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# Enhancing of Efficiency of Solar Panels Combined with Buildings Coating

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**Abstract.** The article is devoted to solving the urgent task of enhancing the energy efficiency of solar panels, combined with coating of buildings. In this article, the authors presented a construction of a solar panel, which serves as a building coating and solar collector. In this paper, it is proposed to consider the possibility of achieving a high temperature of a thermal agent using this design of a solar panel. The dependence of the temperature of the transfer medium in the solar panel on the intensity of solar radiation was presented and on its basis the energy-efficient design of the solar panel was proposed. On the basis of it, the influence of modern and traditional roofing materials and tubes on the amount of solar energy received during the day was investigated. The regularity of the temperature of the internal air in the room, which is located under the solar panel from the design of the solar panel and the intensity of solar radiation, is established.

**Keywords:** Solar energy · Solar panel · Combined heating system · Roof cover · Temperature · Heat transfer coefficient

## 1 Introduction

Recently, the term “energy efficiency class” has confidently entered our daily lives. In Europe, a significant number of residential buildings were built in the postwar period, most of them according to standard designs. Of course, there was no talk of energy efficiency and the use of quality materials then, because the priority was to provide a large number of people with housing in a short time. They also include 5- and 9-storey panel buildings without an attic, there are many such houses not only in Ukraine, but also in Poland, Slovakia, Germany, etc.

These buildings belong to the lowest energy efficiency classes F and G. The actual specific energy consumption of these buildings in Ukraine is at the level of 180–300 kWh/m$^2$, compared to the maximum allowable value of 85 kWh/m$^2$ for 4 and 9-storey buildings in the first temperature zone [1]. The reason for high energy consumption is low thermal performance of building structures, as well as the poor condition of engineering systems.

However, the thermal regime of such buildings is unsatisfactory, not only in the cold but also during the warm period of the year. This is evidenced by the results of real studies and numerous complaints by residents. If during 3–5 days the maximum air


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temperature in the day-time reaches 34 °C and the average temperature at night is 20 °C, then the internal temperature in these premises may exceed 32 °C at an acceptable value of 26 °C.

The problems of energy saving [2], material saving [3] and efficiency of energy [4] are very actual. The energy saving of the heating system [5], ventilation or air conditioning system [6] and quality of indoor air [7] must be ensured. In particular, for this purpose both thermal recuperators in ventilation and air conditioning systems [8] and effect of the variable air volume on energy consumption are widely used [9], so does using vortex tube for decreasing losses of natural gas in engineering systems of gas supply. Generally conducting an energy audit [10] expresses energy savings in monetary terms [11].

Comfortable indoor temperature climate in the premise is an important both social [12, 13] and energetic aspect [14, 15].

At present, a significant number of installations using solar radiation [16] have been developed, as well as a number of circuit solutions for solar thermal systems with such elements. Despite the diversity of designs of solar installations, each of them will work best only under certain conditions [17, 18].

Therefore, it is necessary to analyze known methods of increasing the efficiency of such installations and systems of solar heat supply in general in order to choose their rational circuit decisions. It is also important to study not only each element individually but also the whole system together to get the most possible information about improving the efficiency of this system.

## 2 Recent Research and Publications

Ukraine is in the zone of medium intensity of solar radiation. The value of the density of the solar radiation depends on both the change of seasons and the period of time and latitude. Also, the transparency of the atmosphere and the characteristics of the surface of the ground have a significant impact. Therefore, the annual amount of solar radiation on 1 $m^2$ from the surface of the Earth, varies considerably throughout the territory. However, it is quite obvious that there is a tendency to increase the density of solar radiation and the number of cloudless days in the direction from the North to the South with an appropriate increase of 1 $m^2$ of the Earth's surface of annual solar radiation [19].

Passive, active and combined solar systems are used to convert solar energy into heat. Active solar systems are effective, but have a relatively high cost. Passive systems of solar radiation are environmentally friendly and inexpensive, but it is difficult to control the parameters of the internal air and provide the necessary air exchange in the premises. In order to accumulate the required amount of thermal energy, it is necessary to provide the maximum thermal barrier and install the batteries of considerable size [25].

Combined systems with solar panels are elements of the construction of structures, and also perform the function of perception and transportation of heat and cold, so now it becomes relevant to their use in solar heating systems [20].

The design of solar panel, which contain a protective layer of the coating, a thermal conductive layer and a heat-insulating layer below them, are shown [21].

However, insufficient surface of the touch of pipelines and protective coating affects the heat transfer coefficient between them, significantly reducing it. Considerable metal content of this construction increases the cost of solar panels, reducing the efficiency of their use.

The most effective is a solar panel, the protective layer of which performs the functions of waterproofing, in addition, there is an absorption layer, which allows the installation of flat roofs in general. It also possible to make the most of the materials that are usually used to cover and waterproof the roof [23, 24].

