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Original scientific paper

COMPARATIVE EFFICIENCY ANALYSIS FOR THE DEVELOPED MODELS

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A b s t r a c t: Efficiency is a measure for delivery of the selected goals with minimum use of the existing resources. The researches in the paper are focused on analyzing the quality and efficiency of the products developed, with special emphasis on their use in the renewable resources area. The developed products are mathematical models of systems for producing thermal energy using collectors for sanitary hot water and generation of electricity using photovoltaic panels. The f-Chart method and the PVGIS software were both used in the implementation and development of the mathematical models. The quantitative parameters obtained from the mathematical models developed for both systems show the segments of use and the opportunities for savings and improvements. When cross-references, they can be used to calculate coefficients of quantitative and qualitative indicators, which are then used for comparative analysis of the quality and efficiency of the developed models. The comparative analysis of the specific qualitative indicators shows that the system using collectors for sanitary hot water has far better use of the solar radiation, the annual thermal energy expressed in financial units on annual basis is much greater compared to electricity generated using photovoltaic panel system.

Key words: efficiency; mathematical models; qualitative and quantitative indicators

КОМПАРАТИВНА АНАЛИЗА НА ЕФИКАСНОСТА НА РАЗВИЕНИТЕ МОДЕЛИ

А п с т р а к т: Ефикасноста претставува мера за реализирање на избраните цели со минимално користење на постојните ресурси. Истражувањата во трудот се фокусирани на анализа на квалитетот и ефикасноста на развиените производи, со посебен осврт на користење во областа на обновливите извори. Развиените производи претставуваат математички модели на системи за добивање топлинска енергија со колектори за санитарна топла вода и производство на електрична енергија со помош на фотонапонски панели. При имплементацијата и развојот на математичките модели се користени методот f-Chart и софтверската програма PVGIS. Добиените квантитативни вредности од развиените математички модели за двата система јасно ги покажуваат сегментите на примена и можностите за заштеди и подобрувања. Со нивно вкрстување се пресметуваат коефициенти на квантитативни и квалитативни показатели, преку кои се прави компаративна анализа на квалитетот и ефикасноста на развиените модели. Компаративната анализа на специфичните квалитативни показатели покажува дека системот кој користи колектори за санитарна топла вода има далеку подобра искористеност на сончевото зрачење, добиената годишна топлинска енергија изразена во парични единици е многу поголема во споредба со електричната енергија произведена од системот кој користи фотонапонски панели.

Клучни зборови: ефикасност; математички модели; квалитативни и квантитативни показатели.

1. INTRODUCTION

A growing number of companies are becoming aware that sustainable product development is a key factor in their global competitive positioning. Due to global environmental concerns, the sustainability and the sustainable design have become a major objective for these companies in the recent years. In parallel, the market competitiveness and the accelerated development force the companies to improve their processes for developing new products and technologies. In addition, changes in the consumer demands as well as the rapidly growing production technologies lead to continuous development of new products, but also to continuous improvement of the existing ones. The objective of the companies is to stay competitive in the market by developing new products, but at the same time they must improve or maintain the quality level of the product in order to meet the high demands of the consumers.

The researches in this paper are focused on analyzing the quality and efficiency of a developed product model from contemporary trends, with particular reference to the use of renewables. The developed product will be presented through models that provide value indicators as well as product indicators that contribute to customer satisfaction.

The efficiency (performance) indicators are specific indicators used to define the savings potential as well as to determine the effect from the implementation of efficiency measures. They are relevant because, by correctly combining the true values of the indicators obtained on the basis of the data collected with common or standard values, it is possible to clearly determine in which segments of the system savings are possible – savings that would be useful for the given efficiency [14]. That is, a combination of quantitative indicators will yield qualitative indicators that will be used to make comparative analysis of the quality and efficiency of the developed product [1].

2. REVIEW OF THE LITERATURE RESEARCH

The effectiveness generally describes the extent to which resources, such as time, labor, or the projected cost, are well used to accomplish a task or achieve a goal. It is often used to indicate the ability of a particular work or activity to produce results efficiently, while minimizing waste and minimizing costs [6, 14].

Efficiency is essentially a measurable concept, which quantitatively determines the ratio of outputs to inputs, through indicators or ratios.

The role of the efficiency indicators is to clarify and simplify the understanding of the complex systems. An indicator or set of indicators helps determine the current position compared to the objectives set [14].

