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EFFICIENCY OF SOLAR ROOF WITH TRANSPARENT COVER FOR HEATING SUPPLY OF BUILDINGS

The method of increasing the efficiency of solar energy of solar roof with transparent coatings is considered in this article. The results of studies on the incoming solar radiation of solar roof are described. It is shown that the heat from building roofing material can be effectively used. The dependence between the different orientations of solar roof and its efficiency is established.

Keywords: **solar roof, efficiency of solar energy, solar radiation**

INTRODUCTION

The sharpening of the issues which exist now is related to providing energy for population and industry of Ukraine, and the impact of the energy sector on the environment causes structural changes in the energy system of the country. That is why the development of not only nuclear power but also renewable energy sources is planned. The need to replace non-renewable energy sources is not only related to their depletion, but also to the danger of global scale, which is created by burning coal, oil, gas, peat and increase of CO_2 in the atmosphere.

The issues related to the future ways of energy development escalate more and more every year. On the one hand, the population growth, the desire to improve the living standards of people dictate the expediency of accumulation of energy capacity, moreover, on gigantic rates, on the other hand, the environmental problems arising, exhaustion of natural sources of raw materials, and, above all, oil and gas, require more economic and efficient use of the energy obtained. Fuel and energy resources become more expensive every year both for the industry and for the population.

Solar energy is the most promising resource on the scale of existing types of renewable energy for its environmental cleanliness and prevalence. This is confirmed by a number of experimental studies conducted in the field of solar energy. The amount of solar energy that comes to the Earth is more than the energy of the world's oil, gas, coal and other energy resources. Using just 0.01% of solar energy can provide for all the needs of today's global energy and the use of only 0.1% - fully cover the needs of the future [1].

Therefore, there is a need to implement complex measures on the use of new alternative energy sources. The solution of this problem requires significant changes in the global energy balance. An alternative in this field is the use of non-conventional renewable energy sources: energy of the sun, wind, entrails of the earth, the heat of industrial and sewerage waste, waters etc. They are completely free for the mankind and given to us in virtually unlimited quantities.

The advantages of solar energy over traditional fuels include: the use of solar energy in almost all parts of the Earth's surface, the possibility of direct conversion of solar energy into heat or electricity, the ability to obtain high coolant. Therefore, the development of solar energy is carried out in three main areas: thermal, photovoltaic and thermodynamic [1]. The amount of solar energy arriving at the Earth's surface is 10,000 times more than world's total energy consumption [2]. Solar energy is an inexhaustible source of renewable clean energy. The average amount of solar energy that goes for 1 day per 1 m^2 surface of the Earth is ranging from 7.2 MJ/m^2 in the north to the south 21.4 MJ/m^2 [3]. The climate of Ukraine provides the potential for widespread use of solar energy. Annual flux of solar radiation on the horizontal surface of 1 m^2 in southern Ukraine is 1100÷1380 kWh, and the duration of sunlight is about 2,000 hours per year [4].

Currently there is a number of solar collectors that are different in design, and technical and economic indicators. Flat solar collectors have proved themselves as quite effective and easy to use. But these solar collectors are expensive, elaborately designed. Consequently, at present it is important to improve and develop new solar collectors where the top covering of the solar collector is made of corrugated roofing material of the building. This kind of the solar collector will allow to reduce its cost maximally and increase its durability, transparent coating reduces heat.

Many studies of solar power plant are devoted to the determination of the optimal angles of slope of the flat solar collector to the horizon and the azimuth of its rotation, and also to the improvement of their design [5]. An effective method to increase the efficiency of solar collectors and to reduce their cost is to make the top covering of the solar collector from the roofing material of the building.

1. DESCRIPTION AND WORK OF SOLAR ROOF

Solar roof is based on the task to improve the flat solar collector. This is done because the material heat absorbing solar roof is both the roofing material of the building, thus reducing costs, increase flexibility and simplify the design of the solar collector. Transparent coating significantly reduces solar collector heat, as in the space between the glass and roofing material is a layer of air. Solar roof makes good use of heat roofing material building.

In Figure 1 scheme of solar roof is shown. Solar collector includes top (1) and bottom (2) hose cover, which is located between the tube circuits (3) attached to the top cover and connected to the input (4) and output (5) pipes for supplying coolant. Corrugated roofing material on the inner surface is coated with a selective layer material (6). The inner surface of the lower corrugated mirror coating (7) deposited layer. Coated corrugated insulating layer (8) is located at the bottom.

