International Journal for Quality Research 18(4) 1093–1106
ISSN 1800-6450

Bruno Mendes de Jesus
Newton Galvão de Campos Leite
Luiz Carlos Bevilaqua dos Santos Reis
José Salvador da Motta Reis
Nilo Antonio de Souza
Gilberto Santos[1]
Luís César Ferreira Motta Barbosa

Article info:
Received 10.01.2024.
Accepted 02.06.2024.

UDC – 502.131.1
DOI – 10.24874/IJQR18.04-11

PROPOSED NEW CONSTRUCTION IN SOLAR ENERGY COLLECTION WITH HIGHER EFFICIENCY AND QUALITY

Abstract: *A construction model for an ETC type solar collector with the purpose of helping in the rational use of electric energy aimed at the needs of the small rural producer. A prototype solar collector was proposed and its energy efficiency was analyzed compared to that of a commercial collector. Following this, an analysis of the economic viability of using solar collectors on small properties in the Sul Fluminense region of Brazil was performed. This work can be classified as an applied research with a quantitative experimental approach. The study shows that the use of the solar collector even when shared with the electricity to compensate for its losses, still provides an economic benefit to the final users, and the use of thermosyphon can contribute significantly to improving this result. This study proposed a more effective solar collector model, but this collector was limited to the materials and financial resources available to the project.*

Keywords: *Efficiency; Financial Economics; Sustainability; Solar Energy.*

1. Introduction

The world energy demand grows day by day. The need to meet this demand combined with the population's awareness of the negative impacts of using fossil fuels has increased the interest in sustainable energy sources(Majernik et al., 2015; Ozsoy & Corumlu, 2018; Piepiórka-Stepuk et al., 2016). Solar energy is a promising energy source because it is abundant all over the planet, reliable, freely accessible, cheap and non-polluting (Sarafraz et al., 2019; Saxena & Gaur, 2018; Shafiey Dehaj et al., 2021). Its application occurs in both the domestic and industrial sectors. The use of solar energy for water heating has grown significantly in recent years. Among its main advantages we canhighlight ease of manufacture and operation (Zgodavova et al., 2020), minimal maintenance (Doiro et al., 2017; Santos & Barbosa, 2006) and low cost (Jimenez et al. 2019). We can also highlight, high efficiency compared to other heating systems (Sarafraz et al., 2019; Saravanan et al., 2016; Zhang et al., 2016) and quality of life (Santos et al., 2017; Fonseca et al., 2022).

Brazil currently has a generating capacity of 177,000 MW, 75% of which comes from power plants considered sustainable (Agência Brasil, 2021). In 2018 the agricultural and livestock sector was responsible for the consumption of 6.14% of the energy produced (EPE, 2019). The 2017 Agricultural Census took a snapshot of the

[1] Corresponding author: Gilberto Santos
Email: gsantos@ipca.pt

Brazilian countryside, visiting a total of 7.5 million addresses, it was observed that of the total number of agricultural establishments in the country, 77% were classified as family farms, accounting for 23% of the value of production and occupying an area of 80.9 million hectares, or 23% of the total area occupied by agriculture and cattle ranching. Small producers combine some catastrophic characteristics when one associates the idea of electric energy consumption: low schooling, low technical assistance, and occupation of a considerable slice of the productive market (23%). Specifically within this scenario, cattle raising on family farms is responsible for 58% of the country's milk (IBGE, 2019).

To respond to the growing demand for clean energy, also the growing need for strategic development and the lower emission of waste and pollutants, academia has to seek the breaking of paradigms and innovative alternatives(Araujo et al., 2021; Barbosa et al., 2020; Espuny et al., 2021; Reis et al., 2021).Accordingly, Brazilian public universities can play a key role in helping the implementation of good practices in the field, especially when making use of one of its pillars, which is the extension.

One question becomes unavoidable in this scenario: how can universities contribute to the rational use of electricity in agribusiness? To answer the question, the present work proposes to do an experimental study, aiming to economically quantify the viability of using commercially available and modified solar collectors, that is, with adaptations using technology developed at the Center for Renewable Energy Sources - CFRE of the State University of Rio de Janeiro, aiming at reducing the production cost.

This paper is subdivided into six sections. Section 1 introduces the study, as well as presents the research question and the objective. Section 2 contains the theoretical framework. Section 3 describes the research method. Section 4 presents and discusses the results. Section 5 concludes the study. Finally, in Section 6, the references used in the research are mentioned.

2. Theoretical Framework

Solar energy collectors are a special type of heat exchanger that transform the energy of solar radiation into the internal energy of the medium(Ahmadi et al., 2021; Saxena & Gaur, 2018). The main component of this equipment is a device that absorbs incoming solar radiation by converting the radiative energy into heat, and transferring that heat to a fluid such as air, water, or oil that passes through the collector. The circulating fluid is carried to a thermal energy storage tank from which it can be withdrawn for use at night and/or on cloudy days(Essa et al., 2018; Mondragón et al., 2019).

There are basically two types of solar collectors: non-concentrating or stationary and concentrating. (Ghaderian et al., 2017; Saxena & Gaur, 2018; Verma et al., 2020). A stationary collector has the same area to intercept and to absorb the solar radiation, while a concentrating solar collector usually has concave and reflective surfaces to intercept and focus the radiation of the solar beam to a smaller receiving area, thus increasing the radiation flux(Qin et al., 2017).

