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Energy Efficiency in Heat Pumps and Solar Collectors: Case of Slovakia

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Abstract: Sustainable energy presently represents the energy of the future, which should be based on the application respecting the importance of energy priorities, increasing regional self-sufficiency, regional control of energy, and regulation of resource use. In the area of energy supply, the use of RES has been increasingly popular, mainly due to the instability in the energy market and the political situation worldwide. Paper's ambition is to evaluate the efficiency of the selected RES use in the specific conditions of Slovakia, with the aim to achieve the EU targets. This is important due to the increasing use of RES in Slovakia. The objective of this paper is achieved through an analysis of the energy profit of the RES system, comparing the costs of the proposed solutions. The evaluation is carried out by calculating the energy and economic efficiency of three possible buildings used in the research. Using the data obtained, the results show the most suitable alternative for each building. The resulting findings provide a valuable insight for governments in identifying the best projects for RES use. The result will be methodology creation as a base for local administration and communities to elaborate plans with a goal to extend RES use.

Keywords: consumption of resources; green economy; renewable resources; process of energy production; sustainable energy

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1. Introduction

Currently, heat pumps, solar collectors, and other types of RES are becoming increasingly interesting. This rising trend is apparent both at the global and regional level. According to Elmore et al. and Yendaluru et al., the use of RES is becoming the key for achieving national sustainability of countries [1,2]. There are several factors that have contributed to this rising trend. First, it is the instability in the energy market due to the political situation and the sanctions. As a result, the supply of energy raw materials, such as oil and natural gas, decreased, which caused a significant increase in energy prices. Inflation also plays a significant role in this growth. The second important factor is environmental and political goals. Poudyal et al. researched the main factors contributing to the bad balance between offer and demand on energy and the increasing importance of its use [3]. These factors are related to energy poverty, meaning that countries struggling with energy poverty should increase the use of RES as well [4].

As a member of the European Union, the Slovak Republic is committed to achieving carbon neutrality by 2050. This process has already started, as companies have to meet strict emission standards and power plants that produce electricity from traditional sources of energy, such as coal, are being shut down. In order to achieve this goal, it is necessary to gradually shut down power plants that use traditional energy sources as fuel and then massively invest in RES. However, this applies not only to large industrial enterprises, but also to traditional households. Slovakia is making efforts to achieve this goal [5].

A number of authors have dealt with the evaluation of RES use. Ostergaard et al. addressed the status of research within the application of renewable energy sources [6], focusing on the status of renewable technologies meeting sustainable development goals. However, the results must be put into a broader context together with economic indicators. In Italy, Romano et al. made a technical evaluation, focusing on the energetic and plant aspects, while their economic assessment aimed to define the cost effectiveness criteria [Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period], which can measure the return on investment [7]. From the perspective of economic evaluation, Romano et al. included the national public incentives designed to encourage the production of energy from renewable sources in compliance with the international agreements. Nenu et al. studied the consumption of resources, leading to a minimal impact on the natural and social environment and thus improving the quality of life over the short-, medium- and long-term, finding the optimal solution for an efficient heat regime in the greenhouse [8].

Renewable energy use is a rising trend, having a major role in the concept of sustainable development through the reduction in greenhouse gas emissions, and the economic competitiveness of renewable energy is constantly increasing. Moreover, total investment cost, fuel cost, maintenance cost and expected load-shedding cost in the evaluation of the efficiency of the energy system must be considered [9]. A design procedure for building sustainable hybrid energy systems is presently important, determining the optimal solution set from the view of efficiency [10]. According to Kharrich et al., hybrid energy systems are sometimes not widely used due to some economic aspects, namely the net present cost and cost of energy. Kharrich et al. have indicated an economic hybrid energy system in Saudi Arabia, minimizing these mentioned costs [11]. In Saudi Arabia, the government is planning to make renewable energy an essential part of its energy mix. Here, Alanazi and Alanazi evaluated the climate, environmental, technical, economic and social aspects, as adopted to analyse the suitability of PV technology, ranking its performance at the level around 90% [12].

In this context, Tomekovic and Filipan carried out an economic analysis of the project profitability, showing that the investment to the sized PV system is returnable in present market conditions only if the time value of the money is not taken into consideration [13]. Serban et al. researched the use of solar water heating (SWH) systems, motivated by the desire to reduce energy consumption and, specially, to reduce a major source of greenhouse gas (GHG) emissions in Romania, investigating the economic potential of SWE systems and their contribution to saving energy and emissions reduction [14]. Their results indicate that investing in these systems is cost-effective for households as long as the governmental subsidies increase. The use of solar models is widespread in energy systems; however, there is a gap when assessing their impact in modelling large-scale solar thermal systems integrated in district heating (DH) systems. Therefore, Aliana et al. studied DH plants in Denmark, calculating the cost and economic impact of the model [15]. A photovoltaic power plant shares more electricity production than a wind-turbine generator [16].

