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ANALYSIS OF THE EFFECTIVENESS OF SOLAR SYSTEMS USE IN THE UNIVERSITY CENTRALIZED HEAT SUPPLY SYSTEMS

Є. Бабаєв, Г. Позднякова. **Аналіз ефективності застосування геліосистем в централізованих системах теплопостачання університету.** В роботі проведено аналіз сучасного стану сонячної енергетики для комунальних потреб та можливість застосовувати їх у складі централізованих систем теплопостачання. У південному регіоні через низку причин велике застосування отримали геліо системи. Застосування сонячних колекторів дозволяє значно знизити теплоспоживання будинків у літній період, а часом звести використання традиційних джерел енергії до нуля. Однак в інші періоди року частка заміщення сонячною енергією традиційною є значно нижчою. У таких випадках постає питання – на яке навантаження теплопостачання розраховуватиме систему: літню, зимову чи демісезонну. Від вирішення цього питання залежить кількість сонячних колекторів, кут нахилу та орієнтація з боків світла. В теперішній час найбільш розповсюдженими є сонячні колектори двох типів: пласкі та вакуумні. В роботі проведено порівняльний аналіз їх основних технічних параметрів. Для виконання основних задач дослідження було проведено аналіз основних діючих методик та програмних комплексів для розрахунку роботи геліосистеми у складі комбінованих систем теплопостачання та наведені основні показники, що впливають на ефективність роботи сонячної системи, та рекомендації щодо їх вибору при розрахунках річного видобутку теплоти. Для системи централізованого теплопостачання навчальних корпусів університету було проведено моделювання роботи сонячної станції впродовж року. Для корпусів різного типу, поверховості, площі, призначення за допомогою спеціалізованого програмного комплексу було проведено аналіз ефективності застосування геліосистем із використанням сонячних колекторів різного типу. Показано частку заміщення теплоти сонячними колекторами, із чого витікає доцільність застосування сонячних колекторів на низки корпусів.
Ключові слова: сонячні колектори, частка заміщення теплоти, централізовані системи теплопостачання

E. Babaev, G. Pozdniakova. **Analysis of the effectiveness of solar systems use in the university centralized heat supply systems.** The paper analyzes the current state of solar energy for communal needs and the possibility of using it as part of centralized heat supply systems. Helio systems are widely used in the southern region for a number of reasons. The use of solar collectors allows you to significantly reduce the heat consumption of buildings in the summer, and sometimes to reduce the use of traditional energy sources to zero. However, in other periods of the year, the share of replacement by traditional solar energy is much lower. In such cases, the question arises as to which heat supply load the system will be designed for - for summer, winter or demi-season. To fulfill the main tasks of the research, an analysis of the main operating methods and software complexes for calculating the operation of the solar system as part of combined heat supply systems was carried out. The main indicators that affect the efficiency of the solar system and recommendations for their selection when calculating the annual heat output are also given. For the centralized heat supply system of the university's buildings, a simulation of the operation of the solar plant throughout the year was carried out. For buildings of different types, storeys, area, purpose, an analysis of the effectiveness of solar systems using different types of solar collectors was carried out with the help of a specialized software complex. The share of heat replacement by solar collectors is shown, which shows the expediency of using solar collectors on a number of buildings.
Keywords: solar collectors, share of heat replacement, centralized heat supply systems

1. Introduction

According to existing laws on energy conservation, modern heat supply systems should use renewable energy sources as much as possible [1, 2]. However, the use of such sources in heat supply systems, as a rule, is associated with high specific capital investments and only partial replacement of the required heat capacity. Therefore, it is very important at the design stage to develop a thermal scheme with the most efficient use of the potential of renewable energy sources (sun, air, soil, etc.). In the southern region, due to a number of reasons, helio systems were widely used. The installation of solar collectors allows you to significantly reduce the heat consumption of buildings in the summer, and sometimes to reduce the use of traditional energy sources to zero. However, in other periods of the year, the share of replacement of traditional energy by solar energy is much lower. In such cases, the question arises – for which heat supply load should the system be calculated - for summer, winter or demi-season. The solution to this issue depends on the number of solar collectors, the angle of inclination and the orientation from the sides of the light [3].

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Another important issue is the type of heliosystems. Flat solar collectors and vacuum solar collectors are usually the most widely used. Each type has its advantages and disadvantages compared to the other.

