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EFFICIENCY OF SOLAR ROOF IN GRAVITY HEATING SYSTEMS

Introduction

Solar energy is the most promising resource on the scale of existing types of renewable energy for its environmental cleanliness and prevalence [1]. 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 greater than the energy of the world's oil, gas, coal and other energy resources. Using just 0.01% of solar energy can provide all the needs of today's global energy and the use of only 0.1% fully covers the future needs [2].

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 [3, 4], 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 [6].

1. Description and work of solar roof

Solar roof is based on the task to improve the flat solar collector [7, 8]. This is done because the heat absorbing solar roof material is also the roofing material of the building, thus reducing costs, increasing flexibility and simplifying the design of the solar collector [9, 10]. 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.

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 [11, 12]. 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

Installation consisted of solar roof, tank battery, the radiation source and gauges. The experimental setup is shown in Figure 1.

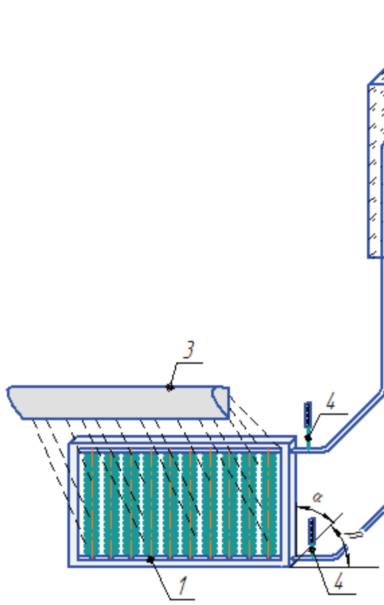

Fig. 1. Scheme of the experimental unit: 1 - solar roof, 2 - accumulator box, 3 - source of radiation, 4 - mercury thermometer

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".

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.

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 was 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 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, α [°];
- x_2 - the angle of slope of the collector, β [°];
- x_3 - the heat flow intensity [W/m^2].

Table 1 presents data on the factors levels and varying intervals.

TABLE 1

Levels of factors and varying intervals

Factor Name	Code	Factor levels			Variation
		–1	0	+1	
Azimuthal angle of the solar collector $\alpha_в$ [°]	x_1	30	60	90	30
The angle of the solar collector $\beta_в$ [°]	x_2	30	60	90	30
The intensity of the heat flux $I_в$ [W/m^2]	x_3	300	600	900	300

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

$$K_{ef} = \frac{Q_i}{Q_{cm}} \cdot 100 \qquad (1)$$

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_{cm} - 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:

$$Q = G \cdot c \cdot \left(t_{vyh} - t_{vh}\right) \qquad (2)$$

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].

TABLE 2

Matrix of experimental design

№	x_0	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$	K_{ef}
1	+	–	–	–	+	+	+	–	0.58
2	+	0	–	–	0	0	+	0	0.68
3	+	+	–	–	–	–	+	+	0.68
4	+	–	0	–	0	+	0	0	0.68
5	+	0	0	–	0	0	0	0	0.75
6	+	+	0	–	0	–	0	0	0.83
7	+	–	+	–	–	+	–	+	0.75
8	+	0	+	–	0	0	–	0	0.75
9	+	+	+	–	+	–	–	–	0.83
10	+	–	–	0	+	0	0	0	0.67
11	+	0	–	0	0	0	0	0	0.75
12	+	+	–	0	–	0	0	0	0.67
13	+	–	0	0	0	0	0	0	0.75
14	+	0	0	0	0	0	0	0	0.83
15	+	+	0	0	0	0	0	0	0.83
16	+	–	+	0	–	0	0	0	0.75
17	+	0	+	0	0	0	0	0	0.83
18	+	+	+	0	+	0	0	0	0.92
19	+	–	–	+	+	–	–	+	0.68
20	+	0	–	+	0	0	–	0	0.75
21	+	+	–	+	–	+	–	–	0.75
22	+	–	0	+	0	–	0	0	0.75
23	+	0	0	+	0	0	0	0	0.83
24	+	+	0	+	0	+	0	0	0.83
25	+	–	+	+	–	–	+	–	0.83
26	+	0	+	+	0	0	+	0	0.92
27	+	+	+	+	+	+	+	+	1.00

Based on the results of experimental studies this nomogram is created. It shows the dependence of azimuthal rotation angle of solar roof α, the angle of rotation of solar roof β, the intensity of the heat flux *Jn* and coefficient of solar efficiency K_{ef} (Fig. 2).