On the basis of the performed analysis of the existing methods for calculating the parameters of the solar panels, it could be concluded that mainly investigated the amount of solar heat that entering to the water in the tubes or possibilities for increasing coefficient of performance or accumulation ability. That is mainly study the parameters of the system, and the study of the microclimate parameters and the overall energy efficiency of the building where the solar panels are installed [6, 25].

## 3 The Purpose and Objectives of the Study

The purpose of the work is to carry out a scientific substantiation of energy efficiency improvement of structures using solar panels of periodic action in conjunction with the coating of the building.

To achieve this goal, the following tasks should be performed:

- to determine the correlation of the parameters of the investigated coolant with the characteristics of the solar panel;
- to determine and optimize the parameters of the resulting coolant flow;
- to study the parameters of the microclimate of premises over which solar panels are installed.

## 4 Methods, Materials and Research Results

Heat losses of the building during the cold period, when the outside air temperature is lower than the required internal temperature, as well as the heat supply of the building during the warm period, when the outside air temperature is higher than the desired internal temperature, occur through elements of external structures (exterior walls, roofs, windows). In new buildings with concrete walls (normal or light concrete, reinforced or unreinforced walls), the thermal barrier is recommended to be embedded in the walls. In the brick walls and walls of the existing buildings, the thermal barrier pipelines are installed on the outer walls and plastered. Plaster is necessary for leveeing the surface for the subsequent laying of thermal insulation, although it is also used to increase the thermal conductivity of the walls [26–28].

The thermal barrier is arranged by separate blocks, the sizes of which correspond to the sizes of internal premises, which allows to regulate the temperature in each room separately. To limit frictional losses, and, thus, the potential power of pumping units, it is required to limit the length of the sections of individual tubular coils to a maximum of 100–120 m. When laying, it is necessary to avoid their intersection.

Regarding the roofs (divided into cold and warm), then in cold roofs, in most cases sloping, the accumulating pipeline is laid in a free space between the roof and thermal insulation. The most effective way to build energy-efficient buildings is to manufacture prefabricated elements with a built-in thermal barrier and accumulating elements that are manufactured at the plant and mounted directly on the construction site. When constructing warm roofs, similar to the construction of external walls, consists in concrete or from the outside of the load-bearing roofing structure into the masonry intended for laying the tubular system [29].

In this study, as the thermal barrier used a solar panel (Fig. 1) consisting of a protective coating 1, which serves as a waterproofing and absorbent layer and located on a heat conducting layer 2, which acts as a battery of thermal energy, which houses corrugated pipelines 4 for supply and removal of coolant, heat-insulating layer 3 to protect the slab from overheating, which is placed under a heat conducting layer on which the heat-reflective screen 5 is located. To evaluate the efficiency of the solar panel it is necessary to conduct analytical calculations.

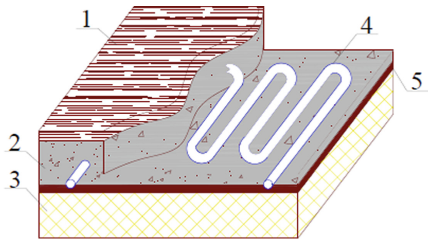


**Fig. 1.** Construction of the solar panel: 1 – protective coating; 2 – heat conducting layer; 3 – thermal insulation layer; 4 – pipeline for supply and removal of heat carrier; 5 – heat reflective screen

The purpose of the analytical calculation is to determine the thermal accumulation properties of the solar panel and to find the optimal parameters. Solar energy will be absorbed by heat absorber. The amount of energy it absorbs depends on the intensity of the solar radiation energy entering the surface of the heat absorber. At an arbitrary time, it can be estimated from known dependencies.

In this paper, it is proposed to consider the possibility of achieving a high temperature of a thermal agent using this design of a solar panel.

The establishment of the relationship between the parameters of the heat carrier and the structural parameters of the solar panel is a rather complicated problem, since the dependence becomes multi-factor. The interaction of factors that determine the course of the process is random and therefore the nature of this process is probabilistic. Experimental work in this direction is related to research on real objects. Proceeding from logical considerations, the following factors will affect the nature of the resulting temperature $t$, °C in the solar panel mainly: tube diameter $d$, mm, tubing $h$, m, heat carrier flow $G$, kg/h, intensity of solar radiation $I$, W/m$^2$. Determine and optimize the function $t$ for different cases of interaction of factors, namely: at different values of the diameter of the tube $d$, the tube step $h$, the flow of the coolant $G$, the intensity of the solar radiation $I$.

