Thermal Efficiency Analysis of Solar Heat Supply Unit Combined with Glass Facade of Building

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Abstract

The work notes the development of non-traditional energy sources in Ukraine. There is a need to improve existing solar collectors and combine these units with structures of external fencing for energy-efficient buildings. Taking into account the popularity of construction with an increased area of glazing, the paper suggests the design of solar collector combined with the glass facade of the building. It gives data about change of the heat carrier temperature at the outlet of the solar collector. It was investigated that the developed model of the solar collector allows generating 132 W/m^2 under the effect of the simulated solar energy intensity of 300 W/m^2. Also, it was studied that the solar collector combined with the glass facade of the building has an average thermal efficiency of 43 %. This efficiency was achieved for cloudy days or for morning and evening heat supply, i.e. when the incoming solar energy to the solar collector is not maximal.

Keywords: solar collector; glass facade of building; temperature of heat carrier; thermal efficiency; energy-efficient house.

1. Introduction

There is a need to improve the norms and standards of Ukraine [1], based on innovative solutions to ensure the non-volatile future of our country, considering the priorities described in the European Union standards on energy efficiency. In Ukraine, there is an energy deficit of fossil fuels, with satisfaction of own needs up to 49 %, with oil production up to 12 % and natural gas up to 25 % [2]. In addition to the consumption of non-renewable energy sources and their cost, their negative impact on the environment should be noted. Taking into account the environmental situation in Ukraine, it is necessary to take measures to reduce the amount of harmful emissions.

The parameters of changes in the solar radiation incoming during the day are studied at metrological stations and data about the solar radiation incoming are described in the relevant literature [3]. Solar energy as the alternative energy source has a number of advantages and could be used for direct conversion to electrical energy and for heat generation by absorption of solar radiation [4], [5]. Direct conversion of solar energy into thermal or electrical energy is one of the main advantages of using solar energy as the energy resource of the future [6]. However, the amount of absorbed solar radiation depends on latitude, atmospheric transparency, characteristics of the earth's surface, time of day, and time of year [7]. The author of [8] described the series of solar heat supply systems and proved their thermal efficiency. For Ukraine, due to the obsolescence of technological equipment powered by traditional organic fuel, the solar heat supply system is the priority for development and improvement. It is necessary to analyze in detail the potential of solar energy in Ukraine to be able to develop new and improved solar heat supply systems.

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Averaging the potential of solar energy that entering on the territory of Ukraine annually, it was found that it composes more than 1.2 (MWh)/m^2 and is much higher than in Germany-1 (MWh)/m^2 or Poland – 1.1 (MWh)/m^2 [9], [10]. As the result, Ukraine's total energy consumption will decrease by 14.75 % if all households are energy efficient [11]. Research and conclusions confirming the need for further research of various configurations of systems for ensuring the microclimate of households due to solar energy are described in paper [12]. Increase in the total area of installed solar collectors could lead to the increase in the cost of the heat supply system.

2. Formulation of the problem

In addition to the consumption of non-renewable energy sources and their cost, their negative impact on the environment should be noted. It is necessary to take measures to reduce the amount of harmful emissions taking into account the environmental situation in Ukraine. The priority solution to this problem is the development of solar collectors for energy-efficient buildings and the application of these installations in solar heat supply systems.

3. Analysis of recent research and publications

A brief description of the history of creating the integrated solar thermal system using active methods of collecting solar energy are given in the literature [13], [14]. Today, various types of solar collectors have been developed [15], [16]. Structurally, there are flat (the heating temperature of the heat carrier is 70 – 75 °C) and vacuum solar collectors (80 – 120 °C), as well as concentrator collectors (120 – 250 °C). The description of such collectors is given in works [17], [18] and others. Studies on the influence of the orientation and angle of inclination of the flat solar collector for year-round use in real natural and climatic conditions of Ukraine and determining of the optimal parameters of its orientation are presented in [19], [20].

