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Feasibility analysis and implementation of an alternative solar heater for low and middle income families in the Abaeté region

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Abstract. *Brazil has a great potential for environmentally clean energy production through solar energy. However, the high investment to acquire the solar water heating system available on the market makes it unviable for a large part of the population. As an alternative, the electric shower is used for bathing, which besides being an expensive piece of equipment, requires a large amount of energy, which generates more spending in homes. Given this context, this study aims to analyze the feasibility and implementation of an alternative low-cost solar heater, ASBC (Aquecedor Solar de Baixo Custo - Low Cost Solar Heater), for low or medium income families, enabling savings and renewable energy generation. The main relevance of the research concerns the ease of access to hot water by low and medium income families, making it possible to partially deactivate the electric shower and, consequently, reduce the expenses with electric energy. Initially, the adopted methodology consisted of determining the amount of hot water and energy consumption in an average family home, as well as surveying the needed material to build the ASBC. Finally, the saving was set, both in kWh and in cash, for an average family located in the city of Abaeté - Minas Gerais. The expected results are economic viability for production, installation and operation of ASBC by low and medium income families for a period of one year. At the end of the study, it was found that the low-cost solar heater allows savings of up to 22 %, enabling great family savings. Energetically, the savings were 90 kWh for a standard family of 4. Considering the price of kWh to be R$ 1.00, the monthly savings are R$ 90.00. In addition, ASBC's efficiency and functionality were validated, making it viable for low and middle income families. Finally, benefits were found both at the environmental level, due to the reduction of pollution in the acquisition of electricity, and at the social level, since the savings generated can improve the quality of life of the studied family.*

Keywords: *Solar energy, Low cost solar heater, Renewable energy, Economy, Social responsibility*

1. INTRODUCTION

National and foreign companies agree that Brazil is one of the most imminent markets for implementing solar power energy generation technology. There are three main reasons for that: intense solar radiation, high incentives to renewable energy sources, regulated by Agência Nacional de Energia Elétrica (Aneel) and parity viability to the utility network (Esposito and Fuchs, 2013).

Considering that the electric sector influences the entire population and moves a great amount of money, the social role of electricity could add a lot more of planning in order to seek better conditions to Brazilian families (Barros *et al.*, 2000).

The popularization of solar energy generation confronts a great barrier of social inequality in the country. This way, solar heaters implantation for low-income and medium-income income is an almost inaccessible goal when it comes to required values.

The social inequality is directly related to Brazil's income distribution, which enables absolute poverty to numerous families. This poverty is associated to the unequal resources distribution in this country, therefore there is an urge on social spending politics that aid or minimize this economical gap (Rocha, 2003).

The high costs to acquire commercial solar heaters makes it difficult for low and medium-income families to use it in Brazil. For that matter, about 92.1 % of the population uses electric energy and just 0.8 % solar energy. Due to this characteristic, most Brazilian families use electric shower due to its low price. According Gerais (2012), although it has a ow purchase price, this single device can consume up to 30 % of monthly electric energy for a family, which makes its

energetic expenses very high.

Within such concept, one can infer that the solar heat system for the house hydraulic system cannot be acquired in all social classes. Given that, an alternative is the Low-Cost Solar Heater (ASBC - Aquecedor Solar de Baixo Custo (in Portuguese)), that can be produced and installed by the end user.

ASBC has been an alternative for reducing residential electricity consumption for some time now, and has been widely studied. For example, Lenz *et al.* (2017) aimed to evaluate a solar heating system whose collector is flat and has a surface of 1m2. For this purpose, experiments were carried out on the premises of the State University of West Paraná, Cascavel campus; data collection was performed with PT100 sensors and pyranometer coupled to a CR-1000 datalogger. Collections were performed every 5 minutes, for a period of one year. The system's monthly efficiency ranged between 33.7 and 53.54%, while the energy absorbed per month ranged between 30.79 and 75.29 kWh/m^2. Thus, the authors concluded that the proposed system is a good option to be used in domestic or rural water heating.

Already de Moura and de Oliveira (2015) built a prototype of ASBC, which worked from 6 am on October 9, 2014 until 6 am on October 10, 2014, located in the city of Montes Claros. The measurement of solar energy is done by a meter model MES-100, while the water temperature was performed by two digital thermometers T1 and T2 model TL8009, obtaining, at the end of the experiment, hot water at 37.1 °C. Finally, the authors measured the water temperature of a traditional shower Maxi Ducha. At the end of the experiment, the authors concluded that the solar collector is efficient both in reducing residential electrical consumption and in terms of bath temperature.

SALOMÃO *et al.* (2014) developed a prototype of ASBC, in the Northwest region of the state of São Paulo, Brazil. The presented prototype was made of PVC, and the water temperatures were collected daily for one year. At the end of the measurements, it was found that the optimum efficiency of the system presents an average gain of 14 °C, when the collector is inclined at 30°; it was also found that the prototype is viable, due to the high incidence of solar radiation in the region.

