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Solar collectors integrated into transparent facades

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Abstract
Due to the fact that the number of natural disasters in the world has increased in recent years, experts note that climate change is the cause. As a consequence of the nature of the needs to improve the fuel and energy complex in the countries in world. This solution could be solar energy and similar energy sources. The paper presents the classification of energy-efficient houses proposed by international standards and its critical analysis. Emphasis is placed on the problem of improving solar collectors integrated into the construction of buildings. The paper presents the temperature characteristics of an experimental solar collector. For the experimental solar collector combined with the translucent facade of the building, thermal characteristics are set, in particular, such as thermal capacity and thermal efficiency.

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1. Introduction

A priority area of environmental and economic research concerns the reduction of the volume of organic fuel production in the fuel and coal industry (Ingaldi, 2015). An alternative solution which can be undertaken to solve these issues is an unconventional branch of energy supply, namely, renewable energy.

The main object of research on renewable energy sources is solar energy. It is important to develop buildings that consume a low amount of energy along with the development of solar power supply.

In Europe, a classification of buildings and structures according to their annual energy consumption is proposed (Hemerys, 2012):

- 'Old buildings' (built before the 70s) where the energy consumption is within 300 kW·h/(m^2·year);
- 'New buildings' (built from the 70s to the 2000s) where energy consumption is less than 150 kW·h/(m^2·year);
- 'Buildings with low energy consumption' where the energy consumption is no more than 60 kW·h/(m^2·year).

In Europe, the construction of the low standard buildings has been prohibited since 2002. In such buildings, installations with active or passive heat supply from solar collectors are often used, as well as other methods and means of reducing energy consumption (Hestnes, 2007). Registered quality mark for new and renovated buildings of low energy consumption is Minergie mark. (Hall, 2013) The above classification also includes:

- 'Passive buildings' for which energy consumption is determined within 15 kW·h/(m2·year);
- 'Zero-energy buildings' that are equipped in such a way that their energy consumption is equal to the amount of energy they produce, i.e. their energy consumption equals zero;
- 'Buildings plus energy', where more energy is generated than the building itself consumes. Such buildings contain additional equipment. For example, heat recuperators, photovoltaic solar collectors, thermal solar collectors, heat pumps, etc.

It should be noted that scientific and technical progress provides a reduction in the cost of energy obtained when using solar collectors. The annual growth of global solar energy productivity in 2020 – 2030 years will be 25% (Mohylko, 2010). However, it is worth noting that buildings in modern design tend to have an increased area of glazing facades.

Research in recent years has shown that the implementation of the potential of heat from the sun will save, in the conditions of Ukraine, more than three million tons of conventional fuel annually (Beznoshchenko, 2006; Selejdak, 2014).

For example, Shchukyna (2011) offers scientific and methodological approach to achieve the maximum possible energy supply to a building by increasing the efficiency of passive and active solar heating systems. In addition, the work provides recommendations for the passive/active method of capturing solar energy through system analysis and modeling, taking into account variable weather conditions and seasonal changes in heat consumption. The rationality of the study of energy supply through the use of flat collectors with corrugated translucent protection for buildings is justified. However, the work does not contain a generalized approach for heat supply of energy-efficient buildings.

2. Recent research and publications

The important point is that with regard to solar collectors for heat supply, there is currently not much information regarding the design features to ensure maximum efficiency of the heat supply system based on them (Babaev, 2016). Aspects of application of integrated solar thermal systems in localities are considered in the paper (Munari, 2007). In the following work, architectural features of buildings, along with the efficiency of using solar thermal systems (COST Action TU1205, 2015) are described. These works provide generalized data about units of thermal characteristics of solar heat supply systems.

Baxi Heating (2007) presents the method of integrating the flat solar collector into the building's surface is described in detail. Therefore, it is worth noting that there are designs of solar collectors where the solar collector is integrated or combined with part of the roof element of the house. This roof has the improved thermal insulation shell, in addition, it can provide the house with electricity.

The utility model of the solar collector is given in (Hatov, 1990) called "shedove covering". This coating contains energy-saving and optically transparent elements bonded together. Also, the solar heating system combined with the house coating is known and is made in the waterproofing bituminous layer (Baramydze, 1992). The solar cascade described in (Marchenko, 1990) is intended for installation on roofs of the house. However, the above designs do not consider the integration of the solar collector into the translucent facade of the building.

For mathematical analysis and calculation of solar collectors, there are formulas for determining, for example, the amount of intensity received on the surface of the solar collector or determining its generating capacity.