Vacuum solar collectors have low heat losses and can work at a fairly low temperature of the outside air, can generate high temperatures, are convenient to install, have low windage, and are relatively easy to maintain. Unlike vacuum flat collectors, it is easier to clear snow, high productivity in summer, lower cost.

Another important factor is the methods and programs for calculating and selecting the main equipment. Quite a lot of works were devoted to this problem, the results of which were included in the software complexes of calculations and selection of the main and auxiliary equipment.

2. Analysis of literary data and formulation of the problem

There are several methods of calculating solar collectors. Each of them has its own properties when selecting input data.

The initial parameters for calculating the share of solar energy of one of the leading manufacturers of solar collectors (Viessmann, Germany) are the amount of heat produced by the corresponding heat sources for a certain period of time, usually a year [3].

The given instructions and design recommendations apply only to the part of the heat supply system that works on solar energy. In our climatic conditions (in Ukraine), a solar system without an additional source of heat cannot provide reliable heat supply. The part of the heating system connected to a traditional energy source is calculated independently of the solar system.

Nevertheless, the interaction between different heat sources is of the utmost importance to achieve the maximum efficiency of the system as a whole and, therefore, for effective energy saving.

The total average annual solar radiation in Ukraine, according to long-term observations, varies from 1000 kWh / (m^2 area) in the northern and central parts of the country to 1350 kWh / (m^2 area) in the Crimea and the southern part of the Odesa region. Due to the fact that actinometric observations are not carried out in all regions of Ukraine, its territory was conditionally divided into 4 zones according to the value of total solar radiation on a horizontal surface.

The values of the total radiation energy given in the normative literature refer to a horizontal surface. Their value is affected by the angle of inclination of the absorbing surface of the collector.

The slope of the absorbing surface changes the angle of incidence of the sun's rays, the intensity of irradiation, and therefore the amount of absorbed energy. That is, the total annual solar radiation energy per unit surface also depends on the angle of inclination of the absorbing surface. The amount of energy is maximum when the sun's rays fall on a surface perpendicular to the sun's rays. Since it is quite difficult to ensure tracking of the sun, it is possible to place the absorbing surface at an angle [4].

In Ukraine, the optimal angle of inclination of the absorbing surface is from 30 to 35 degrees.

Another factor that must be taken into account when calculating the amount of solar energy absorbed is the orientation of the absorbing surface. In the northern hemisphere, the orientation of the absorbing surface to the south is optimal.

Compared to the horizontal position, we get an increase or decrease in results. Between the direction of southeast and southwest and with inclination angles from 25 to 70 °C, it is possible to determine the area in which the performance of the solar installation will be optimal. Significant deviations, for example, in installations on vertical walls, can be compensated by a correspondingly larger area of the collector.

The design power is determined for the design of the solar system. It is used to select the equipment and, above all, to select the heat exchanger.

The lower limit specified in VDI 6002 part 1, the collector specific power of 500 W/m^2, is accepted, but for reliability, we recommend using a higher value – 600 W/m^2 – at low temperatures, i.e. in operating modes with an expected high value of the efficiency factor collector.

For the design of a solar system, the share of heat load replacement – along with productivity – is another important evaluation criterion. This parameter indicates what part of the thermal energy required for use is provided by the solar system.

This approach, which relates the performance of the solar system to the amount of used thermal energy, takes into account heat losses in the heat accumulator and is generally accepted for determining the share of replacement of the thermal load. However, it is also possible to consider the ratio of the productivity of the solar system to the amount of energy additionally obtained from the second

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heat source (boiler). At the same time, the estimated share of replacement of the heat load is higher. When comparing solar systems, it is necessary to take into account which method was used to determine the indicated value of the share of heat load replacement.

Another method of calculation is carried out using the NeoHeatingPro software complex.

Most of the modern methods given in the standards and recommendations for the calculation of solar systems are based on tabular values. This approach has enough disadvantages, the main of which are:

– great complexity of using empirical tables in automated calculations;

– the impossibility of determining heat input from solar radiation at an arbitrary moment of time on an arbitrarily oriented surface.

The problem is that often solar collectors are placed not in specially equipped places and not at a precisely adjusted angle of inclination to the horizon, but directly on the roofs of buildings. This means that the angle between the plane of the collector and the horizon, as well as the deviation of the position of the collector relative to the direction to the south, can be any. In such a situation, tabular data on the arrival of solar radiation for a certain region are unacceptable for engineering calculations [5].