In this regard, it is possible to establish an easy installation ASBC with enough efficiency to supply the needs of a family house that does not afford the equipment available on Brazilian market. The present work prioritized the use of recyclable materials in the assembly of the proposed system; when it is not possible to assemble from such materials, low-cost materials already available on the market are used as an alternative.

Based on the above considerations, the present study studied the implantation feasibility for an ASBC, which is accessible for the low and medium-income population on the city of Abaeté, Minas Gerais, to partially disable the electric shower employment.

2. DEVELOPMENT

At first it is necessary to gather data on solar incidence on the region of Abaeté – MG, the average consumption on electric energy and water, and also the type of solar heater definition.

2.1 Solar irradiation

The energy transfer through solar radiation is decisive for the thermal utilization on fluid heating at solar collectors. However, a series of factors imply directly on the solar irradiation availability, such as: atmospheric conditions, area's latitude and position on time (day hour and day of the year) (Kelman *et al.*, 2005).

On Table 1 it is shown the solar horizontal irradiation in the city of Abaeté -MG , in which the solar heater will be implanted.

Table 1. Solar horizontal irradiation

Solar horizontal irradiation												
Station	Abaeté											
City	Abaeté											
UF	MG											
Country	Brasil											
Latitude (°)	12.101 °S											
Longitude (°)	45.449 °O											
Average solar daily irradiation [kWh/m^2dia]												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Average
6.03	6.21	5.28	5.1	4.62	4.37	4.66	5.53	5.73	5.76	5.40	5.79	5.37

As can be seen, the incident radiation in the region of Abaeté, Minas Gerais, is considered sufficient for the proposed system to be installed and to present a good financial return, as illustrated in the later sections.

2.2 Average Household Expenditure

On this section, it will be investigated the average expenses for a family on electric energy and water. Therefore, the family of 4 people is considered to be living in a popular residence. This place has a single bathroom, on which currently an electric heat system is used, conventionally a shower.

2.2.1 Electric Energy Household Expenditure

On its paper, Procel and Eletrobrás (2005), computed the energy expenses on the most usual household appliances during the day, as expressed in Figure 1.

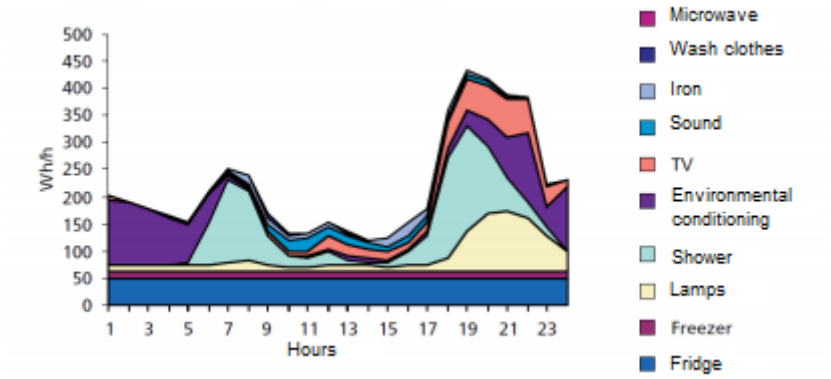

Figure 1. Average Consumption on domestic equipment throughout the day

Procel and Eletrobrás (2005), also identifies the share of consumption on the most important household appliances on Brazil's residences, as shown in Figure 2.

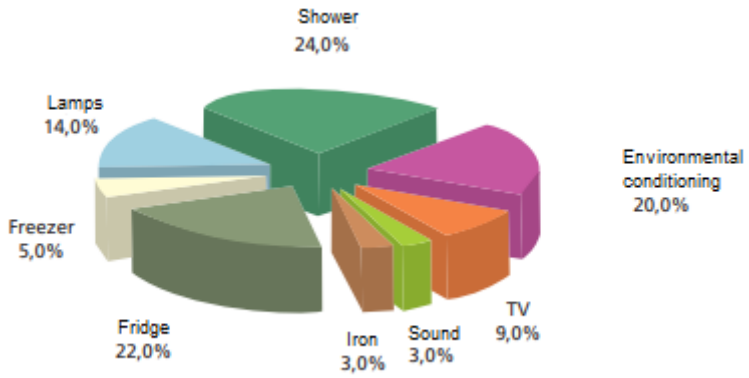

Figure 2. Most important household appliance on average household consumption

This way, it can be noticed that the electric shower is the equipment that has the larger energy consumption on the share. Thus, the average monthly expense for this equipment in a residence with four occupants, is about 90 kWh, or 22 % of the total energy consumption for the residence, considering that each person takes only one daily shower ant that the shower has a 4500 W Power.

The energy bill that is paid by the consumer is the sum of several factors: the energy availability (Generator cost); transmission (transmission costs); and distribution (energy distributor utility) along with the sector's charges and taxes (de Energia Elétrica, 2017). On this context, a medium value of R$ 1.00 per KWh was calculated.

