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Research of efficiency of solar coating in the heat supply system

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ABSTRACT

According to the energy development strategy of Ukraine, implementation of energy efficient buildings is needed, in which external protections are converters of solar energy into heat. The article presents studies of solar coating with direct coolant supply. Studies of the average value of the heat loss coefficient of the solar coating were also carried out. As a result, the efficiency of the solar coating under the mode of forced circulation of the coolant is 0.67, at natural circulation of the coolant – 0.57 and at its direct supply is 0.71. Experimental researches of thermal and physical parameters of a solar covering and system of heat supply on its basis showed in the corresponding dependences influence on its thermal characteristics of dynamic modes of the heat carrier, energy, kinetic characteristics of the environment.

KEYWORDS

solar coating, thermal efficiency, transparent coating, coolant, heat loss

1. INTRODUCTION

According to the energy development strategy of Ukraine, implementation of energy efficient buildings is needed, in which external protections are converters of solar energy into heat. Also these buildings with the combined system of heat supply can provide the building with thermal energy.

Various authors have studied the use of solar energy for heating buildings. They proposed scientific and methodological approaches to finding ways to increase the efficiency of passive and active solar heating systems to achieve the maximum possible energy supply of buildings [1, 2]. Recommendations based on systematic analysis and modeling of both active and passive methods of solar radiation capture and also on the basis of absorbing materials have been developed [3]. This includes thermal insulation materials and shielding of sun protection devices in unstable weather conditions and in accordance with seasonal changes in consumer heat loads.

The prospects of research of alternative energy supply due to use of flat collectors with corrugated translucent protection for houses of only a certain type are substantiated.

At work [4] prospects of installation of small solar systems of district heating with seasonal heat reserves are estimated. Different technical characteristics of solar heating systems

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in Poland, Spain and Germany are described. The researchers paid special attention to the development of seasonal heat accumulators and other components, in particular high-temperature heat pumps required for efficient operation of the installation.

Review by scientists from Romania, Greece and Cyprus of exergetic analysis of solar collectors and processes, which took into account not only different types of solar collectors, but also different applications of solar heating systems, helped to find that exergy analysis, which provides a representative assessment of effectiveness, was identified as a valuable method of evaluating and comparing possible configurations of these systems [5]. The efficiency of exergy heat flows of power systems for joint production of different types of energy from alternative sources was evaluated [6, 7]. Exergetic analysis of solar heat supply systems is given in [8–11].

The argument for the need to integrate solar collectors into the structure of the building was presented in [12]. It has been established that solar collectors, in the case of proper design, are no less efficient than heat pumps. The need to take measures to reduce the cost of the system by adapting solar collectors in building structures during the design and construction of facades and roofs, which confirms the need for further research was also emphasized.

Prospects for the development of energy saving in the European Union indicate the need to improve Ukrainian Norms and Standards [13–16], based on innovative solutions to ensure the energy-independent future of our country. Ukraine has an energy deficit of fossil fuels to meet its own needs up to 49%, taking into account oil production up to 12% and natural gas up to 25% [17]. In addition to the consumption of non-renewable energy sources and their cost, it should be noted their negative impact on the environment. Given the environmental situation in Ukraine, it is necessary to take measures to reduce harmful emissions [18, 19].

2. THE INFLUENCE OF AIR FLOW ON THE EFFICIENCY OF SOLAR COATING WITH NATURAL CIRCULATION OF HEAT

These experimental studies are based on determining the interconnection between speed and direction of air flow, coming to the solar coating, and its coefficient of thermal efficiency [20].

During the experimental studies, the values of the coolant temperature were recorded both in the inlet and outlet pipes of the solar coating and in the height of the heat accumulator. Air flow rate values were measured with a testo-405 anemometer. According to the average values of wind speeds within Ukraine, which corresponded to the normative data, the speed of air flow varied from 2 to 6 m/s. The studies were performed for solar coating at the location of the tubes of the coolant circulation circuit above the heat sink.

The response function is the coefficient of thermal efficiency of the solar coating K_{eff}, determined by the ratio of the amount of heat obtained by varying the speed and direction of air flow, to the amount of heat obtained by the solar heating system with solar coating at $v = 2$ m/s, angle $\psi = 90°$.

Table 1 provides information on the levels and intervals of change of factors.

The scheme of the experimental installation consists of two parts: the part responsible for heat generation, where the main element is the solar coating, and the part relating to heat accumulation (Fig. 1). The photo of the experimental setup is shown in Fig. 2.

The obtained research data are reproduced in graphical form and presented in Fig. 3.