If to accept the simplicity that $I = \text{const}$ the three factor functions $t$ are proposed to express in such a polynomial dependence in general terms Eq. (1):

$$t = \sum_{k=0}^{p} \cdot \sum_{j=0}^{n} \cdot \sum_{i=0}^{m} \cdot a_{ijk} d^i h^j G^k \tag{1}$$

Accordingly, the function will be valid when one factor else is taken into account I, and will acquire the final form Eq. (2):

$$t = \sum_{l=0}^{q} \cdot \sum_{k=0}^{p} \cdot \sum_{j=0}^{n} \cdot \sum_{i=0}^{m} \cdot b_{ijk} d^i h^j G^k I^l \tag{2}$$

To minimize the factors of influence it is necessary to determine the optimal values of the factors $d_0, h_0, G_0, I_0$. The extremum function $t$, which is represented by some functional dependences of $d$, $h$, $G$, $I$ is investigated. However, based on logical considerations, it should be noted that these four variables are independent and may vary at the same time. In connection with this, in the experimental study of the phenomenon, we obtain the function $t$ of several independent variables $t = f(d, h, G, I)$. Its area of definition $D$ is a set of several arguments $d$, $h$, $G$, $I$.

Therefore, the task arose of determining the numerical values $d$, $h$, $G$, $I$ at which extreme values of the universal parameter $t$ are observed, one should consider the question of the maximum (minimum) of the function of four variables and finding its critical points. To do this, it is necessary to predict, at the stage of approximation of the function $t$, at each point in the domain $D$ of this function, its continuity. This condition is easily fulfilled in substantiating the experimental conditions, that is, the choice of boundaries for variance deviations, and further analytic approximation of the results obtained. Guided by the known property of the function of several variables that the continuous function in a closed bounded domain $D$ reaches, at least once the largest (lowest) value of $m$, we state that there is a certain maximum (minimum) of function $t$ in the domain $D$, which is also sought after in our problem. These experimental values $t_{\max}$ correspond to the so-called stationary points of the function $t$, that is, the values of the arguments $d_0$, $h_0$, $G_0$, $I_0$ that are optimal.

To solve the problem, to investigate the function on the extremum, the necessary conditions are as follows: if the function $t = f\ (d, h, G, I)$ reaches the extremum with $d = d_0$, $h = h_0$, $G = G_0$, $I = I_0$, then every partial derivative of the first order of $t$ is converted to zero for these values of arguments. In this case was received a system (3) of four equations with four unknowns, solving which, the point $M\ (d_0, h_0, G_0, I_0)$ will be found.

$$\begin{cases} \dfrac{\partial t}{\partial d} = 0 \\ \dfrac{\partial t}{\partial h} = 0 \\ \dfrac{\partial t}{\partial G} = 0 \\ \dfrac{\partial t}{\partial I} = 0 \end{cases} \tag{3}$$

Solving this system of equations, we find the required value of the values $d_0$, $h_0$, $G_0$, $I_0$ on some section of these arguments, respectively $[d_1; d_2]$, $[h_1; h_2]$, $[G_1; G_2]$, $[I_1; I_2]$.

Since there is no prior assurance of the existence of the extremum of the function $t$, therefore, it is necessary to establish sufficient conditions for the extremum. If function $t$ will have in some environment of point $M$ $(d_0, h_0, G_0, I_0)$ continuous second partial derivatives and if at this point the necessary conditions are fulfilled, then in the case when the second differential Eq. (4) is a positively defined quadratic form, then a function $t = f\ (d, h, G, I)$ has at this point a maximum or a minimum. In the case of these conditions, the function $t$ will be at the point $M$ $(d_0, h_0, G_0, I_0)$ stationary value, and the point itself $M$ – will be called stationary.

$$\partial^2 t = \sum_{i=1}^{4} \cdot \sum_{j=1}^{4} \cdot \frac{\partial^2 t}{\partial d_i\, \partial d_j} \Bigg|\ (d_o,\ h_o,\ G_o, I_o\ )^{\Delta d_i\, \Delta d_j} \tag{4}$$

It is worth investigating on the positive definiteness of the quadratic form Eq. (5):

$$\begin{pmatrix} \dfrac{\partial^2 t}{\partial d^2} & \dfrac{\partial^2 t}{\partial d\, \partial h} & \dfrac{\partial^2 t}{\partial d\, \partial G} & \dfrac{\partial^2 t}{\partial d\, \partial I} \\ \dfrac{\partial^2 t}{\partial h\, \partial d} & \dfrac{\partial^2 t}{\partial h^2} & \dfrac{\partial^2 t}{\partial h\, \partial G} & \dfrac{\partial^2 t}{\partial h\, \partial I} \\ \dfrac{\partial^2 t}{\partial G\, \partial d} & \dfrac{\partial^2 t}{\partial G\, \partial h} & \dfrac{\partial^2 t}{\partial G^2} & \dfrac{\partial^2 t}{\partial G\, \partial I} \\ \dfrac{\partial^2 t}{\partial I\, \partial d} & \dfrac{\partial^2 t}{\partial I\, \partial h} & \dfrac{\partial^2 t}{\partial I\, \partial G} & \dfrac{\partial^2 t}{\partial I^{\,2}} \end{pmatrix} \tag{5}$$

It is advisable to enter the following notation:
$\frac{\partial^2 t}{\partial d^2} = A$, $\frac{\partial^2 t}{\partial h^2} = B$, $\frac{\partial^2 t}{\partial G^2} = C$, $\frac{\partial^2 t}{\partial I^2} = D$, $\frac{\partial^2 t}{\partial d \partial h} = E$,
$\frac{\partial^2 t}{\partial d \partial G} = F$, $\frac{\partial^2 t}{\partial d \partial I} = G$, $\frac{\partial^2 t}{\partial h \partial G} = H$, $\frac{\partial^2 t}{\partial d \partial I} = I$, $\frac{\partial^2 t}{\partial G \partial I} = K$.

