Досліджено прогнозну ефективність застосування гібридних сонячних колекторів, що здатні одночасно генерувати як електричну, так і теплову енергію для енергопостачання багатоповерхових будинків. Новизна роботи полягає у тому, що прогнозування ефективності проводилося з урахуванням динаміки за останні роки та екстраполяції трендів цін до 2045 року на ринку відновлювальної енергетики, на відміну від існуючих підходів, що не враховують їх імовірну зміну за період, що розглядається. За результатами розрахунків змодельоване прогнозну ймовірну ринкову вартість обладнання, з урахуванням його здешевлення через удосконалення технології виготовлення колекторів, монтажу та експлуатаційних витрат за вказаний період. При цьому враховано динаміку «основного» та «зеленого» тарифів на сонячну електричну і теплову енергію. Значення коефіцієнтів детермінації підтвердили достатню адекватність отриманих моделей. Наведено приклад визначення електричного та теплового навантаження багатоквартирного будинку з газовими плитами та вибране відповідне обладнання гібридного сонячного колектора. Запропоновані конструкції та схеми приєднання гібридного колектора до систем електро- та теплопостачання будинку. Модулі колектора типу ATMOSFERA F2PV розташовуватимуться на даху будинку, електрична частина якого через інвертор приєднується до ввідно-розподільного пристрою будинку або до шин низької напруги підстанції напругою 10/0,4 кВ, від якої живиться будинок. Теплоносій від колектора через накопичувальні ємкості подається в теплопункт в систему гарячого водопостачання та опалення будинку. За отриманими результатами дослідження прогнозовано ймовірну енергетичну ефективність (кількість заощадження традиційного палива, т у. п.), економічну (чистий дисконтований прибуток, €), екологічну ефективність (зменшення викидів, що сприяють планетарному потеплінню клімату, т). Термін окупності визначено послідовним розрахунком чистого доходу для кожного року за весь період реалізації інвестиційних вкладень у разі, якщо наведена тенденція ринкових цін не зміниться. Представлено результати розрахунків величини вкладень та прибутку мешканців, що припадають на кожну квартиру будинку, від упровадження інвестиційного проекту

Ключові слова: гібридні сонячні колектори, електрична енергія, теплова енергія, багатоквартирний будинок, ринкові ціни

UDC 621.039:621.31
DOI: 10.15587/1729-4061.2019.174502

STUDY INTO PREDICTED EFFICIENCY OF THE APPLICATION OF HYBRID SOLAR COLLECTORS TO SUPPLY ENERGY TO MULTI-APARTMENT BUILDINGS

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Received date 18.06.2019
Accepted date 17.07.2019
Published date 19.08.2019

1. Introduction

At present, more and more companies are investing into the construction of renewable sources that can simultaneously generate both electricity and thermal energy. Such hybrid solar collectors the type of PVT would become super profitable over a long period of operation. Along with this, they contribute to preventing global climate warming on the Earth through the generation of «clean» energy. In recent years, the price of solar collectors has been gradually reduced worldwide due to the improved technology of their fabrication, however, at the same time, tariffs for solar electric and thermal energy change over time. New fields of hybrid solar technology are developing for a wide scope of application, such as industrial enterprises, agricultural facilities, and residential buildings. Their role becomes more important in line with the world trend for the construction of houses with minimum harmful emissions into the environment. Payback period of the specified renewable power source depends on many factors, such as their cost and installation, tariffs for electrical and thermal energy, a launch year, etc. It is a relevant task to study efficiency of the application of hybrid solar collectors of different design and principle of action that depends on these factors under conditions of changes in price over time in the market of renewable energy.