2.2.2 Hot Water Family Consumption

According to SABESP (2015), a 15-minute shower, with a half-opened valve would spend up to 135 liters of water. This, a 5-minute bath spends at lest 45 liters of warm water. In the place in question, the hot water is only utilized for the bathroom. Considering that a resident showers once a day and one shower takes from 5 to 10 minutes, the conclusion is 270 liters of water, in average, will be spent daily on this house to satisfy 4 people.

2.3 Low cost solar heater

The low costs solar heater aims to be accessible for all low and medium-income social classes. The relatively high traditional solar heater price, on the market, makes it impracticable for most of Brazil's population, since the ASBC brings and elevated economy. This is due to the fact that the material acquisition, assembly and installation will be executed by the user (do Sol, 2009).

The ABSC starts its operation with the solar incidence on the collectors surface; the energy is absorbed and converted to heat, heating the collector's water. The thermosyphon process is then initiated, which is a natural process on which the less dense water is the heated water, which moves to a higher level, on which the isolated thermal tank is. In order to this process to occur, the tank needs to be in a higher level (do Sol, 2009).

The solar heating system as described by do Sol (2009) can be explained In 4 essential parts, which are:

1. Thermal Tank;
2. Collectors;
3. Electric shower with mixer valves;
4. Pipe system;

Figure 3 shows each of this essential parts.

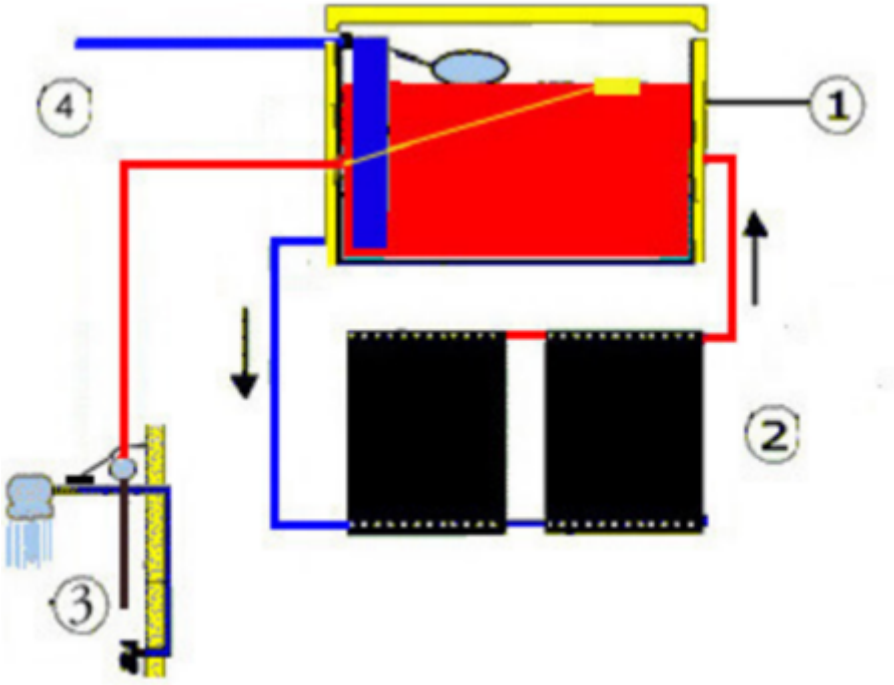

Figure 3. ASBC heating system representation

3. RESULTS AND DISCUSSION

Initially, a survey of the cost of acquiring the materials was carried out. Then, a detailed installation proposal was drawn up. Afterwards, an analysis was carried out in order to verify if the ASBC is economically viable. Finally, a comparison was made between ASBC and heaters commonly available on the market.

3.1 Quotation for necessary materials on the construction of ASBC

A quotation was made for the to be utilized materials for the ASBC, considering the base project as reference. Recycled materials were prioritized. The results are disposed on Table 2.

