

## The Potential and Utilization of Solar Energy for Water and Space Heating in Households in the Autonomous Province of Vojvodina (Serbia)

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This paper investigates the potential and application of solar energy for space and water heating in the Autonomous Province of Vojvodina, Serbia. Vojvodina is characterized by a favorable geographical position, receiving between 2000–2400 hours of sunshine annually, which makes it a suitable region for solar energy utilization. In residential applications, solar thermal systems can meet up to 60–70% of the annual hot water needs of households in Vojvodina. The economic benefits include significant cost savings on energy bills and reduced dependency on conventional fuels. Installing this system in a four-member household would save around 2,400 kWh of electricity annually, valued at approximately 120 EUR. Environmentally, solar heating reduces greenhouse gas emissions and supports Serbia's climate commitments. The practical utility of this study lies in its potential to inform energy policy and promote sustainable energy practices, reducing dependence on non-renewable energy sources and contributing to environmental conservation.

**Keywords:** Emissions reduction, Energy efficiency, Renewable energy, Solar collectors, Solar radiation

### Introduction

Solar energy represents crucial resources for transition to sustainable energy sources at global efforts. In the context of increasing awareness of environmental challenges and the need to reduce greenhouse gas emissions, solar technology is gaining prominence as an efficient means of meeting energy needs.<sup>1,2</sup> Solar heating of spaces and water specifically constitutes a vital area of research and application.

In the context of global efforts to reduce CO<sub>2</sub> emissions and the demand for alternative energy sources, solar heating of spaces and water has proven to be a promising option.<sup>3,4</sup> Numerous studies indicate significant reductions in greenhouse gas emissions and energy savings through the application of solar systems. Additionally, various research highlights the long-term economic benefits of solar systems, further underscoring the importance of this technology in the context of sustainable development.<sup>5,6</sup>

Solar energy is highly attractive and economically justified for use in heating households, industrial, and other buildings. Solar systems enable significant energy savings.<sup>7,8</sup> For example, a well-designed solar

house can save up to 40% of energy for heating and up to 80% of energy for heating sanitary water. It utilizes the significant potential offered by roof and façade solar collectors to provide additional energy.<sup>9,10</sup> Solar systems ensure better energy efficiency, significant energy savings, durability, energy output, return on investment through the obtained energy, a favorable cost-performance ratio, and simple installation.<sup>11,12</sup>

Several recent studies have explored various aspects of solar energy utilization, particularly focusing on the efficiency of different types of solar collectors and their applications in heating systems. For instance, Kalogirou (2004) provides a comprehensive review of solar thermal collectors and their applications, highlighting the advancements in solar energy technology.<sup>13</sup> Additionally, Ji *et al.*<sup>14</sup> studied dual-function solar collectors for space heating, which is highly relevant for regions with similar climatic conditions as Vojvodina.<sup>14</sup>

Other notable works include the research by Ozgener and Hepbasli (2007), which reviews the energy and exergy analysis of solar-assisted heat pump systems. This study emphasizes the importance of integrating solar energy systems with existing

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heating technologies to enhance overall efficiency and sustainability.<sup>15</sup>

In Serbia and Vojvodina, the use of solar energy for heating sanitary water or space is currently minimal, although recent years have seen an increase in its application with the support of state institutions, donations, and user financing. About 55% of the total energy consumed in households in Serbia (and Vojvodina) is supplied by electricity produced by conventional means, a significant portion of which is used for heating sanitary water. It is estimated that using solar energy throughout the year can reduce the costs associated with heating sanitary water by about 60 to 70%.<sup>16,17</sup>

According to the Serbian Energy Efficiency Agency, energy consumption in Serbia could be reduced by more than 50% with more efficient heating and improvements in industrial energy efficiency. Greater use of solar energy in Serbia could achieve significant energy savings and reduce carbon dioxide emissions by about 305,000 to 360,000 tons over a five-year period.