A wide variety of solar collectors are available on the market, they are divided into Flat Plate Collector (FPC), Evacuated Tube Collector (ETC) and Compound Parabolic Collector (CPC) for the stationary type and for the concentrating type, Linear Fresnel Reflector (LFR), Parabolic Trough Collector (PTC), Cylindrical Trough Collector (CTC), Parabolic Dish Reflector (PDR) and Heliostat Field Collector (HFC). Each model has different characteristics in relation to the absorber (apartment, tubular and point), concentration ratio (varies between 1 and 1,500) and working temperature range (varies between 30º and 2,000º C) (Kalogirou, 2003; Verma et al., 2020). The

FPC model is the most popular among solar collectors, with low cost, good durability, and simple construction. (Essa et al., 2018; Saxena & Gaur, 2018; Sheikholeslami et al., 2021; Verma et al., 2020). The ETC model, which was used in this work, is beginning to gain a good following in the market. The ETC has greater energy efficiency compared to the FPC models, especially in areas of cold weather or low light. In addition, its maintenance is simple and low-cost (Ahmadi et al., 2021; Hassanien et al., 2018; Saxena & Gaur, 2018).

Within the context of the ETC solar collector, there is the possibility of using a device that among other advantages improves the heat transport performance. Thermosyphon is a device that can be called a superconductor of heat, although its construction is relatively simple. Since the emergence of the name thermosyphon around 1928, reported by (Japikse, 1973), this device has been studied and improved, for presenting great potential in heat transport. The literature is extensive and includes both experimental and theoretical aspects(Abas et al., 2017; Ersöz, 2016; Koholé & Tchuen, 2020).

The two-phase thermosiphon is best described by dividing it into three sections: evaporator, adiabatic section, and condenser. Heat is supplied to the evaporator, where there is a liquid reservoir at the beginning of the process, providing a phase change to the vapor state. The vapor rises due to the pressure and density difference, passing through the adiabatic section and reaching the condenser. In the condenser section, the steam rejects latent heat, returning to the initial liquid state. Then the gravitational force field acts on the condensate, returning it to the evaporator(Ersöz, 2016; Feilizadeh et al., 2019; Zhang et al., 2016).

Figure 1 shows the closed two-phase thermosiphon in its conventional form, operating in the vertical position, where the liquid filter has its thickness increased relative to the scale of the drawing.

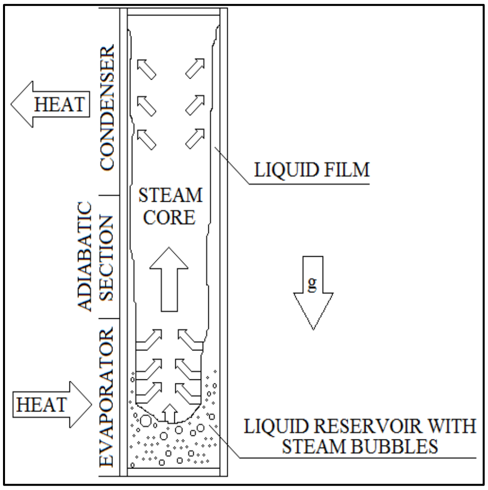

Figure 1. Standard sketch to two-phase closed thermosyphon. Adapted from Ersöz (2016), Feilizadeh et al. (2019), Zhang et al. (2016).

In Brazil several brands sell tubular solar collectors (TSC) with an internal structure composed of a thermosyphon, although the manuals come stating as heat pipe, which is a conceptual misconception, because the latter has a porous structure to allow the return of the liquid film to the reservoir. Both thermosyphon and heat pipe are extensively used to help transport heat in solar equipment, such as collectors(Feliński & Sekret, 2017; Shafiey Dehaj et al., 2021; Vasiliev et al., 2017).

3. Research Method

The present study was carried out in the period between January and November 2021. A prototype solar collector was proposed, and its energy efficiency was analyzed compared to that of a commercial collector. Following this, an analysis of the economic viability of using solar collectors on small properties in the south of Rio de Janeiro state was performed. This work can be classified as an applied research with a quantitative experimental approach (Cardoso et al., 2022; Kothari & Garg, 2019; Sales et al., 2022; Silva et al., 2021).

3.1. Construction of a system for high vacuum

The present work began by assembling a system capable of producing high vacuum, this system was assembled using two pumps attached in series. A mechanical rotary vane vacuum pump Pascal-SD series, model 2005 SD, Adixen® brand, with double stage and pumping speed of 5.4 m3/h, with final vacuum of 0.2 Pa was connected in series to a Drag turbomolecular vacuum pump, model HiPace 80 DN 63 ISO-K, Pfeiffer Vacuum® brand, as shown in Figure 2.

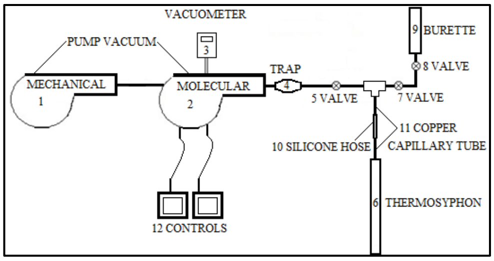

Figure 2. Scheme of the thermosyphon fabrication

This assembly allowed the internal structure of the turbomolecular pump to be protected during the initial vacuum production process, up to the safety limit of the turbomolecular pump start-up. After starting the turbomolecular pump, the mechanical pump is switched off manually and then the time is waited to reach the required vacuum inside the thermosyphon. During this step only valve 5 is open. As soon as the working vacuum is reached, the turbomolecular vacuum pump is switched off via the control panel and the process of filling the thermosiphon with the working fluid is started. Valve 5 is closed, valve 7 is opened, and valve 8 serves as a level control valve to allow the thermosiphon to be filled with the desired amount of working fluid. Following filling, valves 7 and 8 are closed and the capillary tube is throttled by two pressure pliers with flat jaws and the connecting sleeve is broken and the capillary tube sealed with silver solder.