2. Literature review and problem statement

Analysis of the scientific literature [1–13] related to the subject of current work has revealed that solar hybrid collectors the type of PVT represent a set of a combined collector within a single structure, which is composed of a photovoltaic module (PV) for the generation of electric and thermal energy (PT). Paper [1] studied the flow of a fluid and the heat exchange in a module, the phenomenon of heat transfer, between the photovoltaic elements and a heat-carrier. The effect of radiation is taken into consideration in the calculation of conditions for limiting the heat flow fed to the collector. It should be noted that the paper reports analysis into purely technical indicators for a collector's design, which is not associated with its economic indicators over the period of operation. Study [2] addresses control over a hybrid solar installation connected to a single-phase network. Power is supplied to the network using the appropriate control over a single-phase inverter connected to the filter and loads. The active and reactive powers are regulated by using a management strategy focused on voltage, taking into consideration the characteristics for a power grid and loading, tested by simulation. The results obtained confirm only the technical efficiency of existing structure of the installation without analyzing the efficiency and payback period of the control system. Paper [3] gives a broad review of the published scientific works, with an emphasis on research and development over the past decade in terms of renewable and alternative energy. For example, hybrid solar collectors make it possible to rationally utilize building area by combining the parts that generate electricity and heat using different heat-carriers in a single structure. It has been shown that a unit of construction area might yield a significantly large amount of power; however, despite the practical significance of such results, the authors did not consider in detail the impact of forecasted market prices on their effectiveness. Paper [4] outlined basic technologies of solar concentrators, as well as resources of solar energy, based on the characteristics of its radiation. It provides information about using solar concentrators to help convert the solar energy into heat, which is converted into energy by means of a heat engine employing the cycles of Rankin, Brighton, Stirling, and which is designed for the generation, typically, of mechanical energy. The authors performed the thermo-dynamic and feasibility studies to estimate the Rankin organic cycle with a power of 3 MW, connected to a channel concentrator. However, there are no appropriate predictive calculations of the payback period to confirm the effectiveness of this design. Integrating a thermoelectric device into fuel cells is a promising technique to improve the efficiency of hybrid devices that requires effective control over energy consumption in real time [5]. The work is aimed at developing its control system, which makes it possible to both intelligently minimize the consumption of primary energy and the start time at the proper balance of energy in the components of the device between the source and the water tank with a capacity of 50 l. The proposed system meets the needs in energy during the winter and summer day. However, the authors did not give predictive calculations regarding the efficiency of consumption of primary energy under conditions of dynamic market prices for energy carriers. Paper [6] reports the identification and modeling of a hybrid photovoltaic/wind-energy system with a rechargeable battery, which powers electric load through an inverter. The hybrid system is controlled using the software. Topology of the mathematical model and its power management with a system of rechargeable batteries is a special feature of this work. Meanwhile, the use of rechargeable batteries in these systems is not, as a rule, economically efficient because of a series of known significant deficiencies in their operation compared with network systems. The aim of research work [7] is the development of hybrid solar collector with the temperature of water at the outlet of up to 100 °C, which is sterilized due to high temperature. Work of the source continues over the night using electricity from a power grid. However, the authors did not highlight the performance indicators for its work over the period of operation. As it is known, capital subsidies are one of the recognized methods to promote solar photovoltaic systems for investors. Paper [8] analyzed if a given subsidy would affect income received from a solar installation considering two studies, one is without the capital subsidies, while the second – with a 15 % capital subsidy. Another known fact is the analysis degradation of its productivity during the time operation. By analyzing the above parameters, the authors discussed profitable advantages of photovoltaic systems – with and without capital subsidies. Application of hybrid solar collectors of the PVT type would have greatly improved efficiency of a renewable source, which was not considered in that study. The great advantage of using the technology of concentrated solar power (CSP) is that it can be conveniently installed in parallel with existing power plants on fossil fuels, in order to provide the installation with synergy, which could improve effectiveness of existing systems. Paper [9] considers the status of CSP in India and the possible ways for their hybridization with existing coal plants through modeling and optimization of different technologies and economic expediency. Different hybrid variants of the CSP technology are examined in detail, associated with various energy resources, climatic conditions, the presence of land, as well as economic factors. In this case, the paper did not consider efficiency of using helio-systems in parallel with photovoltaic panels. Article [10] highlights the research of aspects that underlie the design of a PVT collector based on which possible conceptual designs are defined. The authors reports results of testing the output of prototypes of PVT collectors, culminating in the thermal characteristics in an open circuit mode similar to efficient solar thermal collectors. This prototype of a collector includes the necessary function of protection against stagnation, without calculating the perspective of economic efficiency of their use. Paper [11] describes the most effective methods for the optimization of hybrid renewable energy systems (HERS) in two stages. First, the author gives a comprehensive overview of the hundreds of the most recent research works on HERS. Second, he performs statistical calculations and analysis of the data acquired at the first stage. Thus, the author confirmed correctness of the overall results that can be considered as a guide for the study into determining the best methods for the optimization of HERS systems that need adjusting to specific operating conditions. Work [12] presented a techno-economic analysis of the application of a hybrid renewable energy system for public lighting, government agencies, and a school area. The study focuses on six different climatic areas in Morocco. The study includes the impact of an interest rate, the price of purchased energy, and climatic conditions for solar and wind power plants, but without their use along with helio-systems. An integrated system for generating electric power by a thermoelectric generator, a solar collector, was designed in [13]. The materials for the original thermal elements were the synthesized newest materials based on lead telluride doped with antimony and solid solutions of lead stannum telluride, which improve efficiency of solar energy conversion; the authors did not provide economic indicators for their prospective application.

The unresolved part of this issue is the actual lack of studies into the predictive effectiveness of application of hybrid solar collector of the PVT type to supply energy to residential buildings considering the dynamics of prices in the market for renewable energy.

3. The aim and objectives of the study

The aim of this study is to determine the predictive effectiveness of application of hybrid solar collectors of the PVT type in order to supply power to multi-apartment residential buildings considering the dynamics of future market prices for renewable energy.

To accomplish the aim, the following tasks have been set:

– to acquire information by means of the electric power quality analyzer Elspec G4500 (Elspec Technologies, Israel); to model, based on it, the actual electric, as well as calculate thermal, loading on a multi-apartment building; by using it, to choose the design, capacity, and a circuit to connect the hybrid collectors to the system of electric and heating supply of the building;

– to model the retrospective and future market prices for hybrid solar panels, as well as their installation, and tariffs for electricity and thermal energy to supply power to a residential building;

– to define predictive energy, economic, environmental efficiency, a payback period, the volume of investments and income by residents of a multi-apartment building from the implementation of an investment project.