The process of selecting efficiency indicators must begin with a precise understanding of the process being considered as a task. The purpose of the efficiency indicators is to enable monitoring and evaluation of the measures applied to improve the processes and protect the environment [4, 5, 6, 14].

One of the methods for comparing the quality and efficiency of a developed product is use of comparative analysis of developed models [6, 7].

A mathematical model can be defined as a set of mathematical relations that describe or define the links between certain physical parameters in the observed process. The mathematical model is a more or less average representation of the actual relationships between the parameters that characterize the process and reflect the most important features of the process.

Tools for modeling and predicting system performance can be used in the mathematical models. The modeling tools provide information on the systems performance, just like performing a realistic physical experiment, but takes less money and time [1, 2, 3].

There are several mathematical models that use the tools for modeling of the forecast of the thermal performances of the systems. The most popular of these are: the f-Chart method [1] and the TRNSYS method [11].

Sanford A. Klein, John A. Duffie and William A. Beckman have developed the f-Chart method, which is recommended and fully implemented in the EN 15316 standard, where this method is described in details. The application of the f-Chart method in the processes that feature thermal performances is used as important practical tool in solving specific engineering problems in various scientific areas [8, 9, 10, 14].

There are many types of software programs that are developed based on mathematical models that enable forecasts of photovoltaic systems performance. Some of the best are: PVGIS [3], PVSyst [12], etc. At the same time, these software programs also use data from various sources to estimate the solar radiation.

The PVGIS software program was developed at the European Commission's Joint Research Center in Ispra, Italy. It is used to estimate the solar radiation on the Earth's surface through satellite data and a mathematical model developed by Mueller, Gracia Amillo et al. [3] to calculate the amount of solar energy.

The PVGIS software program estimates and calculates the *electricity generation* of the photovoltaic panels, from the respective quantity of solar energy. To this end, an algorithm has been developed in the mathematical model by Martin and Ruiz [3].

The foregoing is taken as a starting point for future expansion and research into the application of the mathematical models in the newly developed models of an energy efficient system. Particular emphasis in the researches mentioned in this paper was put on the quality and efficiency of the systems used to generate thermal energy with collectors for sanitary hot water, and systems for generation of electricity from photovoltaic panels.

3. DEFINING OF TOOLS FOR EVALUATION OF QUALITY AND EFFICIENCY INDICATORS

According to ISO 9000:2015 *efficiency* is the ratio between the resources used and results achieved.

Increasing efficiency is achieved by increasing the productivity with the same or reduced resource consumption, or by reducing the consumption of assets with the same or increased productivity. On the other hand, energy efficiency means using a smaller amount of energy (energy source) to perform the same work or function. It is important to note that energy efficiency should never be seen as energy saving, but as efficient use of energy without disrupting the working and living conditions [14].

Efficiency is not only an indicator of careful handling of natural resources, but it is also an indicator of the emissions released to produce a unit of product or energy.

The efficiency indicators that analyze the energy efficiency of a system can be segmented as follows [14]:

- **Macro-indicators**, pertaining to the global economy in its sectors, in the particular industries or per categories (for example, in the energy consumption),
- **Micro-indicators**, pertaining to analysis of the energy intensity of the efficiency of specific companies and/or households.

The energy efficiency indicators are expressed as ratio of energy consumption divided by activity indicator or expressed as quantities of variations in the energy consumption in relation to a particular variable [14].

Different energy efficiency indicators are used for quality analysis of the energy consumption and of the energy efficiency in the household.

The pyramid of energy consumption in households shows that on the top we have the aggregate consumption of all households with the energy consumption indicator per apartment (GJ/apartment) as the best measure of the total consumption. The energy consumption per capita (GJ/capita) can also be used as an aggregate indicator [14].

Following the primary level of consumption, we have the first level of non-aggregated or split energy consumption and their energy indicators, showing that the household energy is spent on heating of the space, water heating, cooking, cooling, lighting, electrical appliances, etc. For example, for heating of the space, the energy indicator is the energy consumption per degree/day (SD) per area of one square meter/kJ (SD/m^2). The second level of non-aggregated or split energy consumption is the consumption per final consumer. For example, the average electricity consumption per refrigerator is shown by the energy consumption by volume (kWh/l), which is actually the volume (the size) of the refrigerator [14].

On the other hand, in order to analyze the economic effects of the investments, indicators that will monitor the investment, which is essentially a product/project assessment method, should be considered.

