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## ORIGINAL RESEARCH PAPER



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# Application of rooftop solar panels with coolant natural circulation

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## ABSTRACT

In line with the energy development strategy of Europe, it is necessary to implement energy efficient buildings, in which the external enclosures are converters of solar energy to thermal. Therefore, the purpose of the publication was the scientific substantiation and development of the solar heating system with the use of rooftop solar panels. Graphical and analytical dependences of the coefficient of thermal efficiency of the solar panel in heat supply system from the angles of solar radiation incoming and the density of the radiation flux were obtained. Analysis of the results showed that the coefficient of thermal efficiency of the solar panel without transparent coating with the placement of pipelines of the circulation circuit of the coolant over the heat absorber increases by 50%.

## KEYWORDS

solar panel, heat accumulator, radiation flux, natural circulation

## 1. INTRODUCTION

Given the global trends in building architecture, including the United States, China, United Arab Emirates and other well developed countries where glass-fronted buildings with dynamic design are expanding, it is advisable to look for new technological solutions for the use of solar thermal systems for this type of buildings. It is also worth paying particular attention to the use of solar thermal systems, elements of which are integrated in the design of external enclosures, for example the roof.

In line with the energy development strategy of Ukraine and Europe, it is necessary to implement energy efficient buildings, in which the external enclosures are converters of solar energy to thermal and which with the combined heat supply system can provide the building with thermal energy.

These are solar heating systems with the use of solar panels with natural circulation of the coolant and their use as part of the roof of the building. They can be widely used in buildings throughout Europe and Ukraine.

## 2. THE AIM OF WORK

Therefore, the purpose of the publication was the scientific substantiation and development of the solar heating system with the use of rooftop solar panels. For this purpose it is

necessary to conduct series of experimental studies of the solar panel, located on the roof, with the natural circulation of the coolant. At the same time it is necessary to consider how efficiency of this panel will be if using or not using the transparent covering. Based on the research, it is necessary in both cases to determine the coefficient of thermal efficiency of the solar panel.

### 3. PREVIOUS STUDIES

Today, energy-efficient architectural construction in conjunction with solar thermal systems is increasingly being considered [1], for example, the use of renewable energy regarding glass and solar architecture.

Today, the construction of energy efficient buildings in Europe is standardized according to [2–4].

Analysis of the main types of solar collectors and global trends in this area showed that the most promising areas for the development of solar thermal systems for energy efficient buildings are improving existing ones and finding innovative, efficient, and cost-effective solutions on the integration of solar collectors into architectural structures of building fences.

The advantage of combined solar collectors related to building designs is that they are simple in design and installation, and can also serve as batteries of solar energy [5–7]. In [6] a heat accumulator is added to the solar panels that are placed on the roof. The unit consists of several layers of Phase Change Material (PCM) slabs with a melting temperature of 29 °C. Technological characteristics of those combinations make it possible to integrate them into single production complexes of technical systems, focused on the use of both traditional and alternative energy sources, however, this design makes the system difficult to install and operate.

A number of works [8, 9] are devoted to the description and study of structures of solar panels. Reference [9] deals with the use of solar electrical panels on the roof. In this article, has reviewed a progressive development in the solar cell research from one generation to other, and discussed about their future trends and aspects. The article also tries to emphasize the various practices and methods to promote the benefits of solar energy.

The main positive point of solar collectors combined with the coating of buildings is that they allow using usable roof area and materials that are widely used for roof structures [10, 11]. In [10] the design of a solar wall, which is effective for system of solar heat supply is offered. At an intensity of radiation of 700 W/m<sup>2</sup> in the mode of circulation, the efficiency of the system of heat solar supply reached 65%, and on the overall efficiency with accumulation in the storage tank  $\eta$  reached around 38%. The research results also allow taking into account the practical efficiency of the system at the design stage.

Also, a number of works dedicated to these combined solar collectors are described in [12, 13]. Reference [12]

states that comprehensive solution of the issues of fixing solar collectors directly to the elements of the roof has broad prospects because, in this case, the possibility of replacing a part of the roof with them can be implemented. Also it was established that at changing incident angles of the heat flow from 90° to 30°, effectiveness of solar roofing reduces insignificantly compared with the flat solar collectors.

It is possible to use a rooftop solar collector to cool the house in the summer, using the energy of the sun. It will also reduce the energy consumption of the home as a whole [14].

Solar panels can be part of a home's roof element. This roof has an improved thermal insulation casing. It can also provide the house with electricity.