4. Characteristics of objects and a procedure for studying the predictive effectiveness of application of hybrid solar collectors

4. 1. Characteristics of the objects of study

The study was carried out using an example of power consumption by a 9-storied 144-apartment building (Fig. 1).

Fig. 1. General view of a 9-storied 144-apartment building

The building has 4 entrances containing 36 apartments equipped with gas stoves. The basic power-consuming equipment (PCE) includes electric lighting and household appliances, each of which is characterized by the particular dynamics of electrical load, for example, an air conditioning unit whose load oscillogram is shown in Fig. 2.

PCE inside a building are the lighting of floor areas, lift, fan installations, pumps of cold, hot water, etc.

The dynamics of electric load on a residential building were measured by the electric power quality analyzer Elspec G4500; the load oscillograms for the phases of input cable, acquired from it, are shown in Fig. 3.

Electricity from the photovoltaic module of a collector is supplied, through a network inverter, along a cable line with a voltage of 0.4 kV to the low-voltage buses at the two-transformer substation BKTP-10/0.4 kV, located at a distance of 25 m; it powers the building. In line with another variant, electricity from a network inverter is supplied along a cable line of 0.4 kV to the input-distribution unit (IDU) at the building (Fig. 4).

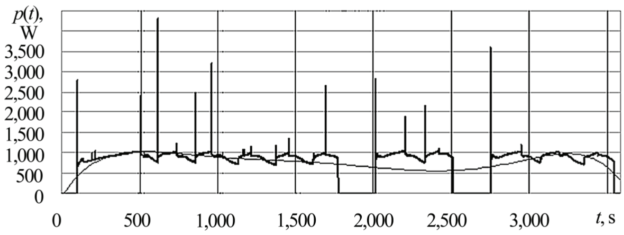

Fig. 2. Oscillogram of active capacity for an air conditioner the type of ECO-i and FTE-23MR

Fig. 3. Oscillograms of the actual evening electric load for the phases of cable input for a 144-apartment building

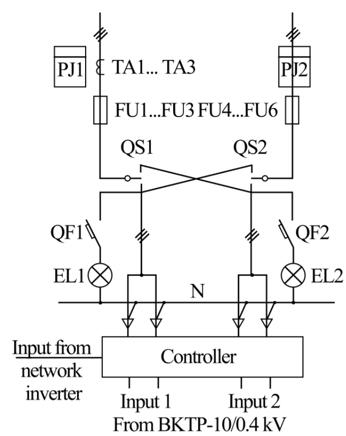

Fig. 4. Connecting circuit of the photovoltaic module through a network inverter to the input-distribution unit at a building

Daily schedule of electric load on the building is shown in Fig. 5.

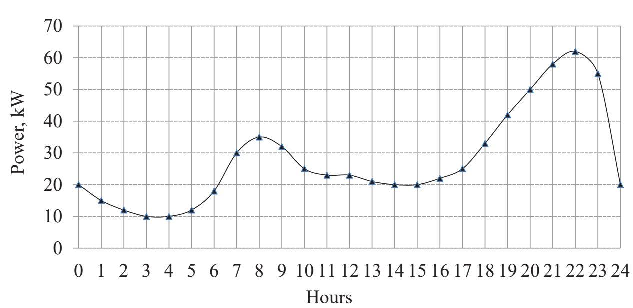

Fig. 5. Daily schedule of electric load on a residential building

Daily schedule of hot water consumption at a residential building is shown in Fig. 6.

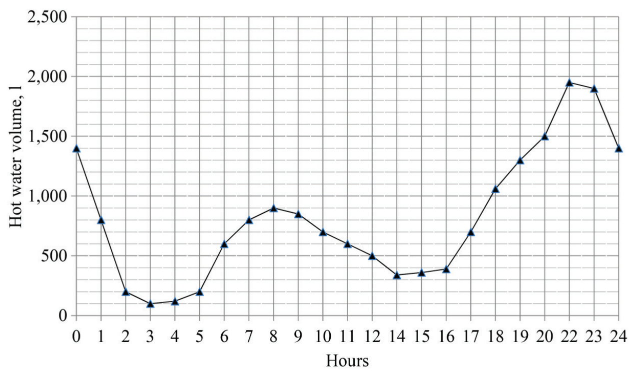

Fig. 6. Daily schedule of hot water consumption at a residential building

The selected source of energy to the building is the hybrid solar collector ATMOSFERA-F2PV (Stalex, Ukraine), which includes a polycrystalline photovoltaic module and a solar thermal collector (Fig. 7).

Such a structure can convert energy of solar radiation into both the electrical energy to power PCE and the heat energy used for hot water supply and to maintain the system for additional heating of premises at a residential building.

The rated electrical capacity of the photovoltaic panel is 300 W, of heat component – 1,037 W. The dynamics in their generation of energy during 24 hours in summer and winter are shown in Fig. 8, 9.