The circuit was well optimized, with very interesting engineering solutions such as, for example, the humidity trap, which in more sophisticated systems is usually implemented costly techniques where equipment and/or substances lower the temperature of the working fluid in an attempt to freeze it and consequently not let it return to the pump. In this work a component was used that caused a loss of pressure retaining all the moisture, which met the needs of the project very well. The whole vacuum circuit was created with the purpose of making the two-phase thermosiphons with a sufficient vacuum for its good operation, being that the lowest vacuum obtained was 0.08 Pa and the highest was 0.1 Pa during the closing process of the thermosiphons.

3.2. Construction of the two-phase thermosyphon

Copper tubes were used and went through a manual internal cleaning process with acetone to avoid contamination of the working fluid - distilled water - with solid residues. Then, their edges were sealed with appropriate caps, using silver solder, where one side receives a capillary tube, as shown in Figure 3, which was responsible for connecting the thermosiphon to the vacuum system.

Figure 3. Capillary Cap

At the end of the filling and sealing process, they had to be checked in relation to the amount of working fluid that each one received. The verification was done by weighing the copper tube before and after the filling with the working fluid, using a precision balance of 5.10-7 kg Kala®. Ten two-phase thermosiphons were built to compose the solar collector to be tested, where each tube was filled with 30% of its total volume with distilled water, which was used as the working fluid. The lowest error in the filling process was 2.2% and the highest was 17.2%. The geometric characteristics of the tubes were: 1.8 m length; external diameter 1.21.10-2 m, and internal volume 2.1.10-4 m3.

To test the operation of the constructed two-phase thermosiphons, two procedures were used: first, the tubes had one of their tips immersed in a boiler with water at approximately 100 ºC, while the other was inspected manually, observing the heating time of the tip and the noise caused in the thermal exchange process; in the second procedure, the tubes were agitated until they produced a noise similar to two metals colliding. These simple inspection methods proved to be very reliable, since when these phenomena in the operation were not observed the tubes presented problems related to leakage.

3.3. Construction of the solar collector

The construction of the prototype started with the main structure made of steel that had the function of accommodating and supporting the weight of the double vacuum tubes with the two-phase thermosiphon. A manifold was built attached to the top of the structure. The manifold, which is the region where the water will circulate, shown in Figure 4, was built with a screw thread system, which did not present major assembly or leakage problems.

For the thermosiphon to be able to fit perfectly into the manifold, a threaded ring was welded onto it as shown in Figure 5. Next, the assembly of the collector itself took place, starting by placing the thermosiphons, checking for leakage from the hot water runoff, assembling the double evacuated tubes, and finally insulating the manifold with expanded polystyrene spray.

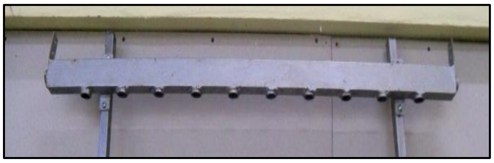

Figure 4. Manifold

Figure 5. Threaded coupling

The purpose was to build a solar collector with double evacuated tubes acquired in the market, but adapting the two-phase thermosiphons inside. Figure 6 shows an overview of the prototype that was fabricated, which had modifications in its structure when compared to those acquired in the market. Fins are generally used to improve the performance of the heat exchange between the thermosyphon and the inner walls of the double tube, as can be seen in Figure 7, which elucidates the use of an aluminum fin around a thermosyphon in the commercially sold solar collector. In the prototype only radiative effects were allowed to conduct and dominate the heat exchange process in the region where the evaporator of the two-phase thermosyphon is located, dispensing with the use of fin that provides increased area and heat transport by thermal conduction.

After the assembly process of the prototype, it was taken to a test station together with a similar solar collector, but acquired commercially from ASUS®. Both the prototype and the commercial collector were carefully installed following the same position. All were mounted oriented to geographic north with a 28° tilt angle.

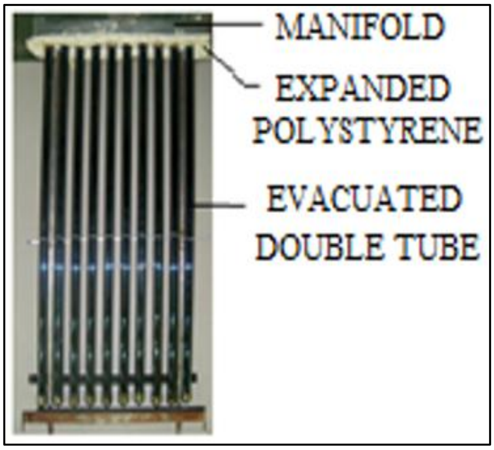

Figure 6. Prototype

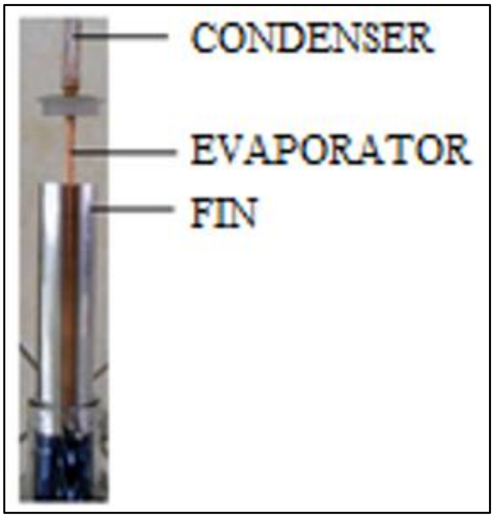

Figure 7. Structure of commercial solar collector

The storage tanks used had a volume of 200 liters and all ducts and connections were properly insulated and maintained a similarity in length and curvature. After a few hours of operation, all models were monitored with a thermographic camera to detect small leaks that could jeopardize the tests.

