24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-0187
DEVELOPMENT AND ANALYSIS OF LOW COST SOLAR HEATHER

Diego de Mendonça Taborda
Eduardo Cadete Machado
Igor Renan Reis Carlos
José Antônio da Silva
Universidade Federal de São João Del Rei, Programa de Pós-Graduação em Engenharia da Energia, São João Del Rei, Brazil
jant@ufsj.edu.br

Abstract. *Solar radiation is indispensable to maintain the life on Earth; it is a clean and renewable energy. It is less used in Brazil compared to its potential. This kind of energy has two main applications: photovoltaic and thermal energy. The aim of this paper is to compare, thermal and economics performance of conventional systems for heating water and a low cost solar heater. In order to do this a prototype was made. The model was made using plates of polyvinyl chloride working as radiations absorbers. The 200-liter thermal vessel was made with polyethylene insulated with Styrofoam. The results obtained with the lowest system show a good effectiveness, despite its lower efficiency when compared to conventional systems. The lowest investment in installation and construction makes the non-conventional systems appropriated, especially for people without good financial condition. The average of thermal efficiency obtained was 32,81% ± 2,20%, while the maximum value was 46,97% ± 2,56%. The maximum temperature, at the outlet solar collector was 49,00°C ± 0,86°C. These values are relative to the specific radiation conditions for the days on which measurements were taken. The proposed method has an average uncertainty of ± 6.70%. Thus, the project reached its technical objectives, besides it made possible the dissemination of this solar heating technology for the neediest population, as an alternative to reduce consumption of electricity for heating bath water.*

Keywords: *Low cost solar heater; alternative solar system; solar radiation; water solar heating.*

1. INTRODUCTION

Solar energy is characterized as inexhaustible energy source, has low environmental impacts and is considered a very promising alternative to meet the challenges of expanding energy demand in Brazil. Solar energy has several applications, among them thermal energy from the radiation, for heating water and Photovoltaic (PV) system, which converts solar energy into electrical energy (HOSSAIN *et al.,* 2015).

The use of solar energy for water heating is an alternative to reduce the costs of the use of electricity because, according to Rodrigues and Matjs (2005), electric showers account for 18% of peak system demand. On average 73% of Brazilian households, use electric showers of 3-8kW for the baths. In south and southeast regions, where approximately the majority of the country's population is concentrated, this index reaches 90%. (NASPOLINI; MILITÃO; RÜTHER, 2010).

Energy concessionaires can also benefit from the use of such heating systems, since the use of showers is a major cause of demand peaks in the electrical system. Thus, by reducing these peaks, it is ensured that the distributed energy is of better quality and that the system is more reliable (NASPOLINI; MILITÃO; RÜTHER, 2010), (ILHA; RIBEIRO, 2012).

Despite all the benefits associated with the use of solar energy, one of the justifications for its little use is the high cost of its installation (RAMAN *et al.,* 2000). For example, a 200-liter solar heater costs an average of US$ 420.00 to US$ 1,600.00 according to the Brazilian Association of Refrigeration, Air Conditioning, Ventilation and Heating, (ABRAVA, 2014).

In this paper it was developed, as an alternative to conventional solar heaters, a prototype of solar heater system, designated as Low Cost Solar Heater (LCSH). It is a cheap equipment based on its materials (usually polymers) and its simplification manufacturing processes. In addition, Ilha and Ribeiro (2012) enumerate as main factors for the reduction of prices of these systems: the fact that the community itself can easily install it.

Using low-cost solar heaters Naspolini and Rüther (2012) obtained a 38% reduction in electricity consumption and reduced the peak of electricity demand by approximately 42%. This was possible because as the shower represents the major energy consumers in the residences of the country, the substitution of the use of the same by the water heated in the heating systems significantly reduced the need to heat the water for baths. This type of heater has a lower efficiency than conventional, but the reduction in installation cost is quite considerable which makes it a great option for the low-income population.

2. EXPERIMENTAL PROCEDURE

2.1 Construction and installation of collector plates

The low cost solar heater (LCSH) of this project was built in the city of Madre de Deus de Minas, located in the southeast of Minas Gerais, Brazil, at the coordinates: Latitude: -21.484°, Longitude: -44.3329°.