The methods for evaluation and ranking of investment products/projects are done using [6]: static and dynamic methods.

The static evaluation of the investment shows the indicators based on the parameters of a representative year of investments use over the economic life of the product/ project. The most commonly used static criteria applicable to energy efficiency projects are the following [6]:

- Return on the investment period.
- Gain rate.
- Investment rentability.
- Energy consumption coefficient.

The dynamic evaluation of the investment indicators involves the use of indicators that refer to all years during the economic life of the investment. The dynamic indicators are more complex indicators because they show the effects of the investments at a discount rate and as such they allow to analyze the economic effects of the investment project in a much more realistic way and to evaluate the justification of the investment. The most well-known dynamic evaluations of investment projects are the following [6]:

- NPV – Net Present Value,
- IRR – Internal Rate of Return,

- PI – Profitability Index.
- DPP – Discounted Payback Period

4. DEVELOPMENT OF MATHEMATICAL MODELS FOR ENERGY EFFICIENCY SYSTEM

In order to be able to define a model of an energy efficient system it is necessary to plan and predict the need for consumption (by volume and capacity), the time needed to implement the project and the opportunities for technology improvement. The next step is to prepare a development study that can be divided into two parts. The first part includes a simulation of the legality of the work in the system (the system drive) and the second part covers the economic evaluation of the system, that is, the objectives of the development plan. The first part defines the creation of a mathematical model of the system, that is, it is necessary to describe the system with mathematical equations and to make approximation with the inevitable neglect and simplification. In the second part, the economic contribution of each energy facility should be assessed and valorized using economic methods. In this research of the results obtained from the mathematical models developed, a comparative analysis of the quality and efficiency of those models is also performed.

The performance of all solar power systems depends on the weather factors (radiation level and distribution, ambient temperature, etc.), the system parameters of the solar systems (type of collector or panel, storage capacity, etc.) and features for the purpose (heating of space, water heating, temperature, electricity generation, etc.). The solar power systems show a nonlinear dependence on the weather conditions and this makes it difficult to accurately analyze their performance by observing their behavior in short weather intervals of average weather conditions. Due to the non-linear dependence of these systems on both short-term (e.g. hourly) and long-term (e.g. seasonal) weather conditions, analyses of these systems require an examination of their performance over a long period of time. As a result, the experiments are very expensive and time consuming and it is difficult to differentiate between the parameters in order to see their effect on the system performance.

The mathematical models can provide analyses of the solar energy systems when the necessary meteorological data is provided. The mathematical models can also provide information on the thermal performance of these systems as well as physical experimentation, but for less time period and finances.

The calculation of the solar energy gains for the system for preparation of sanitary hot water is done using the f-Chart method, implemented in EN 15316-4-3 [2]. The f-Chart method is one of the empirical frameworks that uses standardized metrics to characterize the long-term performance of the solar system.

Calculation of the benefits of the solar energy which is converted into electricity in the photovoltaic panel system is done using the PVGIS software [3].

The following are the input parameters for the mathematical models:

- the geographic latitude and longitude of the location;
- history information about the daily solar radiation;
- history information about the daily temperature;
- the inclination angle and the azimuth;
- the total area for installation of the collectors (panels).

Based on the number of tenants foreseen to live in the residential buildings, the required surface of the sanitary hot water collectors was obtained with mathematical calculation. This surface is taken as input and at the same time limiting factor in order to obtain the required number of panels for the photovoltaic system. The surface of the selected collectors for sanitary hot water is 1.93 m^2, 0.983 m length and 1.965 m height, and the surface of the selected photovoltaic panels is 1.93 m^2, 0.99 m length and 1.950 m height [14].

The developed mathematical models will consider ten cases or options (variants). For all ten cases it is assumed that the collectors or panels are mounted on a roof surface and have the required angle of inclination towards the sun in order to achieve the maximum solar energy gains.

4.1. *Mathematical models for obtaining heat energy with collectors for CTB*

The algorithm for calculation of the total energy quantity required for CTB is based on the “f-Chart“ method and includes the following steps [2]:

1. Defining of the use of thermal solar systems (input data). The defining is about selec-

tion of CTB system, system for heating of residential building and combined system.

- Calculation of the heat required for heating vs. total heat required (P_H).
- Calculation of the heat required for sanitary hot water vs. total heat required (P_W).