Khemissi et al. identified a cost-effective, reliable, and environmentally friendly optimal architecture of solar panels and wind turbines for the purpose of optimal planning of a hybrid renewable power system [17]. Also, according to Yuksel et al., the number of multigenerational energy plants is increasing, revealing that both the energy and exegetic efficiency of the plants are around 50% [18].

A bioeconomy strategy aimed at promoting a sustainable Europe, launched in October 2018, proposes a new indicator in the socio-economic indicator for the bioeconomy, designed to measure the socio-economic performance of the bioeconomy sector [19]. In the area of biomass, a number of studies have been conducted, such as Hrechyn et al., using approaches to modelling involving economic and ecological evaluation of the wooden mass supply chain, depicting ecological effectiveness [20].

Rajnoha and Kánová deal with the issue of increasing the potential of the renewable natural resources mining industries and increasing their efficiency and competitiveness through the specific methodology of industry performance measurement in Slovakia and other countries of the Visegrad 4 [21]. According to Dahash et al., big capacity stocking of heat energy is key for the expansion of heating, based on RES use [22].

Heat pumps are currently achieving an increasingly high share of the market in many countries as a part of the heating technologies that are being established for newly built houses. Heat pumps are being increasingly recognized as a critical technology for the decarbonisation of heating, mainly due to increasing political support in various countries. In 2021, around 190 million heat pump units were in operation in buildings worldwide. The global supply of heat pumps has increased relatively steadily in recent years, especially in primary heating markets such as North America, Europe and North and East Asia. In 2021, heat pumps achieved a record high sales growth mainly in Europe, China, and the United States of America. In addition to achieving climate goals, a very important driving force for heat pumps, especially in the European Union, is energy security, which received increased attention in 2022 [23].

Despite the continued boom, heat pumps still cover only about 10% of global building heating needs. Thanks to this type of heating, the achievement of a scenario of net zero emissions by 2050 is becoming more and more realistic. In this scenario, the global stock of heat pumps is projected to reach around 600 million by 2030, covering at least 20% of global heating needs; however, this requires much greater political support and technical innovation, especially to reduce initial purchase and installation costs, remove market barriers to complex renovations, improve energy performance and harness the potential of heat pumps as a means of enabling energy system integration and flexibility [23].

RES use is important due to the decarbonisation and greenhouse gases decreasing in society, which can be solved through proper energy use in households, as has been studied in Poland [24].

The afore-mentioned review shows there is a gap in the evaluation of RES use in Slovakia and V4. The ambition of the paper is to evaluate the RES use in Slovakia from the perspective of economic and energy efficiency. The objective of the paper is to assess the energy and economic efficiency of the heat pumps and solar collectors with the aim of proposing solutions. Slovakia is a country that has a relatively high representation of low-energy sources in the form of underground and surface water, which enable its use through heat pumps of the water/water type or water/air (or air/air). With a Coefficient of Performance (COP) of around 3−4, the consumption of electricity to drive heat pumps (or heat pump compressors) and an energy mix that prefers the use of electricity over fossil fuels is an advantage [25]. However, the heat pump can be used exclusively for the transformation of environmental energy (thermal energy) through electrical energy (or a noble energy source), while the consumption of electrical energy is significantly lower than with direct electrical heating (which results from COP 3−4) and a relatively high number of heating days (210–280 days depending on the climate and altitude range).

In the research, we deal with problems of economic and energetic evaluation of heat pump and solar collector use in the individual conditions of Slovakia. The research is dealing with the following research questions:

- Spatial location of the assessed object or buildings in the sense of belonging to the climatic area.
- Location of the object in relation to the surrounding environment.
- Characteristics of the object from the point of view of its use, construction and technical parameters.
- Energy audit of the object.
- Device design taking into account previous results.
- Implementation of the obtained procedure as a possible methodology in the concept of the RES use in the given municipality or region in connection with existing registers.

The paper is written in accord with the following structure: the first part deals with materials and methods, including available data, present state of RES use in chosen countries and Slovakia and the process of the research (including four main steps of the research). The second part present results by the way of chosen heat pump summarization, calculation of energy consumption and the costs of electric energy and operation. A results summary of the proposed systems and comparing of the costs is provided. In the frame of the discussion part, the main results are discussed together with other similar researches, and the work is concluded by discussing the limitations and future possible orientation of the research.