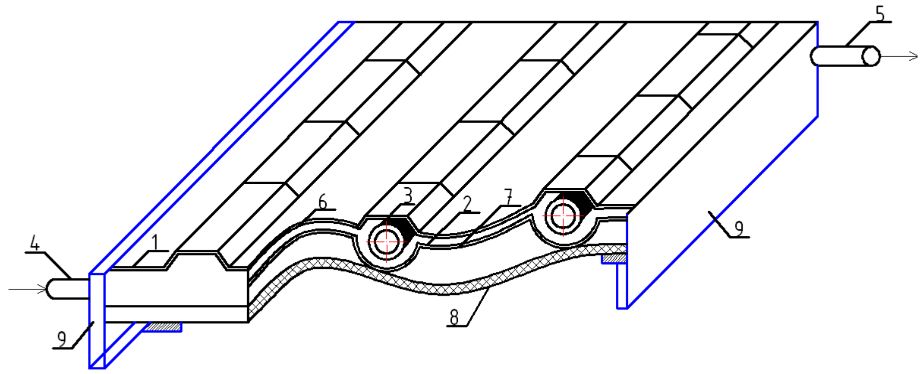

Fig. 1. Scheme of solar roof: 1 - top hose cover, 2 - bottom hose cover, 3 - tube circuits, 4 - input pipe, 5 - output pipe, 6 - selective layer material, 7 - mirror coating, 8 - insulating layer, 9 - chevron

Superior corrugated cover is attached to the rafters, for example, by means of brackets. Sunlight falls on the outer surface of the corrugated outer covering, made of roofing material, the inner surface of which is coated with a selective layer material, which ensures maximum absorption of solar heat at the minimum level of reflection of sunlight back into the atmosphere. The result of this is heating. Heat is transferred by the tubes loop circulation, which circulates coolant. Due to the temperature difference and density difference, the circulation of the coolant is created in the area of input and output sockets created by. The heated coolant is supplied to the consumer. Insulating layer and a transparent top layer would reduce the heat loss.

2. EXPERIMENTAL STUDIES OF SOLAR ROOF WITH TRANSPARENT COVER

Experimental setup for investigating the impact of angles of incidence of radiation on the efficiency of the solar roof was mounted at the National University "Lviv Polytechnic".

Installation consisted of solar roof, tank battery, the radiation source and gauges. The experimental setup is shown in Figure 2.

A special magazine was considered before the experiments. It was made according to the methodology and research plan, which recorded the results. Thermal radiators, which were used, could give power of 1000 W/m^2 heat flux.

Each time before the experiment was started the system was filled with a portion of fresh water. We checked the hermeticity of the system at the operating pressure. The good condition of measuring devices was also tested.

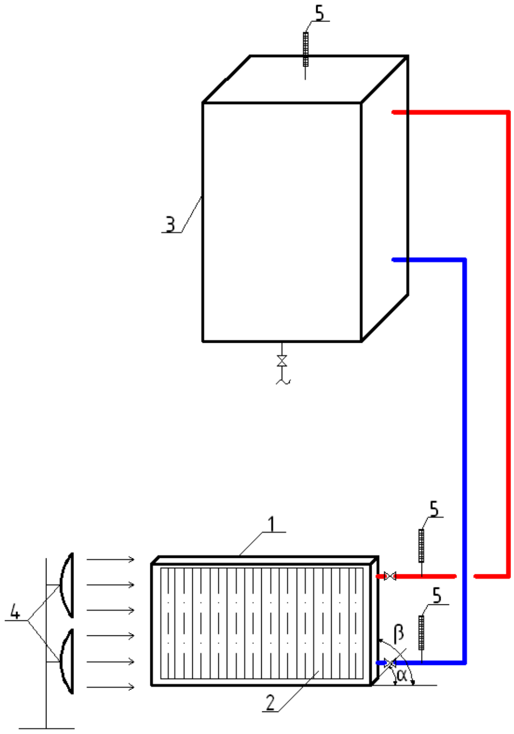

Fig. 2. Chart of the experimental unit: 1 - solar roof, 2 - accumulator box,
3 - source of radiation, 4 - mercury thermometer

Pipelines with rubber hoses are insulated to minimize heat loss during the experimental studies. Storage tank was insulated with mineral wool thickness of 100 mm and covered with a heat coating.

