ANALYSIS OF THERMAL PERFORMANCE OF A WATER HEATING SOLAR SYSTEM USING SOLAR COLLECTOR WITH ABSORBER AREA OF PVC PLATE

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Abstract. *It will be presented a collector to be used in a system to heat water for bath, which main characteristic is its low cost. The collector consists of five plates of PVC with 10 mm thick, 200 mm in width and 1400mm in length, with an area equal to 1.4 meters. The plates were connected in parallel to the ends of PVC tubes of 400 mm. The plates were coated on one side with aluminum sheets of soft drinks and beers cans. The system worked on thermosiphon regimen and was tested in two configurations: the plates uncoated and coated with metallic material, to determine the influence of material on the efficiency of the collector. For both configurations was used EPS plates below the surface to minimize heat losses from the botton. The thermal reservoir of the heating system is alternative and low cost, since it was constructed from a polyethylene tank for storing water, with volume of 150 liters. Will be present to thermal efficiency, heat loss, water temperature of the thermal reservoir at the end of the process and simulation of baths for a home with four residents. The heat will be demonstrated thermal, economic and material viability of the proposed collector, whose main innovation is the use of recyclables materials, cans of beer and soft drinks, to increase the temperature of the absorber plate*

Keywords*: alternative solar collector, heating water, solar energy, recycling, low cost.*

1. INTRODUCTION

In the last two decades the alternative energy was the focus of discussion especially in more developed countries. Aware on the planet does not support much more aggressiveness, it's necessary to find alternative ways to generate energy, not producing evils as significant as those produced by fossil sources. The shares of renewables energy in the matrix of various countries had increased substantially. Several developed nations and until underdeveloped, to a lesser extent, have sought ways of renewable energy supply and energy generation of technology that represent a source of generation of substantial resources, it is clear that these new sources will be used to ensure the preservation of life on Earth.

Countries like the United States, Spain, England, Germany, Portugal, Australia, China, India and others are investing and developing technology to replace fossil fuels for clean energy. A great example of that investment is to obtain a photovoltaic cell with efficiency of 40%, when commercial level reaches only a maximum of 16%. This represents a major advance for the prospect of increase generation of photovoltaic electricity. Countries such as Brazil with potential medium, in the northeast, around 600W/m², have potential for use of this form of energy conversion extremely significant; adding to the fact that our electricity is generated around 80% hydroelectric, that is a conversion of the least hits the environment.

This interest in alternative energy is not primarily the consciousness of the fossil fuels evils. The search for such sources is made by the successive increase in the price of oil. This happened in the 70s where the barrel price went from U$ 3.00 to U$ 40.00 and in this actual decade the barrel price surpassed the mark of U.S. $ 150.00. With this price the use of renewable energy could become competitive.

The most pessimistic forecasts of global scientific community on global warming have been confirmed and the urgency to change course toward renewable sources of wins essential contours. The solar heating of water, the indirect generation of electricity through the use of solar concentrators and the direct conversion of solar energy into electric energy through the use of photovoltaic cells present very viable applications and their use has grown exponentially around the world, especially at more developed countries.

Brazil is a privileged country in relation to its available solar potential, and the northeast region has a potential average around 600 W/m², reaching peaks of about 1000W/m². This potential raises the Northeast region as a very viable for any deployment of solar installations for its various applications.

According to the National Energy Balance (BEN), 2007, 45% of electric power consumption in Brazil is directed to the sector of construction, and 80.0% corresponds to businesses and residences and public administration 20%, reaching 13.8% of the country's Bruit Internal Product (www.mme.gov.br).

The residential sector corresponds to 23% of national consumption of energy and consumption of electric shower is the second largest in a residence, corresponding to 25%, losing only to the refrigerator / freezer with 30%. Its use affects the peak hours of 18:00 to 19:00 hours, corresponding to 8.5% of national demand for energy at this time (Santos, 2008).

These data suggest the importance of replacing the power source by the solar source to get hot water mainly to reduce the consumption of conventional energy, relieving the Brazilian energy matrix.