Using the property of the order of differentiation in partial derivatives the differential determinant (Jacobian) $J$ will look like this:

$$J = \begin{vmatrix} \mathrm{A} & \mathrm{E} & F & G \\ E & B & H & I \\ F & H & C & K \\ G & I & K & D \end{vmatrix}$$

After that it can be noticed as Eq. (6):

$$\begin{aligned} J &= A \cdot \begin{vmatrix} B & H & I \\ H & C & K \\ I & K & D \end{vmatrix} + E \cdot \begin{vmatrix} E & F & G \\ H & C & K \\ I & K & D \end{vmatrix} + F \cdot \begin{vmatrix} E & F & G \\ B & H & I \\ I & K & D \end{vmatrix} + G \cdot \begin{vmatrix} E & F & G \\ B & H & I \\ H & C & K \end{vmatrix} \\ &= A \cdot (-1)^2 \cdot \begin{pmatrix} BCD + 2HKI - I^2C - H^2D- \\ -K^2B \end{pmatrix} \\ &\quad + E \cdot (-1)^3 \cdot \begin{pmatrix} ECD + FKI + HKG - GCI- \\ -HFD - K^2E \end{pmatrix} \\ &\quad + F \cdot (-1)^4 \cdot \begin{pmatrix} EHD + FI^2 + BKG - GHI- \\ -BFD - IKE \end{pmatrix} \\ &\quad + G \cdot (-1)^5 \cdot \begin{pmatrix} EHK + FHI + BCD - GH^2- \\ -BFK - CIE \end{pmatrix} = ABCD + 2HKIA \\ &\quad + AI^2C - AH^2D - AK^2B - E^2CD - EFKI - EHKG + EGCI \\ &\quad + EHFD + K^2E^2 + FEHD + F^2I^2 + BKGF - FGHI - BF^2D \\ &\quad - FIKE - GEHK - GFIH - BCDG + G^2H^2 + GBFK + GCIE \end{aligned} \tag{6}$$

It is necessary to draw appropriate conclusions regarding its positive value ($J > 0$). In the absence of a stationary point $M$ ($d_0$, $h_0$, $G_0$, $I_0$) (due to the lack of necessary and sufficient conditions for the achievement of the extremum function φ) function $t = f$ ($d$, $h$, $G$, $I$) will have a monotonous (growing or decreasing) character. In this case, the greatest value of the function $t$ is found by defining it at the ends of the corresponding segments of the arguments of the function $t$ $[d_1; d_2]$, $[h_1; h_2]$, $[G_1; G_2]$, $[I_1; I_2]$. In this case, the desired value of $t$ will be the largest (least) of the sixteen calculated values of $t$ (the beginning and the end of the segments of the four variables is $2^4 = 16$) Eq. (7):

$$\begin{aligned} &t_1(d_1, h_1, G_1, I_1), \quad t_2(d_2, h_1, G_1, I_1), t_3(d_1, h_2, G_1, I_1), \quad t_4(d_2, h_2, G_1, I_1), \\ &t_5(d_1, h_1, G_2, I_1), \quad t_6(d_2, h_1, G_2, I_1), t_7(d_1, h_2, G_2, I_1), \quad t_8(d_2, h_2, G_2, I_1), \\ &t_9(d_1, h_1, G_1, I_2), \quad t_{10}(d_2, h_1, G_1, I_2), t_{11}(d_1, h_2, G_1, I_2), \quad t_{12}(d_2, h_2, G_1, I_2), \\ &t_{13}(d_1, h_1, G_2, I_2), \quad t_{14}(d_2, h_1, G_2, I_2), t_{15}(d_1, h_2, G_2, I_2), \quad t_{16}(d_2, h_2, G_2, I_2) \end{aligned} \tag{7}$$

The above applies also to the presence of stationary points. The maximum (minimum) values are determined from the calculation $t = f(d, h, G, I)$ both at stationary points and at the ends of the segments. After finding these values it becomes possible to determine the optimal value of the parameter $t_0$.

Since theoretical studies make it difficult to take into account all the factors influencing the work of the solar panel and the solar heat supply system in general, it is therefore advisable to carry out experimental studies.

The installation (Fig. 2) is consisted of a solar panel, an accumulating tank, shut-off and control valves, pipelines and a flow meter.