In this technique, another approach is given, which allows to dynamically determine the amount of solar radiation that reaches an arbitrarily oriented surface in space, at any moment of time for the desired region. This technique is based on the concept of the solar constant - the amount of heat that comes from the Sun to the Earth through space. This value is equal to 1362 W/m^2. When calculating, you need to take into account that approximately 30…35% of this energy is reflected back into space. Then, taking into account the flow of direct solar radiation to the surface at an angle to this flow, equal τ:

$$S_{\mathrm{dr}} = S_{\max} \times \cos\theta \times K_{\mathrm{atm}}, \tag{1}$$

where θ – given angle of incidence of solar rays on the insolation surface, rad.;

S_{dr} – the flow of direct solar radiation to the surface at an angle;

$S_{\max}$ – the maximum flow of solar radiation;

K_{atm} – a coefficient that takes into account the correction for the air mass that the beam must pass:

$$\cos\theta = \sin h \times \cos\alpha + \sin\alpha \times (\cos\psi z \times \tan L \times \sin h + \sin\psi z \times \cos\delta \times \sin\tau), \tag{2}$$

where α – angle of inclination of the plane of the solar collector to the horizon, degrees;

h – the angle that determines the height of the Sun above the horizon at this moment in time, degrees, the sine of this angle is equal;

L – geographic latitude of the area where the solar collector is located, degrees;

ψz – azimuth of the surface of the collector, degrees, that is, the angle between the normal to the plane of the collector and the direction to the south (this allows you to calculate the heat transfer on the surface that is not strictly oriented to the south);

τ – the time angle, degrees, is calculated by a simple formula:

$$\tau - \frac{\pi}{12}(12 - \tau), \tag{3}$$

where τ – solar time for this area, hours;

δ – declination of the Sun, degrees:

$$\delta = 23.25 \times \sin\left\{\frac{2\pi}{365}(284 + N)\right\}, \tag{4}$$

where N – serial number of the day of the year (starting with 1, which corresponds to January 1):

$$\sin h = \cos\tau \times \cos\delta \times \cos L + \sin\theta \times \cos L, \tag{5}$$

$$K_{\mathrm{atm}} = 1.1254 - \frac{0.1366}{\sin h}. \tag{6}$$

The correctness of formula (2) can be easily verified when the surface of the collector is oriented to the south. At the same time, we get a simplified formula for determining the reduced angle of incidence, which can be easily derived later using geometric transformations with a schematic representation of the angles of inclination of the collector and the height of the light above the horizon:

$$\cos\theta = \sin h \times \cos\alpha + \cos h \times \sin\alpha. \qquad (7)$$

Formula (1) allows you to calculate only the amount of direct solar radiation directed at an arbitrary surface. However, each solar collector also perceives the effect of scattered solar radiation. A more complex calculation of this component of the energy supplied to the solar collector is a rather complicated process. However, with sufficient accuracy for an arbitrarily placed surface, this value can be approximated by an empirical dependence:

$$S_{\text{dsr}} = 137.1 - 14.82 \frac{1}{\sin h}, \qquad (8)$$

where S_{dsr} – the flow of scattered solar radiation to the surfaced.

Finally, the total flow of energy, which is brought by solar radiation to an inclined surface arbitrarily oriented in space at latitude L, is equal to:

$$S = S_{\text{dr}} + S_{\text{dsr}}, \qquad (9)$$

where S – the total flow of solar radiation to the surface.

On the basis of the above theoretical explanations, an algorithm was added to the NeoHeatingPro system, which allows you to dynamically model changes in the amount of energy received by the solar collector depending on time (including both the day of the year and the time of day), the position of the collector in space (angle of inclination to the horizon and orientation in relation to the south) and geographical latitude [6 – 10].

The software product **EPS (Eco Power Simulation)** was developed by the Swiss Solar Institute and adapted for Ukrainian conditions by Eco Power.

A feature of this software package is the ability to create calculation schemes for combined heat supply using renewable energy sources (Fig. 1) and to model the heat supply process throughout the year (Fig. 2). The EPS software product has a fairly large database of information on renewable energy sources in different parts of the world, and also allows you to simulate conditions deviating from the standard by yourself.