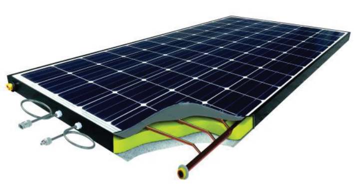

Fig. 7. Hybrid solar collector ATMOSFERA-F2PV

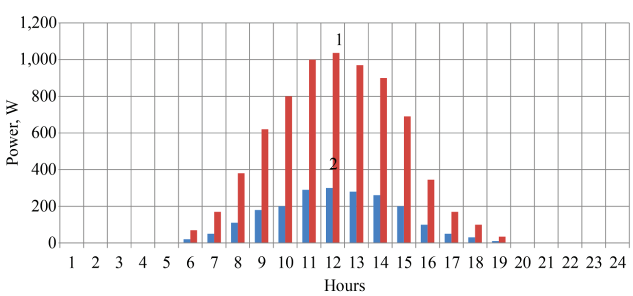

Fig. 8. Generation by a hybrid solar panel over 24 hours in summer: 1 — thermal energy; 2 — electrical energy

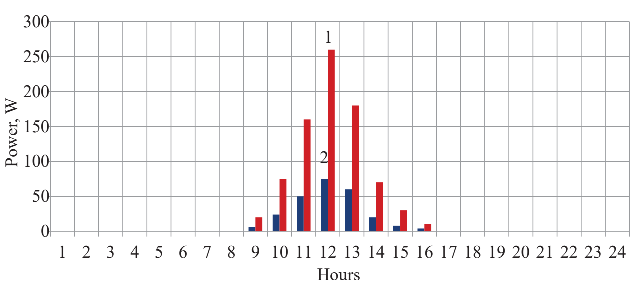

Fig. 9. Generation by a hybrid solar panel over 24 hours in winter: 1 — thermal energy; 2 — electrical energy

Based on the technical data on hybrid solar collectors, their orientation towards the Sun and the region of their installation, annual amount of the generated electric and thermal energy is determined.

4. 2. Procedure for studying effectiveness of the application of hybrid solar collectors to supply power to a residential building

The calculation and selection of a solar collector based on the electrical and heat load on a residential building involves the following procedure.

A model of the estimated electric load dynamics for a 144-apartment building is constructed based on data from measuring electric capacity of the building employing an applied software in the programming environment Mathcad 15.0 (Fig. 5). Based on the estimated value for this capacity we select the maximum capacity of photovoltaic panels in terms of generation in summer. This implies taking into consideration the inclination angle with panels oriented towards the Sun and the climatic conditions for the region where the building is.

Thermal energy generated from a hybrid source using is sent, using a liquid heat-carrier, through the specialized boiler design storage tanks and the heat unit of the building, to the system of hot water supply and heating.

The amount of electric and thermal energy consumed by the building from a hybrid source and a city grid is registered by appropriate counters.

The technical capabilities of the selected hybrid solar panels are used to determine the annual amount of generated electricity and heat energy applying formulae:

$$W_e = \int_0^{365} p_e(t)\mathrm{d}t,\ \mathrm{kW\cdot h}; \tag{1}$$

$$W_h = \int_0^{365} p_t(t)\mathrm{d}t,\ \mathrm{kW\cdot h}, \tag{2}$$

where W_e, W_t is the annual amount of generated electricity and heat energy, respectively, kW·h; $p_e(t)$, $p_t(t)$ is a function of the generation of electric and thermal power over a year, respectively, kW.

The derived values for the annual amount of generated energy are used to determine its cost according to the dynamics in tariffs for solar electric and thermal energy over the period of operation:

$$C_{\Sigma e.t} = \sum_1^T c_{e.i} W_{e.i} + \sum_1^T c_{t.i} W_{t.i}, \tag{3}$$

where $W_{e.i}$, $W_{t.i}$ is the amount of generated electric and thermal energy over the i-th year, respectively, kW·h; $c_{e.i}$, $c_{t.i}$ are the tariffs for electrical and thermal energy over the i-th year, respectively, EUR; T is the operational period of a solar collector.

The decrees by the National Board for regulation of energy and communal services in Ukraine defined the «basic» tariffs (1) for electrical energy and the «green» tariffs (2) for roof-mounted solar power plants with a capacity of up to 100 kW. Based on the source data from 2010 and by extrapolating trends up to 2045, we defined the probabilistic dynamics in the tariffs (Fig. 10).

By extrapolating trends from 2029 to 2045 in line with a linear function, we identified the probabilistic dynamics in the tariff for hot water, shown in Fig. 11.

The cost of hybrid solar collectors in the energy market decreases annually. The probabilistic dynamics in their cost up to 2045 are shown in Fig. 12.

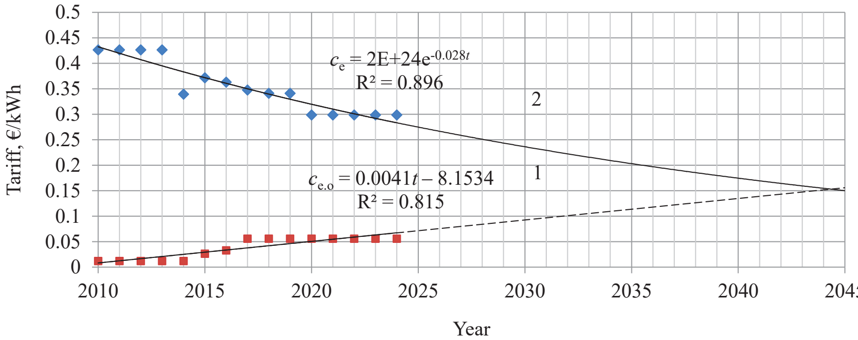

Fig. 10. Dynamics in tariffs for electricity over the period to 2045: 1 — «basic»; 2 — «green» for solar energy