The flow of a stream of direct solar energy I_s, W/m^2, on the surface oriented in an arbitrary way it is advisable to calculate by the formula (1):

$$I_s = I_d \cdot cos\,\theta \tag{1}$$

where I_d – the intensity of the flow of direct solar energy at the earth's surface to the surface perpendicular to the sun's rays at the mass of the atmosphere m, W/m^2; θ – the angle between the radiation direction and the normal to the given surface, deg.

The cosine of the angle θ could be found from the ratio (2):

$$\begin{aligned} cos\,\theta = {} & sin\,\delta\, sin\,\varphi\, cos\,\beta - sin\,\delta\, cos\,\varphi\, sin\,\beta\, cos\,\gamma + \\ & + cos\,\delta\, cos\,\varphi\, cos\,\beta\, cos\,\tau + \\ & + cos\,\delta\, sin\,\varphi\, sin\,\beta\, cos\,\gamma\, cos\,\tau + cos\,\delta\, sin\,\beta\, sin\,\gamma\, sin\,\tau \end{aligned} \tag{2}$$

where β – the angle of inclination of the surface to the horizontal plane, deg;
δ – the declination of the Sun, deg;
φ – the geographical latitude of the area, deg;
τ – the hour angle of the Sun at a given time is counted from the moment of true noon, deg;
γ – the azimuthal angle of the plane, that is, the deviation of the normal to the plane from the local meridian, deg. (Shapoval, 2011)

3. Objectives the formulation of the problem

Technically, it is possible to improve the translucent facade of the building for the energy-efficient house by integrating the solar collector for heat supply. According to this, there is a need for establishing thermal characteristics of the proposed solar collector. Due to the fact that the model of the solar collector will be flat, and the intensity of solar energy is unstable during the day, it is necessary to understand that the proposed model of the solar collector will be effective for preheating the heat carrier in the energy supply system. Therefore, it is necessary to establish exactly the temperature characteristics, thermal power and efficiency of the solar collector in the direct-flow system, that is, due to the installed intake and supply of heat carrier in the heat supply system.

4. Experimental

The efficiency of the solar collector is recommended to be determined by the formula (3) (Shapoval, 2020):

$$\eta_{SC} = \frac{Q_{SC}}{I} \cdot 100\% \tag{3}$$

where Q_{SC} – the specific instantaneous thermal power of the solar collector, W/m^2;
I – the intensity of the source radiation on the heat receiving surface of the solar collector, W/m^2.

The instantaneous thermal power of the solar collector is given for 1 m^2 of its active area could be calculated by the formula (4):

$$Q_{SC} = G \cdot c \cdot (T_{outlet} - T_{inlet}) \tag{4}$$

where G – the specific heat carrier consumption, kg/(m^2·sec);
c – the specific heat capacity of the heat carrier, J/(kg·K);
T_{inlet}, T_{outlet} – temperatures of the heat carrier at the inlet and outlet of the solar collector, K.
The design of solar collector integrated into the glass facade of the building consists of the transparent covering 1 is placed in the body 2 of the translucent facade, containing tubes for circulating the heat carrier 3 (Fig. 1).

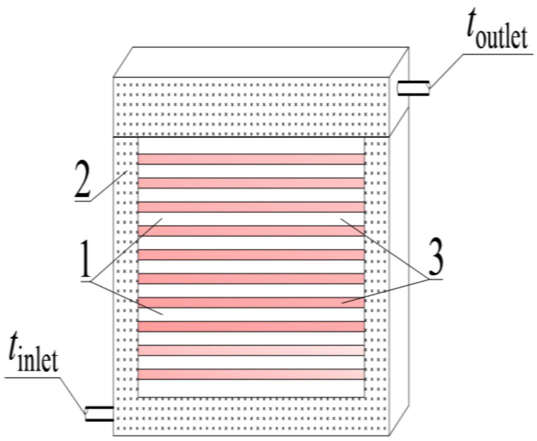

Fig. 1. The solar collector that integrated into the translucent facade of the building: 1 – transparent coating; 2 – the body of the TFB, which contains the heat insulation layer; 3 – tubes for heat carrier circulation

The design of the translucent facade of the building (TFB) with solar collector was studied by the intensity of simulated solar radiation under the volume of 600 W/m^2 in laboratory conditions.

The results obtained were processed using statistical formulas to establish errors. In addition, during the experiments, each experiment was performed twice, under the same conditions, in order to assess the errors. During each experiment, the values of optimization parameters were obtained and averaged.

The deviation of the result of any experiment from the arithmetic mean indicates the variability of parallel experiments. To install this variation it is possible to apply variance (5):

$$s^2 = \frac{\sum_{1}^{n} \left(y_i - y_{cp}\right)^2}{n-1} \tag{5}$$

where (n – 1) – the number of degrees of freedom, which is 1 less than the number of experiments.