2. Materials and Methods

The aim of the paper is to assess the economic and energy efficiency of selected types of RES (in this case, a heat pump) for heating in conjunction with solar collectors, which will be used to prepare hot water. During the research we examined the results data from the Eurostat and Slovakian databases [26,27].

The growth of the heat pump market is primarily influenced by the following trends:

- From a technological point of view, today's heat pumps can cover a wide range of temperatures. They work at an outside temperature of up to −25 °C and increasingly provide hot water with a temperature of up to 65 °C in an efficient way. Thanks to this, their installation is possible in a much larger proportion of buildings than ten years ago;
- The need to accelerate the energy transition in the heating and cooling sector has put heat pumps at the centre of attention of politicians in individual countries. Legislation adopted in the last 8 years is now transposed in all Member States, with its impact gradually beginning to show. Building standards limit the maximum heat demand per square meter, mandate the integration of renewable energy, and prioritize low-energy buildings;
- Constantly increasing demand and sales of heat pumps lead to their lower procurement costs. Economies of scale are reflected at the component and product levels. The rapid decrease in production costs of photovoltaic systems also affects the heating market, and the use of own electricity production in combination with a heat pump system provides a very cheap source of energy for buildings [28] (Figure 1).

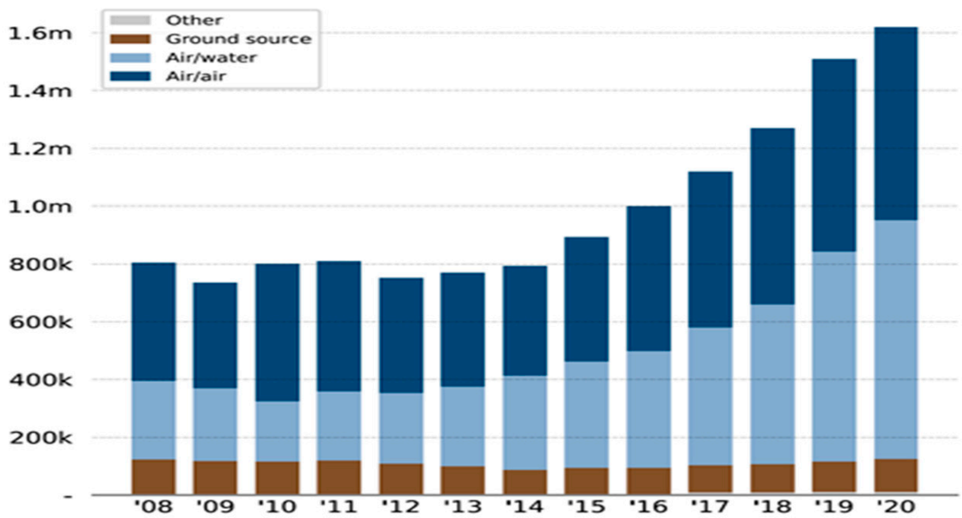

Figure 1. Heat pump sales over time [28].

Most heat pump markets have experienced significant growth. The highest relative gains were achieved by Poland (+43.8%), Germany (+37.2%) and the Netherlands (+30.5%). The declines are more significant only in Norway, where, in 2020, −12.6% fewer heat pumps were sold. The development of sales, especially during the COVID-19 pandemic, indicates a continued strong expansion of the heat pump market in Europe. While the Norwegian market is reaching its peak today, and the history of its development reveals a significant growth perspective for the whole of Europe as well. If all countries had the same market penetration of heat pumps as Norway, annual sales of heating equipment would be dominated by heat pumps. As a result, there would be a significant decarbonisation of the heating sector. In 2020, heat pumps with a heat output of 14.24 GW were installed, producing approx. 27.11 TWh of useful energy and incorporating 16.92 TWh of renewable sources in heating and cooling, avoiding 4.31 Mt of CO_2 equivalent emissions. This is good news for politicians, as it shows the huge untapped potential to reduce Europe's dependence on gas for heating, cooling, and hot water production. However, reaching the target by 2030 would require an annual growth rate of up to 15% and a huge effort in terms of framework conditions, building efficiency requirements and more [28].