This research focuses on identifying the potential of solar energy to reduce reliance on conventional energy sources and to achieve significant cost savings for households. The potential for cost savings and energy efficiency improvements through solar power is substantial, yet the utilization remains underdeveloped.<sup>18</sup>

Recent papers have highlighted the various benefits and efficiencies of solar energy systems (Chen *et al.* 2022; Zhao *et al.* 2022). However, gaps remain in the widespread adoption and optimization of these systems, particularly in regions like Vojvodina where solar energy could play a pivotal role in sustainable energy strategies. Innovations in solar technology and increased governmental support are crucial for advancing the adoption and efficiency of solar energy systems in these region.<sup>19,20</sup>

**Materials and Methods**

**Solar Radiation in Vojvodina**

According to Valentin Energie Software - TSol Pro 4.5, the average annual value of global radiation for a horizontal surface ranges between: 1,294 kWh/m<sup>2</sup> in northern Vojvodina to 1,335 kWh/m<sup>2</sup> in southern Vojvodina; 1,281 kWh/m<sup>2</sup> in the west to 1,294 kWh/m<sup>2</sup> in the east of Vojvodina. The average daily energy of global solar radiation on a horizontal surface in Vojvodina varies from 1.0 to 1.4 kWh/m<sup>2</sup> during January, and from 6.0 to 6.3 kWh/m<sup>2</sup> during July. The ratio of direct to diffuse radiation depends on geographical and microclimatic conditions. Diffuse radiation accounts for 40–60% of global radiation on an annual average, with a higher proportion during the winter months.<sup>18,21</sup>

The solar map of the Autonomous Province of Vojvodina is shown in Fig. 1.<sup>(18)</sup> Average daily values of solar radiation on a horizontal surface for specific locations in Vojvodina are presented in Fig. 2. Comparative analyses of the average values of solar

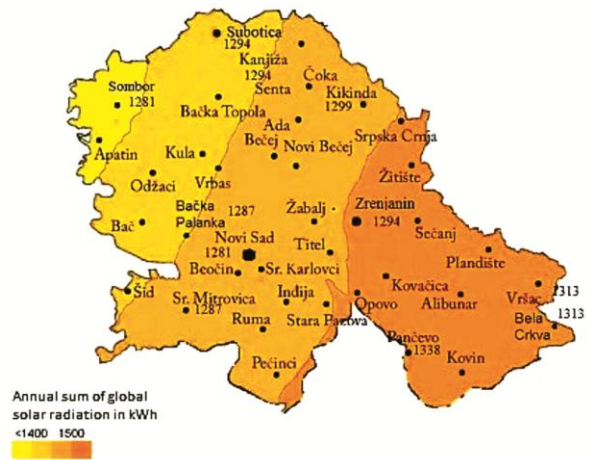


Fig. 1 — Solar map of AP Vojvodina with year zones of sunny spell intervals in kWh/m<sup>2</sup>

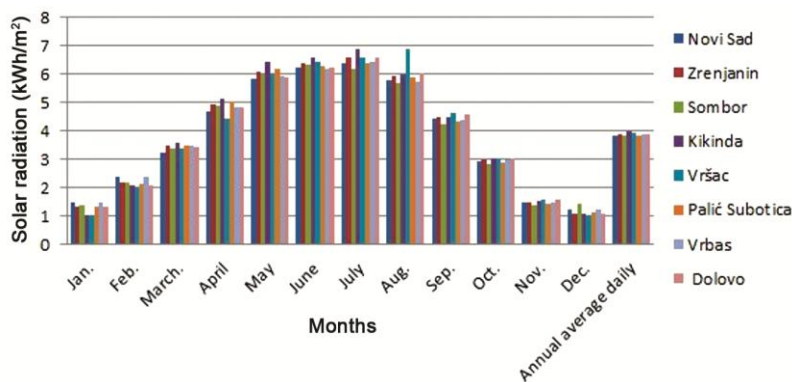


Fig. 2 — Month-wise average daily values of solar radiation on horizontal surface (kWh/m<sup>2</sup>) for some places in Vojvodina

radiation on a horizontal surface for Novi Sad, as the capital of Vojvodina, and other cities in Vojvodina are presented in Fig. 3.

