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Solar water heating in cachoeira do sul: a feasibility and impact assessment

Aquecimento solar de água em Cachoeira do Sul: uma avaliação de viabilidade e impacto

Rithiele dos Santos Ferreira[I], Eduardo Gonçalves Trindade [I], João Vitor Hoffmann Spode[I], André Francisco Caldeira[I], Carmen Brum Rosa[I]. Charles Rech[I], Cristiano Frandalozo Maidana[I], Simone Ferigolo Venturini[I]

[I] Universidade Federal de Santa Maria, Cachoeira do Sul, RS, Brazil

ABSTRACT

This project aims to evaluate the viability of implementing solar water heating systems for homes in Cachoeira do Sul. It will also analyze how this technology influences the comfort and well-being of residents and its contribution to environmental sustainability through the use of renewable energy. The study will detail the technology's operation and explore its practical applications, highlighting key considerations. Ultimately, the goal is to determine if such a project is feasible, efficient, and meets homeowner needs regarding usability and cost-effectiveness, while also promoting environmental sustainability. In essence, this project will assess the feasibility, analyze the impact on residential well-being, and investigate the sustainability benefits of implementing solar water heating systems in Cachoeira do Sul residences.

Keywords: Sustainability; Water heating; Solar energy

RESUMO

Este projeto tem como objetivo avaliar a viabilidade da implementação de sistemas de aquecimento solar de água para residências em Cachoeira do Sul. Além disso, analisará como essa tecnologia influencia o conforto e o bem-estar dos moradores e sua contribuição para a sustentabilidade ambiental por meio do uso de energia renovável. O estudo detalhará o funcionamento da tecnologia e explorará suas aplicações práticas, destacando os aspectos essenciais. Em última análise, o objetivo é determinar se esse tipo de projeto é viável, eficiente e atende às necessidades dos proprietários em termos de usabilidade e custo-benefício, ao mesmo tempo que promove a sustentabilidade ambiental. Em essência, este projeto avaliará a viabilidade, analisará o impacto no bem-estar residencial e investigará os benefícios sustentáveis da implementação de sistemas de aquecimento solar de água em residências de Cachoeira do Sul.

Palavras-chave: Sustentabilidade; Aquecimento de água; Energia solar

1 INTRODUCTION

Between September 25 and 27, 2015, UN member states demonstrated their commitment to transformation by defining 17 Sustainable Development Goals and 169 global targets. Within this framework, Goal 7 underscores the importance of utilizing renewable and sustainable resources, highlighting the pressing need to adopt energy alternatives that preserve the environment and foster sustainability. This global orientation encourages the implementation of innovative solutions, which are increasingly vital for addressing the environmental challenges of our era (United Nations).

The urgency to re-evaluate our energy model is further emphasized by the significantly negative impact of non-renewable energy consumption. As Origo Energia (2021) points out, the excessive use of non-renewable energy damages the environment due to the substantial release of carbon dioxide into the atmosphere. This reality necessitates investment in measures that minimize pollutant emissions.

In this context, the application of solar energy for residential water heating presents itself as a promising alternative. According to Portal Solar, over a 30-year operational lifespan, a standard 6 kWp photovoltaic system can prevent the emission of polluting gases equivalent to the environmental impact of planting enough trees to cover ten football fields. Such data underscores the relevance of solar technology, which offers substantial environmental advantages alongside economic viability.

Given a society heavily reliant on electricity for its daily functions, the environmental and financial consequences of this consumption are becoming increasingly apparent. The high demand for conventional energy not only intensifies environmental challenges but also drives up residential energy costs.

This article proposes a feasibility study of a solar energy water heating system, integrating technical, economic, and environmental considerations. Furthermore, a case study was conducted, illustrating how the implementation of this system can reduce electricity expenses and contribute to the mitigation of greenhouse gas emissions.

In summary, the proposed investigation aims to stimulate discussion on innovation and sustainability by presenting the solar thermal system as a viable alternative to transform conventional energy use in typical residences. By integrating technical analysis, financial benefits, and environmental advantages, this work encourages the reader to consider pathways toward a more sustainable and environmentally responsible future.

2 LITERATURE REVIEW

In his 1995 book, The Demon-Haunted World, Carl Sagan warned against global challenges such as pseudoscience, consumerism, and environmental negligence. He emphasized the dangers of scientific illiteracy, which can worsen issues like global warming, pollution, and deforestation.

