19.2;$$
$$G_{к} = \frac{S^2_{max}}{\sum_1^N S_i^2} = \frac{0.001677}{0.018985} = 0.088 < G_{table.} = 0.2167;$$
$$s^2(y) = \frac{0.038}{54} = 0.0007,$$

where F is Fisher criterion, G_k is Cochran's number; G_{table} is the tabular value of Cochran's number; S^2_{max} is the value of maximum variance;

Statistical processing has been conducted regarding the optimization criterion, with efficiency coefficient chosen as the criterion. Therefore, based on the results of the experimental data obtained, a regression model of the optimization criterion has been compiled K_{ef}:

$$K_{ef} = 0.714 + 0.028x_1 + 0.072x_2 + 0.075x_3 - 0.004x_1x_2 + 0.006x_1x_3 + 0.009x_2x_3 - 0.002x_1x_2x_3 \;, \quad (2)$$

where x_1 is the angle of rotation of the solar collector along the azimuth α, degrees; x_2 is the angle of inclination of the solar collector β, degrees; x_3 is the density of radiation flow I_v, W/m^2.

For the regression model (2) the confidence interval: $\Delta b = \pm 2.069\sqrt{\frac{0.007}{54}} = \pm 0.0074.$

Therefore, neglecting insignificant factors, the regression model will take the following form:

$$K_{ef} = 0.714 + 0.028x_1 + 0.072x_2 + 0.075x_3 + 0.009x_2x_3 \;. \quad (3)$$

The analysis of the regression model coefficients showed that the coefficient of thermal efficiency of the solar collector with transparent covering with tubes of the circulation circuit, located above the heat absorber, is significantly influenced by the density of the radiation flux I_v, while the angles of its incidence β and α have a less significant impact. Based on obtained experimental data a nomogram has been developed (Fig.5).

Based on the data from the nomogram, a functional dependency of the relationship between the coefficient of thermal efficiency K_{ef} in solar system with the natural circulation of the heat transfer fluid and the angles of rotation of the solar collector with transparent covering (α, β) and the density of the radiation flux I_v has been established:

$$K_{ef} = d + (m \cdot \alpha) + (n \cdot \beta) + (c \cdot \alpha^2) + (f \cdot \alpha \cdot \beta) + (k \cdot \beta^2), \quad (4)$$

where $d = 0.2982 - 9.2667 \cdot 10^{-5} \cdot I_v$; $n = -3.333 \cdot 10^{-5} + 2.8333 \cdot 10^{-6} \cdot I_v$; $m = 0.0036 + 8.8333 \cdot 10^{-6} \cdot I_v$; $c = -9.8763 \cdot 10^{-6} + 3.395 \cdot 10^{-8} \cdot I_v$; $f = 3.6112 \cdot 10^{-5} - 7.8705 \cdot 10^{-8} \cdot I_v$; $k = -3.5803 \cdot 10^{-5} - 1.2347 \cdot 10^{-8} \cdot I_v$.

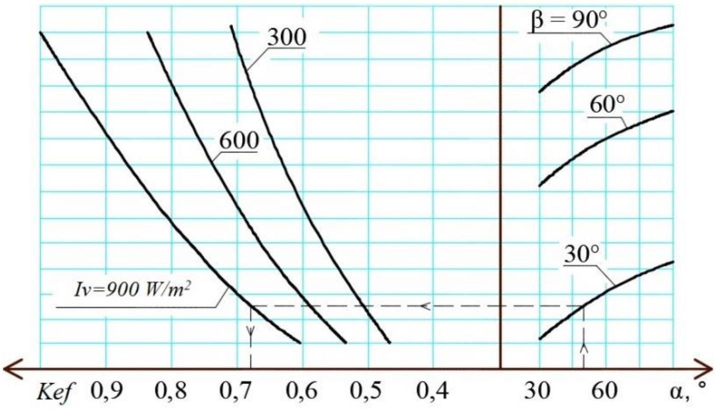

Fig.5. The nomogram of the relationship of the thermal efficiency coefficient of the solar cover with transparent tubes of the circulation circuit, located above the heat absorber, depending on the angles α, β and the density of the radiation flow I_v.

The given expression allows calculating the coefficient of thermal efficiency of a solar collector with a transparent covering, with the arrangement of tubes of the circulation circuit of the heat transfer fluid above the heat absorber, depending on the angles of solar radiation incidence and its intensity.

5. Conclusion

Based on the review of existing combined and hybrid solar heating systems, a design for a hybrid solar collector with a transparent cover and the placement of circulation tubes above the heat absorber is proposed. Through research on the thermal characteristics of the solar cover, it was determined that the coefficient of thermal efficiency (K_{ef}) varies depending on the angles of solar radiation incidence and its intensity (Fig.2 – Fig.4). A regression model was developed based on experimental data. Analyzing the coefficients of this model, it was proven that the presence of a transparent cover leads to a reduction in the efficiency of the solar collector. The regression model showed that this is primarily influenced by the density of radiation. A nomogram was developed based on the research results, depicting the relationship between the coefficient of thermal efficiency of the solar cover with a transparent coating and the arrangement of circulation tube contours over the heat absorber, depending on the angles α and β and the density of radiation flux I_v.

The validity of all results of experimental research was substantiated by testing the adequacy of the obtained mathematical models against the respective criteria of Student, Fisher, and Cochran within the confidence interval boundaries of $\alpha = 0.95$. As a result, a functional dependence was obtained, allowing for the accurate determination of the coefficient of thermal efficiency (K_{ef}) for specific parameters and input data.

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Ефективність застосування гібридних сонячних колекторів у системах теплозабезпечення будівель

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Анотація

Стаття присвячена використанню гібридних сонячних колекторів, як одного із способів підвищення ефективності геліосистем у цілому. Авторами розглянуто конструкцію сонячного колектора з розташуванням трубок циркуляції над теплопоглинаючою поверхнею із прозорим покриттям. Досліджено геліосистему із природною циркуляцією теплоносія (води). За результатами досліджень розроблено номограму взаємозв'язку коефіцієнта теплової ефективності геліопокриття з прозорим покриттям із розташуванням трубок контуру циркуляції теплоносія над теплопоглиначем залежно від кутів та густини потоку випромінювання. Як результат отримано функціональну залежність, яка дозволяє точно визначати коефіцієнт теплової ефективності для конкретних параметрів і вхідних даних. Наведені дослідження вказують на потребу у застосуванні гібридних сонячних колекторів для забезпечення ефективного збору сонячної енергії та підкреслюють важливість подальших досліджень і вдосконалення конструкції елементів таких систем для зменшення забруднення навколишнього середовища і підвищення стійкості систем теплопостачання.

Ключові слова: гібридний сонячний колектор; теплопоглинач; геліосистема; коефіцієнт теплової ефективності.