During the experiments, each experiment was performed twice under identical conditions in order to be able to estimate the error. During each experiment, values of optimization were obtained, and they were averaged.

The situation was put under control to ensure that the other factors (solar energy through the window, smooth surface shading of the solar collector, etc.) did not affect the experiment. Natural air flow does not exceed 1 m/s, which did not affect the results of experiments, but made it possible to remove the excess heat during the experiment, as the result the ambient temperature during the experiment slightly increased.

During the experiment were measured: the intensity of energy flow, coolant temperature at the inlet of the solar collector, the temperature of the coolant at the outlet of the solar collector, the temperature of the coolant in the tank - battery.

The intensity of the flow of the energy emanated by the source was measured by an actinometer. The temperature of the heat carrier was measured at three points of the system (at the outlet of the collector, at the collector inlet and in the accumulator box) by the mercury thermometer. Environment air temperature and its speed were measured by the thermoelectric generator anemometer TESTO 405 - V1.

After the end of the experiments the thermal radiators were excluded, coolant circulation was stopped, heat carrier was sprinkled and the system was completed by the new portion of the cooled coolant.

We made up the three-factor planning matrix with the factors interaction. As the factors we chose:

– x_1 - azimuthal angle of turning of the solar collector, $\alpha_в$°;
– x_2 - the angle of slope of the collector, $\beta_в$°;
– x_3 - the heat flow intensity [W/m^2].

Table 1 presents the factors levels and varying intervals:

Table 1. **Levels of factors and varying intervals**

Factor Name	Code	Factor levels		Variation
		–1	+1	
Azimuthal angle of the solar collector $\alpha_в$ [°]	x_1	30	90	60
The angle of the solar collector $\beta_в$ [°]	x_2	30	90	60
The intensity of the heat flux $I_в$ [W/m^2]	x_3	300	900	600

The optimization parameter was the efficiency coefficient $К_{ef}$, as the change of the fall angle of beams influences the efficiency of the solar collector combined with the roof of the building.

$$К_{ef} = \frac{Q_i}{Q_{ст}} \cdot 100 \quad (1)$$

where:

Q_i - the heat energy received by the solar collector combined with the roof of the building at the fall angle of beams $\alpha = 90°$, $\beta = 90°$ and $I_в = 900$ W/m^2;
$Q_{ст}$ - the heat energy received by the solar collector combined with the roof of the building at different fall angles of beams and different radiation intensity.

Heat received by solar roof is determined by the formula:

$$Q = G\,c\,(t_{vyh} - t_{vh}) \quad (2)$$

where:

G - coolant flow rate [kg/s];
c - specific heat of fluid [J/(kg K)];
t_{vyh}, t_{vh} - coolant temperature at the inlet and outlet of the solar collector [K].

We get the following equation of regression on the basis of the data in Table 1:

$$y = 0.859 + 0.041x_1 + 0.074x_2 + 0.041x_3 - 0.009x_1x_2 - 0.006x_1x_3 - \\ - 0.009x_2x_3 + 0.02x_1x_2x_3 \quad (3)$$

Table 2. **Matrix of experimental design**

№	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	y
1	+	–	–	–	+	+	+	–	0.58
2	+	+	–	–	–	–	+	+	0.68
3	+	–	+	–	–	+	–	+	0.75
4	+	+	+	–	+	–	–	–	0.83
5	+	–	–	+	+	–	–	+	0.68
6	+	+	–	+	–	+	–	–	0.75
7	+	–	+	+	–	–	+	–	0.83
8	+	+	+	+	+	+	+	+	1

After analyzing the coefficients of regression equations, we can conclude that the greatest impact on the efficiency of solar roof is the angle and intensity of heat flow and the azimuthal angle of the solar roof not significantly affected. The interaction of the first and second factors, and the second and third slightly influence the efficiency of solar systems, and the interaction of the first and third - even less.