This paper presents the thermal and economic viability of a solar heating of water, using a collector built from PVC plates, utilized in environments coverage. It is also presents an innovation on existing work with this type of surface coverage, which is made with cans of beer for the obtaining of a higher temperature in the absorber plate. It will be studied two configurations, namely: uncoated and coated plates. The storage tank is alternative (and cost well below the thermal tanks used in conventional solar heating systems (Santos, 2008).

The heating system proposed is destined for obtaining of hot water for bathing of a four people family in replace to the electric shower. It will be presented average data for the proposed heating system, for two configurations, working in thermosyphon.

2. BIBLIOGRAPHIC REVIEW

To promote the heating of water for the bath are used conventional and alternative collectors. The conventional collectors consist of a box of aluminum profile or glass fiber, thermal insulation of glass wool, aluminum plate absorber; absorber grid of copper tubes and transparent glass cover, working on a thermosyphon or continuous flow using a pump for the movement of the working fluid.

The alternative collectors are usually made of materials with lower cost and have the main purpose the socialization of water solar heating. Several generations of alternative collectors using absorber plastic tubes have been developed and tested in the LMHES/UFRN.

The main objective of the study of these collectors is to reduce the cost of manufacturing, searching the socialization of its use in heating systems for domestic and industrial water. With this objective, several studies were developed, demonstrating that the plastics solar collectors at low cost have been studied since the 70s (Santos, 2008).

Souza (2004) study compared two types of collectors, an alternative and a conventional plan, demonstrating the competitiveness of an alternative collector with absorber grid consisting of multiple PVC tubes on the collector with the conventional copper tube.

Souza (2005) studied an alternative collector consisting of three elements: cash, grid absorber and glass. The box was manufactured in composite material and the absorber grid was composed of multiple PVC tubes connected in parallel, using a configuration that allowed the reduction of space between the tubes. It was shown the thermal, economic and material viability of the proposed solar collector.

Souza (2006) studied an alternative heating system of low-cost composed by an alternative solar collector and a alternative thermal reservoir. The collector had absorber PVC grid and the tank was made from a polyethylene drum of 200 liters, used for water storage and / or rubbish, covered by the composite material based on gypsum, ground EPS and water. It was shown the thermal viability, economic and material of the system under study.

Souza (2007) studied an alternative heating system consisting of a collector with absorber grid of PVC tubes connected in parallel through T connection of same diameter and a alternative heat reservoir built from a drum coated with a polyethylene cylinder made in glass fiber. It was shown the thermal viability, economic and material of the system under study.

Another alternative heating system at low cost with the objective of socializing the solar water heating was developed and built in the Technology Business Incubator Center - CIETEC/SP in 1999 and received the name of Solar Collector of Low Cost - ASBC. The ASBC has similar collectors to those used in swimming pools, not possessing, therefore, transparent cover. This system for a four-person family is composed of three collector plates of 0.91 meters of interconnected PVC and painted in black and a reservoir of volume equal to 170 liters. Each plate collector consists of a modular PVC profile of with PVC tubes attached to their ends. (Varella, 2004).

Another alternative collector was developed and built in 2004 by the Society of the Sun, an NGO (non-governmental organization), using PET bottles and packages of milk, Tetra Pak. This collection consists of 80 PET bottles and has absorber grid formed by eight PVC tubes connected in parallel. Tests performed with the ASBC and the collector of PET showed that the ASBC is 17.2% more efficient (Costa, 2007).

Santos (2008) presented an alternative system for solar heating of water consists of one or two collectors and an alternative water storage tank also alternative, whose main purpose was to socialize the use of energy to be primarily used by low-income populations. The collectors were constructed from the use of PET bottles, cans of beer and soda and PVC tubes from ½ ". These collectors were trained for only three elements: pet bottle, cans and absorbers tubes. It was shown the thermal, economic and of material viability of the collectors studied.