The heat conducting layer is made of cement-sand solution with the addition of plasticizer SANPOL (The com-position of the solution can be as follows: sand – 400 kg, cement M400-200 kg, water – 30 l, plasticizer Sanpol – 4 kg). In the heat-conducting layer, there are 2 types of pipelines: used for the traditional heating system – TOPTERM MULTILAYER PIPE PEX/AL/PEX and for floor heating – PRANDELLI/TUBORAMA 02 STOP. Under the heat conducting layer and along the perimeter above the foam polystyrene, a heat-reflective layer (aluminum foil) is arranged. The pipelines used to connect the solar panel and the battery of the battery are made of rubber hoses and insulated to minimize heat losses during experimental studies. Radiators WildWind-IRH-3.0 were used to simulate solar radiation. The battery-accumulator (plastic capacity of 0.056 $m^3$) was insulated with CERESIT PU Profi Montage mounting foam 50 mm thick and also covered with heat-reflective coating.

The coefficient of thermal conductivity of foam is $\lambda = 0.032$ W/(m K). It was conditionally divided into three volumes, inside each center mounted sleeves for the installation of resistance thermometers. The intensity of the energy flux emitted by the source was measured by an actinometer. The temperature of the coolant at the inlet and outlet in the solar panel and in the tank-accumulator was measured with 50 M resistance thermocouples operating with the RT-0102 regulators. The ambient air temperature and its temperature were measured using a thermal anemometer TESTO405-V1.

Experimental studies were conducted under the following conditions, assumptions and simplifications:

– the density of thermal radiation is assumed to be homogeneous throughout the surface of the solar panel;
– solar panel was not shaded;
– the influence of the reflected radiation from surrounding objects and from the solar panel was not taken into account;
– the confidence probability of the results of the experiment is $\alpha = 0{,}95$.

According to the results of experimental studies, the value of the temperature of the heat-carrier, depending on the design of the solar panel and the intensity of solar radiation, is shown in Fig. 3.

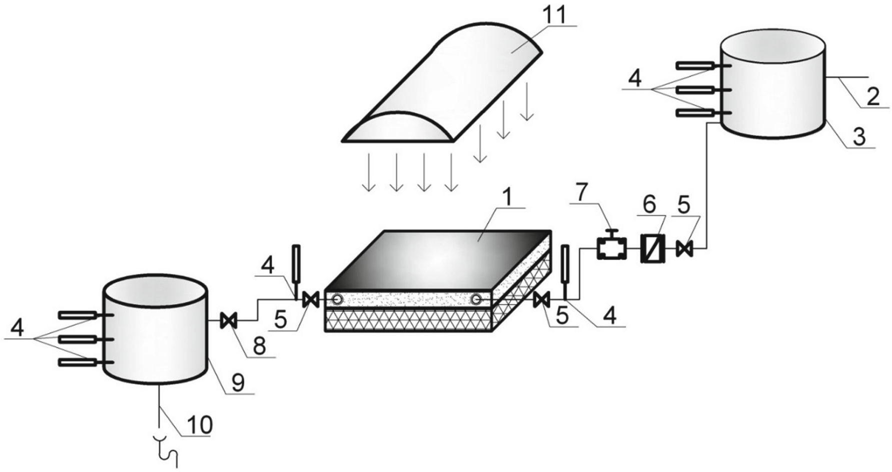


**Fig. 2.** Diagram of the experimental installation: 1 – solar panel; 2 (8) – pipeline of cold (heated) transfer medium; 3 (9) – tank of cold (heated) transfer medium; 4 – thermal sensor; 5 – stop valves; 6 – Rotameter; 7 – balancing valve; 10 – drainage pipeline; 11 – infrared heater.

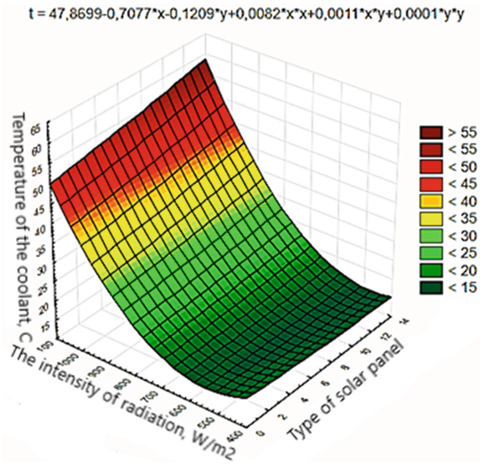


**Fig. 3.** Temperature change of transfer medium depending on the design of the solar panel and the intensity of solar radiation

Also, the dependence of the efficiency of the solar panel on the intensity of the solar radiation, the different types of coating, the diameters and steps of the tubes, as well as their species and the consumption of the coolant of rice were obtained (Fig. 4).