The system was built based on the LCSH's Manual of Manufacturing and Experimental Installation of Low Cost Solar Heater elaborated by Sociedade do Sol (2007).

For the construction of the system, US$ 61.00 were spent with the collector, US$ 77.30 with the thermal reservoir, US$ 42.00 with the installation of the system. In addition, US$ 160.00 were spent with the responsible labor force to install the system. Therefore, the total acquisition cost of the materials and installation of the system was US$ 340.30.

The collector is composed of a PVC board attached to a 32 mm of diameter PVC tube with a length of 70 cm, glued by an isophthalic resin mixed with marble powder. Figure 1 presents images of the construction of the LCSH.

Subsequently, a leakage test has to be performed after the resin has dried to verify possible holes and leaks. Then the board is painted with matte black paint to increase the absorption of solar energy. Figure 1 shows the absorber plate.

Figure 1: a) Absorber plate already glued to the 32 mm tube; b) Collectors after the application of black ink
Elaborated: By The author

According to Sociedade do Sol (2007), it is necessary to use one collector plate for every 100 liters of water to be heated. Then for a system of 200 liters would be necessary two collector plates. However due to the low efficiency of the collector plates it is advisable to use an extra plate. Factors such as wind, rain, pollution or even ambient temperature directly influence the efficiency of the collector, since it has no cover or insulation.

The collectors were joined as follows: two plates in parallel, and one in series with the other two that were in parallel.

The angulation and positioning of the collectors followed the information quoted by Siqueira, Vieira and Damasceno (2011) and Siqueira (2009). In these works, it was defined that the collectors operating in the south hemisphere, as it is in Brazil, are oriented to the north and should be inclined at an angle equal to local latitude. In the case of installations with natural circulation, the collector should have a slope of more than 10º in addition to the local latitude. This additional slope facilitates the natural circulation process and compensates for the annual variation of solar declination. This ensures that the system is positioned perpendicular to the radiation for the winter, time that the system is requested more.

The ideal angle for positioning the collectors would be 31º, being 21º due to the latitude of the city plus the 10º to compensate the annual variation of the declination of the radiation. However, due to structural problems, the collectors were affixed to the roof structure of the house, which has a slope of 23°, this variation is small but may affect the performance of the LCSH during winter.

In the construction of the reservoir, first drilled the holes in 200 liters-polyethylene drum (550 mm diameter x 850 mm height): two for the circulation of the water by the natural circulation process, one for cold water coming in from the city water supply, and another for the shower outlet. Afterwards the flanges were fitted. The drum has been coated with Styrofoam to increase the thermal insulation, and is then coated by a tarpaulin to protect the thermal insulation. Figure 2 shows the images of the alternative thermal reservoir used in this project.

The collector plates were installed in the roof's residence. After fixing, the pipes of the collector plates were connected with the flanges in the reservoir. The outlet system for the shower supply has been fitted with hot water PVC pipes that withstand temperatures of up to 80° C, and its required working temperature is approximately 70° C. The use of this thermal PVC tubing instead of the traditional copper tubing is justified by two reasons. PVC-hot-water specific piping is cheaper than copper tubing. The other reason is that after sometime copper releases particles in the water, which can cause fouling and can be harmful to health. Figure 3 shows the installation of the system.

Figure 2: a) 200 L polyethylene drum; b) Coated reservoir; c) Reservoir ready to be installed. Elaborated: By The author

Figure 3: a) Installation of the thermal reservoir; b) Heating system ready Elaborated: By The author

2.2 Instrumentation

To calculate the efficiency of the solar collector the solar heating system was instrumented with thermocouples type K, as shown in Fig. 4. These were installed in three positions, one in the cold-water intake of the collectors, one in the hot water outlet of the collectors and one inside the thermal reservoir for temperature control.