Searching the manual that came with the commercial manifold, it was observed that the term heat pipe was used instead of thermosyphon. To solve the question the heat pipe - Fig. 6(b) - was opened and the working fluid was quantified and chemically analyzed by the Department of Chemistry and Environment at the university. A fluid similar to distilled water was found, but mixed with a powder that was identified as a mixture of copper and copper oxide.

The liquid part occupied 4.02% of the total volume and the most interesting discovery was that the tube was not a heat pipe as advertised in the manufacturer's manual, but a two-phase thermosyphon, as there was no capillary structure to ensure the return of the condensed liquid.

3.4. Procedure for reading experimental data

To read the experimental data required to analyze the collectors, thermocouples were manufactured with compensating wire to lower the cost of the project. The wire used was composed of the Chromel-Alumel alloy, known in the market as conductor wire presenting the code KX, with a diameter of 1.8 mm, which is suitable for working with type K thermocouples. Records of the inlet and outlet temperatures of the water in the head and the water coming from the network were made by an automated eight-channel data acquisition system - Fieldlogger from Novus® Produtos Eletrônicos Ltda.

All thermocouples were calibrated based on the ice melting temperature, room temperature (compared to a YOKOGAWA® Thermo Collector TM10 sensor) and water boiling temperature respecting the height of the city of Resende - RJ. From the comparison of results, fit curves were extracted for each thermocouple. Then, first degree correction equations were used to minimize the thermocouple error. The temperature of the thermal reservoir was obtained indirectly, minimizing errors due to possible fluid stratification within the reservoir.

A calorimeter was used, thus allowing accounting for energy production in the form of heat. Daily samples of similar amounts of water were extracted from the collectors at pre-established times.

Based on the temperatures involved in the process and the mass of water contained in the calorimeter, it was possible to use the equation of conservation of energy to calculate the sensible heat, thus obtaining the value of energy gain in the form of heat throughout the analyzed period. It is important to report that before each collection made by the calorimeter, there was always a disposal of 3 liters of water, thus ensuring that the analyzed water was always coming from inside the boiler and not from the piping, although a very short stretch of duct was used in the water extraction position.

4. Results and Discussions

The motivation of this work was to present to rural producers located in the south fluminense region of the state of Rio de Janeiro, a viable alternative to supply the demand for hot water at a lower cost than at present. In this region small rural properties prevail in larger numbers that need a daily demand for hot water, which today is guaranteed using equipment that runs on electricity.

When it comes to cleaning milking equipment and tanks, water temperature is important, as the chlorinated alkaline detergent (product used for sanitizing) does not work well at low temperatures. In the initial rinse the ideal water temperature is between 35 and 43 ºC, which facilitates the removal of the coarser residues and maximizes the efficiency of the next cleaning cycles. For hose washing, the use of hot water facilitates and speeds up the process, because the fat from the feces dissolves more easily, allowing a more efficient and hygienic(Azevedo et al., 2016; Elmoslemany et al., 2010; Piepiórka-Stepuk et al., 2016).

The demand for hot water for personal hygiene of employees and restricted areas that have artisan cheese production was also considered, as well as the demand coming from the property's headquarters. The estimated average value of hot water consumption was 5,000 liters per day.

To this end, a prototype was developed with part of the technology developed at CFRE and a comparison was made in terms of energy accumulation with a similar commercial heat collector. The objective in this case was to show the possibility of small-scale construction of mixed collectors, part industrial and part handcrafted that can present good results. Concomitantly with the experimental study, an economic viability study was carried out, applied specifically to the reality of the rural producers in the south fluminense region. In this case, only solar collectors that were easily accessible to the producers through the national market were used for comparison.

4.1. Experimental analysis

With the determination of the temperatures of interest, the equation below could be used to account for the energy stored in the calorimeter throughout the insolation period, which in the Resende region is 6 hours:

$$\boldsymbol{Q} = \boldsymbol{m}\boldsymbol{c}_{\boldsymbol{p}}(\boldsymbol{T}_{\boldsymbol{CAL}} - \boldsymbol{T}_{\boldsymbol{SN}}) \quad (1)$$

Where Q is the heat stored in (kJ), m is the mass collected by the calorimeter in (kg), cp is the specific heat at constant water pressure in (kJ/(kgK)), TCAL and TSN are the temperatures of water in the calorimeter and the supply network respectively in (ºC). A single water collection was performed by the calorimeter always at 12 o'clock for six months. The results of all temperature profiles over time and the amount of mass extracted were analyzed and checked, showing a recurrence of the results on days with similar climates. In this way 10 days were strategically chosen, representing various climatic situations such as: hot days, cloudy days, etc. The result was added up and presented in Table 1.