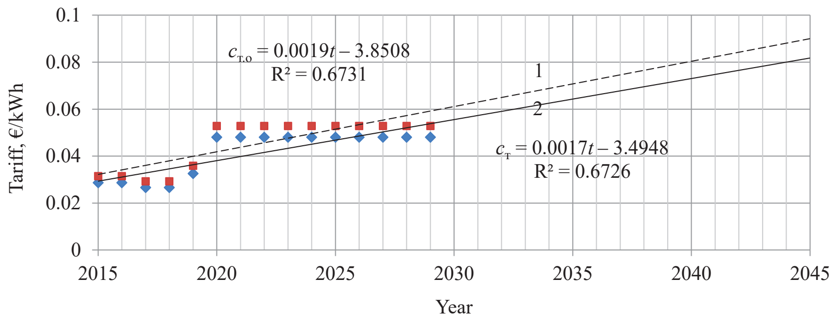

Fig. 11. Probabilistic dynamics in tariffs over the period to 2045: 1 — «basic» for hot water; 2 — «green» for solar hot water supply

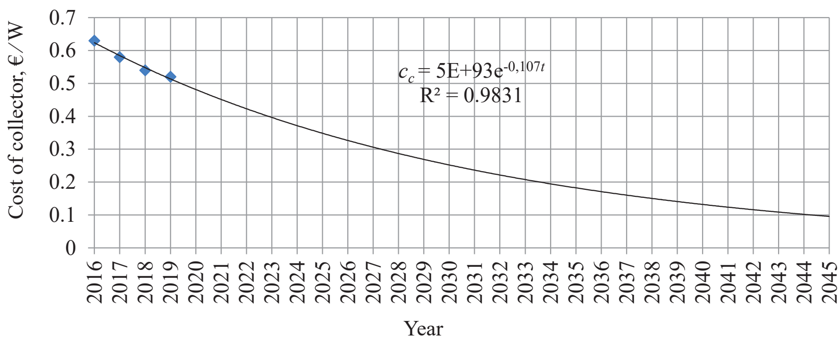

Fig. 12. Probabilistic dynamics in the cost of hybrid solar collectors over the period to 2045

The cost of hybrid solar collectors to supply power to a residential building is determined from formula:

$$C_{h.s.c.} = c_p \cdot N_p, \quad (4)$$

where c_p is the cost of a single hybrid solar panel; N_p is the number of solar panels for a residential building, determined based on the results from measuring power for the phases of a supply cable:

– based on the results from measuring power for the phases of a supply cable:

$$P_{\Sigma s.c} = P_A + P_B + P_C, \quad (5)$$

$$N_p = \frac{P_{\Sigma s.c}}{p_{e.c}}, \quad (6)$$

where $p_{e.c}$ is the electric capacity of a single panel.

The cost of installation and launching operations is determined as follows:

$$C_{inst} = 0.3 C_{h.s.c}. \quad (7)$$

General capital costs for the installation of collectors are determined from formula:

$$K_{h.s.c} = C_{h.s.c} + C_{inst}. \quad (8)$$

The resulting annual profit from the use of hybrid solar collectors, determined based on the cost of electric $C_{e.col}$ and thermal $C_{t.col}$ energy, is calculated from formula:

$$R_{\Sigma e.t} = C_{e.col} + C_{t.col}. \quad (9)$$

Consumption of natural fuel at thermal electric plants to generate electricity is determined from formula [14]:

$$Q_{TEP} = \frac{W + \Delta W}{q_0}, \quad (10)$$

where W is the amount of generated electricity, kWh; ΔW are the power losses in electric networks, which could take about 10 % of the consumed electric power at a site; q_0 is the specific equivalent fuel consumption for electricity generation, g/kWh.

Application of hybrid solar collectors, due to the generation of «clean» electrical and thermal energy, prevent the formation of emissions into the environment. The amount of gross emissions from the j-th polluting substance when burning the i-th kind of fuel at thermal power plants will equal:

$$E_{ji} = (W + \Delta W) c_{ji}, \quad (11)$$

where c_{ji} is the emission rate of the j-th polluting substance when burning the i-th kind of fuel, g/kWh.

5. Results of studying the effectiveness of application of hybrid solar collectors to supply power to a residential building

The estimated electric capacity of the residential building shown in Fig. 5 is 60 kW; 200 panels for hybrid solar collector were chosen that are freely arranged over the area of 400 m^2 on the roof of a residential building with an area of 1,200 m^2 (Fig. 13).

Known formulae are applied to calculate the inclination angles of panels oriented towards the Sun, distances between the rows, as well as other settings, to obtain the maximum electric and thermal energy.

For example, distance between the rows is determined from formula:

$$D = \frac{A \sin\left[180 - (\alpha + \beta)\right]}{\sin\beta}. \quad (12)$$

The proposed design for a hot water supply system in a residential building from a hybrid solar collector that is mounted on the roof of the residential building is composed of the following elements (Fig. 14).