Table 2. Price quotation on materials for the ASBC construction

Materials for manufacturing and installing the heater	Quantity	Unitary value	Amount
Water tank - 310 L	1	R$ 149.90	R$ 149.90
PVC Ball Valve – weldable 25 mm	3	R$ 6.50	R$ 19.50
PVC Flange for water tank 25 mm c/r	5	R$ 8.55	R$ 39.20
PVC Tee - 20 mm	80	R$ 0.49	R$ 43.75
PVC Tee connection	80	R$ 0.60	R$ 48.00
PVC reducer - 25 to 20 mm	5	R$ 0.40	R$ 2.00
PVC LR Coupling- 25 mm	5	R$ 1.99	R$ 9.95
PVC Cap Screwed - 25 mm	4	R$ 0.55	R$ 2.20
PVC welding coupling - 25 mm	8	R$ 0.46	R$ 48.75
PVC CAP (weldable CAP) - 20 mm	6	R$ 0.69	R$ 4.14
PVC adapter (glued to screwed) - 25 mm	4	R$ 0.95	R$ 3.80
PVC Elbow 90° - 25 mm	10	R$ 0.40	R$ 4.00
PVC Cruve 90° - 25 mm	4	R$ 3.30	R$ 13.20
PVC Weldable union - 25 mm	6	R$ 6.98	R$ 41.88
PVC Weldable pipe - 25 mm	35	R$ 2.65	R$ 92.75
PVC Weldable pipe - 20 mm	55	R$ 2.15	R$ 118.25
PVC drainage tube - 40 mm	8	R$ 2.98	R$ 56.75
Nipel - 1/2”	2	R$ 0.98	R$ 1.96
White Tee screwed connection- 1/2”	2	R$ 2.50	R$ 5.00
PVC Elbow 90° - screwed - 1/2”	1	R$ 2.40	R$ 2.40
Crepe Tape 19 mm	1	R$ 6.00	R$ 6.00
Sintetic polish Paint – Matt Black – 900 ml	1	R$ 24.99	R$ 24.99
Solvent - 900 ml	1	R$ 12.00	R$ 12.00
Brush paint - 10 cm	1	R$ 13.50	R$ 13.50
PVC glue incluing brush 175 g (high temperature)	1	R$ 17.90	R$ 17.90
High Cure Tape - meter	5	R$ 7.90	R$ 39.50
Galvanizes wire n° 16	1	R$ 15.90	R$ 15.90
Water Blocking Tape 1/2”	1	R$ 6.90	R$ 6.90
Sandpaper gr. 100	1	R$ 1.50	R$ 1.50
Thermal protector cape for tanks – incap	1	R$ 199.00	R$ 199.00
Discharge box buoy	1	R$ 6.00	R$ 6.00
Faucet Buoy 25 mm	1	R$ 17.80	R$ 17.80
Total			R$ 1068.37

3.2 Installation Proposition

Given the variety of methods to manufacture a solar heater, the project was customized in order to use the as many possible low costs materials which also less harms the environment.

The easiness on assembly and installation is also prioritized. The details for the installed heater is shown in Figures 4, 5, 6, 7.

The project installation was divided accordinly to its main components: thermal tank, collector plates, electric shower using mixing valves and pipe system.

3.2.1 Thermal Tank

The thermal tank purpose is to store and maintain the water heated by collector plates. For ASBC, it can be used recycled barrels (as long as they were not storing chemical products previously), styrofoam boxes and even traditional water tanks, that need to be revested by a plastic film to avoid leaking.

For the recommended tanks, a 310 liters water tank was chosen, as it can be easily bought in construction stores or even reused. The Figure 8 demonstrates a coated water tank.

The tank still has two complementary intern components for its functioning, controlling water inflow and outflow in the system. The first is the turbulence reducer, attached to the buoy valve pipe. Its function is to lead the cold water directly to the bottom of the tank, reducing contact with the warm water which is stored on the upper part of the tank.

The second is the level buoy, usually made with the following material: conduit; flexible conduits and a buoy. The buoy can be made of different materials, as plastic bottles or a piece of Styrofoam, and must be placed by the end of the