Table 1. Heat stored by the calorimeter in 10 days

Solar collector	Stored heat (kJ)
Commercial	125.7
Prototype	139.8

The average uncertainty value of the instruments used and their final contribution to the variables of interest were calculated using the expression presented by Holman (2012):

$$u_Q = \pm\left[\left(\frac{m}{Q}\frac{\partial Q}{\partial m}u_m\right)^2 + \left(\frac{c_p}{Q}\frac{\partial Q}{\partial c_p}u_{c_p}\right)^2 + \left(\frac{\Delta T}{Q}\frac{\partial Q}{\partial \Delta T}u_{\Delta T}\right)^2\right]^{\frac{1}{2}} \quad (2)$$

Table 2 reports the uncertainties related to the instruments, while Table 3 reports the uncertainties related to the variables of interest.

Table 2. Laboratory instruments and uncertainty

Instruments name	Measurement	Accuracy	Uncertainty level [%]
Thermocuples – Type K	Temperature	±0.5 ºC	0.07
Thermo Collector – TM 10	Temperature	±0.05 ºC	0.03

Table 3. Experimental variables and uncertainty

Solar collector	Stored heat (kJ)
Commercial	125.7
Prototype	139.8

4.2. Economic analysis

The cost of equipment and materials is presented in Table 4. An imprecision of 25% was considered, resulting from the evaluation of the imprecision of the values of the quotations made. The total investment for the implementation of the solar collector system and auxiliary equipment is presented in Table 5.

Table 4. Budget for equipment and materials

Cost of equipment and materials	
Item	R$
10 reservoirs (400 liters)	13,000.00
26 solar collectors (2 m^2)	18,410.00
Piping and Fittings	2,000.00
Supports for the collectors	6,500.00
Imprecision (25%)	9,978.00
Total Cost	49,888.00

Table 5. Total investment for system implementation

Total Investment	
Item	R$
National equipment	49,888.00
Spare Parts	798.00
Civil works	11,050.00
Earthwork	850.00
Administrative Expenses	998.00
Total Investment	63,583.00

The benefit of the use of solar collectors is the savings generated by the decrease in the use of electric energy for heating. Assuming an average loss of the solar collector/thermal reservoir set of 30%, the result is a net 3,234 kWh/month that can be saved. For the heating of the consumption water, 5,000 l/day, from 20ºC to 45ºC, the use of 10 boilers of 2,200 W during 7 hours a day is required. With the tariff of 0.5606 R$/kWh for electricity supply for the rural class, this results in a net saving of 1,813 R$/month in electricity. There will also be an average electricity consumption of 1.386 kWh/month to supply the heating due to the losses of the solar heating system.

For the economic study the following items were considered: total budget value of equipment and materials was adopted 25 %

imprecision, as presented in Table 4; total investment value were included spares, being adopted 2 % in relation to the value of equipment and materials; civil works, assembly and supervision of construction and start-up; earthworks; and training and administrative expenses, as presented in Table 5; annual annual maintenance cost, equivalent to 2 % of the total investment value; annual operational cost, equivalent to 30% of the energy consumed annually for heating the water consumed, referring to the supply of electricity to the boilers; income tax and social contribution of 34% applied to the gross profit of the project, discounting the annual costs of maintenance, operation and depreciation; useful life for the system of 10 years; and minimum rate of attractiveness of 6% per year.Table 6 shows that the results were favorable for the implementation of the heating system with solar collectors, showing economic viability.

Table 6. Total investment for system implementation

Indicators	Values
NPV [R$]	47,769.00
IRR [%]	19.4
Payback [ano]	4.3

A sensitivity analysis was developed to consider scenarios of the risk of increasing CAPEX (investment cost). Figure 8 shows that up to a value of around R$120,000.00 for the investment cost, the IRR is above the MIRR (Minimum Rate of Attractiveness). This can also be seen from Figure 9, which indicates that up to this amount of CAPEX the NPV is still positive, becoming zero at just R$120,000.00. This value is 89% greater than the estimated CAPEX for the project, which is R$ 63,583.00.

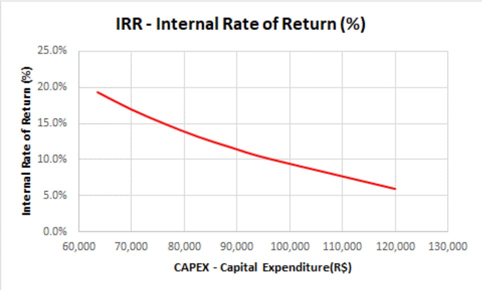

Figure 8.IRR variation with CAPEX

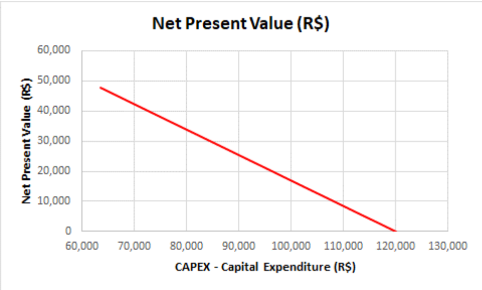

Figure 9. Variation of NPV with CAPEX increase

Since the minimum rate of attractiveness for a project is mainly a function of the basic interest rate, the Selic, and this rate varies over time, a sensitivity analysis was also prepared as a function of the increase in the AAR, presented in Figure 10. It can be observed that the project presents economic viability even with the AAR at 12%. The value of the AAR to zero the NPV is 19%.