Thermal solar systems are most commonly used for heating domestic hot water, technical water, swimming pool water, and similar applications. They can also support space heating in various types of buildings, including houses and halls. This application is more suitable for buildings utilizing low-temperature heating systems (such as floor, ceiling, or wall heating) that are well-insulated, meaning their heat losses are on par with low-energy buildings.<sup>22,23</sup> In the climatic conditions of Vojvodina, solar technologies are combined with other heating sources to ensure sufficient heat supply during periods of low or no solar radiation (such as evenings, mornings, nights, and winters).

**Utilization of Solar Energy for Household Energy Needs**

In the Autonomous Province of Vojvodina, households account for approximately 52% of total electricity consumption, industry about 27%, the energy sector about 2.9%, and other consumption around 18.4%. For thermal energy consumption, households account for about 73.6%, industry about 1.3%, and other consumption about 25%. These data indicate that households are the predominant consumers of both types of energy, highlighting the importance of energy consumption rationalization and

the need to pay special attention to the application of renewable energy sources, particularly solar energy. If the costs for domestic hot water preparation and heating are high due to inefficient heating methods or expensive fuel financial savings will be greater when using solar heating systems.

It is also confirmed that solar heating does not release harmful emissions into the atmosphere that would contribute to the greenhouse effect or climate change.<sup>18,24</sup> A functional collector with a surface area of 2 m<sup>2</sup> reduces carbon dioxide (CO<sub>2</sub>) emissions by 500 to 1,000 kg per year.

**Solar Heating of Domestic Hot Water**

The most commonly used systems are closed active systems for solar heating of domestic hot water, such as "Solkom 2," which consist of a primary and secondary installation circuit. The efficiency of using such a system with a central water heater is favorable because it eliminates the need for multiple water heaters in a household. Additionally, during winter, the solar water heater can be heated via the central heating system, electric heating, or another supplementary heating method, and the system operation is automated. On an annual basis, solar collectors can save on average 60 to 75% of the energy needed for domestic hot water preparation per household. The share of solar energy can, of course, be increased, but in such cases, the investment costs per unit of obtained heat rise exponentially. Solar heat for domestic hot water preparation is suitable for use wherever there is high hot water consumption.<sup>9,25</sup> In family homes, using standard collectors for heating domestic hot water typically achieves temperatures of 45 to 60°C.

Knowing the daily hot water consumption allows for determining the storage tank volume. It should be 2 to 2.5 times the daily consumption to cover peak consumption and also bridge periods without solar radiation.

The approximate dimensions of solar water heating systems based on the number of household members are provided in Table 1. The energy effects of the solar collector (tilt angle - 45 degrees) per square meter for the city of Zrenjanin are presented in Table 2. The average daily useful amount of heat in kWh/m<sup>2</sup> and the required collector area by month in m<sup>2</sup> are presented in Fig. 4.

According to the results of research conducted by the European association "INTERATOM," the cost of heating water for households using flat solar

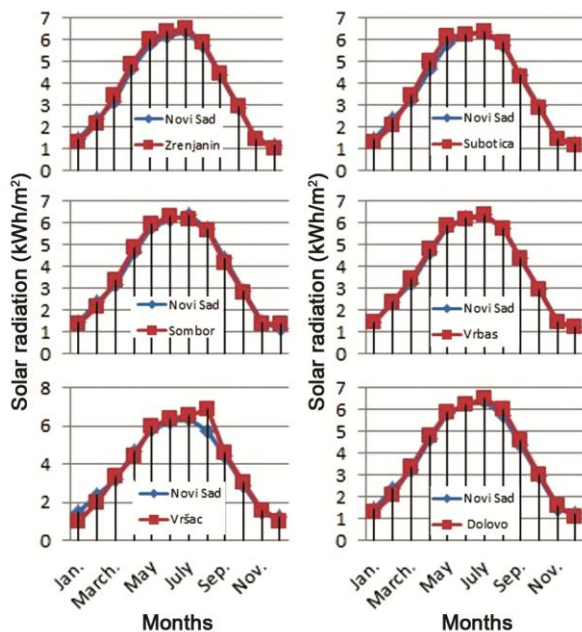


Fig. 3 — Comparative analyses of the month-wise average daily solar radiation values on a horizontal surface (kWh/m<sup>2</sup>) for Novi Sad versus other cities in Vojvodina