2. Calculation of the dimensionless coefficient X (similar to the ratio of losses vs. heat required).

- Calculation of the collector surface (A).
- Calculation of the heat loss coefficient in all pipes in the collector loop (U_{loop}).
- Determination of the usefulness factor of a collector loop (collector and pipe) (η_{loop}).
- Calculation of the reference temperatures difference (ΔT).
- Calculation of the adjustment factor (f_{st}) of the accumulation reservoir, which depends on the configuration of the system (heating system of solar plus additional system).
- Attribute of the volume of the accumulation reservoir for heating or preparation of CTB.

3. Calculation of the dimensionless coefficient Y (similar to the ratio of losses vs. heat required).

- Determination of the zero factor of usefulness (η_0).
- Determination of the average radiation on the collectors' surface (I_m).

4. Calculation of the heat obtained for heating and preparation of CTB and the total heat gain.

5. Calculation of additional energy consumed for the auxiliary devices in the heat solar system.

6. Calculation of the system heat losses of the heat solar system.

- Determination of the heat losses of the solar accumulation reservoir.
- Determination of the heat losses between the heat solar system and the backup heater.

7. Calculation of the renewable losses of the heat solar system.

- Determination of the renewable energy consumption of the auxiliary devices.
- Determination of the renewable heat losses of the accumulation reservoir.
- Determination of the renewable heat losses between the distribution of the thermal solar system and the backup heater.

In this paper we consider only the case when the system is used for obtaining CTB from solar energy.

4.2. *Mathematical model for generation of electricity with photovoltaic panels*

The amount of solar energy that shines on the photovoltaic panels – PVP, is transformed into electricity. The model analyzes a grid-connected photovoltaic system, i.e. the system has no batteries to store the generated electricity. It is established that the photovoltaic panels will be fixed, and the inclination angle and the azimuth will be automatically determined by the PVGIS software according to its algorithms.

The input parameters in the calculation are the following [3]:

1. Geographical location of the photovoltaic panels is the City of Skopje, with geographical latitude of 41.996 degrees and a geographical longitude of 21.432 degrees.

2. The adopted type of photovoltaic panel is polycrystalline – silicon type of panel.

3. The sun radiation database adopted in the software is PVGIS-CMSAF.

4. The adopted losses of the photovoltaic system are determined at 14%.

5. The surface for installation of photovoltaic panels is determined to be equal to the size of the surface of the collectors installed for CTB.

The mathematical model for generating electricity with photovoltaic panels covers the same parameters and cases reviewed as the mathematical model for generating thermal energy with collectors for CTB. The purpose is to make a comparative analysis and comparability of the results obtained between these two models in order to determine the individual efficiency of the systems. The calculated surface area in the mathematical model for the CTB collectors is assumed to be equal to the surface area of the photovoltaic panels.

5. COMPARATIVE ANALYSIS OF THE PARAMETERS IN THE MATHEMATICAL MODELS

The comparative analysis is a method by which different or similar objects or phenomena are analyzed. It can help to compare the structure and tendency of these phenomena. The comparative analysis can reveal structural, functional or genetic similarities, differences, or similarities of a number of phenomena. The quantitative values obtained from the developed mathematical models for both systems clearly show the segments of application and the potential for savings and improvements. If we cross-reference them we will be able to calculate the coefficients of qualitative indicators, which enable comparative analysis of the quality and efficiency of the developed models.

5.1. *Comparative analysis of the quantitative values from the mathematical models*

The calculated quantitative values of the mathematical models for heat generation with CTB collectors and for electricity generation from PVP are shown in Table 1. The calculated values refer to the same solar radiation and for same surface of the collectors or panels. They show the calculated values for the annual amount of energy obtained from the solar radiation with the collectors for CTB, $Q_{w,sol,out,y}$ and the annually generated electricity from PVP, $E_{el,pv,out,y}$ for the ten considered cases.

Figure 1 graphically shows the estimated annual quantity of energy for CTB and the calculated electricity generated from the PVP which was obtained from the solar radiation for the ten cases considered. The graph clearly shows that the utilization of the solar radiation for the CTB collectors is higher compared to PVP panels.