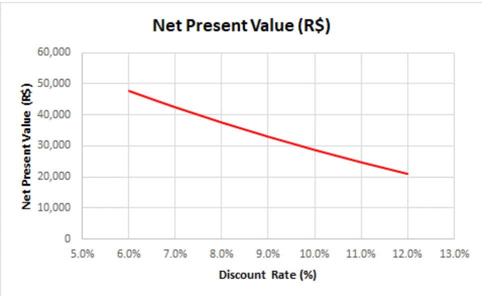

Figure 10. Variation of NPV with increasing attractiveness rate

5. Conclusion

A comparison between a solar collector of the ETC model consisting only of double evacuated tubes, and a similar collector, but with the insertion of a two-phase thermosyphon in its core was carried out. The thermosyphon, despite having been built with proprietary technology in order to reduce costs, since in the study region it still has an unviable price for small rural producers, proved to be able to produce a stored energy 11.2% higher than the conventional model. The objective of investigating the use of this technology in terms of improved heat production was achieved. It is understood that improvements can be implemented in future studies, such as the use of fins. A survey of the production cost of the thermosyphon was not carried out, because it was evident that at the time of the development of this work it would be cheaper to manufacture than to purchase the similar ETC models on the market, since they are imported and the U$$/R$ exchange rate varied between R$5.162 and R$5.619.

To elucidate the advantage of the use of solar collectors for hot water production when compared to the current practice on smallholder farms, a detailed economic analysis compared the use of a conventional ETC collector with the practices currently used, i.e. the use of a boiler.The result shows that it is possible to save 1,813 R$/month on the bill paid to the utility company responsible for providing electricity in the Sul Fluminense region, with a payback of 4.3 years. The study shows that the use of the solar collector even when shared with the electricity to supply its losses, still provides an economic benefit to the final users, and the use of thermosyphon can contribute significantly in improving this result.

Acknowledgment: This study was funded by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES) - Financial Code 001.

References:

Abas, N., Khan, N., Haider, A., & Saleem, M. S. (2017). A thermosyphon solar water heating system for sub zero temperature areas. *Cold Regions Science and Technology*, *143*, 81–92. https://doi.org/10.1016/j.coldregions.2017.08.012

Agência Brasil. (2021). *ANEEL: electricity generation increased 795 MW in August*. Agência Brasil. https://agenciabrasil.ebc.com.br/radioagencia-nacional/geral/audio/2021-09/aneel-geracao-de-energia-eletrica-aumentou-795-mw-em-agosto

Ahmadi, A., Ehyaei, M. A., Doustgani, A., El Haj Assad, M., Hmida, A., Jamali, D. H., Kumar, R., Li, Z. X., & Razmjoo, A. (2021). Recent residential applications of low-temperature solar collector. *Journal of Cleaner Production*, *279*, 123549. https://doi.org/10.1016/j.jclepro.2020.123549

Araujo, M. J. F. de, Araújo, M. V. F. de, Araujo Jr, A. H. de, Barros, J. G. M. de, Almeida, M. da G. de, Fonseca, B. B. da, Reis, J. S. D. M., Barbosa, L. C. F. M., Santos, G. & Sampaio, N. A. D. S. (2021). Pollution Credit Certificates Theory: An Analysis on the Quality of Solid Waste Management in Brazil. *Quality Innovation Prosperity*, *25*(3), 1–17. https://doi.org/10.12776/qip.v25i3.1574

Azevedo, C., Pacheco, D., Soares, L., Romão, R., Moitoso, M., Maldonado, J., Guix, R., & Simões, J. (2016). Prevalence of contagious and environmental mastitis-causing bacteria in bulk tank milk and its relationships with milking practices of dairy cattle herds in São Miguel Island (Azores). *Tropical Animal Health and Production*, *48*(2), 451–459. https://doi.org/10.1007/s11250-015-0973-6

Barbosa, L. C. F. M., Mathias, M. A. S., Santos, G.& De Oliveira, O. J. (2020). How the Knowledge of the Major Researchers Is Forging the Business Strategy Paths: Trends and Forecasts from the State of the Art. *Quality Innovation Prosperity*, *24*(3), 1. https://doi.org/10.12776/qip.v24i3.1404

Cardoso, R. P., Reis, J. S. da M., Sampaio, N. A. de S., Barros, J. G. M. de, Barbosa, L. C. F. M., & Santos, G. (2022). Sustainable Quality Management: Unfoldings, Trends and Perspectives from the Triple Bottom Line. *Proceedings on Engineering Sciences*, *4*(3), 359–370. https://doi.org/10.24874/PES04.03.013

Doiro, M.; Fernández, J.F.; Félix, M.J.; Santos, G. (2017). ERP - machining centre integration: a modular kitchen production case study. Procédia Manufacturing,13, 1159-1166. https://doi.org/10.1016/j.promfg.2017.09.178

Elmoslemany, A. M., Keefe, G. P., Dohoo, I. R., Wichtel, J. J., Stryhn, H., & Dingwell, R. T. (2010). The association between bulk tank milk analysis for raw milk quality and on-farm management practices. *Preventive Veterinary Medicine*, *95*(1–2), 32–40. https://doi.org/10.1016/j.prevetmed.2010.03.007

EPE. (2019). 2018 Statistical Yearbook of electricity 2017 baseline year. In *Ministério de Minas e Energia*. Empresa de Pesquisa Energética.