Table 1 — Approximate sizing of solar water heating systems based on household size

Number of users	Collector area (m <sup>2</sup> )	Reservoir volume (Liters)
2–3	3–4	200
3–4	5–6	300
4–5	6–7	400

Table 2 — Needed surface area of solar collector for known average value of needed heat energy (example for needed average 10 kWh of daily heating energy location - Zrenjanin, inclination-45° – average energy efficiency – 0.45)

—	Average daily usable heat (kWh/m <sup>2</sup> )	Total monthly usable heat (kWh/m <sup>2</sup> )	Monthly needed collector surface area (m <sup>2</sup> )
January	1.553	48.148	6.438
February	1.862	52.148	5.369
March	2.406	74.597	4.156
April	2.800	84.010	3.571
May	3.104	96.213	3.222
June	3.186	95.583	3.139
July	3.601	104.164	2.976
August	3.372	104.527	2.969
September	3.104	93.1162	3.222
October	2.555	79.2185	3.913
November	1.732	51.972	5.772
December	1.500	46.506	6.666

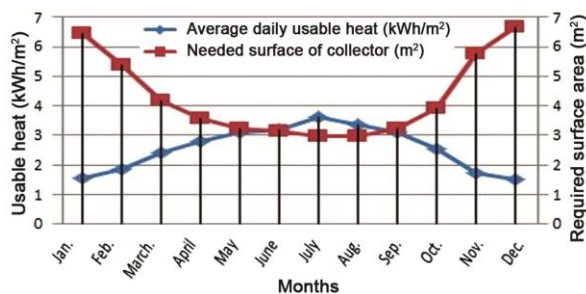


Fig. 4 — Average daily usable heat quantity in kWh/m<sup>2</sup> and needed surface of collector by months in m<sup>2</sup>

collectors, in areas with more than 1,600 hours of sunshine per year already 1:1 compared to other water heating systems.

To illustrate a simple calculation of investment payback time, consider an example related to a portion of domestic hot water preparation in a family house. Required investments range from 15 to 25 EUR/m<sup>2</sup>, or 900 to 1,500 EUR per household. The effectiveness of heating domestic hot water from April to October is approximately 80% of the required energy, while from October to April, this coverage is around 30%.

#### Solar Heating of Houses

During the winter period, the overall energy impact of solar radiation is lower than in summer but still

significant for use in house heating systems as a supplementary heating source. This way, up to 30% or more of the heat energy required for heating houses can be covered. Solar systems cannot be sufficiently utilized for central water heating systems during the coldest periods—winter. However, as soon as external conditions become more favorable, the potential to use heat from solar energy collectors increases. The best effect of using solar energy for heating family houses and other residential-commercial buildings is achieved during the transitional periods between autumn and winter, and between winter and spring, and also during winter with better sunshine. Even such energy contributions are significant, and the greatest effects are achieved in energy-efficient houses (high thermal insulation characteristics) and energy-efficient heating systems (floor-wall systems), i.e., low-temperature heating systems.<sup>26,27</sup>

Due to the variability of solar radiation (intensity of power) throughout the day, month, and year, it is neither economically justified nor technically feasible to install solar heating systems that would enable complete heating of houses throughout the winter period. For the same reasons, solar heating systems are combined with systems using other energy sources, which consume conventional forms of energy: liquid fuel, gas fuel, electricity, solid fuel, etc. The solar technology market demands increasingly better solutions for solar collectors with higher energy efficiency.

Economically, it is important to note that solar installations cannot fully cover 100% of the energy needs of a family house for its complete heating. Solar heating can cover approximately 15 to 40% of the annual energy needs of a well-insulated building equipped with a low-temperature heating system (floor, wall, or ceiling heating).