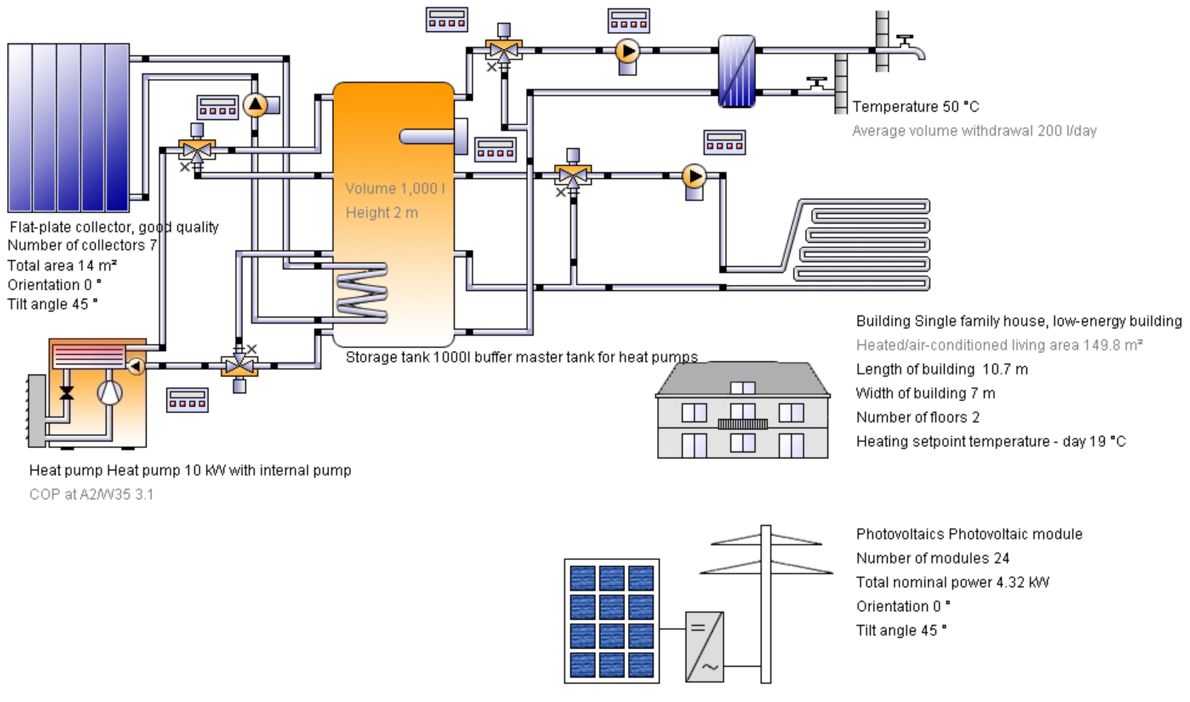

Fig. 1. An example of a calculated thermal scheme in the EPS program

3. The purpose and objectives of the research

The main goal of the research is to analyze the effectiveness of using solar collectors of various types to replace the thermal energy of university buildings, and to determine the share of replaced thermal energy.

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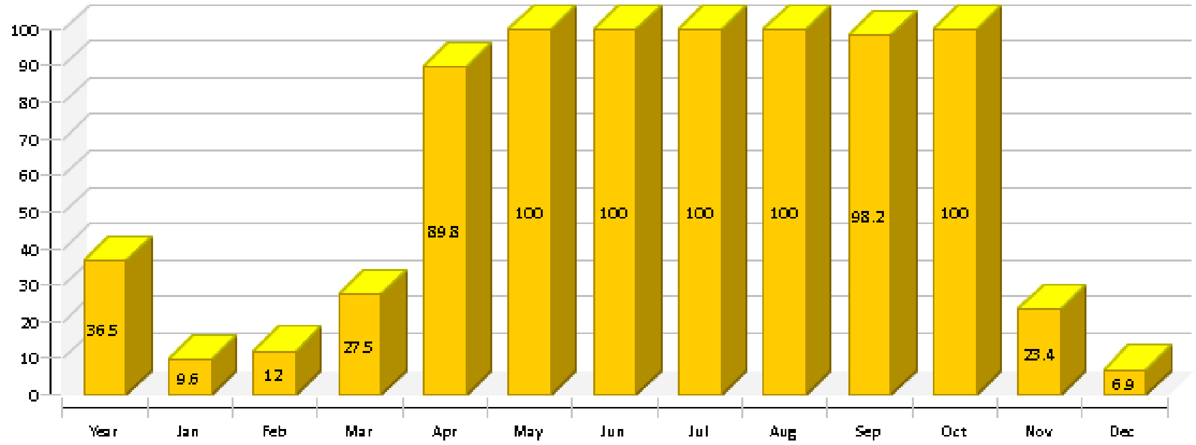

Fig. 2. A fragment of the result of simulation of the combined heat supply system – percent replacement of the required thermal energy with solar energy

To achieve the set goal, it was necessary to solve the following tasks:

– with the help of a specialized software complex, conduct a simulation of the operation of the solar system for different types of housings;

– to determine the share of replacement of heat from centralized heat supply systems by solar systems for different types of housing.