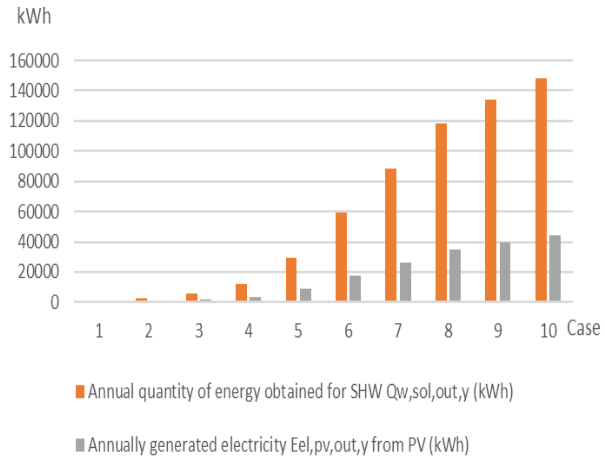

Fig. 1. Annual quantity of produced energy

Table 2 shows the calculated values of the total investment for the system with CTB collectors, and Table 3 shows the calculated values for the total investment for the system for generation of electricity with PVP, according to current market prices.

If we compare the total investment of both systems it can be seen that the system of collectors for CTB costs twice as much as the system with PVP.

The Figure 2 graphically shows the comparatively calculated investment for the two systems at current market prices. It can be seen from the graph that the investment in the CTB system is significantly higher, even more than twice the investment in the PVP system for the ten cases considered.

T a b l e 1

Annual quantity of energy obtained from the solar radiation for the considered cases

Case	Calculated collectors surface area, A (m^2)	Adapted number of collectors for AHW and PV	Collectors surface area (m^2)	Annual quantity of energy obtained for SHW $Q_{w,sol,out,y}$, (kWh)	Annually generated electricity $E_{el,pv,outy}$ from PV (kWh)	Comparative ratio of annual energy quantity
1	2.82	1	1.93	1227	363	3.38
2	4.69	2	3.86	2554	723	3.39
3	9.39	5	9.65	5836	1810	3.22
4	18.78	19	18.3	11844	3630	3.26
5	46,94	23	46.32	29175	8720	3.35
6	93.88	49	94.57	59280	17800	3.33
7	140.82	73	140.89	88639	26600	3.34
8	187.76	97	186.21	117994	35300	3.34
9	211.23	109	210.37	134212	39600	3.39
10	234.70	122	235.46	148068	44300	3.34

Table 2

Total investment for CTB collector's system (Eur)

Adopted number of collectors for SHW	SHW collector cost	Cost of combined water heater	Cost of solar & system controllers	Cost of pipes, fittings, expansion, etc.	Contingency 20%	Total investment for the system with collectors for SHW
1	350	350,00	150	350	240	1440
2	700	400,00	150	350	320	1920
5	1750	800,00	250	650	690	4140
10	3500	1100.00	700	1200	1300	7800
24	8400	1570.00	1500	1900	2710	16260
49	17150	3700.00	2300	3900	5410	32460
73	25550	6500.00	3500	4900	8090	48540
97	33950	7500.00	4500	7000	10590	63540
109	38150	7900.00	5500	8500	12010	72060
122	42700	8500.00	6000	9000	13240	79440

Table 3

Total investment for CTB system (Eur)

Adopted number of collectors for PV	PV collector cost	Cost of solar inverters	Cost of fittings, cables, etc.	Contingency 20%	Total investment for the system with PV
1	153	350	75	101	679
2	306	350	98	131	886
5	765	850	242	323	2180
10	1530	1300	425	566	3821
24	3672	1900	836	1114	7522
49	7497	3500	1650	2199	14846
73	11169	5000	2425	3234	21828
97	14841	6650	3224	4298	29013
109	16677	7300	3597	4795	32369
122	18666	8000	4000	5333	35999

Fig. 2. Graphic overview of the total cost of the systems

The following Table 4 shows the values of the annual energy obtained from the CTB and PVP systems expressed in euros. The annual energy of the CTB system expressed in euros is obtained from the calculated quantities of energy expressed in kWh multiplied by the price per unit of kWh of electricity for households. The annual electricity generated by the PVP system expressed in euros is derived from the electricity produced in kWh by the PVP system, multiplied by the unit price per kWh, regulated in accordance with the current prices for photovoltaic power plant.

The current cost per kWh of electricity distributed to households and the cost per kWh of electricity generated by a photovoltaic power plant are taken from the official announcement of the Energy Regulatory Commission of the Republic of Macedonia [13].