On the basis of experimental studies, according to Fig. 3, it is established that the efficiency of solar coating with a transparent coating in the solar heating system with natural circulation of the coolant under the influence of air flow on it is reduced to 35%.

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

$$y = 0.717 - 0.058x_1 - 0.059x_2 + 0.094x_3. \quad (1)$$

Based on the analysis of the coefficients of the regression model, it was found that the factors x_1 and x_2 affect the response function approximately equally, and with their increase, the thermal efficiency of the solar coating with a

Table 1. Factors, levels and intervals of their variation

Factor	Marking	Levels of relevant factors −1	0	+1	Interval between levels
Air flow rate, v (m/s)	x_1	2	4	6	2
The direction of air flow ψ (°)	x_2	0	45	90	45
Radiation flux density, I_{rad} (W/m^2)	x_3	300	600	900	300

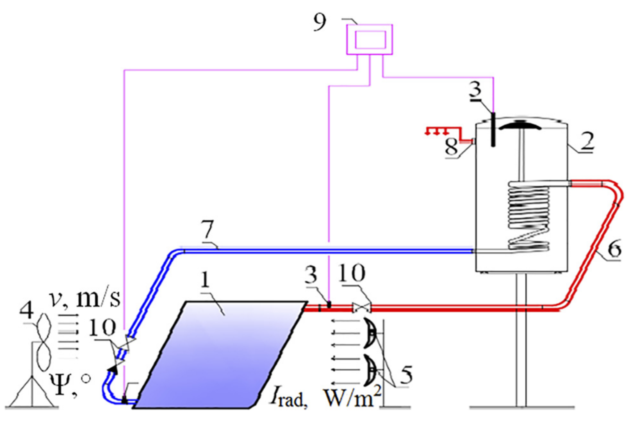
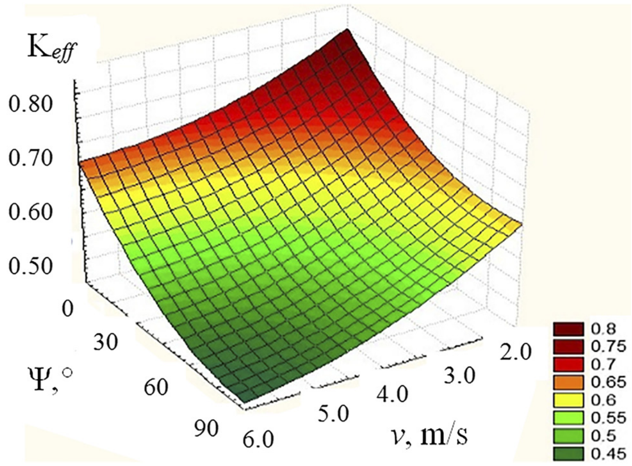
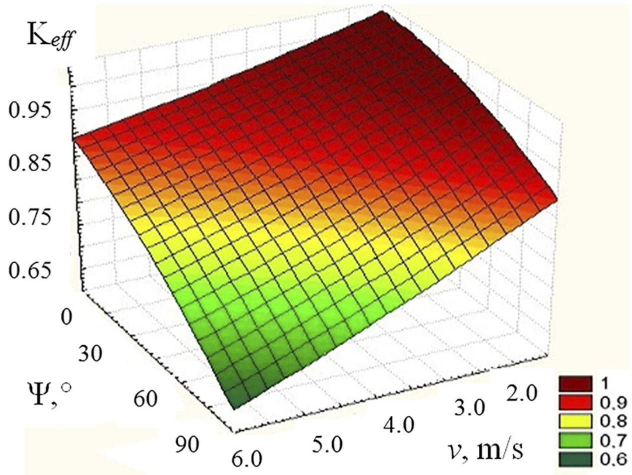


Fig. 1. Scheme a of the solar heating system for research, 1 – solar coating; 2 – heat accumulator; 3 – resistance thermometers; 4 – fan; 5 – radiation source; 6 – supply pipeline; 7 – return pipeline; 8 – coolant pipeline to the consumer; 9 – display; 10 – shut-off and control valves

Fig. 2. Photo of the solar heating system for research



a)



b)

Fig. 3. Coefficient of thermal efficiency of solar coating with transparent coating in the solar heating system with natural circulation of the coolant by a) I_{rad} = 300 W/m^2, b) I_{rad} = 900 W/m^2

transparent coating will decrease. The factor x_3 has the most significant effect on the response function.