Adopting renewable energies is crucial for lessening the environmental impact of traditional energy production. Solar energy, for instance, emerges as a more sustainable alternative. This global discussion is central to the UN's Sustainable Development Goal 7, which aims to significantly increase the use of renewable energies by 2030, promoting balanced and equitable development within Agenda 2030.

Within the context of residential energy consumption in Brazil, the electric shower plays a significant role. Data from Penereiro, De Melo, and Coradi (2010) indicate that this appliance accounts for approximately 24% of total household energy consumption, even exceeding items like refrigerators (22%), air conditioners (20%), and lighting (14%). In southern Brazil, the prevalence of electric showers can reach nearly 98% of households, representing about one-third of total residential energy use. This highlights that while an indispensable part of daily life, the electric shower presents a considerable challenge to sustainable energy consumption. It's also important to recognize that while showers are a major point of energy demand for water heating, other activities and appliances contribute to overall consumption, necessitating a comprehensive analysis of energy solutions.

According to TAB Energia (2020), a solar thermal system utilizes solar collectors to capture the thermal energy from solar radiation, heating water that is then directed to a thermal storage tank, commonly known as a boiler. Proper sizing of this system is essential to meet the daily hot water demand of the residence where it is installed. Moreover, the system configuration can vary depending on the circulation methods and the types of collectors used.

Figure 1 – Solar Thermal System

Source: https://pim.cpcompany.com/dedu/como-e-o-funcionamento-do-aquecedor-solar.html

Solar water heating systems employ either natural or forced circulation methods. Natural circulation, also known as thermosiphon, relies on the principle that heated water becomes less dense and rises, displacing cooler water in the storage tank, thus establishing flow. Simpler systems utilize this thermosiphon effect. Forced circulation, on the other hand, employs motorized pumps and is typically used in applications requiring larger water volumes, such as swimming pools (Gomes, 2012, p. 162).

These systems can also be equipped with various types of solar collectors, including covered, uncovered, and vacuum collectors. The efficiency of these collectors is intrinsically linked to the climatic conditions of the installation site, as the intensity of solar radiation directly impacts the system's performance. Consequently, each collector type exhibits unique characteristics, most notably the temperature difference achieved between the water entering and leaving the collector.

A crucial aspect of implementing a water heating system is determining the residence's hot water demand, as this directly dictates the system's required size. Hot water demand can be calculated using two primary methods. The first involves measuring individual water consumption at each outlet within the residence to estimate the total daily volume needed. The second method relies on average per capita consumption figures, considering estimates per person and incorporating regional factors such as climate, cultural habits, and user profiles.

The performance of solar thermal systems is inherently dependent on several factors, including the type and quality of the collectors, their orientation and tilt, and the level of solar incidence at the installation site. Furthermore, proper sizing of the hot water storage tank is essential for ensuring the system's overall efficiency.

In regions with high solar incidence, these systems demonstrate greater effectiveness. Conversely, adverse weather conditions or cloudy days can partially reduce their performance. Therefore, precise calculations of the collectors' area and the storage tank's capacity are essential, rigorously considering the relevant climatic variables for the specific municipality.

In essence, with careful planning, a solar water heating system can effectively meet a residence's hot water demand, minimizing waste and ensuring user satisfaction.

The sizing process for such a system necessitates a rigorous approach to data collection and analysis. This step is crucial to ensure the hot water supply aligns with the specific needs of a residence.

This study established parameters to enable a more in-depth evaluation of the system's viability. To illustrate this analysis, a residence with four occupants and three points of use in Cachoeira do Sul, Rio Grande do Sul, Brazil, was considered.

Based on these parameters and the collected information, the hot water demand was determined alongside an analysis of the region's climatic data. These two factors are indispensable for ensuring the effective operation of the solar water heating system in both the municipality and the specific residence.

Initially, the daily hot water demand for the four-occupant residence in Cachoeira do Sul was established by considering the average consumption data per point of use provided by Soletrol, as illustrated in Figures 2 and 3. For this residence, the considered points of use were the bath, kitchen, and washbasin.