3. MATERIALS E METHODS

The collector developed is composed of five plates of PVC 200mm wide and 10mm thick, used in environments roofing, connected in parallel through tubes of PVC. It works under thermosyphon regimen, for a heated water volume of 150 liters. It has the following dimensions: length (l) - 1.40 m, width (b) - 1.0 m, thickness (e) - 0.01 m. Area = 1.40m².

For fixing the PVC plates in tubes of water was made a rip in them through the use of drill and saw. To seal the space between the two areas was used polyester resin. The PVC plates that form the absorber grid of the collector were painted of black for better absorption of incident solar radiation

To decrease the thermal losses of the collector were placed EPS plates of 20.0 mm in the below surface.

The processes of manufacture and assembly of the collector are formed by the following steps:

1. Cut of PVC tubes of 40mm diameter for entrance and exit water of collector;
2. Opening of tears in the tubes to plug the PVC plates using saw;
3. Sanding of features for greater adhesion of the resin;
4. Coupling of the plates to in tears of tubes,
5. Placing the polyester resin in the spaces between plates and tear;
6. Cutting of beer cans for the preparation of aluminum plates covered PVC plates;
7. Painting the absorber surface;
8. Cut of EPS plates for thermal insulation of the collector.

The alternative thermal reservoir of 150 liters was made from a drum of 200 liters of polyethylene. The tank was opened on its top cover and was placed in a drum made in fiber glass with a thickness around 5.0 mm. The cover of the reservoir was built in fiberglass. In the space between two basic elements, cylinder and drum polyethylene fiber was placed EPS ground.

The heating system proposed works under in thermosyphon to a volume of water equivalent to 150 liters and was tested for the diagnosis of their thermal efficiency. To determine the flow rate it was considered that all the water in the reservoir circulated by the collector, corresponding therefore to relation between the volume of the reservoir (150liters) and time to test the system (seven hours).

It was measured the parameters that characterize and are needed for the analysis of their thermal performance, as also the susceptibility of the absorber plate to reach the critical level for the beginning of thermal degradation of PVC tube, around 60 ° C (Duffie, 1991, Souza, 2008). The collector was tilted by 15.5 ° S latitude.

It were measured the temperature of entrance and exit of collector fluid, the absorber plate temperature at various points, temperature of water in the thermal reservoir at various points (lower, ¼, ½, ¾ and upper), ambient temperature and global solar radiation. It also measured the time necessary to standardize the temperature of water in thermal reservoir.

The temperatures of the entrance and exit fluid were measured in the period between 08:00 and 15:00 hours, at intervals of 30 minutes, the temperature of the collector and absorbers tubes were measured from 15 to 15 minutes between 11:00 and 13:00 hours, period of maximum radiation and constant, which evaluates to the maximum loss by collector, the temperature of the water was measured after seven hours of operation. The tests were performed on days with good solar conditions, high rates of direct and global solar radiation and low cloud cover to allow a more realistic comparison between different days.

The susceptibility to the beginning of the process of thermal degradation can be diagnosed through of temperature levels achieved by the external surface of absorbers tubes, which should not reach 60 ° C.

The autonomy of the system was also evaluated with regard to the number of days in which the system was able to provide hot water in the temperature of bath ideal for a residence with four people.

The baths were simulated at 07:00, 12:00 and 18:00 hours, taking up 40 liters of hot water reservoir of heat, through a registry located at 2/3 of its height from its base. Emphasized that the simulation of the baths has been a more critical condition than what happens in the real situation, without the mixture of hot water tank with cold water from the network.

To test the thermal efficiency of the heat reservoir is filled it and connect to the proposed collector. After a day of operation of the heating system, at 15:00 hours, measured up the temperature of water in the reservoir, corresponding to 45°C and cut it communication with the collector to prevent the heat exchange between the reservoir and the collector at night.

It has been one of cromel-alumel thermocouple in the thermal reservoir alternative proposed to measure the temperature of the water, another on the outside surface to measure its temperature and another to measure ambient temperature. The test was to measure these temperatures, each hour during all the night to quantify the drop in temperature of the water mass in the reservoir. The temperatures were measured using a digital thermometer.