Solar energy is rightly ranked as one of the simplest, most affordable and cleanest forms of renewable energy that can be obtained from the sun. The use of solar energy has no negative impact on the environment, provided that the installation of such equipment is appropriately located. There are many principles of transferring solar energy into other forms of energy: the most common is the conversion of solar energy into electrical energy using photovoltaic panels or thermal energy using solar panels. Electricity can be produced from solar energy either directly or indirectly. The direct transfer of solar energy into electrical energy takes place in PV cells using the photovoltaic effect. Transfer to thermal energy most often occurs in solar panels where the water is heated [29]. The solar collector is currently the most widely used technology for converting solar energy into thermal energy. Here, the sun's heat is heated on the black surface of the collector, which subsequently heats the water and stores it in reservoirs or distributes it as needed. Solar collectors are widely used in the private sector as well as in households. The ways of using solar connectors include heating of hot water in households, industry and commercial buildings, year-round or seasonal heating of pool water, and heating of various types of operations (buildings, greenhouses, saunas) [29].

The subsidy for RES use in Slovakia amounts to several thousand euros. Furthermore, owing to the state program, the share of RES in Slovakia's energy mix is increasing. This includes heat pumps and solar collectors, with the former being used for heating and hot water and the latter being primarily used for heating hot water and pool water, either separately or in combination with another source.

The EU as a whole has a RES rate averaging around 21.8%; Slovakia is long-term at around 17%. The improving of the index is only slight; for example, in 2020 it was 16.9% and in 2021 it was 17.3%. Therefore, the EU increased the goal in 2030 to achieve the RES rate, which was formerly 32% and raised to 45%. This is necessary for transforming the energetic system in all EU countries, including Slovakia. All this is illustrated by Table 1.

Table 1. RES rate in 2022 in chosen EU countries.

No	Country	Percentage Rate
5.	Slovakia	17.4%
1.	Sweden	62.6%
2.	Finland	41%
3.	Latvia	40.5%
4.	Austria	36.4%
6.	Hungary	14.1%
-	EU average	21.8%

Source: [30,31].

The structure of RES use in Slovakia is, according to Figure 2, given mostly to the gross consumption of the electricity, heat production and cooling and transport.

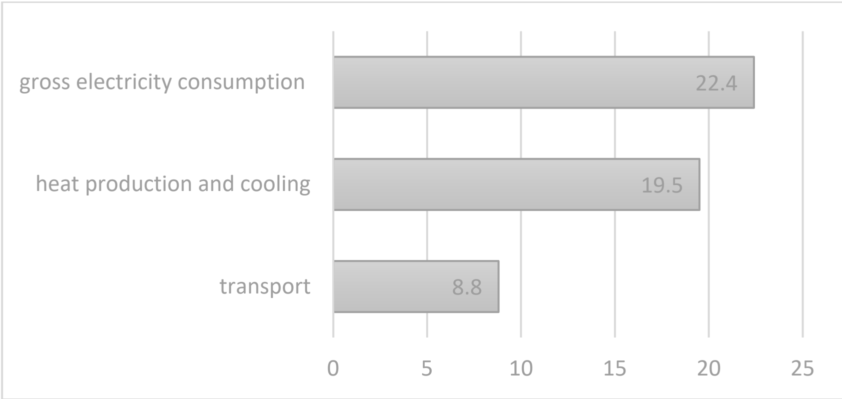

Figure 2. RES use structure in Slovakia (%). Source: [31].

In order to fulfil this objective, it is necessary to complete the following steps (see Table 2).

Table 2. Research chart.

Step 1	Characteristics of the locality	Meteorological and climatic characteristics	• Average temperature during the heating period • Number of frosty days; • depth of soil freezing; • Average monthly atmospheric precipitation total.
		Geological and hydrogeological conditions	• Geological construction; • Rock environment; • Depth and orientation of the underground water flow; • Abundance of wells.
Step 2	Analysis of chosen objects	Calculation of heat performance, heat need and heat losses	• Rooms ranking; • Building and construction elements; • Area of the heating space
Step 3	Suggestion of heat pumps	The choice of heat pump	• Climatic factors • Hydrogeological factors • Selection of heat pump type • Actual calculation of heat losses, heat input and heat demand
Step 4	Suggestion of solar collectors	A design of solar system	• Average intensity of solar radiation • Actual amount of energy • Heat needed for the hot water preparation • Thermal efficiency • Required area and No of collectors • Energy profit of solar system

Step 1: For the geological, hydrogeological and climate characteristics of the area, we utilized the Hydrogeological map of Slovakia from the Climate Atlas of Slovakia (Slovak Hydrometeorological Institute, Bratislava, Slovakia) from the archive of the State Geological Institute, Dionýz Štúr.

Step 2: Technical suggestions of buildings were based on the standard STN 73 4301 dwelling buildings (basic demands for suggestion of dwelling buildings, architectonic and functional demands, light and technical demands, acoustic and hygienic demands,

demands on static and operation security, demands on fire protection, demands on energetic savings and heat protection, demands on barrier-free use, urbanistic and architectonic demands, evaluation of eclipse time, diagram of shading).