It is advisable to show savings when installing solar collectors in energy-efficient buildings instead of the consumption of the traditional fuel. French scientists cite aspects of covering the deficit of traditional fuel with the help of energy-efficient buildings [21]. The paper [22] presents the results of Danish energy modeling and the development of Danish typologies of residential buildings taking into account energy efficiency. The Silvertree building in London is cost-effective to operate than a conventional traditional building of the same size and consumes 25 % less energy. Curved strips of aluminum with photovoltaic elements are located on the facades of this building, which saves a significant part of traditional fuel. In addition, solar collectors could be combined into one system with another type of installation that generates alternative energy from another type of renewable source. For instance the same building uses geothermal heat pumps for heating and cooling in the energy supply system [23].

The promising engineering idea is the combination of passive power systems with external building elements [24], [25]. The advantage of combined solar collectors connected with building structures is their ease of installation, and they could also serve as solar energy accumulators [26]. The technological characteristics of such combinations make it possible to integrate them into unified production complexes of technical systems focused on the use of both traditional and alternative energy sources.

4. The main material

Taking into account the promising direction of solar energy for Ukraine and the need to improve solar collectors for use in energy-efficient buildings, the experimental model of the solar collector combined with the glass facade of the building was developed. Since the window design is the least studied element in the energy-efficient house with the increased glazing area.

Experimental studies of the thermal efficiency of the solar collector combined with the glass facade of the building (window) containing polyvinyl chloride circulation pipes located inside the structure were carried out to determine its efficiency due to simulated solar radiation of 300 W/m^2. This amount of heat energy corresponds to the amount received by the solar collector during the morning and evening solstices. The income of solar radiation on the collector combined with the glass facade of the building was studied when using the simulator of the solar energy intensity. The experimental setup consisted of the light transparent coating, the body with the heat insulation layer and tubes located inside the body for the heat carrier circulation. The photo of the experimental solar collector combined with the glass facade of the building in the laboratory is shown in Fig.1.

Fig.1. The photo of the proposed experimental solar collector combined with the glass facade of the building.

The average Δ in the temperature of the heat carrier during the experiment in the solar heat supply system is shown in Fig.2. During the research, the temperature growth curve of the heat carrier increased by 10% in 20 minutes of the experiment. We could also see the increase of the heat carrier temperature in the supply pipe because the heating system with such solar collector operates with the constant supply of heat carrier, and, accordingly, its supply to the consumer. The heat carrier in the solar heat supply system came directly from the network pipeline, which causes instability of the heat carrier temperature at the entrance to the solar collector.

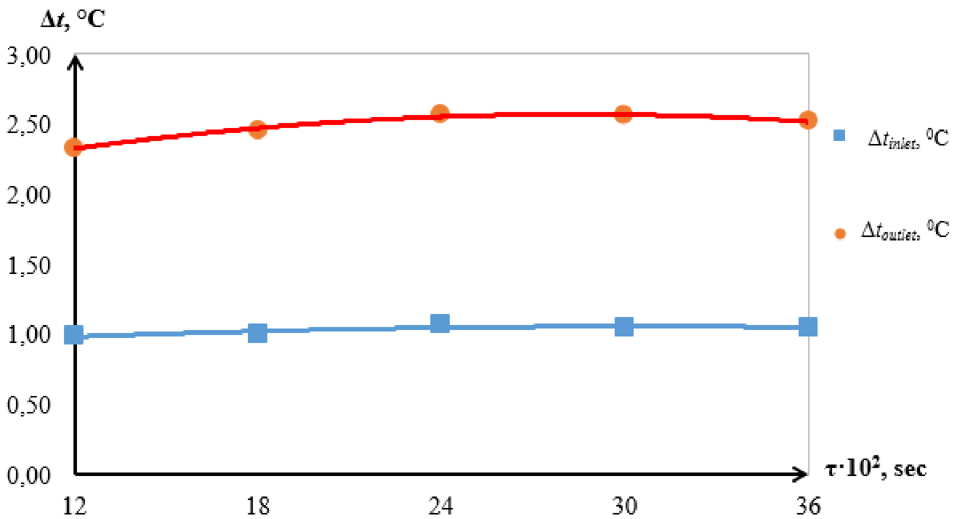

Fig.2. The temperature Δ of the heat carrier at the inlet Δt_{inlet}, °C and the outlet Δt_{outlet}, °C from the solar collector during the experiment.