The heat loss global coefficient (U_{loss}) was determined by the parameters power absorbed by the collector (***Pabs***.), power transferred to the working fluid ($\boldsymbol{P_u}$), plate mean temperature ($\boldsymbol{T_{pm}}$), ambient temperature ($\boldsymbol{T_a}$), collector area (***A***), the mass flow (m) specific heat of the fluid (c_p), the difference of temperature of the fluid in collector (ΔT),incident global solar radiation (I) and absorb capacity (α_p), using the equations shown below (Santos, 2008; Duffie, 1991). The heating system proposed alternative is shown in Fig (1).

$$P_{abs} = \tau_v . \alpha_p . I . A \quad (1)$$

Where:

P

$P_{abs.}$- absorbed power by the collector (W)

τ_v - coverage transparent transmissivity;

α_p - absortivity of tube painted in black

I - global solar radiation (W/m²)

A – collector area (m²)

$$P_u = \dot{m} . c_p . \Delta T \quad (2)$$

Where;

P_u - power transferred to the working fluid (W);

$\dot{m}$ - mass outflow (Kg/s);

c_p - specific heat of the fluid – J/Kg.°C)

ΔT - difference of temperature of the fluid in the system (°C)

$$P_p = P_{abs} - P_u \quad (3)$$

Where:

$P_{abs.}$- absorbed power by the collector (°C)

$P_{p.}$- - lost power (W)

$$U_{loss} = \frac{P_p}{A.(T_{pm} - T_a)} \quad (4)$$

Where:

U_{loss} - global coefficient of thermal loss (W/m².°C);

T_{pm} - plate average temperature – (°C);

T_a - ambient temperature – (°C).

The thermal efficiency of the water solar heating system was determined through the parameters of the Equation (5).

$$\eta_t = \frac{P_u}{A . I} \quad (5)$$

Figure 1. Water heating solar system in test.

4. RESULTS AND DISCUSSIONS

Tables 1, 2 and 3 present the average results obtained for four days of tests in the two configurations and Figure 2 shows the behavior of the thermal parameters measured and calculated

Table 1. General average results - Configuration uncoated

DAYS OF TEST	ΔT (C°)	I (KW/m²)	ηt (%)	T_{lower} (c°)	T1/4 (c°)	T1/2 (c°)	T3/4 (c°)	T_{upper} (c°)
DAY 1	*10.9*	*0.70*	*28.0*	*41.2*	*44.5*	*45.3*	*45.0*	*45.6*
DAY 2	*10.7*	*0.71*	27.1	*45.0*	*46.3*	*48.2*	*49.0*	*49.2*
DAY 3	*10.8*	*0.71*	27.3	*44.5*	*47.1*	*48.2*	*48.5*	*48.7*
AVERAGE	***10.8***	***0.71***	***27.4***	***43.6***	***46.0***	***47.2***	***47.5***	***47.8***

Table 2. General average results - Configuration with coated

DAYS OF TEST	ΔT (C°)	I (KW/m²)	ηt (%)	T_{lower} (°C)	T1/4 (°C)	T1/2 (°C)	T3/4 (°C)	T_{upper} (°C)
DAY 1	*9.2*	*0.69*	*24.0*	*45.9*	*46.8*	*48.0*	*48.1*	*48.0*
DAY 2	*9.2*	*0.69*	*24.0*	*46.3*	*47.6*	*48.6*	*48.8*	*48.7*
DAY 3	*10.6*	*0.71*	*26.9*	*43.9*	*46.6*	*48.5*	*48.5*	*48.3*
AVERAGE	***9.7***	***0.70***	***25.0***	***45.4***	***47.0***	***48.4***	***48.5***	***48.3***

Table 3. General average results for each configuration studied.