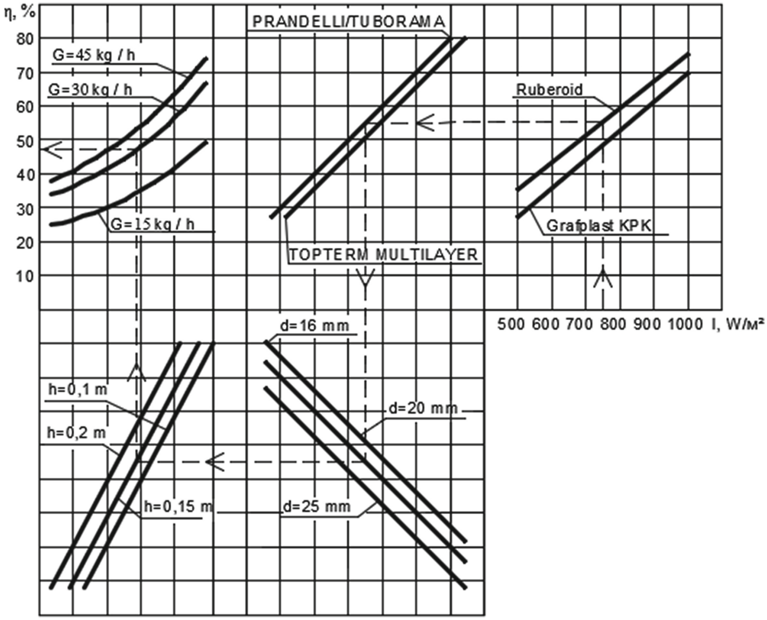


**Fig. 4.** Efficiency *η*, % of solar panels with different structure

Taking into account the analytical studies of heat absorption of the investigated solar panel, the dependence of the temperature of the internal air, depending on the design of the solar panel and the intensity of solar radiation in Fig. 5, where:

1. Ruberoid, TOPTERM MULTILAYER, $d = 16$ mm, $h = 0.1$ m, $G = 15$ kg/s;
2. Ruberoid, TOPTERM MULTILAYER, $d = 20$ mm, $h = 0.15$ m, $G = 30$ kg/s;
3. Ruberoid, TOPTERM MULTILAYER, $d = 25$ mm, $h = 0.2$ m, $G = 45$ kg/s;
4. Ruberoid, PRANDELLI/TUBORAMA, $d = 16$ mm, $h = 0.1$ m, $G = 15$ kg/s;
5. Ruberoid, PRANDELLI/TUBORAMA, $d = 20$ mm, $h = 0.15$ m, $G = 30$kg/s;
6. Ruberoid, PRANDELLI/TUBORAMA, $d = 25$ mm, $h = 0.2$ m, $G = 45$ kg/s;
7. Grafplast KPK, TOPTERM MULTILAYER, $d = 16$ mm, $h = 0.1$ m, $G = 15$ kg/s;
8. Grafplast KPK, TOPTERM MULTILAYER, $d = 20$ mm, $h = 0.15$ m, $G = 30$ kg/s;
9. Grafplast KPK, TOPTERM MULTILAYER, $d = 25$ mm, $h = 0.2$ m, $G = 45$ kg/s;
10. Grafplast KPK, PRANDELLI/TUBORAMA, $d = 16$ mm, $h = 0.1$ m, $G = 15$ kg/s;
11. Grafplast KPK, PRANDELLI/TUBORAMA, $d = 20$ mm, $h = 0.15$ m, $G = 30$ kg/s;
12. Grafplast KPK, PRANDELLI/TUBORAMA, $d = 25$ mm, $h = 0.2$ m, $G = 45$ kg/s.

Thus, the use of modern roofing materials and pipes and insulation can reduce indoor air temperature more than 10 °C.

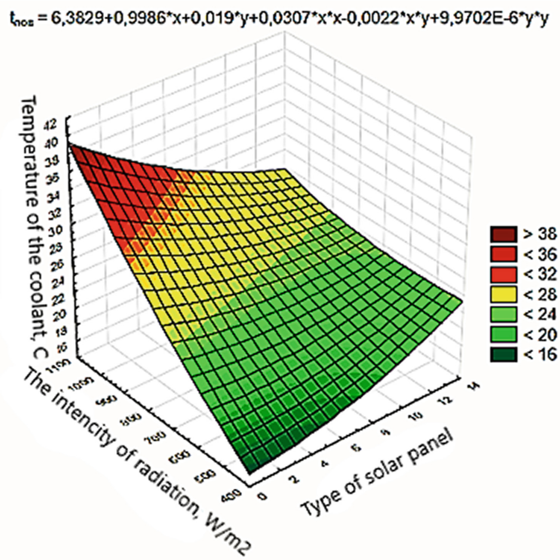


**Fig. 5.** Internal air temperature, $t_{in}$, °C depending on the type of the solar panel and radiation intensity, $I$, W/m$^2$

## 5 Results and Discussion

Based on the results obtained during the analytical and experimental studies, dependences were obtained for determining the temperature of the coolant in the solar panel. Based on the values of the temperature of the coolant in the solar panel, as well as the data on the intensity of solar radiation, the energy-efficient design of the solar panel was proposed. The protective coating of this solar panel is made in the form of a waterproofing layer and coated with a rubber-graphite composition Grafplast PDA, it is expedient to use the PRANDELLI/TUBORAMA 02 STOP floor heating pipes with a diameter of pipes $d = 16$ mm and tubes $h = 0.1$ m.