It was analyzed that on average, the solar collector produces heat energy of 132 W/m^2 under the incoming simulated solar energy intensity of 300 W/m^2. The thermal power graph is shown in Fig.3. The thermal power has a parabolic curve. It could be concluded that due to the variability of the temperature at the entrance to the solar collector, the curve of the thermal power of the solar collector changes.

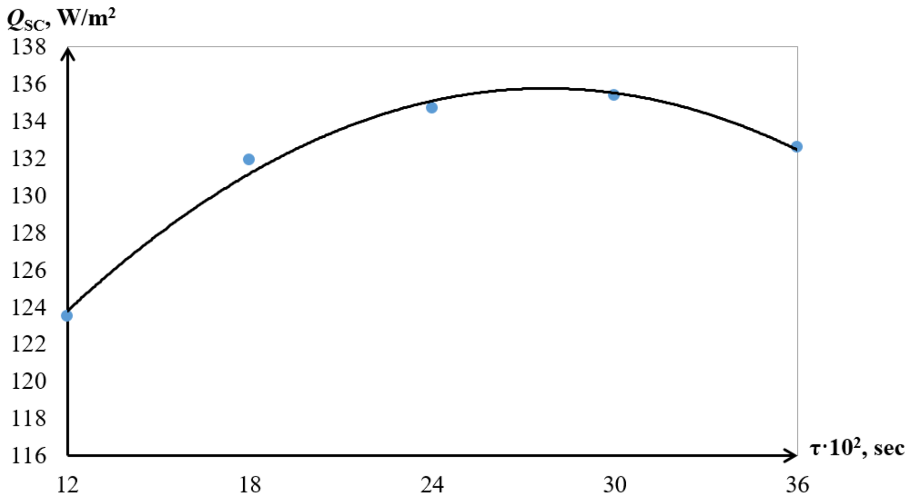

Fig.3. The change of the thermal power generated by the solar collector Q_{sc},W/m^2 during the experiment.

The solar heat supply system with the proposed solar collector was estimated using the energy that the system produces instantly, namely each 10 min (Fig.4).

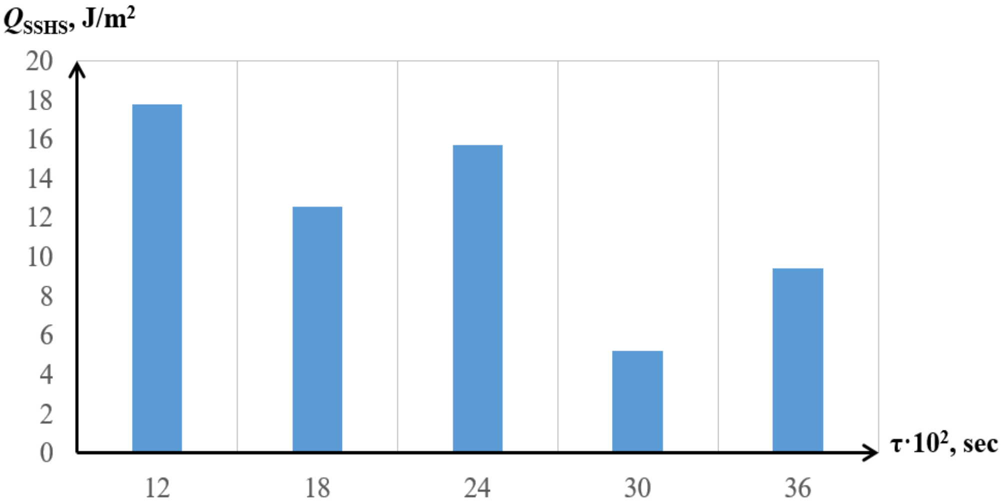

Fig.4. The amount of the energy Q_{SSHS}, J/m^2 each 10 min which was produced by the solar heat supply system that include the solar collector combined with the glass facade of the building during the experiment.

The uneven nature of the change in the values of the ten-minute specific heat energy could be explained as the result of the parabolic change in the thermal power generated by the solar collector unit. The solar collector was not investigated under the high intensities, therefore the amount of energy received from the solar heat supply system was low, but sufficient for the preheating of the heat carrier which circulates in the traditional installation or low-temperature heat supply for the consumer.