To carry out the reading of the temperatures indicated by the thermocouples, a digital multimeter and thermometer of the brand Minipa, model ET-2042C were used. For the measurement of the local solar radiation, a solarimeter model Maxwell 7834, series: 002 / fifth series was used. Measurements of the water temperature at the inlet and outlet of the collector and at the reservoir inlet were carried out every one hour. The mass flow of water recirculating into the system was determined by measuring the flow of water entering the thermal reservoir. A flowmeter was used for this purpose.

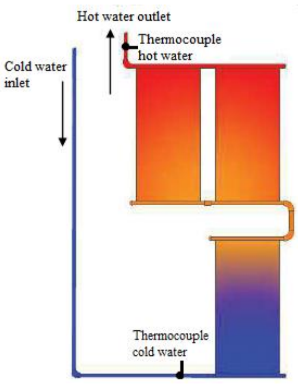

Figure 4: Heater operating diagram.
Elaborated: By The author

In the thermocouple, it must be considered that there is an uncertainty of ±0.75% of the measurement value of the thermocouple. The multimeter displays an uncertainty of ±1% of the measured value, when it reads temperature data, and ±0.5% of the measured value, for voltage data. Finally, the pyranometer has an uncertainty of ±0.5% of the measurement value.

With all instrumentation equipment mounted, measurements of temperature and radiation were carried out for 3 days, from 11/18/2014 to 11/20/2014. During those three days were measured the water inlet and outlet plate collector's, from the interior of the thermal reservoir and the local solar radiation was also collected in the same plane of the collector plate.

3. RESULTS AND DISCUSSION

3.1 Collector's efficiency

After collecting the temperatures data of: water reservoir, ambient, cold-water inlethot-water outlet and the radiation incident on the plates, the thermal efficiency of the collectors could be determined.

The thermal efficiency of the collector depends on optical and thermal properties. It can be characterized as instantaneous efficiency, defined as the fraction of insidious solar energy in the collector that is converted into useful energy for the working fluid (DAVIDSON; WOOD, 1996).

This value is obtained through the relation between the heat rate assigned to the collectors by solar radiation and the useful heat rate, which is the heat that is transferred to the water due the heating.

Eq. 1 gives the heat rate assigned to collectors.

$$\dot{Q}_I = IA \tag{1}$$

Where:

$\dot{Q}_I$ is the heat rate assigned to collectors in W;
I is the Intensity of solar radiation in W/m²;
A is the collector's area in m².

The useful heat rate given to water is given by Eq. 2.

$$\dot{Q}_u = \dot{m}C_p(T_{out} - T_{in}) \tag{2}$$

Where:

$\dot{Q}_u$ is the useful heat ratein W;
$\dot{m}$ is the water flow into the solar collector, in kg/s;
C_p is the specific heat of the water ate constant pressure, which value is 4174 J/kg. °C;
T_{out} is the outlet temperature of the collector in °C;
T_{in} is the inlet temperature of the collector in ° C.

Once the heat rates ($\dot{Q}_I$) and ($\dot{Q}_u$) are calculated, the thermal efficiency of the collectors is determined from Eq. 3.

$$\eta_{collectors} = \frac{\dot{Q}_u}{\dot{Q}_I} \tag{3}$$

Where:

$\eta_{collectors}$ is the thermal efficiency of the collectors.

The ratio of the measured data and the results obtained through Eq. 1 to Eq. 3 are show in Fig. 5 to Fig. 7.

The data were measured between 08h and 16h. As shown in Tab. 1 the collector plates obtained an average thermal efficiency of 32,81% ± 2,20% varying between 36,69% ± 2,28% and 28,19% ± 2,14%. These values are compatible with the thermal efficiency found by Siqueira (2009). In this paper the average thermal efficiency of 36% was reached. This efficiency could be improved by employing an insulation box in the collector to minimize heat losses for the environment.

The average temperature of the heated water was around 41.4°C ± 0,72 °C, which is a pleasant temperature for the bath. The ideal temperature for the bath is the same of the human body, which rotates around 36 °C to 37 °C.

The maximum temperature reached by the collector plates was 49ºC. This value was close to the maximum values found in the literature, where studies carried out with the same collector model reached values above 53 ºC Siqueira (2009).