#### Results and Discussion

Vojvodina annually receives an average of about 2,000 to 2,100 hours of sunshine. If every household in Vojvodina (630,000 to 700,000, including weekend and auxiliary buildings) had just one solar collector with a surface area of 2 m<sup>2</sup> for heating sanitary water, the annual energy savings would be equivalent to the thermal energy obtained by burning approximately 700,000 × 2 m<sup>2</sup> × 100 liters/m<sup>2</sup> = 140,000,000 liters of oil or about 1.4 × 10<sup>9</sup> kWh of energy. Over an operational lifespan of 30 to 50 years, this would amount to about 4 × 10<sup>6</sup> to 7 × 10<sup>6</sup> tons of e.N. The results and key analyses of this study are presented in Table 3.

Table 3 — Results and key analyses of study

Parameter	Value
Average sunny hours per year in Vojvodina	2,000 to 2,100 hours
Households in Vojvodina	630,000 to 700,000
Solar collector area per household	2 m <sup>2</sup>
Energy saved per year	1.4 × 10 <sup>9</sup> kWh (1.4 × 10 <sup>6</sup> MWh)
Energy equivalent in oil	140,000,000 liters
Exploitation period energy savings (30 to 50 years)	4 × 10 <sup>6</sup> to 7 × 10 <sup>6</sup> tons of e.N.
The potential of solar collectors for water heating in Vojvodina	1.4 × 10 <sup>6</sup> to 2.8 × 10 <sup>6</sup> m <sup>2</sup>
Number of thermal solar collectors needed	500,000 to 1,400,000
Average annual energy provided by collectors	800 to 1,600 million kWh (800 GWh to 1,600 GWh)
CO <sub>2</sub> emissions reduction	232,000 to 464,000 tons annually
Energy gain in winter per m <sup>2</sup> per day	1.2 to 3.0 kWh
Monthly energy gain per m <sup>2</sup> in winter	36 to 90 kWh
Annual heating season energy gain per m <sup>2</sup>	360 kWh
Optimal inclination for annual solar radiation	40° to 45°
Optimal inclination for summer	30°
Optimal inclination for winter	60°
Increased annual sun radiation at 30° inclination	13–14%
Increased annual sun radiation at 45° inclination	12–13%

For approximately 700,000 households with 2 to 4 m<sup>2</sup> of solar collectors per household in the Autonomous Province of Vojvodina, and the average use of installations for heating sanitary water to temperatures meeting technical requirements of 40 to 50 °C, there is a potential for the application of 1,400,000 to 2,800,000 m<sup>2</sup> of solar collectors for water heating needs in all households in Vojvodina.

These are quantities ranging from a minimum of 500,000 to a maximum of 1,400,000 thermal solar collectors with an average unit surface area of about 2 m<sup>2</sup>. From an energy perspective, such a number of solar collectors (with an average annual efficiency of 800 kWh/m<sup>2</sup>) could provide approximately 800 to 1,600 million kWh of energy annually. This energy, primarily in the form of thermal energy, would largely replace the equivalent consumption of electrical energy and partially substitute fossil fuels used for heating domestic hot water. Consequently, this would enable a reduction in carbon dioxide emissions by approximately 232,000 to 464,000 tons per year.

During the winter period, the total energy effect of solar radiation is lower than in summer but still

efficient enough for use. For example, from commercial types of solar collectors, energy obtained during the heating season—per square meter and per day—ranges (depending on the month and location) from 1.2 to 3.0 kWh. This means that PSE (Photovoltaic Solar Energy) can transfer to a heat consumer from 36 to 90 kWh per month from one square meter of collector surface. During the heating season, the effect of solar radiation can yield about 360 kWh of thermal energy per square meter of PSE.

For the territory of the Autonomous Province of Vojvodina, the optimal slope solar collector for a south-facing surface to maximize solar radiation capture throughout the year is an angle of about 40 to 45°. For solar collectors primarily used in the warmer part of the year (late spring, summer, early autumn), when better effects are expected, the optimal slope is around 30°. For solar collectors expected to perform better in the colder part of the year (late autumn, winter, early spring), the optimal slope is about 60°. For example, a surface inclined at an angle of 30° annually receives about 13 to 14% more irradiated energy than a horizontal surface. For a surface inclined at an angle of 45°, the annual irradiated energy value is about 12 to 13% higher than a horizontal surface.