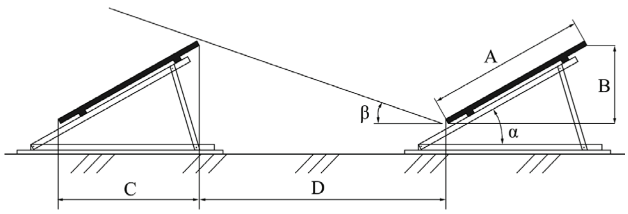

Fig. 13. Arrangement of solar collectors, distances between rows, inclination angles and their orientation towards the Sun

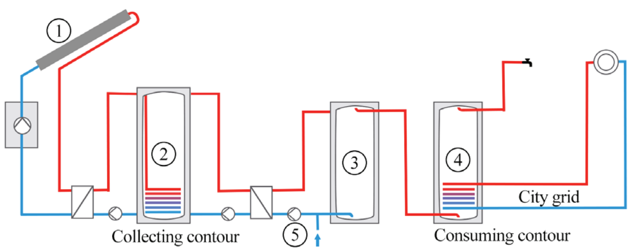

Fig. 14. A hot water supply system for a residential building from a hybrid solar collector: 1 – hybrid solar collector; 2 – collecting tank; 3 – preliminary water heater; 4 – water heater; 5 – system of cold water supply

Specifically, the main element (1) of the hybrid solar collector that converts light energy into thermal energy and heats the heat-carrier that flows into the collecting tank (2). After the preliminary water heater (3) water enters the water heater (4), used for hot water supply to residents with the excess water fed into the city network. After the cold-water system (5), water fills the collecting contour in which it is heated by the solar collector. Hot water from the consuming contour is used for a variety of needs.

Effectiveness of an investment project is defined by such indicators as a net present value *NPV* of the project implementation. It is derived by discounting, that is reducing cash flows for future periods to their present value. In this case, it is determined separately for each year based on the difference between the inflow and outflow of funds to be collected over the period of the project's operation, which is determined from formula [13]:

$$NPV = \sum_{t=0}^{25} \frac{R_t - B_t}{(1+k)^t}, \qquad (13)$$

where R_t is the profit over the t-th year; B_t are the annual expenditures over the t-th year, determined as the difference between the annual capital cost K_t and operational cost C_{oper}; k is the coefficient of discounting based on an interest rate for bank loans.

For the case of a positive value for the net present value *NPV*, the project is considered feasible, otherwise – it would generate losses (Fig. 15, 16).

Using an iteration method, we determine a discounting coefficient k at which:

$$NPV = \sum_{t=0}^{25} \frac{R_t - B_t}{(1+k)^t} = 0. \qquad (14)$$

Internal rate of return *IRR* is the rate of discounting at which the net present value *NPV* equals zero, that is, the investment project is profitable if *IRR* exceeds the minimum interest rate for bank loans.

The result of calculating the internal rate of return (*IRR*) of the investment project is shown in Fig. 17.

Based on the results of calculation, the internal rate of return (*IRR*) of the investment project is 19.5 %.

The volume of investments and profit by inhabitants at each apartment, based on the «green» and «basic» tariffs over the period of operation of the hybrid solar collectors, launched over the respective year, is shown in Fig. 18, 19.

Energy efficiency of the application of hybrid solar collectors over the period of operation, that is, the amount of savings in conventional fossil fuels, due to the generation of «clean» energy, would equal 19,100 t conditional fuel.

Economic efficiency of the application of hybrid solar collectors over the period of operation, that is, the net present value and the investment project's payback period over the years of their installation would equal:

– based on a «green» tariff: 2019 – EUR 201,921: 8.3 years; 2020 – EUR 230,131: 7.3 years; 2030 – EUR 291,592: 3.7 years; 2040 – EUR 361,044: 2 years;

– based on a «basic» tariff: 2019 – the project is unprofitable; 2020 – EUR 163,335: 18 years; 2030 – EUR 249,558: 4 years; 2040 – EUR 295,342: 2 years.

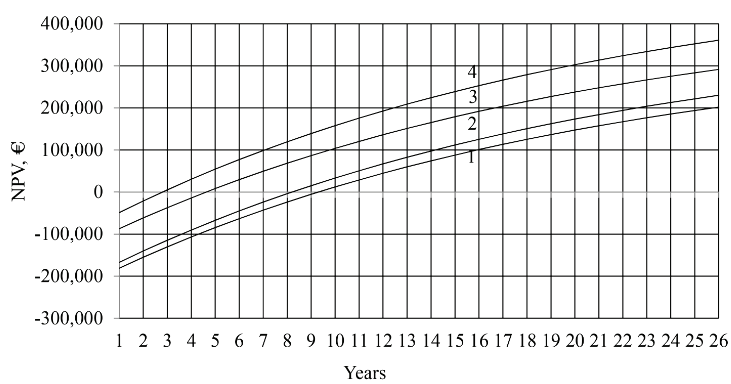

Fig. 15. Result of calculating the net present value of the investment project based on the «green tariff», implemented, respectively, in: 1 – 2019; 2 – 2020; 3 – 2030; 4 – 2040