Table 4

Annual energy in the systems expressed in euros, for the ten cases

Case	Adopted number of collectors	Annual quantity of energy obtained for CTB $Q_{w,sol,out,y}$ (kWh)	Annually generated electricity $E_{el,pv,out,y}$ from PVP (kWh)	Annual energy from the SHW system expressed in money (Euros)	Annual energy from the PV system expressed in money (Euros)
1	1	1227	363	123	58
2	2	2454	723	245	116
3	5	5836	1810	584	290
4	10	11844	3630	1184	581
5	24	29175	8720	2918	1395
6	49	59280	17800	5928	2848
7	73	88639	26500	8864	4240
8	97	117994	35300	11799	5648
9	109	134212	39600	13421	6336
10	122	148068	44300	14807	7088

The Figure 3 graphically shows the annual energy received from the system with the collectors for CTB and the electricity generated from the PVP system expressed in euros. The graph clearly shows that the system with the CTB collectors yields more benefits than the PVP system. It should be borne in mind that the electricity generated by PVP under the current conditions of this research is subsidized by 60% more than the cost of electricity for households. If equalization of a single kWh of energy generated for both systems, then the CTB system would have even greater advantage.

Table 5 shows the time required for return on investment. It is a static indicator of the efficiency of the system from an economic point of view. This indicator is obtained by dividing the investment of the system with the CTB collectors and the PVP system expressed in euro currency, with to the annual energy obtained from the CTB and the PVP systems, expressed in euros.

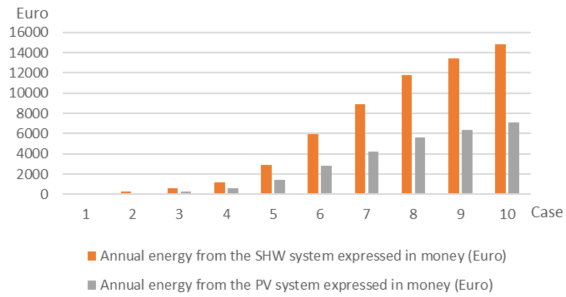

Fig. 3. Annual energy from the systems expressed in monetary unit (euros)

Table 5

Time for return on investment for the CTB and the PVP systems

Case	Adopted number of collectors	Total investment for the system with collectors for SHW (Euros)	Annual energy from the SHW system expressed in money (Euros)	Return on the investment period from the system with collectors for SHW (Years)	Total investment for the system with PV (Euros)	Annual energy from the PVP system expressed in money (Euros)	Return on the investment period from the system with PV (Years)
1	1	1440	123	11.74	679	58	11.69
2	2	1920	245	7.82	886	116	7.66
3	5	4140	584	7.09	2180	290	6.61
4	10	7800	1184	6.59	3821	581	6.58
5	24	16260	2918	5.57	7522	1395	5.39
6	49	32460	5928	5.48	14846	2848	5.21
7	73	48540	8864	5.48	21828	4240	5.15
8	97	63540	11799	5.39	29013	5648	5.14
9	109	72060	13421	5.37	32369	6336	5.11
10	122	79440	14807	5.37	35999	7088	5.08

The reduction in the photovoltaic panels capacity of approximately 0.8% annually [14], as well as the costs of regular annual maintenance of the systems which account for 1% annually of total investment are neglected, as parameters in the calculations made in this research [14].

The Figure 4 graphically shows the return on investment for the CTB and the PVP systems, computationally derived from the mathematical models and expressed over a period of years. It can be clearly seen from the graph that the return on investment for both systems (the PV and the PVP) is almost the same.

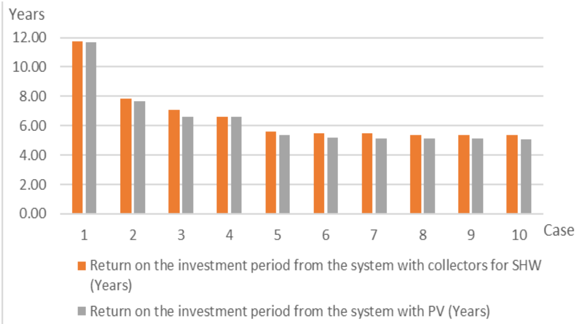

Fig. 4. Time for return on investment for the CTB and the PVP systems

5.2. *Comparative analysis of the qualitative indicators*

The following Table 6 shows the coefficients of the qualitative indicators for the yearly generated amount of energy for the CTB and the annually generated electricity from the PVP expressed in kWh. The ratio is made comparatively to the surface of the collectors of the CTB system and, correspondingly, to the surface of the panels of the PVP system, expressed in m^2. The qualitative indicator is obtained by dividing the annually received or generated amount of energy of the collectors ($Q_{w,sol,out,m}$ for the CTB, $E_{el,pv,out,y}$ for the PVP), with the surface of the CTB system collectors and, respectively, with the surface of the PVP system panels, for each of the ten cases.