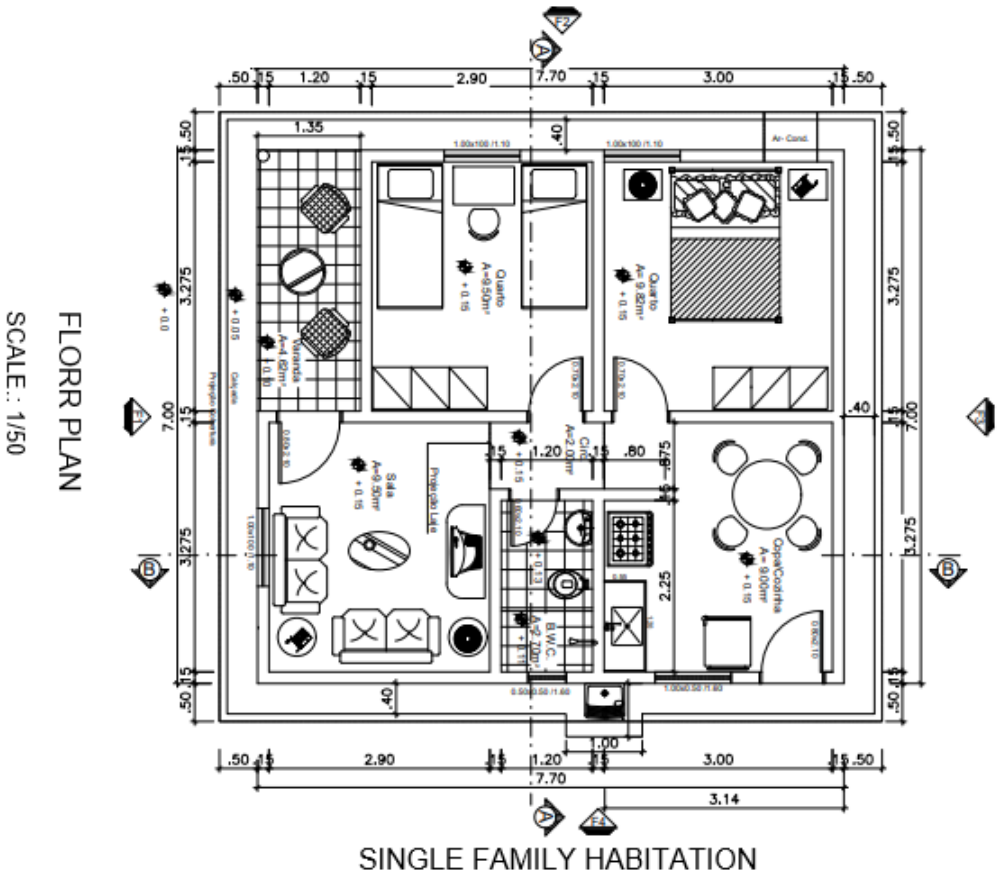

Figure 4. Family residence's Floor Plan – in which the solar heater implantation was done