As a result of experimental data processing graphic dependence of interrelation (K_{eff}) of solar coating with a

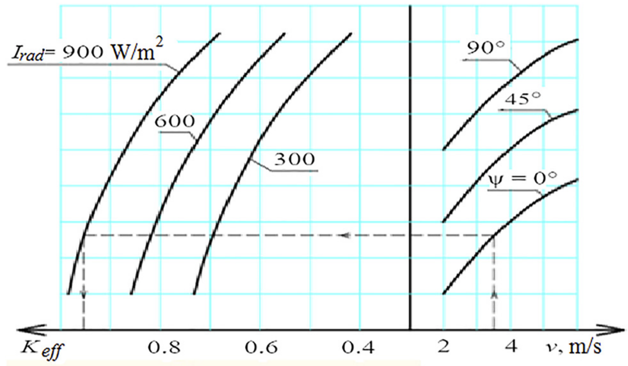


Fig. 4. Monogram of the interconnection (K_{eff}) of solar coating with a transparent coating in the solar heating system with natural circulation of the coolant from the air flow rate v, the direction ψ of the air flow and its radiation density I_{rad}

transparent coating in the solar heating system with natural circulation of the heat from the air flow rate v, the air flow direction ψ and the radiation flux density I_{rad} is received (Fig. 4).

Based on the research data processing, the following regression model was obtained:

$$y = 0.704 - 0.063x_1 - 0.058x_2 + 0.07x_3 - 0.006x_1x_2 - 0.006x_1x_3 - 0.08x_2x_3. \quad (2)$$

As a result of the analysis of the regression model, it was found that the air flow rate (x_1) has a greater impact than the direction of flow (x_2) on the response function, and most affects - the radiation flux density (x_3).

The obtained graphical dependence makes it possible to calculate the value of the coefficient K_{eff} of solar coating with transparent coating in the solar heating system with natural circulation of the coolant.

3. EFFICIENCY OF SOLAR COATING WITH DIRECT COOLANT SUPPLY

Based on the data of the conducted experimental researches the nomogram of interrelation of coefficient of thermal efficiency K_{eff} solar coating with a transparent covering in system of heat supply with direct supply of the heat carrier and angles of receipt of a stream of radiation α and β and its density I_{rad} is developed (Fig. 5).

Equation (3) is obtained from the graphical dependence (Fig. 5), which allows determining the value of the coefficient from the angles of receipt of radiation stream α and β and its density I_{rad} with an error of 5%,

$$\begin{aligned} K_{eff} = &\left(0.29 + 9.2\cdot 10^{-5}\cdot I_{rad}\right) \\ &+ \left(-3.3\cdot 10^{-5} + 2.8\cdot 10^{-6}\cdot I_{rad}\right)\cdot\alpha \\ &+ \left(0.003 + 8.8\cdot 10^{-6}\cdot I_{rad}\right)\cdot\beta \\ &+ \left(-9.8\cdot 10^{-6} + 3.3\cdot 10^{-8}\cdot I_{rad}\right)\cdot\alpha^2 \\ &+ \left(3.6\cdot 10^{-5} - 7.8\cdot 10^{-8}\cdot I_{rad}\right)\cdot\alpha\cdot\beta \\ &+ \left(-3.5\cdot 10^{-5} - 1.2\cdot 10^{-8}\cdot I_{rad}\right)\cdot\beta^2. \end{aligned} \quad (3)$$

Equation (3) shows the interdependence of K_{eff}, the angles of receipt of radiation stream α and β and its density I_{rad}.

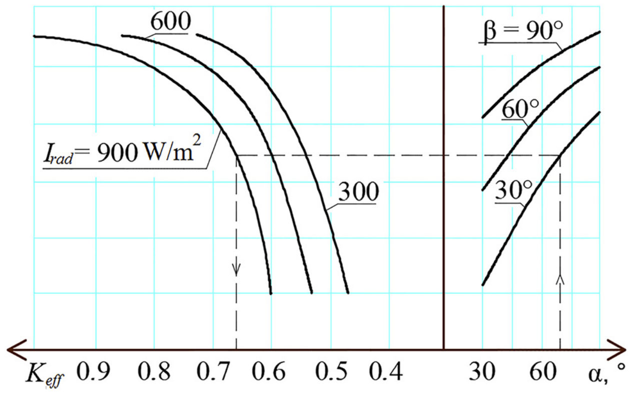


Fig. 5. Monogram of the interconnection (K_{eff}) of solar coating with a transparent coating in system of heat supply with direct coolant supply and angles of receipt of radiation stream α and β and its density I_{rad}