4. Methods of conducting research and processing experimental data

In the work, the amount of heat that can be obtained from the sun for various buildings of the university when two types of solar collectors are installed on the roof was calculated with the help of the above methods and software complexes: vacuum and flat.

Depending on the roof design, the number of vacuum and flat type collectors was calculated (Table 1) and simulation was carried out. The simulation results are presented in the appendices.

Table 1

The estimated number of collectors on the roofs of buildings

Name of the building	Number of vacuum collectors	Number of flat collectors
The main educational building	184	253
Heat engineering laboratory	16	32
Auxiliary building	45	88
Chemical institute building	80	132
Radio engineering institute building	80	132
Thermal power institute building	88	121
Institute of Computer Systems building	56	77

5. Results of experimental bench research

For each of the buildings, the annual distribution of heat from solar collectors was obtained, for example, for the main building (Fig. 3, Fig. 4). An analysis of work throughout the year was carried out forall types of buildings and the share of replacement of thermal energy by solar energy was determined (Table 2).

Table 2

The percentage of replacement of thermal energy by solar energy during the year

Collector type	The main educational building	Heat engineering laboratory	Radio engineering institute building	Chemical institute building	Institute of Computer Systems building	Auxiliary building	Thermal power institute building
Flat	12.78	20.97	34.16	18.28	20.30	65.34	18.28
Vacuum	11.51	7.57	23.24	10.77	12.22	28.97	10.77

	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Solar thermal energy to the system [Qsol]													
kWh	225395	3117	5891	12676	21775	33545	36040	37547	32927	22561	12799	4546	1970
Total fuel and/or electrical energy consumption of the system [Etot]													
kWh	6041	180	268	467	594	735	773	836	741	569	462	265	151
Irradiance onto collector area [Esol]													
kWh	428396	10475	15195	27583	41805	59852	63851	64983	57282	41570	25800	11851	8151
Electrical energy consumption of pumps [Epar]													
kWh	6041	180	268	467	594	735	773	836	741	569	462	265	151
Heat loss to indoor room (including heat generator losses) [Qint]													
kWh	5960	-117	-59	83	374	793	1175	1379	1263	788	347	33	-99

Fig. 3. Results of simulation of annual heat production from solar systems for the main university building using vacuum collectors (184 units)

	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Solar thermal energy to the system [Qsol]													
kWh	250389	2312	5118	12710	23858	38394	41641	44282	38118	25121	13335	4126	1375
Total fuel and/or electrical energy consumption of the system [Etot]													
kWh	6391	150	250	468	630	818	836	910	825	626	492	255	131
Irradiance onto collector area [Esol]													
kWh	734336	17955	26046	47282	71660	102596	109450	111391	98190	71257	44224	20315	13971
Electrical energy consumption of pumps [Epar]													
kWh	6391	150	250	468	630	818	836	910	825	626	492	255	131
Heat loss to indoor room (including heat generator losses) [Qint]													
kWh	7737	-136	-74	92	467	1061	1539	1795	1642	1016	419	28	-115

Fig. 4. Results of simulation of annual heat production from solar systems for the main university building using flat collectors (253 units)

The obtained results of numerical modeling show the amount of heat received from solar energy. As can be seen from the Table 2, the largest percentage has a low-rise building with a developed roof surface. In contrast, high-rise university buildings have a lower percentage of heat energy substitution. The influence of the orientation of the housings on the total amount of received solar energy should be noted separately.

Conclusions

1. The work analyzed the existing methods and software products for the calculation and selection of the main equipment of solar systems, and modeled the operation of solar systems throughout the year for various types of university buildings. According to the given task, a simulation of the operation of solar systems for two types of solar collectors was carried out, as well as the share of replacement of thermal energy by solar energy for centralized heat supply was obtained. The following results were also obtained:

2. The use of solar energy for the heating needs of university buildings during the heating period can replace no more than 10% of the required thermal energy;

3. The use of seasonal accumulation of heat from the sun can increase the percentage of replacing traditional energy with solar energy up to 30%;

4. The use of solar collectors on high-rise buildings significantly reduces the share of replacing thermal energy with solar energy.

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