As to the calculation of the heat input, heat demand and heat loss were processed according to the standard STN EN 12831-1: 2019 Heating systems in buildings, as well as the method for calculation of projected heat input and the orientation calculation of heat loss (less detail in comparing of STN EN):

$$\phi_{HL,build} = \sum_i \phi_{T,ie} + \phi_{T,iae} + \phi_{T,ig} + \phi_{V,build} + \sum_i \phi_{hu,i} - \sum_i \phi_{gain,i} \quad (1)$$

where

$\phi_{HL,build}$ design heat load of the building.

$\sum_i \phi_{T,ie} + \phi_{T,iae} + \phi_{T,ig}$ transmission heat loss due to the heat transmission directly or indirectly to the exterior for all heating spaces (1) according to paragraph 6.3.2 from STN EN 12831-1:2019.

$\phi_{V,build}$ ventilation heat loss of whole building according to paragraph 6.3.3 from STN EN 12831-1:2019.

$\sum_i \phi_{hu,i}$ sum of additionally power consumption for heating that are appearing at the same time at the external calculation conditions.

$\sum_i \phi_{gain,i}$ sum of heat profits that are appearing at the same time at the external calculation conditions.

In the case of the simplified calculation, the G coefficient is estimated based on the type of construction or insulation, or according to the estimation of the building construction depending on the time period of the construction. This means the calculation will be:

- Old house without insulation: G = 2;
- Old house additionally and partially insulated: G = 1.5;
- House constructed after 1990: G = 1.1;
- House constructed after 2005: G = 0.8;
- House constructed between 2010–2015: G = 0.6;
- House constructed after 2015: G = 0.4.

G can also be estimated by an expert comparison of heat input with similar objects in a given location (climatic area). Further considerations include whether the heat is involved only in the heating/cooling or also the preparation of hot water.

For the evaluation of energy demand and quantification of possible heat loss, the following heat-related and technical standards were used:

- STN EN ISO 13790:2008—Energy performance of buildings. Calculation of energy use for space heating and cooling;
- STN EN ISO 13789:2008—Thermal performance of buildings. Transmission and ventilation heat transfer coefficients;
- STN EN ISO 13370:2008—Thermal performance of buildings. Heat transfer via the ground
- STN EN ISO 10077-1:2007—Thermal performance of windows, doors and shutters. Calculation of thermal transmittance
- STN EN ISO 6946:2008—Building components and building elements. Thermal resistance and thermal transmittance
- STN 73 0540-2:2013—Thermal protection of buildings. Thermal and technical characteristics of building constructions and buildings, Part 2: Functional demands
- STN 73 0540-3: 2013—Thermal protection of buildings. Thermal and technical characteristics of building constructions and buildings, Part 3: Characteristics of the environment and construction products.

Step 3: The choice of a heat pump depends on several climate-related and hydrogeological factors. The type of heat pump is chosen as follows:

Air/air uses a gaseous medium as an environmental energy source (ambient air) and the heating is implemented as warm air (i.e., there is no water radiator); however, it is also possible to use the heat pump as an air conditioning unit in reverse operation.

In the case of an air/water heat pump, the priority is the water heating system, but compared to classic radiators (90/70 °C), the area of these radiators is larger, due to the lower output temperature; therefore, its use in floor or ceiling heating is ideal.

Water/water can be an open system (i.e., water flows from a watercourse or lake directly to the exchanger) or a closed system (water serves as a mean of transfer of the heat to another medium in a closed system, e.g., the exchanger is in contact with alcohol or ethylene glycol and the medium heat from water).

Ground/water is similar to a closed water/water system, with the difference being that energy is taken from the ground and the system is installed at a non-freezing depth. The thermal conductivity of the soil is important here, and the exchanger is located in the well.

Thus, the power input of the heat pump must cover heat loss and reserve. As a rule, a nominal power of 70% of the heat pump power is considered. An important factor here is COP (Coefficient of Performance), which determines the ratio of heat output to electrical input (note, this is not efficiency, because this number is always greater than 1, it is usually at the level of 3 to 4.)

The analysis of the energy profit of solar system is based on the global solar radiation for the given location as well as by measuring in situ or using a climatological model (provided for a fee by SHMÚ) through a GIS system or from the Climate Atlas of the Slovak Republic. That is the theoretical amount of solar radiation. In addition, the real amount of radiation is determined by the shading of the panels or cloud cover.

After these analyses, the actual calculations of heat losses, heat input and the heat demands were performed using the technical standard STN EN 12831-1 and the day-degree method. Based on the results achieved, we move on to the selection and description of heat pumps before then choosing the most suitable alternative.