Also, for clarity, the results of experimental studies are presented in three dimensions (Figs. 3, 4):

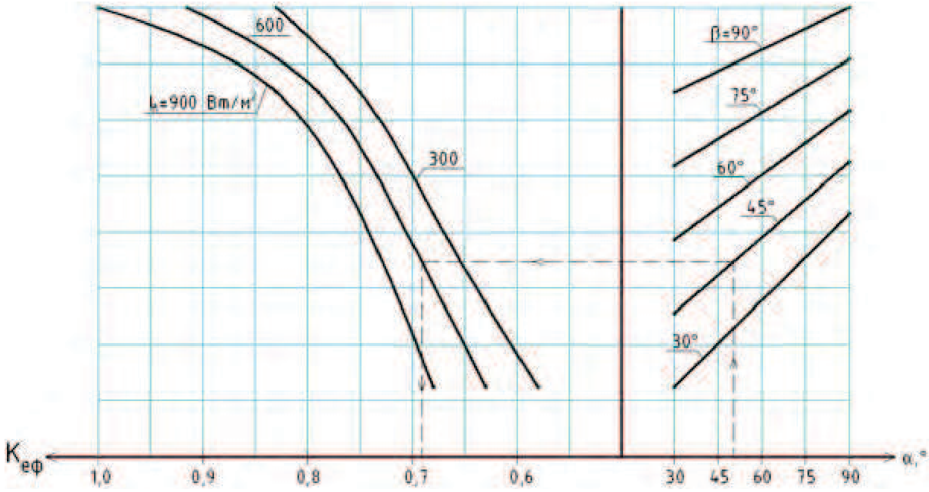

Fig. 2. Nomogram. The dependence of the efficiency of solar α, β and I_B

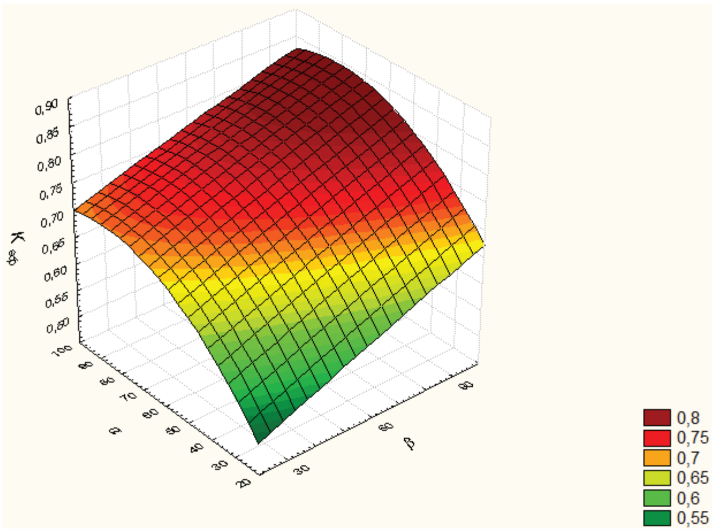

Fig. 3. The results of experimental studies in three dimensions for $I = 300$ W

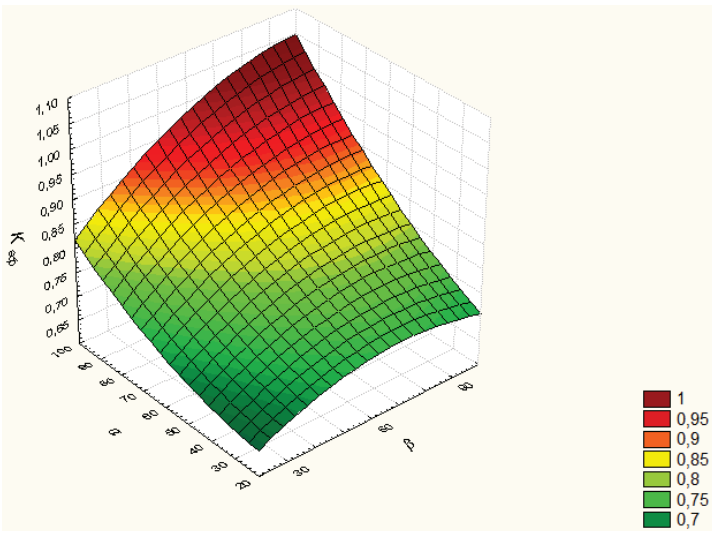

Fig. 4. The results of experimental studies in three dimensions for $I = 900$ W

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

Conclusions

The 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 Jn = 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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Abstract

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 of building roofing material can be effectively used. The dependence between the different orientations of solar roof and its efficiency is established.

Keywords: solar roof, solar radiation, solar heating supply, efficiency

Efektywność dachów solarnych z grawitacyjnym systemem grzewczym

Streszczenie

W artykule rozpatrzono sposób na zwiększenie efektywności energii słonecznej dachu solarnego z przezroczystą pokrywą. Opisano wyniki badania dochodzącego promieniowania słonecznego na dachu solarnym. Pokazano, że jest możliwe skuteczne wykorzystanie ciepła materiałów pokrywy budynku. Ustalono zależność pomiędzy różnymi orientacjami dachu solarnego a jego efektywnością.

Słowa kluczowe: dach solarny, promieniowanie słoneczne, efektywność