Table 1 – Average Consumption per Point of Use

Consumption point	**Minimum consumption**	**Maximum consumption**	**Daily cycle (minute/person)**	**Consumption temperature (ºC)**
bath shower	*3 liters/minute*	*15 liters/minute*	*10*	*39–40*
bathroom sink	*3 liters/minute*	*4.8 liters/minute*	*2*	*39–40*
kitchen sink	*2.4 liters/minute*	*7.2 liters/minute*	*3*	*39–40*
washing machine	*90 liters*	*200 liters*	*washing cycle*	*39–50*

Source: Soletrol

Table 2 – Examples of the Average Consumption per Point of Use

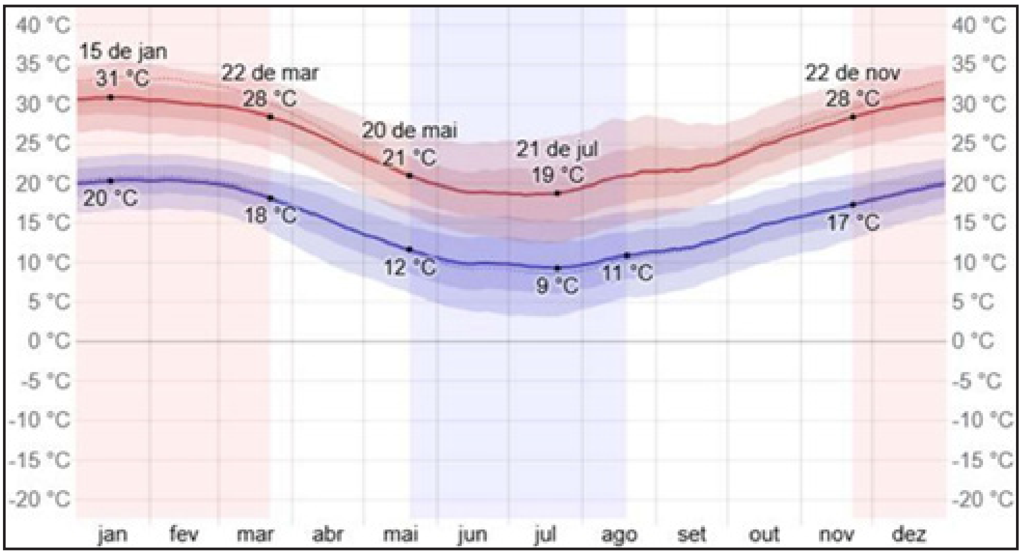
Bath shower	**Bathroom sink**	**Kitchen sink**	**Total**
*5 residents * 90 liters*	*5 residents * 4 liters*	*5 residents * 15 liters/meal * 2 meals*	
450 liters	*20 liters*	*150 liters*	*660 liters*

Source: Soletrol

Considering the residents' needs, the total calculated hot water demand reached 556 liters per day. This figure accounts for 360 liters used for bathing, based on four people consuming 90 liters each daily. Kitchen usage amounts to 180 liters per day, with each of the four occupants using 15 liters per meal across three daily meals. Finally, washbasin usage totals 16 liters per day, with each person using 4 liters.

In parallel, a study of the climatic conditions in Cachoeira do Sul was conducted, focusing on the minimum and maximum temperatures as reported by Weather Spark (Figure 4) and the average solar irradiation data from CRESESB (Figure 5). This climatic analysis is crucial for accurately sizing both the solar collectors and the thermal storage tank.

Figure 2 – Graph of Minimum and Maximum Temperatures in Cachoeira do Suldd



Source: Weather Spark

Figure 3 – Description of the Average Solar Irradiation.Source: CRESESB

Station: Cachoeira do Sul
Municipality: Cachoeira
Latitude: 30° S
Longitude: 52.849° O

Angle	Inclination	Monthly daily solar irradiation (kWh/m²·day)											
		Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Horizontal Plane:	0° N	6.50	5.94	4.99	3.82	2.79	2.30	2.50	3.25	3.72	4.88	6.24	6.78
Same as latitude:	30° N	5.76	5.68	5.31	4.61	3.75	3.25	3.46	4.09	4.07	4.80	5.64	5.88
Highest annual average:	22° N	6.06	5.86	5.33	4.49	3.56	3.06	3.26	3.95	4.05	4.91	5.90	6.22
Highest monthly low:	50° N	4.73	4.92	4.93	4.62	3.96	3.52	3.70	4.19	3.87	4.26	4.70	4.75

Source: CRESESB

Field research conducted by SOLETROL in Rio Grande do Sul indicates that, on average, a collector area of 1.8 m^2 is recommended for every 100 liters of daily consumption. Therefore, to meet the calculated demand of 556 liters, approximately 10 m^2 of collectors is estimated to be necessary, and the storage tank capacity should be around 600 liters to ensure adequate hot water storage.