Step 4: As a result of the analysis, a design of solar systems is created for each building based on the average intensity of solar radiation and the actual amount of energy that falls per day on [m^2] of the illuminated area and the ambient temperature. Subsequently, the heat needed for the preparation of hot water and the thermal efficiency, the required area and the number of solar collectors was calculated. Based on the results, an analysis of the energy profit of the solar system was made comparing the costs of our proposed solutions with an electric and gas boiler.

3. Results

As a part of the research, we assess the economic and energy efficiency of the heat pumps and solar systems that we have designed for the given buildings. For heat pumps, we will determine the energy consumption that the heat pumps will need to be able to function in operation. Then, we will calculate the annual costs associated with this operation and compare the results with the annual costs for an electric boiler.

In the case of solar systems, we will determine how much consumption the given system can cover in a year and find out by how much the annual cost for the preparation of hot water will be reduced. Subsequently, we will compare it with the annual costs for a gas boiler. Due to getting to know the conditions that prevail on the site, determining the heat losses, calculating the heat input and the need for heat for heating, we were able to select the most suitable heat pumps for each object. The selection is shown in the following Table 3.

Table 3. Summary of the chosen heat pumps.

Building	Building 1	Building 2	Building 3
Heat pump	Alterra SWC 102K3 (Ait Slovakia, Ltd. Bratislava, Slovakia)	Vitocal 200-S 230 V, type D10 AWB-M-E-AC 201.D (Imperials, Ltd., Trnava, Slovakia)	Vitocal 200 g 400 V BWC 201.B10 (Imperials, Ltd., Trnava, Slovakia)
Power consumption [kW]	9.34	12.6	9.8
Type	ground-water	air-water	water-water

Source: own processing according to www.alphainnotec.sk; www.ozonius.sk (accessed on 21 December 2023) [32–37].

With such evaluation, we must consider the thermal performance of the heat pump and the performance number given by the manufacturer. The number expresses the ratio of the pump's heat output and the pump's electrical input. Thanks to this number, and the need for heating heat, we can determine the consumed electrical energy using the following relationship:

$$Consumed\ electrical\ energy\ [\text{kWh}] = \frac{heat\ need}{performance\ number} \tag{2}$$

The data and the results, obtained by the calculation, are presented in Table 4.

Table 4. Energy consumption.

Building	Building 1	Building 2	Building 3
Heat pump	Alterra SWC 102K3	Vitocal 200-S 230 V, type D10 AWB-M-E-AC 201.D	Vitocal 200 g 400 V BWC 201.B10
Performance number	5.05	5.0	5.3
Heat demand: [kWh/year]	11,141.19	16,051.9	12,463.83
Energy consumption [kWh/year]	2206.18	3210.38	2351.67

Source: own processing according to www.alphainnotec.sk; www.ozonius.sk (accessed on 21 December 2023) [32–37].

With the data available, we can determine the estimated costs that are necessary for the operation of the heat pump. We will find out the price of electricity at the VSE (Eastern Slovakian Electricity Power Plants) distributor. We choose the D6 EKO DOM tariff. The achieved results are summarized in Table 5.

Table 5. Costs of electric energy.

Building	Building 1	Building 2	Building 3
Heat pump	Alterra SWC 102K3	Vitocal 200-S 230 V, type D10 AWB-M-E-AC 201.D	Vitocal 200 g 400 V BWC 201.B10
Energy consumption [kWh/year]	2206.18	3210.38	2351.67
Price of electricity [EUR/kWh]		0.1420	
Electricity costs [EUR]	313.28	455.87	333.94

Source: own processing according to www.alphainnotec.sk; www.ozonius.sk; www.thermosolar.sk (accessed on 21 December 2023) [32–39].

Based on the data, we can compare the annual costs with another heating source (in our case, an electric boiler.) We know the initial costs of purchasing a heat pump. With a heat pump functioning on the air-water principle, we only need to count the purchase of the equipment and the costs of floor heating. In the case of the ground-water heat pump, the initial costs will be higher due to ground collectors, and for a water-water heat pump, the costs will increase due to the drilling work on the exploitation and infiltration well. To calculate the cost, it is necessary to consider increasing of cost of carbon emissions, analysed with reference to the EU standards [40]. However, we will only deal with the prices of the devices and their operating costs during the year, which we will then compare.

The prices of electric boilers vary widely, but the maximum price is at the level of EUR 3000. We chose the D5 KOMPLET tariff for electric heating take-off points at a price of 0.1420 [EUR/kWh], which is the same as the D6 EKODOM tariff we mentioned for heat pumps.