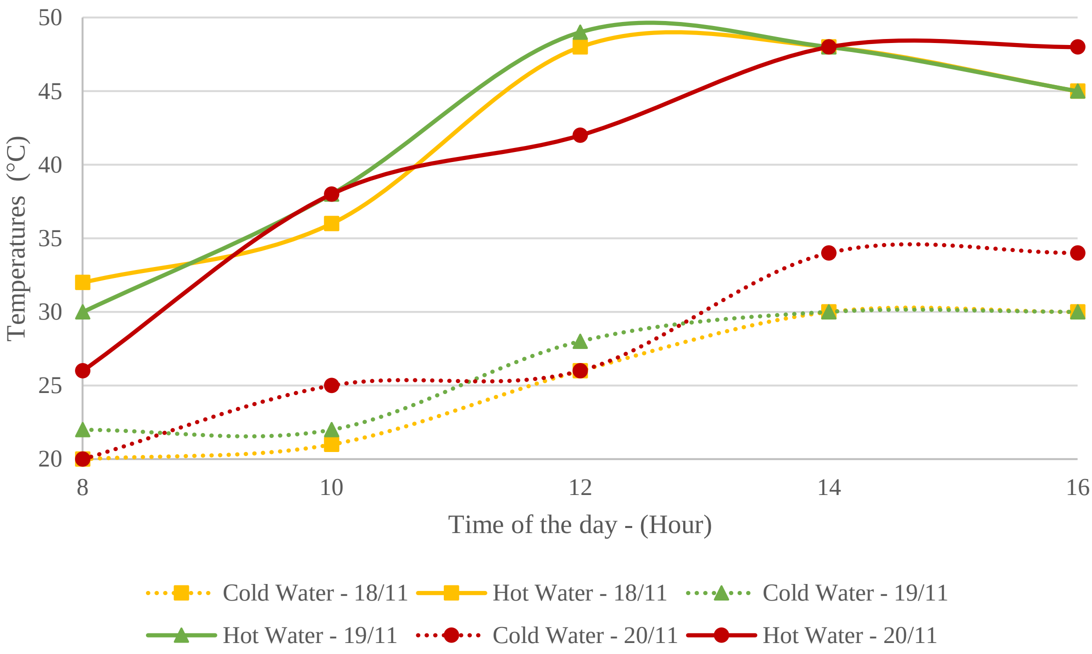

Figure 5: Temperatures of the collector

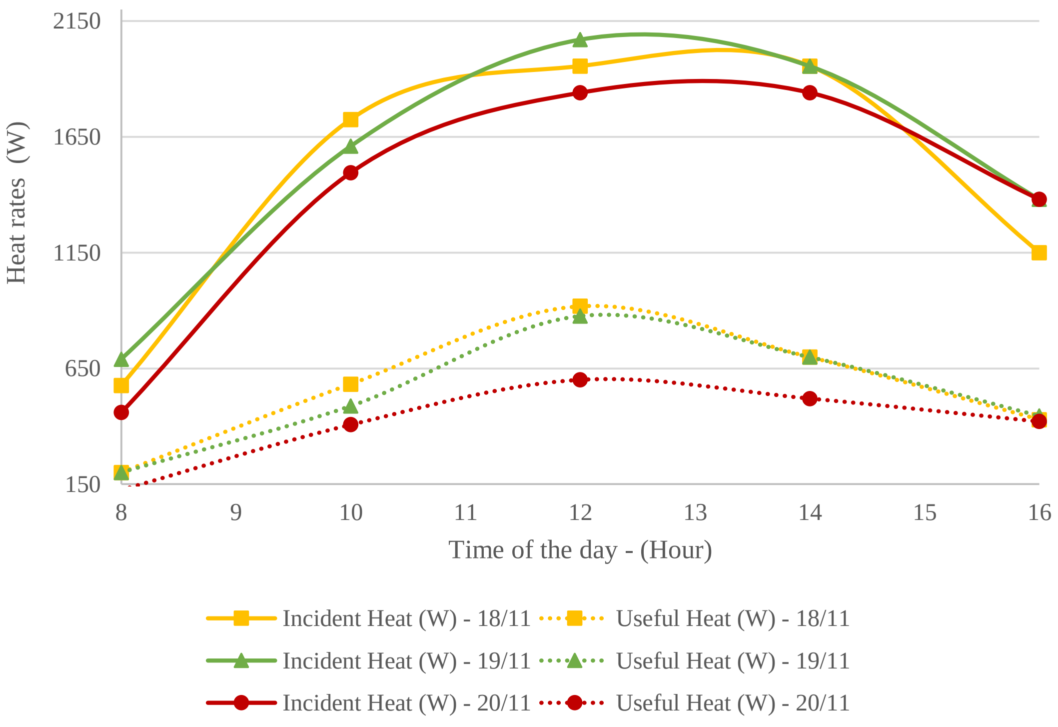

Figure 6: Heat rates

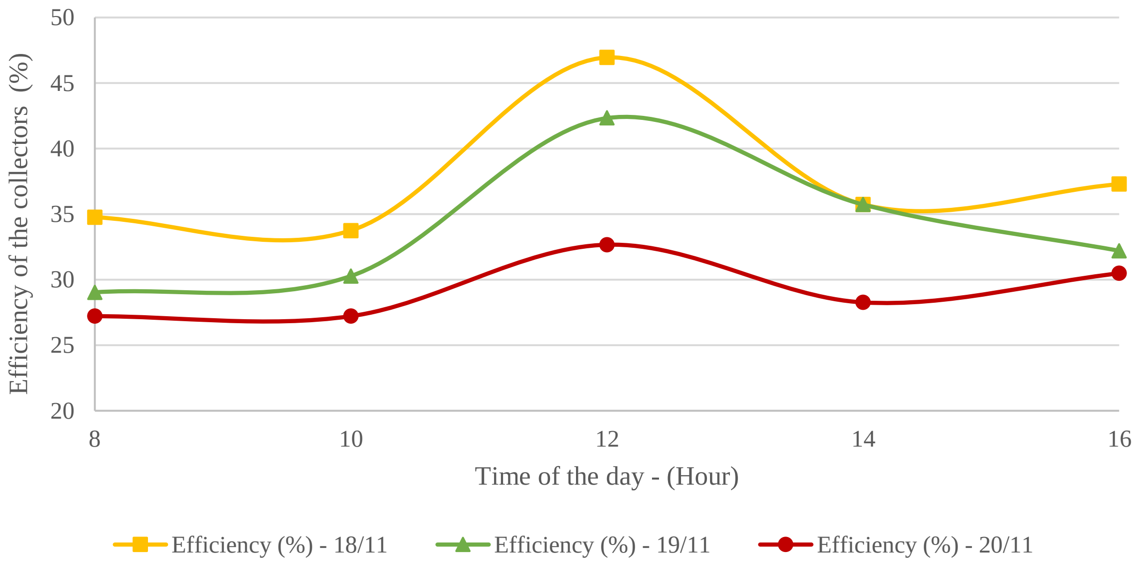

Figure 7: Efficiency of the collectors

Table 1: Average of data collected

Average	Temperatures (°C)		Mass flow (kg/s)	Radiation	Heat rate (W)		n (%)
	Cold water	Hot water		(W/m²)	Incident	Useful	
18/11	25,40±0,45	41,80±0,73	0,00790±2,4E-4	4,47±0,07	1472±22	540±32	36,69±2,28
19/11	26,40±0,46	42,00±0,74	0,00790±2,4E-4	4,68±0,07	1541±23	517±32	33,55±2,18
20/11	27,80±0,49	40,40±0,71	0,00750±2,3E-4	4,26±0,06	1403±21	395±29	28,19±2,14
Total Average	26,50±0,47	41,40±0,72	0,00780±2,4E-4	4,47±0,07	1472±22	484±31	32,81±2,20