Figure 5 graphically shows the ratio of the annually generated quantity of energy of the CTB systems and the surface of the collectors, as well as the ratio of the annually generated quantity of electricity from the PVP systems and the surface of the panels, to the ten cases considered. From the calculations it is evident that there is an average of the received or generated quantity of energy from both systems.

Figure 6 clearly shows that the average annual energy generated in the CTB systems per surface unit, expressed in m^2, is three times higher than the average annual electricity generated from the PVP system per surface unit, expressed in m^2.

Table 7 shows the coefficients of the qualitative indicators for the annually generated energy from the collector systems for the CTB and the annually generated energy with the PVP systems expressed in euro currency. The ratio is made comparatively to the surface of the collectors of the CTB system and correspondingly to the surface of the panels of the PVP system, expressed in m^2. This qualitative indicator is obtained by dividing the annually obtained or generated quantity of energy expressed in euro currency, by the surface of the collectors or the panels, expressed in m^2, for the ten cases considered.

Table 6

Annual quantity of energy generated from the CTB and PVP systems in relation to the surface area of the collectors

Case	Collectors surface area for SHW, A (m^2)	Annual quantity of energy obtained for SHW $Q_{w,sol,out,y}$ (kWh)	Ratio of the annual quantity of energy obtained for SHW $Q_{w,sol,out,y}$ (kWh) and the surface (kWh/m^2)	Annually generated electricity $E_{el,pv,out,y}$ from PV (kWh)	Ratio of annually generated electricity $E_{el,pv,out,y}$ from PV (kWh) and the surface (kWh/m^2)
1	1.93	1226.64	635.57	363.00	188.08
2	3.86	2454.00	635.75	723.00	187.31
3	9.65	5835.81	604.75	1810.00	187.56
4	19.30	11843.68	613.66	3630.00	188.08
5	46.32	29175.42	629.87	8720.00	188.26
6	94.57	59280.10	626.84	17800.00	188.22
7	140.89	88638.57	629.13	26500.00	188.09
8	187.21	117994.39	630.28	35300.00	188.56
9	210.37	134212.39	637.98	39600.00	188.24
10	235.46	148068.24	628.85	44300.00	188.14

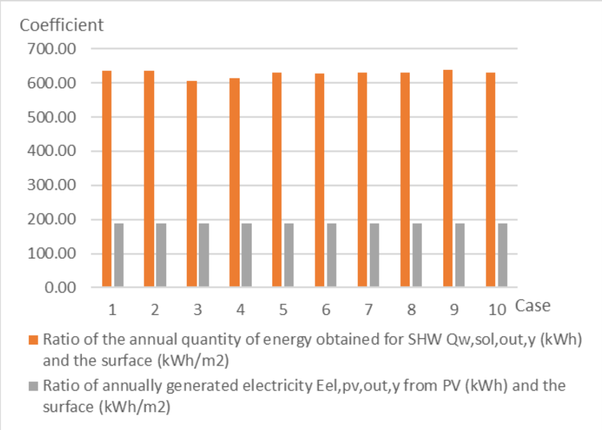

Fig. 5. Ratio of the annually generated quantity of energy of the CTB and the PVP systems and the surface of the collectors or the panels

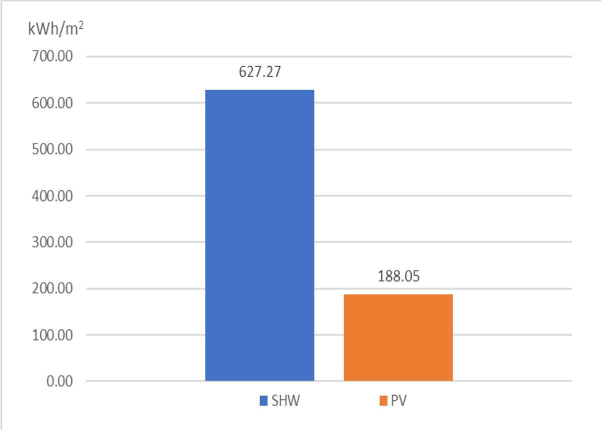

Fig. 6. Average annual generated quantity of energy of the CTB and PVP systems and the surface of the collectors or the panels