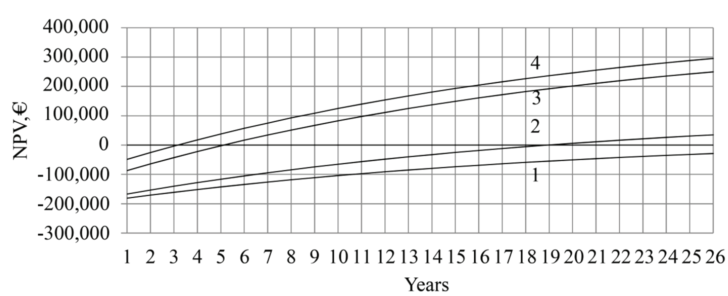

Fig. 16. Result of calculating the net present value of the investment project based on the «basic» tariff, implemented, respectively, in: 1 – 2019; 2 – 2020; 3 – 2030; 4 – 2040

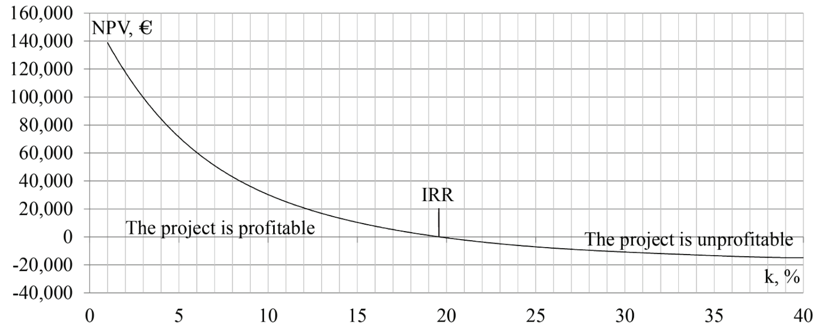

Fig. 17. Result of calculating the internal rate of return (*IRR*) for the investment project

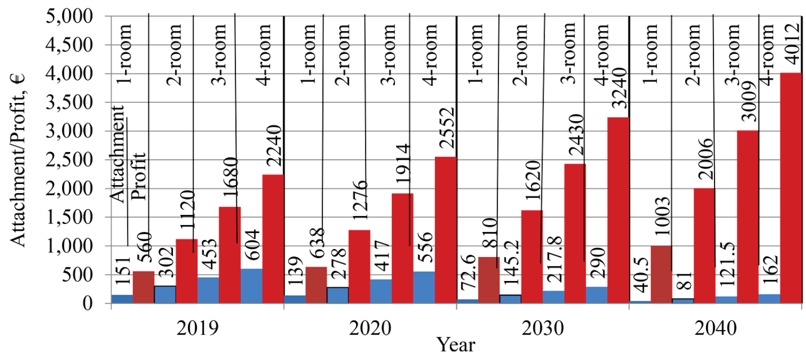

Fig. 18. Result of calculating investments and profit by inhabitants at each apartment, based on the «green» tariff over the period of operation of the hybrid solar collectors, launched in the respective year

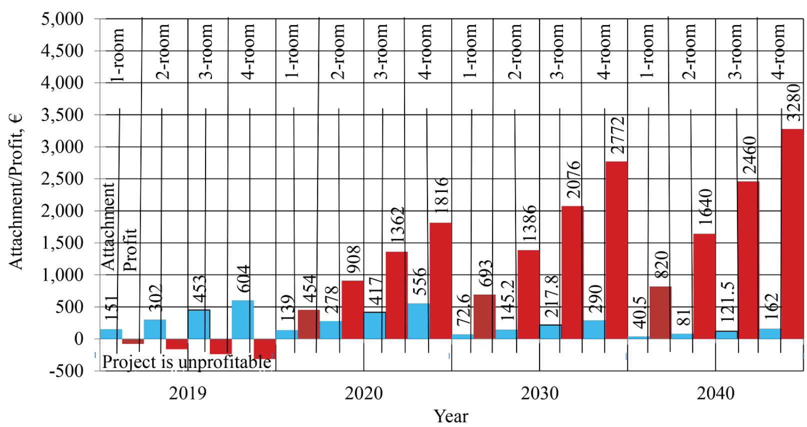

Fig. 19. Result of calculating investments and profit by inhabitants at each apartment, based on the ««basic» tariff over the period of operation of the hybrid solar collectors, launched in the respective year

Ecological efficiency of the hybrid solar collectors over the period of operation, that is preventing emissions into the environment, which form a greenhouse effect that contributes to the global climate warming on the Earth, is about 6,355 t. Respective calculations were performed applying formula (11).