Ersöz, M. A. (2016). Effects of different working fluid use on the energy and exergy performance for evacuated tube solar collector with thermosyphon heat pipe. *Renewable Energy*, *96*, 244–256. https://doi.org/10.1016/j.renene.2016.04.058

Espuny, M., Faria Neto, A., da Motta Reis, J. S., dos Santos Neto, S. T., Nunhes, T. V., & de Oliveira, O. J. (2021). Building New Paths for Responsible Solid Waste Management. *Environmental Monitoring and Assessment*, *193*(7), 442. https://doi.org/10.1007/s10661-021-09173-0

Essa, M. A., Mostafa, N. H., & Ibrahim, M. M. (2018). An experimental investigation of the phase change process effects on the system performance for the evacuated tube solar collectors integrated with PCMs. *Energy Conversion and Management*, *177*(June), 1–10. https://doi.org/10.1016/j.enconman.2018.09.045

Feilizadeh, M., Estahbanati, M. R. K., Khorram, M., & Rahimpour, M. R. (2019). Experimental investigation of an active thermosyphon solar still with enhanced condenser. *Renewable Energy*, *143*, 328–334. https://doi.org/10.1016/j.renene.2019.05.013

Feliński, P., & Sekret, R. (2017). Effect of PCM application inside an evacuated tube collector on the thermal performance of a domestic hot water system. *Energy and Buildings*, *152*, 558–567. https://doi.org/10.1016/j.enbuild.2017.07.065

Fonseca, L., Silva, V., Sá, J.C., Lima, V., Santos, G., Silva, R. (2022). B Corp versus ISO 9001 and 14001 certifications: Aligned, or alternative paths, towards sustainable development? *Corp Soc Responsib Environ Manag.* 29, 496–508. https://doi.org/10.1002/csr.2214

Ghaderian, J., Sidik, N. A. C., Kasaeian, A., Ghaderian, S., Okhovat, A., Pakzadeh, A., Samion, S., & Yahya, W. J. (2017). Performance of copper oxide/distilled water nanofluid in evacuated tube solar collector (ETSC) water heater with internal coil under thermosyphon system circulations. *Applied Thermal Engineering*, *121*, 520–536. https://doi.org/10.1016/j.applthermaleng.2017.04.117

Hassanien, R. H. E., Li, M., & Tang, Y. (2018). The evacuated tube solar collector assisted heat pump for heating greenhouses. *Energy and Buildings*, *169*, 305–318. https://doi.org/10.1016/j.enbuild.2018.03.072

Holman, J. P. (2012). Experimental Methods for Engineers. In *McGraw-Hill Companies, Inc.* (8ª). McGraw-Hill Companies, Inc.

IBGE. (2019). Agricultural Census 2017: definitive results. In *Censo agropecuário* (Vol. 8). Instituto Brasileiro de Geografia e Estatística.

Japikse, D. (1973). Advances in Thermosyphon Technology. In *Advances in Heat Transfer* (Vol. 9, Issue C, pp. 1–111). https://doi.org/10.1016/S0065-2717(08)70061-3

Jimenez, G., Santos, G., Sá, J.C., Ricardo, S., Pulido, J., Pizarro, A., Hernández, H. (2019). Improvement of productivity and quality in the value chain through lean manufacturing - A case study. *Procedia Manufacturing* 41, 882-889. https://doi.org/10.1016/j.promfg.2019.10.011

Kalogirou, S. (2003). The potential of solar industrial process heat applications. *Applied Energy*, *76*(4), 337–361. https://doi.org/10.1016/S0306-2619(02)00176-9

Koholé, Y. W., & Tchuen, G. (2020). Experimental and numerical investigation of a thermosyphon solar water heater. *International Journal of Ambient Energy*, *41*(4), 384–394. https://doi.org/10.1080/01430750.2018.1472641

Kothari, C. R., & Garg, G. (2019). Research methodology methods and techniques. In *New Age International* (4º). New Age International.

Majernik, M., Bosak, M., Stofova, L., & Szaryszova, P. (2015). Innovative Model Of Integrated Energy Management In Companies. *Quality Innovation Prosperity*, *19*(1). https://doi.org/10.12776/qip.v19i1.384

Mondragón, R., Sánchez, D., Cabello, R., Llopis, R., & Juliá, J. E. (2019). Flat plate solar collector performance using alumina nanofluids: Experimental characterization and efficiency tests. *PLOS ONE*, *14*(2), e0212260. https://doi.org/10.1371/journal.pone.0212260

Ozsoy, A., & Corumlu, V. (2018). Thermal performance of a thermosyphon heat pipe evacuated tube solar collector using silver-water nanofluid for commercial applications. *Renewable Energy*, *122*, 26–34. https://doi.org/10.1016/j.renene.2018.01.031

Piepiórka-Stepuk, J., Diakun, J., & Mierzejewska, S. (2016). Poly-optimization of cleaning conditions for pipe systems and plate heat exchangers contaminated with hot milk using the Cleaning In Place method. *Journal of Cleaner Production*, *112*, 946–952. https://doi.org/10.1016/j.jclepro.2015.09.018

Qin, J., Hu, E., Nathan, G. J., & Chen, L. (2017). Concentrating or non-concentrating solar collectors for solar Aided Power Generation? *Energy Conversion and Management*, *152*(June), 281–290. https://doi.org/10.1016/j.enconman.2017.09.054

Reis, J. S. da M., Espuny, M., Nunhes, T. V., Sampaio, N. A. de S., Isaksson, R., Campos, F. C. de, & Oliveira, O. J. de. (2021). Striding towards Sustainability: A Framework to Overcome Challenges and Explore Opportunities through Industry 4.0. *Sustainability*, *13*(9), 5232. https://doi.org/10.3390/su13095232

Sales, J. P. de, Reis, J. S. da M., Barros, J. G. M. de, Fonseca, B. B. da, Junior, A. H. de A., Almeida, M. da G. D. de, Barbosa, L. C. F. M., Santos, G.& Sampaio, N. A. de S. (2022). Quality Management in The Contours of Continuous Product Improvement. *International Journal for Quality Research*, *16*(3), 689–702. https://doi.org/10.24874/IJQR16.03-02

Santos, G.; Barbosa, J., 2006. QUALIFOUND - a modular tool developed for Quality Improvement in Foundries. *Journal of Manufacturing Technology Management*, *17*(3), 351-362. https://doi.org/10.1108/17410380610648308.