T a b l e 7

Annual generated from the CTB and PVP systems in relation to the surface of the collectors or the panels, expressed in euros

Case	Collectors surface area for SHW, A (m^2)	Annual energy from the SHW system expressed in money (Euros)	Ratio of annual energy from the system for SHW expressed in money (Euros) and the surface (Euros/m^2)	Annual energy from the PV system expressed in money (Euro)	Ratio of annual gain in euros from the PV system and the surface (Euro/m^2)
1	1,93	123	63,56	58	30,09
2	3,86	245	63,58	116	29,97
3	9,65	584	60,47	290	30,01
4	19,30	1184	61,37	581	30,09
5	46,32	2918	62,99	1395	30,12
6	94,57	5928	62,68	2848	30,12
7	140,89	8864	62,91	4240	30,09
8	187,21	11799	63,03	5648	30,17
9	210,37	13421	63,80	6336	30,12
10	235,46	14807	62,88	7088	30,10

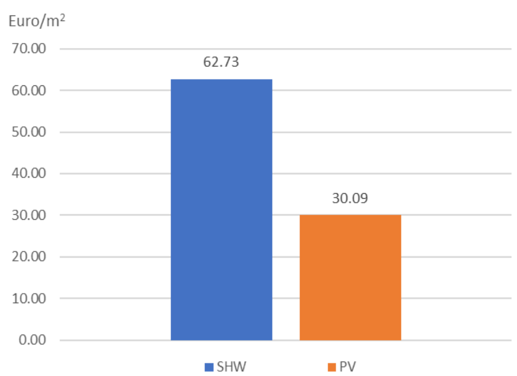

Fig. 7. Average annual energy from the CTB and PVP systems, expressed in money, in relation to the surface of the collectors or the panels

Figure 7 graphically shows the average annual energy output generated by the CTB and PVP systems expressed in euro currency, relative to the surface of the collectors or the panels. The graph clearly shows that the average annual quantity of energy expressed in euro currency of the CTB systems per m^2 is twice as much as the average annual electricity generated by the PVP systems, expressed in euro currency, per m^2.

6. CONCLUSION

The developed mathematical models consider ten cases where it is assumed that the collectors or the panels are mounted on a roof surface with the required angle of inclination towards the sun in order to achieve maximum gains from the solar radiation. Meteorological data were taken as input parameters.

The calculation of the thermal output for the system for preparation of sanitary hot water is done using the f-Chart method, and the calculation of the electricity generated in the photovoltaic system is done using the PVGIS software.

The results obtained from the calculation were used to do comparative analysis of the quantitative and qualitative indicators, thus the conclusions were the following:

1. The solar radiation utilization for the CTB collectors is three times higher than the PVP panels. It is taken into consideration that the calculated surface area of the collectors for CTB is a limiting factor on the basis of which an equal number of CTB collectors and PVP panels is adopted.

2. The investment in the CTB system is significantly higher, even twice as much than the investment in the PVP system.

3. The annual energy output of the PVP system expressed in euro currency is twice the annual electricity generated by the PVP system expressed in euro currency, taking into account that the electricity produced by PVP under the current conditions applicable in the time of this research is subsidized by 60% more than the cost of electricity for the households.

4. The time for return on investment for both systems (CTB and PVP) is almost the same, so the profitability of the investment is equal.

5. The average annual quantity of heat energy generated by the CTB system, expressed per surface unit (m^2) is three times higher than the average annual electricity generated by the PVP system expressed per surface unit (m^2).

6. The average annual quantity of heat energy generated by the CTB system expressed in euro currency per surface unit (m^2) is twice that of the average annual electricity generated by the PVP system expressed in euro currency per surface unit (m^2).

Taking into account all the results obtained, the effectiveness and efficiency of the sanitary hot water system is evident. It should be noted that the lifespan of both systems according to the data obtained from the manufacturers of collectors or panels is approximately the same. One should not neglect the fact that the efficiency of the photovoltaic panels is operationally declining every year, so within 25 years of use it would be 80% of the original.

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