To support the project's goals of energy efficiency and economic viability, market research and technical analysis were conducted to identify the optimal solution. Based on the gathered data, a system was selected that combines an initial kit—comprising a 600-liter thermal storage tank and three solar panels—with the possibility of expanding the number of collectors to achieve the required energy capture area. This combination emerged as the most promising option for meeting the project's needs, effectively balancing investment and performance.

ERASOLAR Energia, a brand specializing in alternative renewable energies and the official reseller of Komeco, offers a solar water heating kit priced at R$6,793.84. The kit includes a 600-liter thermal storage tank and three solar panels, each measuring 1.96 m × 1.0 m, with a monthly energy production capacity of 76.1 kWh/m^2.

As previously mentioned, each solar collector measures 1.0 m × 1.96 m, providing an area of 1.96 m^2 per panel. Consequently, the three panels included in the initial kit offer a total area of 5.88 m^2. However, the system's calculated requirement for the residence is at least 10 m^2 of collector area. Therefore, the project was expanded to include the acquisition of three additional identical panels, bringing the total collector area to 11.76 m^2. The ERASOLAR Energia reseller website lists the individual price of this solar water heating panel model at R$1,340.00. With the need for three extra panels, the total investment for these additional collectors amounted to R$4,020.00.

Considering both the initial kit and the supplementary collectors necessary to achieve the required capture area, the total estimated budget for the solar water heating system reached R$10,813.84, excluding installation costs.

Focusing solely on shower usage for a family of four—where each person averages a 15-minute shower daily, totaling approximately one hour of daily use—the estimated energy consumption is 5.5 kWh per day, equivalent to 165 kWh per month. Using the average rate of R$0.85 per kWh (according to Origo Energia, 2023), the cost of water heating for showers alone is approximately R$140.25 per month. This projects to the following expenses:

- Monthly: R$140.25
- Annually: R$1,683.00
- Over 6 years: R$10,098.00

Given the total estimated investment for the system installation of R$10,813.84, the estimated payback period is approximately six years and six months.

Periodic system inspections are advisable, with annual maintenance performed as needed. While repairs tend to be minimal in the initial years, the need for adjustments increases as the equipment ages. An average annual maintenance cost of around R$600.00 is estimated—just over one-third of the annual expense for conventional energy consumption without a boiler.

Over a typical lifespan of 20 to 30 years, the accumulated maintenance costs can average around R$12,000.00. Considering a 20-year horizon, the total savings resulting from the reduction in the electricity bill for showers alone can range from R$10,800.00 to R$33,660.00.

The monthly energy demand of the solar water heating system can be calculated using the following expression (1):

$$Dmontli \text{ —— } Qday \;\; N \;\; (Tacs - Ta\,f) \;\; 1.16 \quad 10^{*3} \qquad (1)$$

Where:

- Dmonth: monthly energy demand (kWh/month);
- Qday: daily consumption of hot water at the reference temperature Tacs (liters/ day);

- N: number of days in the month;
- Tacs: temperature used for quantifying the hot water consumption (°C);
- Taf: temperature of the cold water from the network (°C).

An essential step in sizing the solar water heating system to meet year-round user needs is determining the energy demand. This is facilitated by organizing the collected data on daily hot water consumption, temperature variations, and solar irradiation into a table (Figure 6), which allows for an integrated visualization of these factors.

Table 3 – Table Relating the Variables of the Expression with Values Obtained from Our Research

Calculations work for sizing a residential water heating system						
T(acs)	**45 °C**			**Collector efficiency**	**162.6 kWh/month**	
Month	**Average**	**TAF (°C)**	**DE month (kWh/mês)**	**N (Day/ Month)**	**Maximum**	**Minimum**
January	25.5	20.5	489.85	31	31	20
February	25.0	20.0	451.47	28	30	20
March	24.0	19.0	519.84	31	29	19
April	20.0	15.0	580.46	30	25	15
May	16.5	11.5	669.79	31	21	12
June	14.5	9.5	686.88	30	19	10
July	14.0	9.0	719.78	31	19	9
August	16.0	11.0	657.86	30	21	11
September	17.0	12.0	659.79	31	22	12
October	20.0	15.0	580.46	30	25	15
November	22.5	17.5	549.83	31	28	17
December	24.5	19.5	493.39	30	30	19

Source: the authors

Based on the sizing calculations, it's possible to predict the potential results for users of this water heating system. As previously determined, the minimum required area for solar collector installation was approximately 10 m^2. However, the designed system incorporates a total solar collector area of 11.76 m^2, ensuring a capacity exceeding the initial estimate.