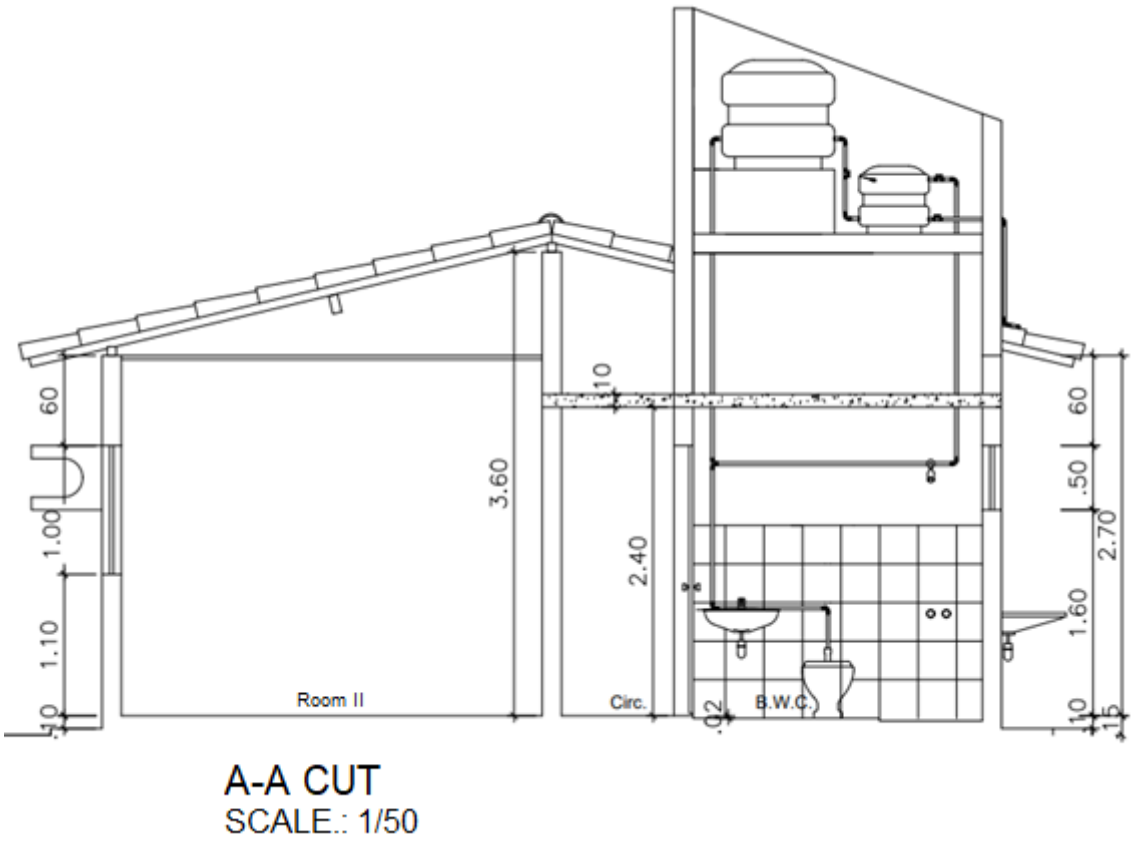

Figure 5. AA Section – in order to observe the ASBC hydraulic system

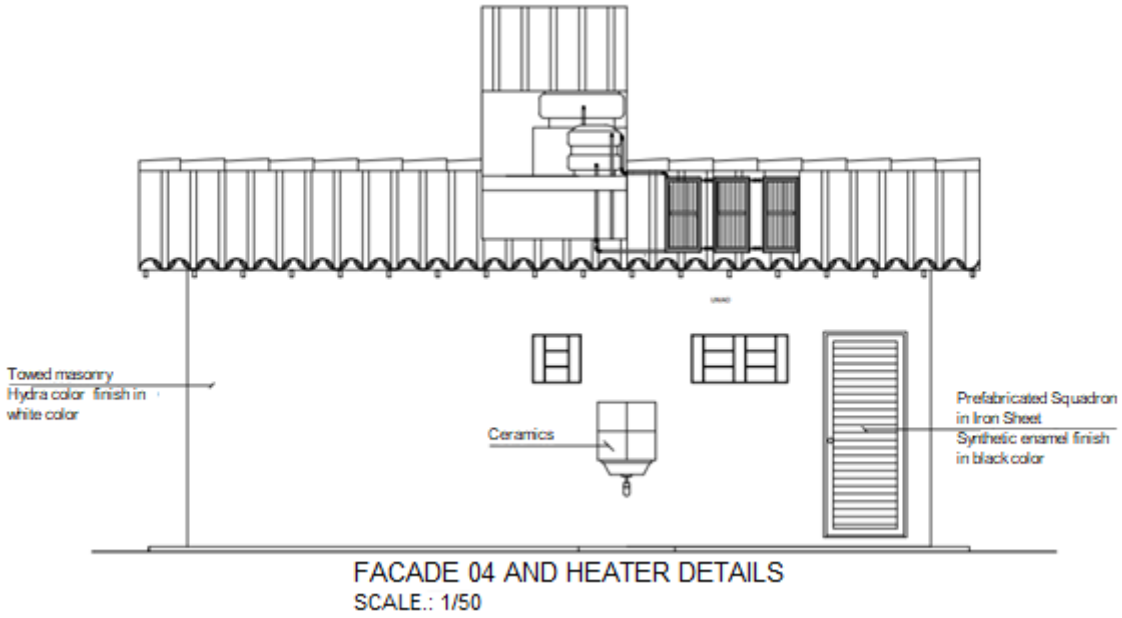

Figure 6. Residence Front – Low Cost Solar heater implanted

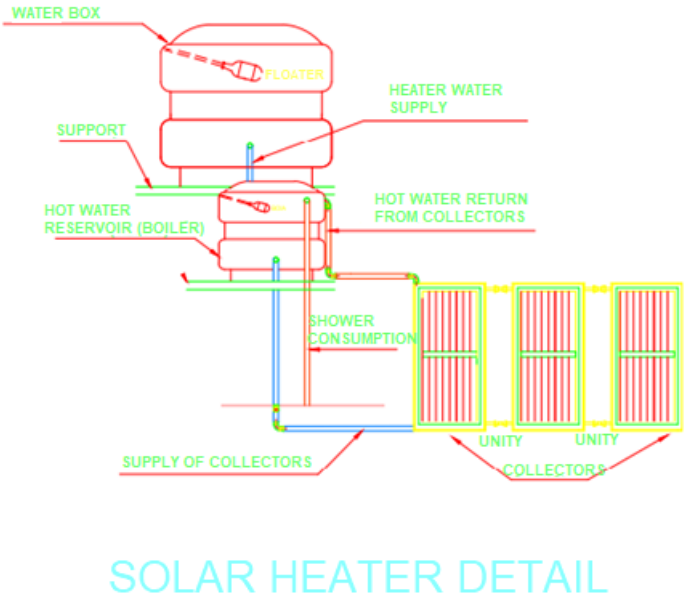

Figure 7. Details of the solar heater on the designated residence

Figure 8. Water tank coating

conduit. This component collects the water on the superior part of the tank, that is, the warmer water and directs it to the shower, as presented in Figure 9.

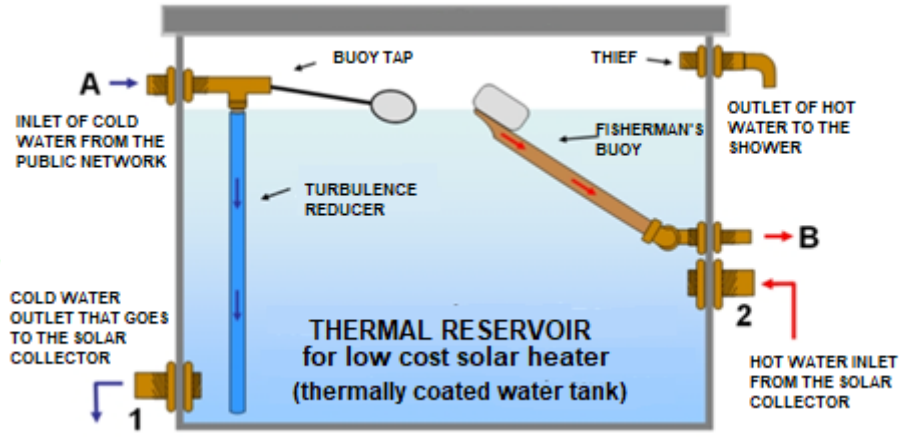

Figure 9. Detailed scheme for the tank system

3.2.2 Collector Plates

The collector plates are the main part of the equipment, and its function is to heat the cold water that comes from the water tank through solar radiation. They are formed by pipes, which should be painted black in order to absorb the maximum possible radiation. Therefore, the hot water expands, being less dense than the cold water, flowing to the superior level tank.