Santos, D., Rebelo, M., Doiro, M., Santos, G. (2017). The Integration of certified Management Systems. Case Study – Organizations located at the district of Braga, Portugal. *Procedia Manufacturing, 13*, 964-971. https://doi.org/10.1016/j.promfg.2017.09.168

Sarafraz, M. M., Tlili, I., Tian, Z., Bakouri, M., & Safaei, M. R. (2019). Smart optimization of a thermosyphon heat pipe for an evacuated tube solar collector using response surface methodology (RSM). *Physica A: Statistical Mechanics and Its Applications*, *534*, 122146. https://doi.org/10.1016/j.physa.2019.122146

Saravanan, A., Senthilkumaar, J. S., & Jaisankar, S. (2016). Experimental studies on heat transfer and friction factor characteristics of twist inserted V-trough thermosyphon solar water heating system. *Energy*, *112*, 642–654. https://doi.org/10.1016/j.energy.2016.06.103

Saxena, G., & Gaur, M. K. (2018). Exergy analysis of evacuated tube solar collectors: a review. *International Journal of Exergy*, *25*(1), 54. https://doi.org/10.1504/IJEX.2018.088887

Shafiey Dehaj, M., Ahmadi, M., & Zamani Mohiabadi, M. (2021). Assessment of a heat pipe solar collector with nanofluids. *Environmental Science and Pollution Research*, *28*(5), 5316–5331. https://doi.org/10.1007/s11356-020-10797-x

Sheikholeslami, M., Farshad, S. A., Ebrahimpour, Z., & Said, Z. (2021). Recent progress on flat plate solar collectors and photovoltaic systems in the presence of nanofluid: A review. *Journal of Cleaner Production*, *293*, 126119. https://doi.org/10.1016/j.jclepro.2021.126119

Silva, H. de O. G. da, Costa, M. C. M., Aguilera, M. V. C., Almeida, M. da G. D. de, Fonseca, B. B. da, Reis, J. S. da M., Barbosa, L. C. F. M., Santos, G.& Sampaio, N. A. de S. (2021). Improved Vehicle Painting Process Using Statistical Process Control Tools in an Automobile Industry. *International Journal for Quality Research*, *15*(4), 1251–1268. https://doi.org/10.24874/IJQR15.04-14

Vasiliev, L. L., Grakovich, L. P., Rabetsky, M. I., Vassiliev, L. L., & Zhuravlyov, A. S. (2017). Thermosyphons with innovative technologies. *Applied Thermal Engineering*, *111*, 1647–1654. https://doi.org/10.1016/j.applthermaleng.2016.07.101

Verma, S. K., Gupta, N. K., & Rakshit, D. (2020). A comprehensive analysis on advances in application of solar collectors considering design, process and working fluid parameters for solar to thermal conversion. *Solar Energy*, *208*(August), 1114–1150. https://doi.org/10.1016/j.solener.2020.08.042

Zgodavova, K.; Bober, P.; Majstorovic, V.; Monkova, K.; Santos, G.; Juhaszova, D. (2020). Innovative methods for small mixed batches production system improvement: The case of a bakery machine manufacturer. *Sustainability (Switzerland), 12*, 6266. https://doi.org/10.3390/su12156266

Zhang, T., Pei, G., Zhu, Q., & Ji, J. (2016). Investigation on the Optimum Volume-Filling Ratio of a Loop Thermosyphon Solar Water-Heating System. *Journal of Solar Energy Engineering*, *138*(4), 1–10. https://doi.org/10.1115/1.4033403

Bruno Mendes de Jesus
Universidade do Estado do Rio de Janeiro,
Resende,
Brazil
brunomendesdejesus@outlook.com
ORCID 0000-0003-2277-7243

Newton Galvão de Campos Leite
Universidade do Estado do Rio de Janeiro,
Resende,
Brazil
nleite@fat.uerj.br
ORCID 0000-0001-8570-5218

Luiz Carlos Bevilaqua dos Santos Reis
Universidade do Estado do Rio de Janeiro,
Resende,
Brazil
bevilaquareis@gmail.com
ORCID 0000-0002-3176-5546

José Salvador da Motta Reis
Centro Federal de Educação Tecnológica Celso Suckow da Fonseca
Rio de Janeiro,
Brazil,
jmottareis@gmail.com
ORCID 0000-0003-1953-9500

Nilo Antonio de Souza Sampaio
Universidade do Estado do Rio de Janeiro,
Resende,
Brazil
nilo.samp@terra.com.br
ORCID 0000-0002-6168-785X

Gilberto Santos
ESD - Polytechnic Institute of Cavado and Ave,
Barcelos,
Portugal
gsantos@ipca.pt
ORCID 0000-0001-9268-3272

Luís César Ferreira Motta Barbosa
Centro Federal de Educação Tecnológica Celso Suckow da Fonseca
Rio de Janeiro,
Brazil
luiscesarfmb@gmail.com
ORCID 0000-0003-4739-4556