The following graph in Figure 3 shows a comparison of the annual costs of operating a heat pump and an electric boiler. As the graph demonstrates, the annual operating costs of an electric boiler are several times higher than the costs of a heat pump. It is true that, in the case of new buildings, the initial investment in purchasing a heat pump is higher than in the case of an electric boiler, but we can use a government subsidy that will help us reduce the costs. Moreover, heat pumps have a long service life, there is an instability in the energy market and energy prices constantly increase. When we consider these factors, in the end, the investment in heat pumps is convenient; nevertheless, it is higher at the beginning. However, over the course of a few years, it will gradually return to the investor as money saved, which would be paid for through the energy consumed during the operation of the electric boiler.

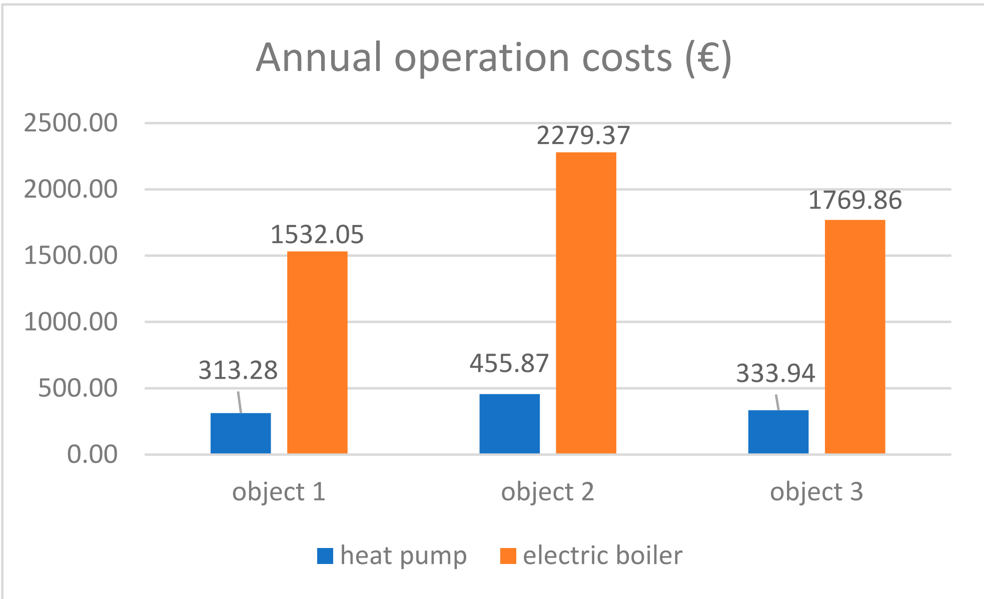

Figure 3. Comparison of annual operation costs. Source: own processing.

Based on the collected data and the calculations, we tried to design a solar assembly for each building consisting of solar collectors and a hot water tank. When assembling, we took into account the parameters of the collectors, which have an impact on the resulting energy production and thus can affect the energy efficiency. The second factor was the price of the system, as we tried to find a solution that would be as economically efficient as possible. In Table 4, we can see a summary of the proposed systems and a cost comparison between a gas boiler and a combination of a gas boiler and solar collectors. As Table 6 shows, thanks to the proposed solutions, the costs of heating hot water will drop significantly. The initial costs of purchasing solar systems are initially high, but, thanks to the state program Green Homes, we are able to reduce the costs significantly, and, over time, the investment will begin to return in the form of saving the money that would been used to pay for gas.

Table 6. Summary of proposed systems and costs comparison.

Building	Building 1	Building 2	Building 3
Solar assembly	3 × collector Viessmann Vitosol 100-FM SH1F, 1 × hot water tank (Imperials, Ltd., Trnava, Slovakia)	4 × collector Viessmann Vitosol 200-FM SV2F, 2 × hot water tank (Imperials, Ltd., Trnava, Slovakia)	4 × collector Thermosolar TS 300, 1 × hot water tank (Thermosolar Slovakia, Žiar nad Hronom, Slovakia)
Gas consumption without collectors [kWh/year]	4206	7360	5260
Gas consumption with collectors [kWh/year]	1198	2149	1386
Gas price [EUR/kWh]		0.043	
Gas costs without collectors [EUR]	180.86	316.48	226.18
Gas costs with collectors [EUR]	51.51	92.4	59.6

Source: own processing according to [32–43].