One of the advantages of the proposed system is the ability to cover the roofs of buildings in general with minimal financial costs.

This makes it possible to save energy that would be spent on heating the heating system of the hot water supply system of the building, as well as on the air conditioning system, since the use of solar panels reduces the temperature of the overhead panel, which in turn reduces the air temperature in the room under the solar panels. Dependences were obtained for determining the temperature of the indoor air, depending on the design of the solar panel and the intensity of solar radiation, which made it possible to assess the effect of the use of solar panels and increase the class of energy efficiency of the building. In the future, it is planned to carry out a complex of studies on providing the temperature regime of premises with the use of combined systems of solar heat supply in wall constructions, since the developed system is designed for heat supply systems with solar panels installed on the roof covering.

## 6 Summary and Conclusions

In this work the design of a solar panel is presented, which can be used as a roof covering and a solar collector. From this work, the following may be concluded:

1. The function t is defined and optimized for various cases of interaction of the factors, namely: at different values of the diameter of the tube *d*, m, the tube step *h*, m, the heat carrier flow rate *G*, kg/s, the intensity of the solar radiation *I*, W/m$^2$.
2. As a result of experimental research, the empirical dependencies of solar panels and the solar system in general on the flow rate of the coolant, the step and diameter of the tubes and the intensity of the heat flow to calculate their efficiency have been obtained.
3. As a result of studies of solar panels, its rational design features were identified, which are: diameter of pipes $d = 16$ mm, tube pitch $h = 0{,}1$ m.
4. It is established that the effectiveness of the solar panel decreases with increasing the tube pitch from $h = 0.1$ m to $h = 0.15$ m for 5% and when the diameter of the tubes changes from $d = 16$ mm to $d = 20$ mm, the efficiency decreases by 3%, and the average efficiency of the solar panel 50%.
5. Application of modern roofing materials and types of pipes, can increase the efficiency of the solar panel by 8% compared with traditional roofing materials and tubes.
6. It is established that when using solar panels, it is possible to reduce the temperature of the internal air, with respect to the temperature of the outside air by more than 10 °C (depending on the design of the solar panel and the intensity of solar radiation).

## References


1. DBN V.2.6-31:2016. Construction of buildings and structures. Thermal insulation of buildings. Kyiv, MBAZHKHU, 70 (2016)
2. Gumen, O., Spodyniuk, N., Ulewicz, M., Martyn, Y.: Research of thermal processes in industrial premises with energy-saving technologies of heating. Diagnostyka **18**(2), 43–49 (2017)
3. Selejdak, J., Ulewicz, R., Ingaldi, M.: The evaluation of the use of a device for producing metal elements applied in civil engineering. In: 23rd International Conference on Metallurgy and Materials, Conference Proceeding, pp. 1882–1888 (2014)
4. Klymchuk, O., Denysova, A., Shramenko, A., Borysenko, K., Ivanova, L.: Theoretical and experimental investigation of the efficiency of the use of heat-accumulating material for heat supply systems. Phys. Eng. **3**, 32–40 (2019). https://doi.org/10.21303/2461-4262.2019.00901
5. Zhelykh, V., Venhryn, I., Kozak, K., Shapoval, S.: Solar collectors integrated into transparent facades. Prod. Eng. Arch. **26**(3), 84–87 (2020). https://doi.org/10.30657/pea.2020.26.17
6. Zhelykh, V., Shapoval, P., Shapoval, S., Kasynets, M.: Influence of orientation of buildings facades on the level of solar energy supply to them. In: Blikharskyy, Z. (ed.) EcoComfort 2020. LNCE, vol. 100, pp. 499–504. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-57340-9_61
7. Lis, A., Spodyniuk, N.: The quality of the microclimate in educational buildings subjected to thermal modernization. In: E3S Web of Conferences, vol. 100, p. 00048 (2019). https://doi.org/10.1051/e3sconf/201910000048