The graphic efficiency of the solar collector design and the system solar heat supply with such collector are shown in Fig.5.

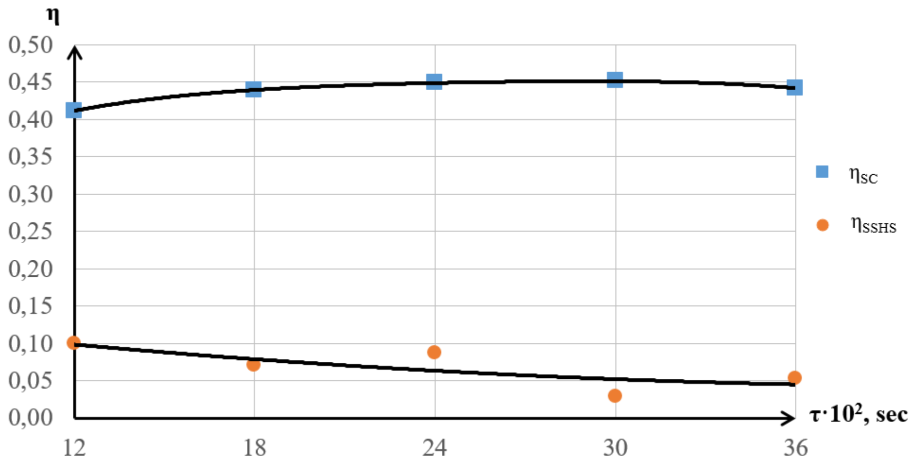

Fig.5. The change of the efficiency of the solar collector design η_{SC} and the system solar heat supply with such collector η_{SSHS} during the experiment.

It was investigated that the efficiency of the solar heat supply system was approximately 7 % under the simulated solar radiation. This efficiency was achieved in the mode of direct supply and intake of heat carrier in the system, which is sufficient for preheating the heat carrier in the energy supply system.

5. Conclusion

Summarizing the above-mentioned data, it could be argued that the solar collector model is effective for combining with the construction of the glass facade of the building, such as the window. The study was conducted to establish the thermal characteristics of the solar collector under the intensity of the simulated solar energy incoming on the solar collector area with the capacity of 300 W/m^2 with the aim to confirm the possibility of using the solar collector in the solar heat supply system. The experimental solar collector achieved the generation of 135 W/m^2 of thermal energy. The maximum efficiency achieved by the solar collector was 45 %.

The established data allow us to assert the possibility of using the proposed installation of the solar collector in heat supply systems, in particular, by combining this installation with the glass facade of an energy-efficient building. It is worth noting that the installed thermal characteristics of the solar collector combined with the glass facade of the building allow us to confirm hypothetical ideas about the possibility of widespread introduction of solar collectors in the market.

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Аналіз теплової ефективності установки сонячного теплопостачання суміщеної із конструкцією світлопрозорого фасаду будівлі

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Анотація

В праці наголошується на розвитку нетрадиційних джерел енергії в Україні. Наголошується на потребі вдосконалення існуючих сонячних колекторів та суміщення цих установок із конструкціями зовнішнього огородження для енергоефективних будівель. Враховуючи популярність будівництва із збільшеною площею засклення, то в роботі запропоновано конструкцію сонячного колектора суміщеного із скляним фасадом будівлі. Наводяться дані щодо зміни приросту температури теплоносія на виході із сонячного колектора. Досліджено, що розроблена модель сонячного колектора дозволяє генерувати 132 Вт/м^2 за дії імітованого інтенсивності сонячної енергії 300 Вт/м^2. Досліджено, що сонячний колектор суміщений із скляним фасадом будівлі має ефективність 43 %. Така ефективність буде відповідною для теплопостачання в хмарні дні або ж в період ранкового чи вечірнього теплопостачання, тобто не за максимуму надходження сонячної енергії на конструкцію сонячного колектора.

Ключові слова: сонячний колектор; скляний фасад будівлі; температура теплоносія; теплова ефективність; енергоефективний будинок.