Given the wide range of research on solar heating systems and in rooftop solar panels, an urgent task has arisen to investigate in more detail rooftop solar panels, the types of their designs and characteristics.

### 4. EXPERIMENTAL RESEARCH

A number of studies have been performed to determine the thermal efficiency of solar panel without transparent coating. Initially, the tubes of the circuit of the coolant circulation were placed under the heat absorber. The installation for the experiments contained solar panel, heat accumulator, thermal radiation source (thermal emitter for simulating solar radiation), as it is shown in Fig. 1.

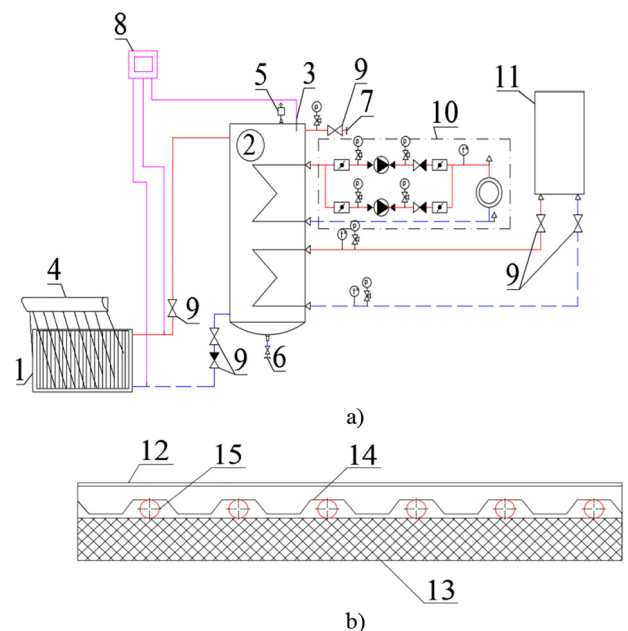


Fig. 1. a) Scheme of the experimental setup; and b) the solar panel; 1 – solar panel; 2 – heat accumulator; 3 – resistance thermometers; 4 – source of thermal radiation; 5 – air exhaust valve; 6 – drain of coolant; 7 – supply of coolant to the consumer; 8 – display; 9 – shut-off valves; 10 – pumping group; 11 – boiler unit; 12 – transparent coating; 13 – thermal insulation; 14 – heat absorber; 15 – polypropylene tubes of the coolant circulation circuit

As a heat accumulator used a tank-battery with water as a coolant. Since the solar panel is a part of the building's coating, its heat absorber is at the same time a coating. Under the heat absorber there is a layer of thermal insulation, the thickness of which is 50 mm. The pipelines and heat accumulator of the solar heat supply system contained thermal insulation. The design of the solar panel and the mounting of emitters made it possible to change orientation in order to investigate the influence of the angles of heat radiation incoming of to the surface of the solar panel in two mutually perpendicular directions (in the horizontal plane in azimuth  $\alpha$  and in the vertical plane  $\beta$ ). The results of the experimental studies were recorded according to the plan of their conduct. Flow meters and rotameters were installed on the return pipeline of the coolant of all experimental plants.

The following simplifications and assumptions were made during the experimental studies: the density of the radiation flux was considered uniform over the entire area of the solar panel; shading of the heat absorber did not occur; the reflected energy from the surrounding objects was not taken into account.

At the beginning of each experiment, the experimental setup was filled with new coolant (water), the air was removed, and leakage of the system and the suitability of the measuring equipment were checked. Significant values were recorded during the experimental studies: density of the radiation flux, the temperature of the coolant in the inlet and outlet pipelines of the studied solar panel, coolant temperature by the height of the heat accumulator.

Specific consumption was defined as  $1 \text{ kg}/(\text{m}^2 \cdot \text{min})$ , the weight of the coolant in the heat accumulator was set as 75 kg per  $1 \text{ m}^2$  of solar panel. Coolant temperatures were measured in the inlet and outlet pipelines of the solar panel and in the height of the heat accumulator with the appropriate equipment (Regulator-meter Type RT-0102 with resistance thermometers 50 m). The density of the radiation flux was measured with using InfraRed (IR) power meter LS122A and actinometer. The studies were conducted with the natural circulation of the coolant. During the studies the pumping group was shut off.

Experiment planning was conducted. The factors influencing the experiment were determined, where  $x_1$  is the angle of rotation of the solar panel in azimuth  $\alpha$ , degree;  $x_2$  is the angle of inclination of the solar panel  $\beta$ , degree;  $x_3$  is the density of the radiation flux  $I_{rad}$ ,  $\text{W}/\text{m}^2$ .