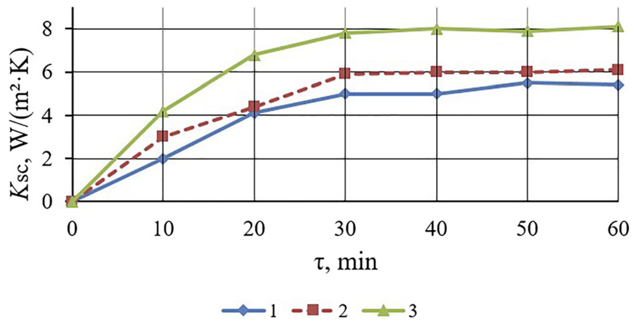


Fig. 6. The average value of the heat loss coefficient of the solar coating K_{SC}, W/(m$^2\cdot$°C) during the experiment, 1 – forced circulation of the coolant; 2 – natural circulation of coolant; 3 – direct supply of coolant

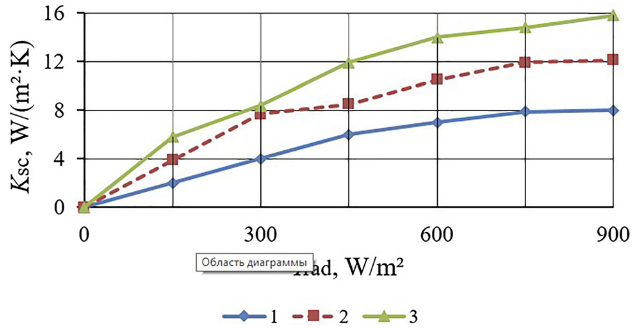


Fig. 7. Dependence of the heat loss coefficient of the solar coating K_{SC} from the radiation flux density I_{rad} and air flow rate: 1 – v = 6 m/s; 2 – v = 4 m/s; 3 – v = 2 m/s

4. STUDY OF THE EFFICIENCY OF SOLAR COATING IN THE HEAT SUPPLY SYSTEM

A study of the efficiency of the solar coating at different modes of movement of the coolant was carried out. The analysis of a solar coating at forced circulation of the coolant, natural circulation of coolant and direct supply of coolant was carried out. The heat loss coefficient of the solar coating was analyzed.

The efficiency of the solar coating η_{SC} was determined by the formula [21, 22]:

$$\eta = \frac{Q_{SC}}{I_{rad}} \cdot 100\%\,, \tag{4}$$

where Q_{SC} is the value of the specific instantaneous thermal power of the solar coating, W/m^2; $Q_{SC} = G \cdot F_{SC} \cdot c \cdot (t_{in} - t_{out})$, where G is the value of the specific consumption of the coolant, kg/(s$\cdot$m^2); c is the value of the specific heat of the coolant, J/(kg$\cdot$K); t_{in}, t_{out} are the value of the coolant temperature in the inlet and outlet pipes of the solar coating, °C; I_{rad} is the radiation flux density, W/m^2; F_{SC} is the solar coating area, m^2.

The heat loss coefficient of the solar coating K_{SC}, determined by the methods given in [23–26] was investigated. In particular, Fig. 6 shows the average value K_{SC} within 60 min of the experiment for three modes of operation of a solar coating.

Figure 7 also shows the dependence of the heat loss coefficient of the solar coating K_{SC} from the radiation flux density I_{rad} and air flow rate v. This will summarize the study and conclude on the effectiveness of the use of solar collectors of different design and principle of operation.

As a result of the conducted complex experimental researches it is found out that efficiency of a solar coating η_{SC} under the mode of the forced circulation of the heat carrier makes 0.67, under natural circulation 0.57, on direct feed 0.71, and the average heat loss coefficient is 8 W/(m^{2}K).

5. CONCLUSION

On the basis of experimental researches of thermal characteristics of heat supply system with a solar coating it is defined that its thermal efficiency with the transparent coating in the mode of direct supply of the heat carrier by varying the angles of incidence of the radiation flux α and β from 90° to 30° decreases by 39%, and with changes in air flow rate from 2 to 6 m/s and its direction from 0° to 90° – decreases by 20%.

As a result of the conducted complex experimental researches of thermal and physical parameters of a solar covering and system of heat supply on its basis it is found out influence on its thermal characteristics of dynamic modes of the heat carrier, energy, kinetic characteristics of the environment, the corresponding graph-analytical dependences. Also it was obtained that:

– the efficiency of the solar coating η_{SC} under the mode of forced circulation of the coolant is 0.67, at natural circulation of the coolant – 0.57 and at its direct supply is 0.71;
– total heat loss coefficient for solar coating K_{SC} is $8\,W/(m^2 \cdot K)$.

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