8. Adamski, M.: Mini longitudinal flow spiral recuperator. Healthy Build. Europe (2017). https://doi.org/10.1051/matecconf/20141801001
9. Kapalo, P., Spodyniuk, N.: Effect of the variable air volume on energy consumption – case study. Mater. Sci. Eng. **415**(1), 012–027 (2018). https://doi.org/10.1088/1757-899X/415/1/012027
10. Aedah, M., Mahdi, J.: Energy audit a step to effective energy management. Int. J. Trend Res. Dev. **5**(2), 521–525 (2018). ISSN: 23949333
11. Savchenko, O., Voznyak, O., Myroniuk, K., Dovbush, O.: Thermal renewal of industrial buildings gas supply system. In: Blikharskyy, Z. (ed.) EcoComfort 2020. LNCE, vol. 100, pp. 385–392. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-57340-9_47
12. Basok, B.I., Davydenko, B.V., Farenuyk, G.G., Goncharuk, S.M.: Computational modeling of the temperature regime in a room with a two-panel radiator. J. Eng. Phys. Thermophys. **87**(6), 1433–1437 (2014). https://doi.org/10.1007/s10891-014-1147-5
13. Bilous, I., Deshko, V., Sukhodub, I.: Building inside air temperature parametric study. Mag. Civil Eng. **68**(8), 65–75 (2016). https://doi.org/10.5862/MCE.68.7
14. Buyak, N., Deshko, V., Sukhodub, I.: Buildings energy use and human thermal comfort according to energy and exergy approach. Energy Build. **146**(1), 172–181 (2017). https://doi.org/10.1016/j.enbuild.2017.04.008
15. Deshko, V., Buyak, N.: A model of human thermal comfort for analysing the energy performance of buildings. Eastern-Eur. J. Enterp. Technol. **4**(8–82), 42–48 (2016). https://doi.org/10.15587/1729-4061.2016.74868
16. Shapoval, S., Zhelykh, V., Spodyniuk, N., Dzeryn, O., Gulai, B.: The effectiveness to use the distribution manifold in the construction of the solar wall for the conditions of circulation. Pollack Periodica **14**(2), 143–154 (2019). https://doi.org/10.23939/chcht11.04.503
17. Shapoval, S., Spodyniuk, N., Zhelykh, V., Shepitchak, V., Shapoval, P.: Application of rooftop solar panels with coolant natural circulation. Pollack Periodica **16**(1), 132–137 (2021). https://doi.org/10.1556/606.2020.00218
18. Ulewicz, M., Zhelykh, V., Kozak, K., Furdas, Y.: Application of thermosiphon solar collectors for ventilation of premises. In: Blikharskyy, Z., Koszelnik, P., Mesaros, P. (eds.) Proceedings of CEE 2019: Advances in Resource-saving Technologies and Materials in Civil and Environmental Engineering, pp. 180–187. Springer International Publishing, Cham (2020). https://doi.org/10.1007/978-3-030-27011-7_23
19. Košičanová, D., Fedorčák, P.: Reducing energy consumption with using ventilation and solar cooling, school building's case study. Pollack Periodica **6**(2), 131–138 (2011). https://doi.org/10.1556/pollack.6.2011.2.11
20. Bryuner, K., Buxmajyer, Yu., Flyush, Yu., Myuster-Slavych, B.: The use of solar thermal energy in industry. Gleisdorf (2015)
21. Neumann, F., Patschke, M., Schoennenbeck, M.: Heliothermal flat collector module having a sandwich structure. Patent 7610911, USA, Eckert Seamans Cherin & Mellott, LLP, N 10/530384 (2009)
22. Riegger, C.: Transpired solar collector walls: use solar, save green. Interface 5–8 (2008)
23. Zhelykh, V., Voznyak, O., Yurkevych, Y., Sukholova, I., Dovbush, O.: Enhancing of energetic and economic efficiency of air distribution by swirled-compact air jets. Prod. Eng. Arch. **27**(3), 171–175 (2021). https://doi.org/10.30657/pea.2021.27.22
24. Voznyak, O., Spodyniuk, N., Savchenko, O., Sukholova, I., Kasynets, M.: Enhancing energetic and economic efficiency of heating coal mines by infrared heaters. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu **2**, 104–109 (2021)
25. Zhelykh, V., Dzeryn, O., Shapoval, S., Furdas, Y., Piznak, B.: Study of the thermal mode of a barn for piglets and a sow, created by combined heating system. Eastern-Eur. J. Enterp. Technol. **5**(8–89), 45–50 (2017)

26. Ulewicz, M., Zhelykh, V., Furdas, Y., Kozak, K.: Assessment of the economic feasibility of using alternative energy sources in Ukraine. In: Blikharskyy, Z. (ed.) EcoComfort 2020. LNCE, vol. 100, pp. 482–489. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-57340-9_59
27. Myroniuk, K., Voznyak, O., Yurkevych, Y., Gulay, B.: Technical and economic efficiency after the boiler room renewal. In: Blikharskyy, Z. (ed.) EcoComfort 2020. LNCE, vol. 100, pp. 311–318. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-57340-9_38
28. Shapoval, S., Zhelykh, V., Venhryn, I., Kozak, K.: Simulation of thermal processes in the solar collector which is combined with external fence of an energy efficient house. In: Blikharskyy, Z., Koszelnik, P., Mesaros, P. (eds.) Proceedings of CEE 2019: Advances in Resource-saving Technologies and Materials in Civil and Environmental Engineering, pp. 510–517. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-27011-7_65
29. Venhryn, I., Shapoval, S., Voznyak, O., Datsko, O., Gulai, B.: Modelling of optical characteristics of the thermal photovoltaic hybrid solar collector. In: International Scientific and Technical Conference on Computer Sciences and Information Technologies, vol. 1, pp. 255–258 (2021)