Solar/thermal energy systems for heating domestic water are designed to dominate water heating during the warmer half of the year. In winter, hot water is typically provided by boilers that usually operate on electricity or indirectly from the building's conventional heating system, with solar thermal energy systems supporting on sunny days. This means that annually, about 60% of the energy needed for heating domestic water can be supplied by solar thermal energy systems.

In solar hybrid systems (with more solar collectors), some building heating is also provided during autumn and spring months. Optimally designed installations can supply 20 to 40% of the building's total energy needs, depending on how well it is insulated and the required heating degree. For specially designed buildings—houses using passive solar heating principles can cover 50 to 90% of the building's energy needs.

The potential energy savings identified in this study, which consider the application of solar collectors for water heating in Vojvodina, are supported by extensive research into the efficacy of solar thermal systems in similar climatic conditions. For instance, Duffie and Beckman (2013) in their

comprehensive study on solar engineering highlighted that regions with moderate insolation levels, such as Vojvodina, can significantly benefit from solar water heating systems, particularly when optimal system design and installation practices are employed.<sup>28</sup>

Furthermore, the environmental benefits, including the reduction in CO<sub>2</sub> emissions, align with findings from a study by Lund *et al.*<sup>29</sup>, who examined the broader impacts of integrating solar energy into existing energy infrastructures. Their research showed that in regions with similar energy demands, solar thermal systems not only reduce reliance on fossil fuels but also contribute to energy security and long-term sustainability goals.<sup>29</sup>

Moreover, Quaschnig (2016) provides an analysis of the seasonal variations in solar energy production, emphasizing that even during winter months, solar thermal systems can provide a meaningful contribution to energy needs, particularly when integrated with other renewable energy sources.<sup>30</sup> This supports the findings of this study, which indicate that solar collectors in Vojvodina can supply a significant portion of household energy needs, even during the colder months.

Despite its potential, the widespread adoption of solar heating in Vojvodina faces challenges such as high initial costs for installation and equipment, which can be a barrier for both residential and commercial users, as well as the need for trained professionals to effectively design, install, and maintain solar heating systems.

To overcome these barriers, several measures can be recommended:

- Increased government incentives for solar installations can reduce the financial burden on consumers.
- Investing in training programs for technicians and engineers can build the necessary technical expertise at the local level.
- Supporting research and development of solar technologies can lead to more cost-effective and efficient solutions tailored to the specific climatic conditions of Vojvodina.

By addressing the technical and financial challenges through targeted policies and incentives, Vojvodina can harness its solar potential to promote sustainable energy practices and contribute to broader climate goals.

Future research should focus on overcoming these barriers through innovative solutions and supportive policies that encourage the adoption of solar energy systems.

For commercial buildings and industrial processes, larger solar thermal installations can be utilized. These systems are often coupled with thermal storage solutions to manage demand fluctuations and ensure a consistent energy supply. Industrial applications in Vojvodina, such as food processing and textile manufacturing, can particularly benefit from solar process heat.

## Conclusions

This structure provides a comprehensive academic paper on the application of solar energy for heating purposes in Vojvodina. It includes an introduction, exploration of technologies, applications, benefits, challenges, and recommendations. The application of solar energy for space and water heating in Vojvodina holds significant promise, offering both economic and environmental benefits. By addressing the technical and financial challenges through targeted policies and incentives, Vojvodina can leverage its solar potential to foster sustainable energy practices and contribute to broader climate goals. In residential settings, solar thermal systems can provide a significant portion of the energy required for water heating and space heating. Studies have shown that in Vojvodina, a well-designed solar thermal system can cover up to 60–70% of a household's annual hot water needs. For space heating, combining solar thermal systems with energy-efficient building designs can substantially reduce reliance on conventional heating fuels.

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