3.2 Efficiency of the reservoir

To determine the thermal efficiency of the water reservoir, measurements were made of the water temperature for 18 hours. The reservoir temperature data are shown in Tab. 2. The value of reservoir efficiency is obtained by comparing the energy that it accumulates when the system starts in the morning and when it stops, at night. This is done through Eq. 4:

$$\eta_{reservoir} = \frac{Q_{period1}}{Q_{period2}} = \frac{c_p T_{r1}}{c_p T_{r2}} \quad (4)$$

Where:

$\eta_{reservoir}$ is the reservoir efficiency;
$Q_{period1}$ is the accumulated energy in the reservoir, in J;
$Q_{period2}$ is the energy accumulated in the reservoir at a later time, in J;
T_{r1} is the temperature inside the reservoir at an instant of time, in °C;
T_{r2} is the temperature inside the reservoir at a later time point, in °C.

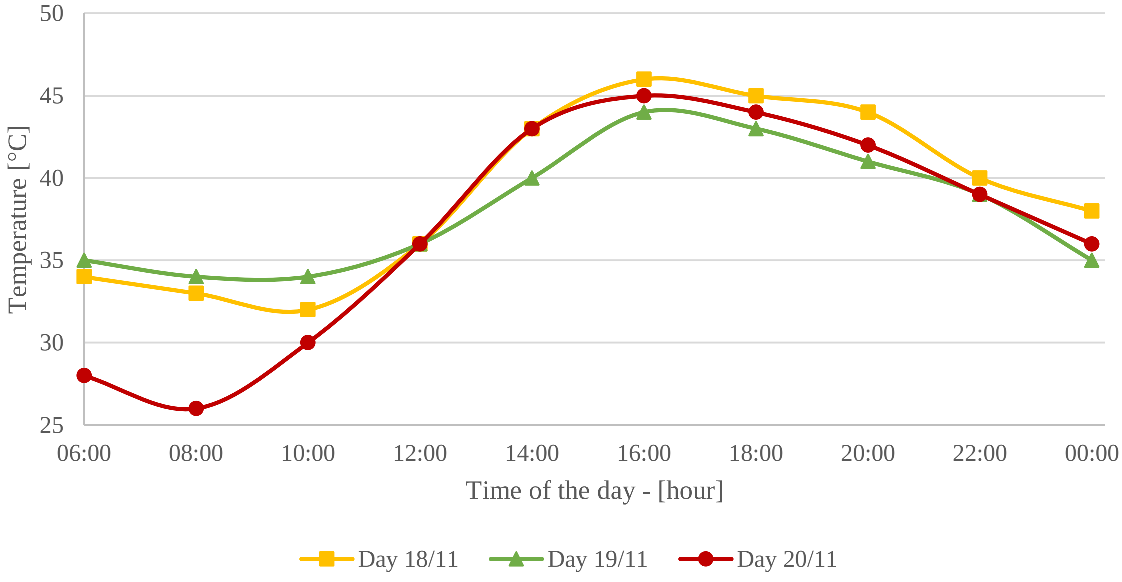

Figure 8: Reservoir temperature

It can be seen from Fig. 8 that from the moment the sunsets, the water temperature in the reservoir begins to decrease gradually. This occurs because with in the absence of solar radiation, the process of water movement due to density difference does not occur. Therefore, the heating system does not work. From this moment on, the thermal reservoir becomes a key part of the system, since it is responsible for maintaining the thermal energy stored during the day. The alternative thermal reservoir had an average temperature drop of 11 ºC between 18:00 h, time that the sun sets, until 06:00 h, time that the sun rises. This value is slightly above the values found in literature if projects similar to this one, with the use of alternative thermal reservoirs, where the average temperature drop is about 7.5 °C (COSTA, 2007). In the conventional thermal reservoirs, the reduction is of the order of 3.5 º C to 5 ºC, which shows a temperature gradient in relation to the proposed reservoir of 7.5 ºC.

For the calculation of the thermal efficiency of the reservoir Eq.4 were used, where the amount of energy stored in the reservoir at 18:00 on 18/11 and the amount of energy stored in the reservoir at 06:00 on 19/11 were determinate. Once in possession of these energy values, a ratio was calculated between the stored energy at 06:00 and the stored energy at 18:00, thus achieving the efficiency of the drum of 77.78% ± 1,93% from 18/11 until 19/11 And 65.11% ± 1,61% from 19/11 to 20/11. It should be noted that in these days there was no consumption or replacement of water from the reservoirs.