6. Discussion of results obtained in the study of effectiveness of the application of hybrid solar collectors

Solar energy is considered to be very promising for use both in industry and in the housing and communal services: the effective use of solar energy has been addressed in the current work. The object chosen for this study is a 9-storey 144-aparment building; measurements of its electrical and thermal loads revealed their irregularity over 24 hours (Fig. 2, 3, 5). This is explained by the modes of operation of household appliances related to the daily schedule of the building's inhabitants. The maximum load on the building is during the day and in the evening, and since the maximum intensity of solar insolation is during a daytime period, a network type of power supply is selected that runs parallel with the city electric and heat networks. Among the various structures and principle of action described in [1–13], a special role belongs to hybrid solar collectors of the PVT type, which can simultaneously generate both the electric and thermal energy. This decreases investments and reduces the area for their arrangement, in contrast to their separate installation. In addition, the generation of electric power increases by up to 30 % due to the additional cooling of a photovoltaic panel by a heat-carrier from the thermal component of the collector. However, in general, such indicators for competitiveness of renewable sources of energy as the energy, economic, environmental efficiency, as well as the net present value and an investment project's payback period, depend on the dynamics in a series of factors: they were modeled in the current research. These include, first of all, the cost of modules whose market prices over recent years have gradually decreased due to the improved technology of their fabrication, confirmed by the results from analyzing their price over recent years (Fig. 12). Climatic conditions for their arrangement and the panels' orientation towards the Sun significantly affect the generation of electric and thermal energy during the day and over a year (Fig. 8, 9, 13). The uniformity of power supply over the year is ensured due to the parallel operation of the collector with the municipal electric and heat networks. A growth in the «basic» and «green» tariffs for solar electric and thermal energy over the period of operation of solar collectors affects the effectiveness of their use depending on the year they are launched (Fig. 15, 16). An analysis of these indicators based on the results of this study has revealed, for example, a reduction in the payback period for the investment project from 8.3 to 2 years and an increase in the net present value from EUR 201,921 to EUR 361,044, based on «green» tariffs when launching it in 2019 and 2040, respectively, under condition that the trend of today's prices in the market of renewable energy continues. However, given the current «basic» tariffs for energy carriers, the situation, as calculations show, is more complicated, because only in the future, when these rates increase significantly, such investment projects involving hybrid solar collectors would be profitable (Fig. 16, curve 1). This is due to the fact that the project's payback period is 30 years, which exceeds the period of its operation: the invested funds would not be returned to inhabitants. Thus, the profitability of implementing such projects today is null without a state support, in the form of «green» tariffs, cheaper loans, subsidies, compensation for the residents' investments into renewable energy sources.

The paper presented estimated investments in the project and profit of residents, depending on the number of rooms and tariffs for electricity and thermal energy and the year the project is implemented (Fig. 18, 19). They testify to a significant rise in profit in the future due to the different dynamics of prices in the market for renewable energy. However, accuracy of the research results is limited by the capabilities to predict the dynamics of market prices, which is an obstacle to obtaining an accurate forecast for the effectiveness of implementation of the proposed investment project. A would-be transition from existing tariffs to competitive bidding and long-term agreements would attract more attention to similar calculations of efficiency of the introduction of hybrid solar collectors, given in this work.

An important area of the further research into this issue is the systematic comprehensive analysis of a volatile situation in the market of renewable energy. That would make it possible for manufacturers to plan production, and for potential consumers to estimate the application appropriateness under market conditions.

7. Conclusions

1. The research results have made it possible to determine the estimated electrical and thermal load on a multi-apartment building, which is 60 and 115 kW, respectively. That has enabled modelling its daily dynamics; based on it, 200 panels of a hybrid solar collector were chosen with a total generated capacity of 207.4 kW. Excess electricity and a heat carrier, during the period of a minimum load on the building, are supplied into the city electric and heat networks, respectively. In the hours of insufficient solar insolation, the required amount of energy is obtained from respective city networks, registered by counters.

2. A retrospective model has been constructed, based on available information for recent years, as well as based on the extrapolation, of the probable future market prices for hybrid solar panels and tariffs for electricity and heat energy up to 2045, required to supply energy to a residential building. The values of trends for years the solar collectors are to be launched (2019, 2020, 2030, 2040) were used to predict respective market prices for the collectors. For example, it is predicted that they would decrease from EUR 0.52 in 2019 to EUR 0.1 in 2045. The «green» tariffs over this period would decrease from EUR 0.3 to EUR 0.15, while the «basic» ones – increase from EUR 0.05 to EUR 0.15, etc. These data would make it possible in the future to determine the effectiveness of introducing solar collectors.

3. The predicted energy efficiency of the investment project has been determined, which implies saving about 191,00 t of fossil fuel equivalent by generating energy with a hybrid solar collector. It is predicted that the economic efficiency, that is the net present value over the years a solar collector is installed, would equal: based on a «green» tariff: 2019 – EUR 201,921; 2020 – EUR 230,131; 2030 – EUR 291,592; 2040 – EUR 361,044; based on a «basic» tariff: 2019 – the project is unprofitable; 2020 – EUR 163,335; 2030 – EUR 249,558; 2040 – EUR 295,342. In this case, the payback period over these years would equal: based on a «green» tariff – 8.3; 7.3; 3.7; 2 years; based on a «basic» tariff – 30; 18; 4; 2 years, respectively. Such an increase in the net present value of the project in the future and a decrease in the payback period is due to decreasing price for collectors and increasing «basic» tariffs for energy generation using a renewable source. Environmental effectiveness, which prevents harmful emissions into the environment through the generation of «clean» electric and thermal energy by a hybrid solar collector, is about 6,355 t. This indicator is one of the main characteristics for competitiveness of the proposed investment project aimed at reducing the anthropogenic influence on the environment. The paper has presented the estimated investments in the project and the profit by residents at the apartment building depending on tariffs for solar electric and thermal energy and a year a project is implemented, which testify to an increase in profit from realizing the project in the future.

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