Based on the results of experimental studies this nomogram is created. It shows the dependence of azimuthal rotation angle of solar roof $\alpha_в$, the angle of rotation of solar roof $\beta_в$, the intensity of the heat flux $I_в$ and coefficient of efficiency solar K_{ef} (Fig. 3). Based on the results of experimental studies we get empirical equation:

$$y = (0.525 + 10^{-4} I)(0.016 + 0.23 \cdot 10^{-3} I)(-3.34 + 0.101\,\beta) + (0.0655 + 0.45 \cdot 10^{-3}\beta)\alpha +$$
$$+ (0.8 \cdot 10^{-3} \pm 0.002 \cdot 10^{-3} I)\big((-3.34 + 0.0101\beta) + (0.0665 + 0.45 \cdot 10^{-3}\beta)\big)^2 \quad (4)$$

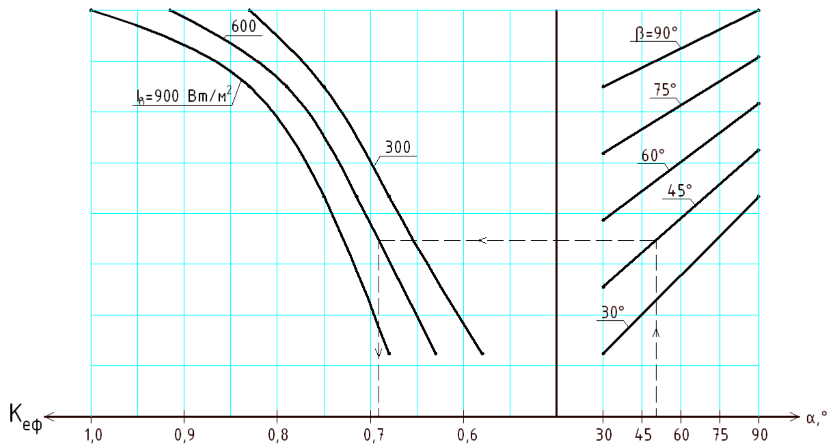

Fig. 3. Nomogram. The dependence of the efficiency of solar α, β and $I_в$

Also, for clarity, the results of experimental studies are presented in three dimensions (Fig. 4):

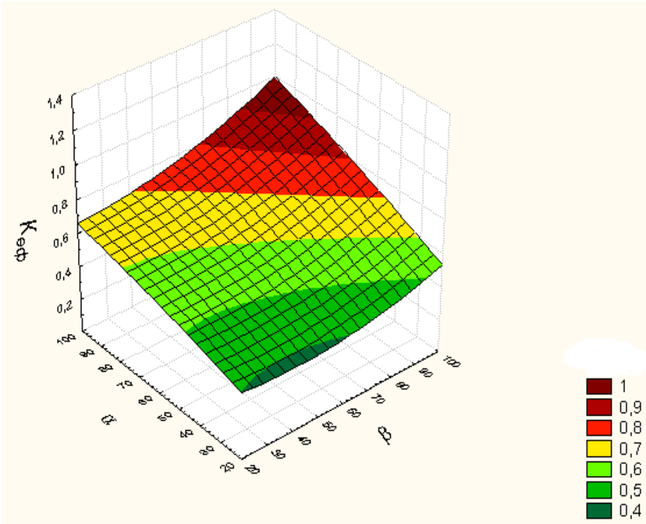

Fig. 4. The results of experimental studies in three dimensions

These nomograms and graphics show that the effectiveness of solar roof by changing the angle of incidence α and β from 90° to 30° is reduced by 32%, indicating a slight drop in the efficiency of solar systems.

CONCLUSIONS

Studies have shown the effectiveness of the solar roof at large angles of radiation incidence (morning and evening). So efficiency ratio K_{ef}, with the intensity of the heat flux $I_в = 300$ W/m^2, varies from 1 to 0.68 when changing the incidence angle of 30° to 90°, which indicates the possibility of widespread use of solar and efficient work during the day.

In particular, by changing the angles of incidence of heat flow from 30° to 90° solar efficiency using solar roof reduced by only 32%,whereas the efficiency of solar systems using conventional flat solar collector is reduced to 50%.

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ZASTOSOWANIE KOLEKTORÓW Z PRZEZROCZYSTĄ POWŁOKĄ DO OGRZEWANIA BUDYNKÓW

W tym artykule rozpatrzono sposób zwiększenia efektywności energii słonecznej z kolektorów z przezroczystą pokrywą. Opisano wyniki badań pochłaniania promieniowania słonecznego przez kolektor. Pokazano, że możliwe jest skuteczne wykorzystanie ciepła od materiałów okrywy budynku. Ustalono zależność pomiędzy różnymi orientacjami kolektora a jego efektywnością.

Słowa kluczowe: **kolektor słoneczny, efektywność energii solarnej, promieniowanie słoneczne**