4. Discussion

The consumption of electrical energy to drive the heat pump results from the COP (which ranges from 3 to 4), i.e., by consuming 1 kW of electrical energy, the heat pump produces the equivalent of 3 to 4 kW of thermal energy (note that energy is not about "production", only about transformation from one form to another, or changes in the "density" of energy, because the heat pump works with a medium with a temperature of 4–12 °C at the input and 53–69 °C at the output, depending on the working medium used, the so-called "refrigerant"). Since the output temperature is lower than the standard temperature of the heating elements (90/70), it is necessary to increase the heat exchange surface of the heating elements, or installation of floor/ceiling heating and installation of an additional heat source, in case of increased heat consumption (direct electric heating that is part of the heat pump circuit). There are several bases for comparison:

1. Comparison of current energy consumption with the proposed solution (based on previous energy bills);
2. Comparison with purely electric heating.

The paper is dedicated to both existing households that wish to switch from traditional sources to RES, or use a combination of sources, and to new constructions, in the case of which it is advised to consider a heat pump as a heating source right from the start. To achieve the main objective of the paper, we first addressed the current state of the problem in Slovakia and abroad. Next, we continued with the analytical part, in which we analysed the climate and meteorological, geological, and hydrogeological conditions of the chosen location in detail. We mainly focused on the average monthly temperatures, the average temperature during the heating season, total precipitation, geological structure, depth, and abundance of groundwater. This kind of analysis is necessary, as the heat pump is a device that uses the energy of the environment. In the next step, we suggested the buildings. We focused mainly on room layouts and the building and construction materials, as their properties have an impact on the heat loss of the selected objects. Subsequently, according to the technical standard STN EN 12831-1, we calculated heat losses and heat input, determining the total heat demand using daily temperatures. Based on the results achieved, we moved on to the selection and description of heat pumps. Using all the data obtained and the subsequent comparison, we selected the most suitable alternative for each building.

Next, we focused on the design of solar collectors for selected buildings. The necessary step was to determine the values of the average intensity of solar radiation, the actual amount of energy that falls per day on [m^2] of the illuminated surface, and the ambient temperature. This was followed by the calculation of the heat demand for hot water heating [44], thermal efficiency, required area, and number of solar collectors. The last step was the analysis of the energy gain of solar systems and their eventual optimization. After the calculations, we performed an energy and economic evaluation of our solutions by comparing the operating costs of electric and gas boilers. Based on this comparison, we concluded that our proposed solutions were energetically and economically efficient.

RES use and RES development has a barrier, resulting especially from the different conditions of EU countries [45], particularly the political, administrative, infrastructural and socio-economic aspects. The European Union is a consistent region regarding the speed of renewable energy advancement, and the obstacles to such progress are not accurate [46]. Since the paper is limited to the case of Slovakia, future research would be orientated to the comparing of the situation in other EU countries, especially from the view of the V4 group situation. However, presented results could be used for improving of the state policy, as well as the development of regions and communities in the area of RES use in Slovakia, which could contribute to the improving of the development of regions and countries.

5. Conclusions

The analysis of photovoltaic and solar thermal technologies in this study provides a valuable insight for the government of the country in identifying the best projects for solar energy technologies. The results of the research should support investment decision-making in business and industry investment strategies to aim for the economic development of the renewable resource industries. It offers an evaluation of the potential and economic performance of other industries, with a possible comparison with European countries and potential investors worldwide. The research is limited, as it fails to take into account the uncertainty in the power availability of RES, which can be included in future research in tandem with including and extending the evaluation by the ecological effectiveness.

This paper is limited to the evaluation of the use of the chosen RES type (mainly heat pump and solar collector) in Slovakia from the perspective of economic and energy effectiveness. Due to the 3E approach, the future research would be extended to the evaluation of the environmental effectiveness to a provide triple bottom line (people, profit, and planet) in the area of RES use. Concerning the technical and economic analysis of the RES use, it would be equally beneficial to consider the net present value evaluation (NPV), as determined by Ahmad and Zhang and Poudyal et al. [47,48]. According to Ma and Javed, it is optimal to make hybrid system of RES [49]. Analysed RES types can be considered for RES microsystems and hybrid photovoltaic systems, which could be better in comparison to other energy sources [50,51]. To make an effective energy system, the combination of solar water heaters and smart buildings can be considered as well, as determined by Zening et al. [52]. The evaluation of RES use can be compared before and after the COVID-19 crisis [53]. The presented results provide valuable information for the next evaluation, as mentioned above.

The suggested methodology can be a base for local administrations and communities to create plans with the goal to extend RES use in administrations and regions. With connection to the application "List of Buildings" led by the Office of Geodesy, cartography and cadaster of Slovakia [54], it would create strong support for extension of knowledge and use of concrete types of RES with orientation to the specific conditions in a given area.

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