Furthermore, the selected solar collectors have an energy production capacity of 76.1 kWh per month per square meter. This configuration results in a total system capacity of 894.9 kWh per month, offering an efficient and sustainable water heating solution. Analyzing the monthly energy demand presented in Figure 7, which ranges from 451.47 to 719.78 kWh/month, demonstrates a satisfactory energy generation capacity and confirms the system's viability. This reinforces its suitability from both environmental and economic perspectives, considering the potential for long-term reductions in energy consumption costs.

3 FINAL CONSIDERATIONS

Considering the aspects discussed, the proposed solar water heating system proves to be both satisfactory and promising. Its appeal lies not only in meeting users' energy demands and providing financial returns but also in its crucial role as a sustainable alternative in today's world.

Firstly, regarding residential energy demand, which fluctuates between 451.47 kWh/month and 719.78 kWh/month, the system's generation capacity of 894.9 kWh/month ensures that energy needs are consistently met throughout the year, confirming its technical efficiency. Furthermore, the system boasts a short payback period, and given its service life of 20 to 30 years, the accumulated savings on expenses, particularly those associated with water heating, can reach up to R$33,660.

Finally, and perhaps most importantly, the system distinguishes itself through its commitment to environmental sustainability. In a global context that necessitates a shift towards clean energy alternatives, adopting this system leads to a reduction in the reliance on non-renewable sources, as well as a decrease in carbon emissions and the mitigation of environmental impacts, all while promoting the rational use of natural resources. Consequently, the system is not only presented as a technically and financially viable solution but also as a strategic asset for environmental preservation and sustainable development, embodying a responsible and forward-thinking approach for future generations.

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Authorship contributions

1 – Rithiele dos Santos Ferreira

Mechanical Engineering Academic, Universidade Federal de Santa Maria – Cachoeira do Sul.
https://orcid.org/0009-0002-1425-1911 • rithiele.ferreira@acad.ufsm.br
Contribution: Conceptualization, Methodology, Writing - Original Draft Preparation, Formal Analysis and Investigation

2 – Eduardo Gonçalves Trindade

Mechanical Engineering Academic, Universidade Federal de Santa Maria – Cachoeira do Sul.
https://orcid.org/0009-0000-8341-0643 • eduardo.trindade@acad.ufsm.br
Contribution: Conceptualization, Methodology, Writing - Original Draft Preparation, Formal Analysis and Investigation

3 – João Vitor Hoffmann Spode

Mechanical Engineering Academic, Universidade Federal de Santa Maria – Cachoeira do Sul.
https://orcid.org/0009-0002-3103-0870 • joao.vitorhoffmannspode@gmail.com
Contribution: conceptualization, methodology, writing - original draft preparation, formal analysis and investigation

4 – Charles Rech

PhD in Mechanical Engineering, Professor of the Mechanical Engineering Course, Universidade Federal de Santa Maria – Cachoeira do Sul.
https://orcid.org/0000-0001-8523-6300 • charles.rech@ufsm.br
Contribution: Conceptualization, Methodology, Original Draft Preparation, Formal Analysis, Investigation, Review & editing

5 – Cristiano Frandaloso Maidana

PhD in Mechanical Engineering, Professor of the Mechanical Engineering Course, Universidade Federal de Santa Maria – Cachoeira do Sul.
https://orcid.org/0000-0003-3137-6177 • cristiano.maidana@ufsm.br
Contribution: Conceptualization, Methodology, Original Draft Preparation, Formal Analysis, Investigation, Review & editing

6 – André Francisco Caldeira

PhD in Electrical Engineering Professor of the Electrical Engineering Course, Federal University of Santa Maria – Cachoeira do Sul.
https://orcid.org/0000-0002-4939-2709 • andre.caldeira@ufsm.br
Contribution: Review & editing.

7 – Simone Ferigolo Venturini

PhD Studies in Progress in Production Engineering, Federal University of Santa Maria.
https://orcid.org/0000-0002-9439-0008 • simone.venturini@gmail.com
Contribution: Review & editing.

8 – Carmen Brum Rosa

Professor in the Graduate Program in Production Engineering (PPGEP), Federal University of Santa Maria.
https://orcid.org/0000-0002-0173-081X • carmen.b.rosa@ufsm.br
Contribution: Review & editing

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