According to Urbano (2012) Urbano (2012), for each 100 liters of hot water needed for a residence, it is necessary an 1 m^2 collector. Considering this calculation, a 4 people family that spend 270 water liters per day, three 1 m^2 collectors will be required.

For each collector's assembly, 2 bars of 32 by 67 cm and 20 bars of 20 for 144 cm, with a 4 cm gap to the borders and 1cm gap between parallel bars, according to the system adopted on Figures 10 and 11.

Concerning the system proper functioning, the collector plates need to be in a lower level compared to the tank and tipped accordingly to the house's roof.

3.2.3 Electric shower with the mixer

According to do Sol (2009), the mixer function for the low cost solar heater is to enable the acclimatization of the bath water temperature, as the device adjusts the hot water flow, as evident on Figure 12.

3.2.4 Piping system

The piping system must be installed externally, not being necessary to embed it on the wall. This way, the resident avoid to break or reform brickwork for the pipe passage.

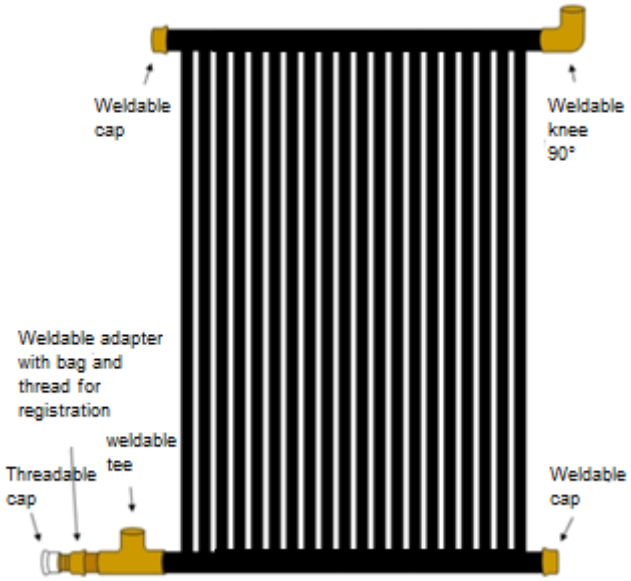

Figure 10. Assembly Scheme for collector plate

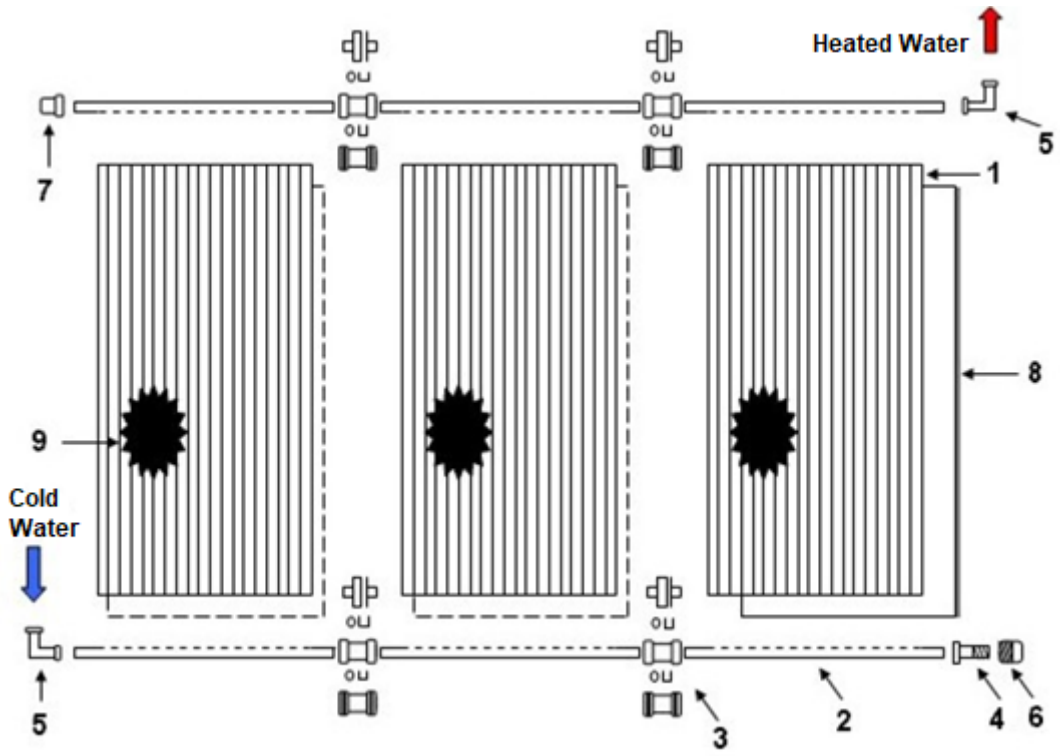

Figure 11. Collector Plates installation scheme

The pipe has some specific characteristics:

- • The entire hot water pipes should contain a thermic protection, revested by polipex, to avoid the heat lost by atmosphere contact;
- • Pipes that are external to the system also have to be imbedded in thermal insulator and UV rays protection in order to avoid fast deterioration for the sun exposed pipes.