Table 1 provides information on the levels of the determining factors and their variation intervals.

The response function selected the coefficient of thermal efficiency of the solar panel  $K_{eff}$ , which indicates the effect of changes in the angles of solar radiation incoming and the density of the radiation flux on the thermal characteristics of the solar panel:

$$K_{eff} = \frac{Q_{ha,i}}{Q_{ha,const}}, \quad (1)$$

where  $Q_{ha,const}$  is the amount of heat accumulated in the heat accumulator at the angles of solar radiation incoming  $\alpha = 90^\circ$  and  $\beta = 90^\circ$  and its density  $I_{rad} = 900 \text{ W}/\text{m}^2$ ;  $Q_{ha,i}$  is the amount of heat accumulated in the heat accumulator at different angles of solar radiation incoming and density of the radiation flux  $I_{rad}$ .

The amount of heat stored in the heat accumulator:

$$Q_{ha} = m_{ha} \cdot c \cdot (t_{st} - t_{end}), \quad (2)$$

where  $m_{ha}$  is the mass of the coolant in the heat accumulator, kg;  $c$  is the value of specific heat of the coolant,  $\text{J}/(\text{kg} \cdot ^\circ\text{C})$ ;  $t_{st}$ ,  $t_{end}$  are the corresponding values of the temperatures of the coolant in the heat accumulator (start and end of studies),  $^\circ\text{C}$ .

The results of experimental measurements of the solar panel without transparent coating in the system of heat supply with natural circulation of the coolant were obtained. Graphical dependencies (Figs 2 and 3) at different densities of the radiation flux were obtained.

From the graphical dependencies, presented in Fig. 2, is observed the fact that the coolant in the outlet pipeline from the solar panel, which does not contain a transparent coating during the experiment, reached a temperature of  $20\text{--}22^\circ\text{C}$ .

As a result of analyzing of experimental data presented in Fig. 3, found that the thermal efficiency of the solar panel, which does not contain a transparent coating in the solar heat supply system with the natural circulation of the coolant, with changing the angles of solar radiation incoming  $\alpha$  and  $\beta$  from  $30$  to  $90^\circ$  increases by 67%.

Based on these experiments, was developed a nomogram, which shows the interrelation of coefficient of thermal efficiency  $K_{eff}$  solar panel without transparent coating and the angles of solar radiation incoming  $\alpha$  and  $\beta$ , density of the radiation flux  $I_{rad}$  (Fig. 4).

Based on the data of Fig. 4, functional dependence is obtained:

Table 1. Factors, levels and intervals of their variation

Factor	Mar-king	Levels of relevant factors			Interval between levels
		−1	0	+1	
The angle of rotation of the solar panel in azimuth $\alpha$ , deg;	$x_1$	30	60	90	30
The angle of inclination of the solar panel $\beta$ , deg;	$x_2$	30	60	90	30
Density of the radiation flux $I_{rad}$ , $\text{W}/\text{m}^2$	$x_3$	300	600	900	300