5. Results and discussion

The temperature of the heat carrier at the outlet of the solar collector during the experiments was on average 17% higher relative to the input temperature of the heat carrier (Fig. 2). The ambient temperature changed during the experiment from 19.2 °C to 20.5 °C and increased by 7%.

When studying the instantaneous power of the solar collector, namely every 10 minutes, the character of generation is variable, which may be due to fluctuations in the temperature at the inlet of the solar collector (Fig. 3). Since the solar heat supply system with the SC integrated in the TFB worked in the direct flow mode, and the heat carrier was supplied directly from the network cold water pipeline. The amount of instantaneous specific heat power received from the solar collector differs between the minimum and maximum value of no more than 9.6%.

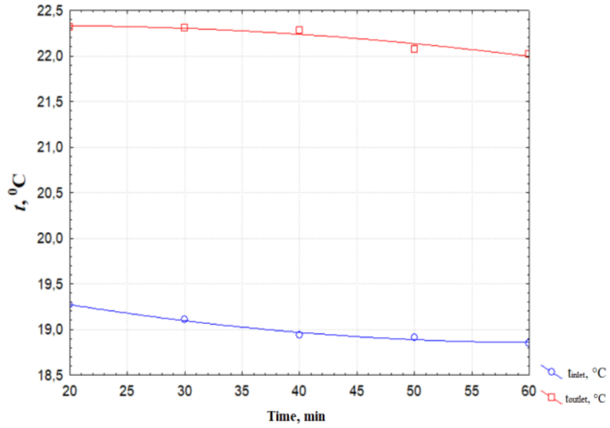

Fig. 2. The change of the heating temperature of the heat carrier in the inlet pipe t_{inlet}, °C and the outlet pipe t_{outlet}, °C of the solar collector during the experiment

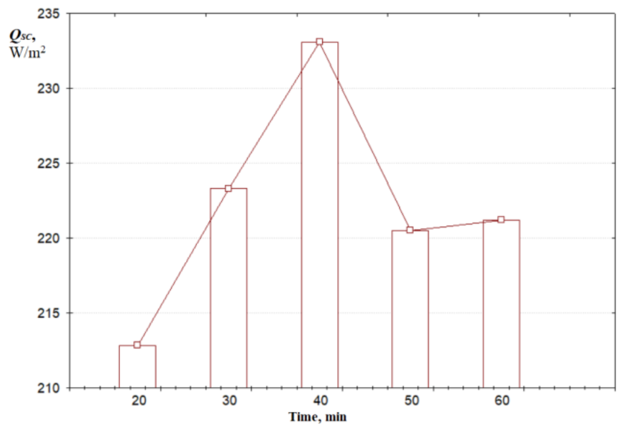

Fig. 3. Change in the specific instantaneous power of the solar collector integrated in the TFB during the experiment

The thermal efficiency of the solar collector after the system entered the stabilization mode did not have the significant oscillatory character (table. 1). However, it is worth noting that the maximum thermal efficiency of the solar collector reaches at the 40 minutes of the experiment, as well as the specific instantaneous power of the solar collector.

Table. 1. Changes in the thermal efficiency of the solar collector during the experiment

Time of the experiment, min	Thermal efficiency of the solar collector η_{SC}
20	0,35
30	0,37
40	0,39
50	0,37
60	0,37

Setting the thermal efficiency at 37% could be considered effective for implementing such solar collectors in practice.

6. Summary and conclusion

Summing up the above described trend of combining or integrating solar collectors in the design of outdoor fencing is becoming more and more popular. Since the solar collector model was tested for supplies from the network pipeline and the average intensity of simulated solar radiation of 600 W/m^2 and reached ≈ 37% of thermal efficiency, this design could be recommended for large-scale implementation in energy-efficient buildings and structures.

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太阳能集热器集成到透明立面中

關鍵詞
玻璃幕墙
太阳能集热器
热容量
热效率
节能建筑

摘要

由于近年来世界上自然灾害的数量增加，专家指出气候变化是原因。 由于需要改善世界各国燃料和能源综合体的性质。 该解决方案可以是太阳能和类似的能源。 本文介绍了国际标准提出的节能住宅的分类及其批判性分析。 重点放在改进集成到建筑物建筑中的太阳能收集器的问题上。 本文介绍了实验性太阳能收集器的温度特性。 对于结合了建筑物的半透明外墙的实验性太阳能收集器，尤其要设置热特性，例如热容量和热效率。