3.3 Experimental Uncertainty

Using the data presented in section 2.2 regarding the uncertainties of the instruments used in the measurements, the calculation of the overall uncertainty of the measurements can be done.

In the Tab.1 and Tab. 2, besides the values measured in the installed system, there are also the values associated to the uncertainties of each measurement.

It is important to note that the temperature uncertainty shown in Tab. 1 contains the uncertainties associated with the thermocouple, pyranometer and the multimeter. First there is the uncertainty associated with the temperature measured at the thermocouple. Subsequently there is the uncertainty of the multimeter, which reads the value obtained in the thermocouple. In an analogous way, the e uncertainties related to the reading of the incident radiation must be considered. There is the uncertainty associated with the pyranometer, which measures the amount of incident radiation. And then there is the uncertainty reading the voltage value on the multimeter. To find the value of the propagation of uncertainty, the methodology described in Cabral (2004) was adopted.

To obtain the propagation of uncertainty of the values measured through Eq. 1 to 4, it is necessary to use the methodology described by Klein (2001) and Couto (2006). The software, Engineering Equation Solver was used to perform the calculations.

The proposed method has an average uncertainty of ± 6.70%. This value could be even lower if the temperature and radiation data were measured directly, without the use of the multimeter to perform the measurements obtained by the thermocouple and the pyranometer.

3.4 Economic Analyses

Conventional residential water heating systems cost on average US$ 1000 for a system with a capacity of 200 liters, and these prices include the costs of installation (BENLI, 2016). For comparison purposes, the cost of manufacturing and installation of the proposed prototype was only US$ 180.60. If a comparison is made between these values with the minimum value of the conventional system that is US$ 1000, we have an economy of more than 82%. This becomes a good alternative for low-income populations.

For the calculation of Net Present Value, the adopted rate was 0.5%, the value usually obtained when investing the money in a conventional savings fund, that is, a low risk investment. The revenues of each month, US$ 9.62, correspond to the amount saved using the Solar Heater of Low Cost. Therefore, in one year, the revenue is US$ 115.38. In addition, the annual interest rate of 6%. The period of analysis stipulated was ten years. This is because according to Siqueira, Vieira and Damasceno (2011) the useful life of a low cost solar heater varies from 10 to 15 years.

In order for the project to be viable, economically speaking, the Net Present Value must be greater than zero, and the Internal Rate of Return must be greater than the minimum rate of attractiveness, since the minimum attractiveness rate represents the minimum return that is expected of a particular project. The net Present Value obtained in this project, at final of 10 years, was US$ 688.98, and with an Internal Rate of Return of 72%. Therefore, the simple Payback, not considering currency devaluation, was 1.4 years, and considering the currency devaluation the discounted payback was only 1.5 years, showing the project viability.

4. CONCLUSIONS

The use of the LCSH proved to be viable in economic terms and system efficiency. Although thermal efficiency is lower than conventional systems, the cost of even it is around four times smaller. The average efficiency for the days measured and with the specified radiation of the suggested system ranged from 28,19% ± 2,14% to 36,69% ± 2,28% and the average temperature of the heated water was 41.40°C ± 0,72°C. The reservoir is viable too, according its thermal efficiency and cost. This alternative reservoir reached a thermal efficiency of 77.78% ± 1,93%, which is great compared to its cost, only a quarter of the cost of a conventional one. Similar results were found by Souza *et al*. (2010), were they found that their alternative reservoir had almost the same thermal efficiency then others conventional ones.

It should be noted that the values found for the thermal efficiency of the collectors and the thermal reservoir refer to the specific radiation conditions of the days on which the measurements were made.

Finally, there was a reduction in the consumption of electricity, which allows the return on investment in about 18 months. The proposed solution is a great alternative for the low-income population, since the cost of equipment is relatively low.

5. ACKNOWLEDGEMENTS

This work was supported by CAPES and FAPEMIG.

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