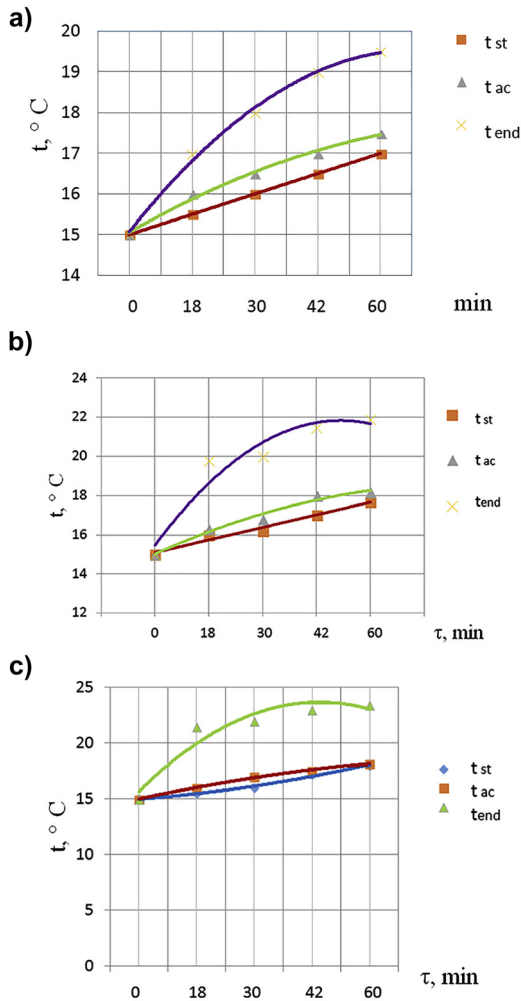


Fig. 2. Change in coolant temperature ( $t_{st}$  at the entrance,  $t_{end}$  at the exit) of solar panel, which does not contain a transparent coating in the solar heat supply system with the natural circulation of the coolant and in the heat accumulator,  $t_{ac}$  at the angles of solar radiation incoming  $\alpha = 60^{\circ}$  and  $\beta = 60^{\circ}$  and its density: a)  $I_{rad} = 300 \text{ W/m}^2$ ; b)  $I_{rad} = 600 \text{ W/m}^2$ ; c)  $I_{rad} = 900 \text{ W/m}^2$

$$\begin{aligned}
 K_{eff} = & 6.6151 \cdot 10^{-6} \cdot \alpha^2 + 7.4392 \cdot 10^{-6} \cdot \alpha \cdot \beta - 0.0021 \cdot \alpha \\
 & + 9.0466 \cdot 10^{-6} \cdot \beta^2 - 0.0032 \cdot \beta - 5.0 \cdot 10^{-9} \cdot I_{rad}^2 \\
 & - 4.4296 \cdot 10^{-5} \cdot I_{rad} \cdot (0.0003 \cdot \alpha^2 + 0.0004 \cdot \alpha \cdot \beta \\
 & - 0.1039 \cdot \alpha + 0.0004 \cdot \beta^2 - 0.1611 \cdot \beta + 5.808) \\
 & + 0.0001 \cdot I_{rad} + 0.0057 \cdot (0.0003 \cdot \alpha^2 + 0.0004 \cdot \alpha \cdot \beta \\
 & - 0.1039 \cdot \alpha + 0.0004 \cdot \beta^2 - 0.1611 \cdot \beta \\
 & + 5.808)^2 + 0.3142.
 \end{aligned} \quad (3)$$

Using the above dependency it is possible to obtain the values of the thermal efficiency coefficient of solar panels without transparent coating in the solar heat supply system with natural circulation of the coolant depending on the determining factors.

Experimental studies of the solar panel using a transparent coating in the solar heat supply system with the natural circulation of the coolant were also carried out. A transparent

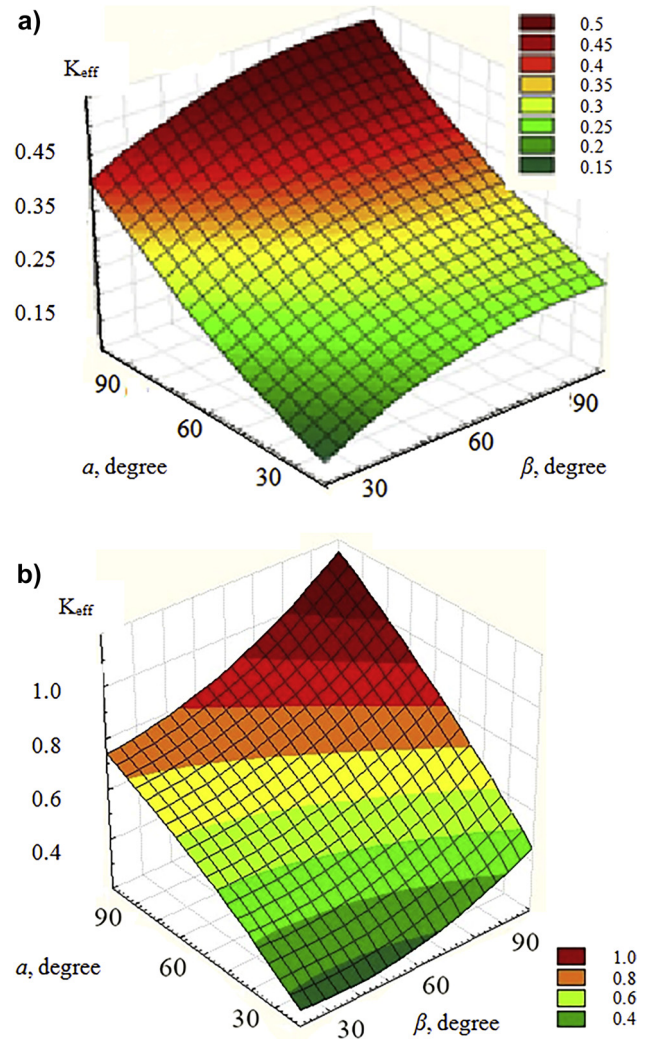


Fig. 3. Thermal efficiency of a solar panel that does not contain a transparent coating in the solar heat supply system with the natural circulation of the coolant at a)  $I_{rad} = 300 \text{ W/m}^2$ ; b)  $I_{rad} = 900 \text{ W/m}^2$