3.3 Economic Viability

In order to verify if the proposed system is economically viable, the first step is to assure the operability on the proposed ASBC. Thus, water on the tank needs to be collected using a thermometer (of at least 110ºC scale), every day

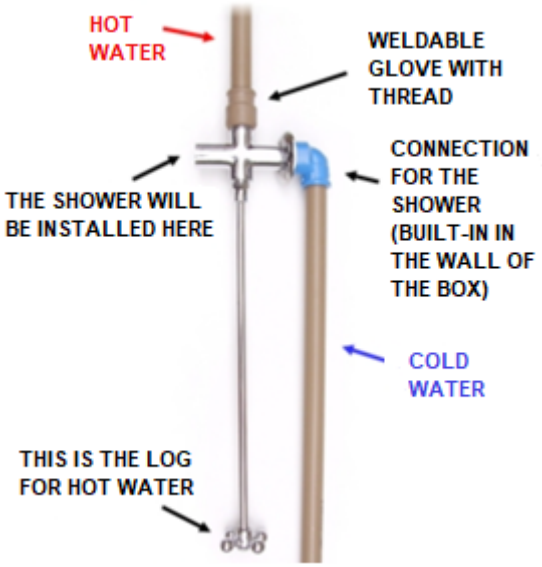

Figure 12. Hot and cold water mixer layout

during a month at 5 P.M. timezone GMT-3 (Brasilia's timezone). For a better accuracy, the average temperature of the day was used, as demonstrated on Equation 1.

$$T_m = \sum_{n=1}^{30} \frac{T}{n} \tag{1}$$

Onde:
T_m = medium temperature;
T = mesaured temperature
n = time period.

In conclusion, the ASBC functioned correctly for one month, and the generated savings can be verified. For that matter, a simple comparation between the energy bill on the month previous to the installation and subsequent to it. Hence, the savings can be calculated by the monthly consumption with the shower and the solar heater, multiplied by the kWh value, achieving the saved amount by the project.

From the data analysis conducted on the literature references, the conclusion is that the ASBC manufacturing and installation is not only viable, but also a low cost investment and with a high savings capacity for residences, saving up to 22 % of the kWh, previously consumed by the electric shower

According to de Energia Elétrica (2017), the energy bill that is paid by the consumer is the sum of several factors: the energy availability (Generator cost); transmission (transmission costs); and distribution (energy distributor utility) along with the sector's charges and taxes. For a residence in the city of Abaeté, the average pirce for the kWh is R$1.00. So, considering the previous energy consumption studied, the obtained saving with the ASBC implementation is R$90,00 per month. This way, in order to recover the investment, 12 months utilization would be necessary.

3.4 Comparing ASBC to commercial heaters

The solar heating industry on Brazil is quite modest yet. Therefore, just small service providers companies exist, on major cities (essentially capital cities).

To compare the ASBC to industrialized solar heaters, it was necessary to make a quotation on service provider companies. The name of the companies will not be mentioned, in order to avoid exposure. That said, two quotations were conducted, on companies x and y.

Company x would provide the installation, covering all materials, by a total of R$ 4800.00. The quotation made by company Y submitted a better price, by a total of R$ 3222.00.

Table 3, below, compares in a condensed way the comparison between the three mentioned solar heaters.

Given the payback time for the ASBC and the available heaters on the market, it is proven that the ASBC investment brings more benefits in relation to costs and investment payback time.

Table 3. Investment Comparison

System	Value (R$)	Monthly Savings (R$)	Payback (Months)
ASBC	1068.37	90.00	12
Heater company Y	3222.00	90.00	36
Heater company X	4800.00	90.00	54

4. CONCLUSION

The present study verified that the low cost solar heater enabled saves up to 22 % for a 4 people family, living in Abaeté, Minas Gerais. This way, great savings were generated for the resident, validating the ASBC as an as efficient and functional system as the market's available equipment. In addition, its cost-benefit makes it highly viable for medium and low-class population, facilitating the acquisition of a solar heater, as the price difference of an ASBC compared to a solar heater available on the market is about R$ 2942.63.

It was also established that the monthly savings for a residence is of 90 kWh within the ASBC implementation, considering that the kWh price is on average R$ 1.00, it is possible to infer an monthly saving of R$ 90.00 for not using the electric shower. The investment then paid in up to a year utilization.

The proposed ASBC implantation, which is considered cost-effective, is also considered ecological viable given the fact that it reduces the energy utilization of sources that pollute the environment. Additionally, the generated savings by the proposed device allows a better quality of life for the medium and low-income population, making it socially viable.

5. ACKNOWLEDGEMENTS

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