coating (glass) was used to reduce convective heat losses from the solar thermal absorber. The response function is the coefficient of thermal efficiency of the solar panel  $K_{eff}$ , indicating the effect of varying of the angles of solar radiation incoming on the amount of heat, obtained by the solar thermal system from the solar panel. In particular, Fig. 5 presents the research data, obtained as a result of experiments.

Based on the analysis of the experimental data presented in Fig. 5 it is found that coefficient of thermal efficiency of a transparent coated solar panel in the solar heat supply system with the natural circulation of the coolant at changing the angles of solar radiation incoming  $\alpha$  and  $\beta$  from  $30^{\circ}$  to  $90^{\circ}$  increases by 32%, while for a flat solar collector by 60%.

Based on the processing of these studies, the following regression model was obtained:

$$y = 0.796 + 0.027 \cdot \alpha + 0.054 \cdot \beta + 0.054 I_{rad}. \quad (4)$$

Based on experimental data a nomogram of interrelation of thermal efficiency coefficient  $K_{eff}$  in the solar heat supply



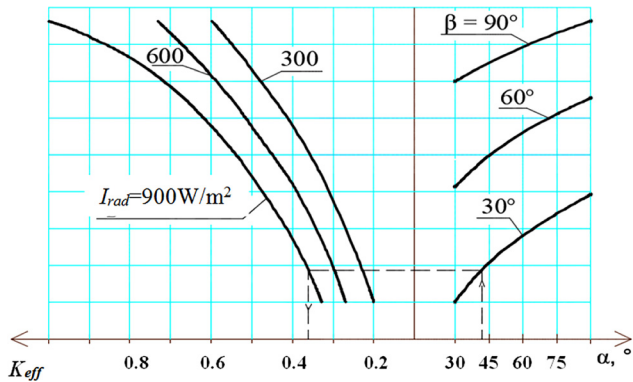


Fig. 4. Interrelation nomogram of solar panel  $K_{eff}$  without transparent coating in the solar heat supply system with the natural circulation of the coolant and density of the radiation flux  $I_{rad}$  and angles of solar radiation incoming  $\alpha$  and  $\beta$

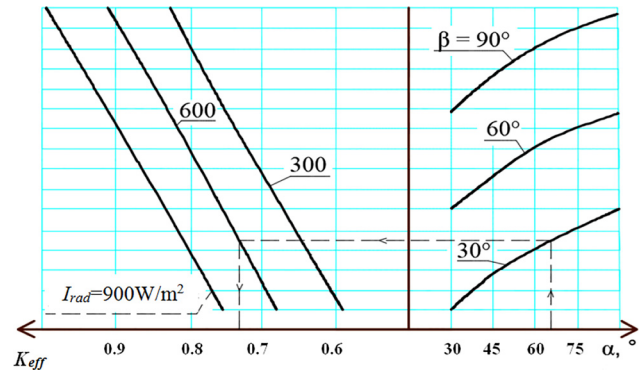


Fig. 6. Interrelation nomogram of solar panel  $K_{eff}$  with transparent coating in the solar heat supply system with the natural circulation of the coolant and the angles of solar radiation incoming  $\alpha$  and  $\beta$  and density of the radiation flux  $I_{rad}$

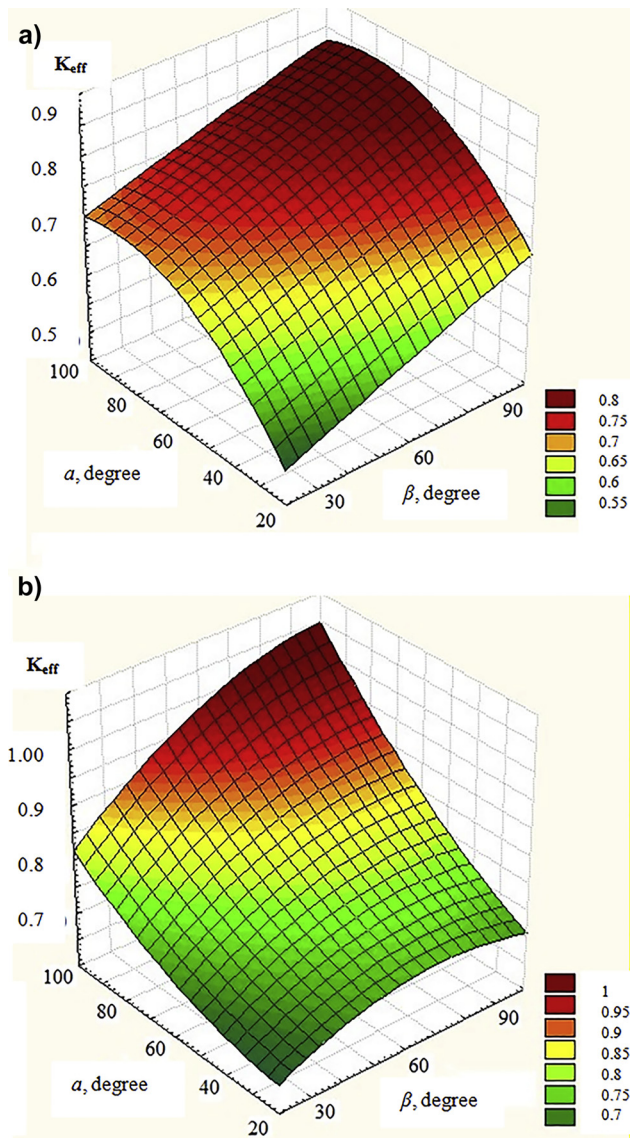


Fig. 5. The coefficient of thermal efficiency of the solar panel with transparent coating in the solar thermal system with natural circulation of the coolant, at the density of the radiation flux; a)  $I_{rad} = 300 \text{ W/m}^2$ ; b)  $I_{rad} = 900 \text{ W/m}^2$

system with the natural circulation of the coolant and the angle of rotation of the solar panel in azimuth  $\alpha$  and its inclination  $\beta$  and density of the radiation flux  $I_{rad}$  is developed (Fig. 6).

Using the above dependency it is possible to obtain values of the coefficient of thermal efficiency of the solar panel with a transparent coating in the solar heat supply system with natural circulation of the coolant depending on the angles of solar radiation incoming and the density of the radiation flux.

## 5. CONCLUSIONS

The article substantiates the necessity and proposes a new direction of development of energy-saving combined solar heating systems with elements integrated into the roof of the building.

The design of rooftop solar panels with natural circulation of the coolant is developed. Analysis of existing systems has shown that this system is more efficient and economical than a system with a heat accumulator, as its design is easier to install and operate. Also, rooftop solar panels that uses water as a coolant are more economical than a system with electric solar panels and can be widely used in buildings.

On the basis of the experimental research of the solar panel on the roof with the natural circulation of the coolant graphical-analytical dependences of the coefficient of thermal efficiency of the solar panel were obtained. The following factors were taken into account: angles of solar radiation incoming and the density of the radiation flux.

The analysis of the results of the experimental data confirmed that the coefficient of thermal efficiency of the solar panel without transparent coating with the placement of pipelines of the circulation circuit of the coolant over the heat absorber if the angles  $\alpha$  and  $\beta$  change from 30 to 90° increases by 50%.

On the basis of the conducted studies of thermal characteristics of the solar panel are determined that the coefficient of thermal efficiency of the solar panel at densities of

the radiation flux of  $300 \text{ W/m}^2$  varies from 0.47 to 0.77% for changes in the angles of its incoming from  $30$  to  $90^\circ$ . The coefficient of thermal efficiency of the solar panel transparent coating with circulating pipes located above the heat absorber, at changes in the angles of solar radiation incoming from  $90$  to  $30^\circ$  decreases by 41%.

It is found that the coefficient of thermal efficiency of the solar panel in the solar heat supply system with direct supply of coolant for changes in angles of flow of radiation  $\alpha$  and  $\beta$  from  $30$  to  $90^\circ$  increases by 40%.

Unlike conventional flat solar collectors, the efficiency of the rooftop solar panels when changing the angles of incidence of heat flux is reduced slightly. In addition, the rooftop solar panels can be used in the summer to cool the house. This will reduce energy consumption for the house as a whole.

The use of rooftop solar panels and solar walls as elements integrated in the construction of external enclosures of buildings, allows to increase the practical efficiency of these systems up to 65%. Given this fact, in the future it is planned to conduct a detailed comparison of the structures of rooftop solar panels and solar walls and study their integrated operation.

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