TYPE CONFIGURATION	ΔT (C°)	I (KW/m2)	ηt (%)	T_{lower} (°C)	T1/4 (°C)	T1/2 (°C)	T3/4 (°C)	T_{upper} (°C)
COATED	*9.7*	*0.70*	*25.0*	*45.4*	*47.0*	*48.4*	*48.5*	*48.3*
UNCOATED	*10.8*	*0.71*	*27.4*	*43.6*	*46.0*	*47.2*	*47.5*	*47.8*

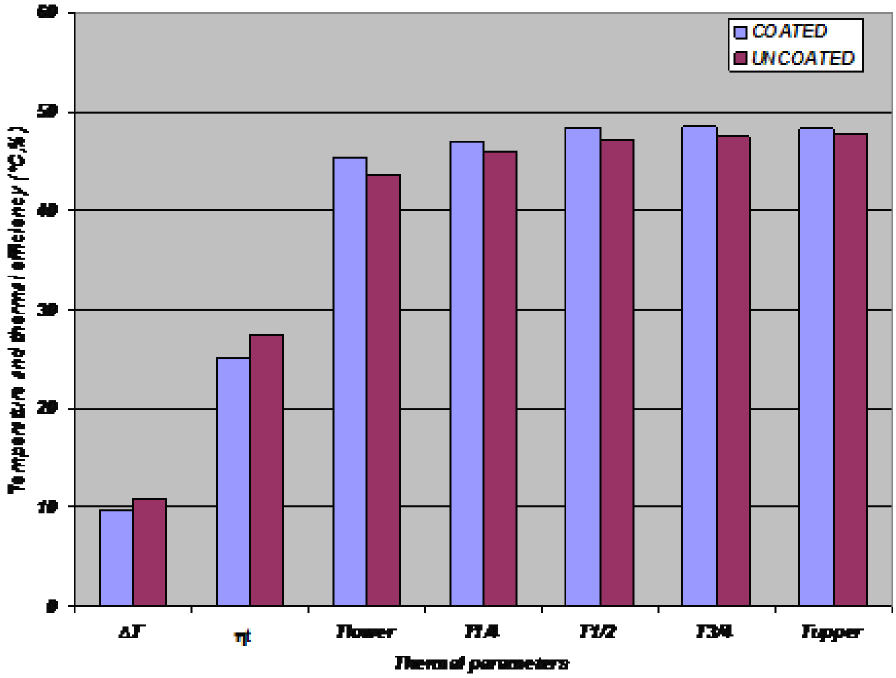

Figure 2. Thermal parameters of the heating solar system.

The values of the parameters measured are higher for the configuration without coated. This means that sheet of aluminum that coated the PVC plates, decreased the amount of heat transmitted to the working fluid. It was expected that the sheet painted of black to increase the temperature of PVC plate, but happened a heat loss, in function of the creation of an additional thermal resistance between the hot source and receiving source of heat. The temperature gradient generated was 11% higher for the configuration without coated thermal efficiency 10% higher for the same configuration and the temperatures inside the heat reservoir were almost equal.

The average efficiency of the collector under study for the best configuration was around 27%, slightly below the majority of alternative collectors, with thermal efficiency around 30 to 35%.

The average global solar radiation for all days tested was around 700W/m², showing up the right choice for the comparison test between the two configurations. Were selected days of low or no cloudiness to the characterization of solar conditions identical for all days.

Regarding the heat loss of the collector, was expected at a significant level in function of collector did not cover transparent to minimize convective and radioactive exchange with the environment and is not contained in a box with insulation on the bottom and sides.

The levels of temperature measurements show that the placement of EPS plates below the surface of the plate absorber provided to minimize of the heat loss since the maximum temperature reached on the surface of the collector was 33.0 ° C, and environment temperature for the time chosen was 30 ° C.

As regards the thermal degradation of PVC the critical level for initiating the process degraded, corresponding to 60° C (Souza, 2006) was not reached, since the maximum temperature in the absorber plate in the top surface was 47.2°C and average temperature was 42.5 ° C.

The coefficient of heat loss can be calculated using the equations shown above, with the parameters needed for calculations with the corresponding period of increased incidence of solar radiation.

$$P_{abs} = 0.80x1.4x750 = 840{,}0 Watts$$

$$P_u = 10^3 \frac{kg}{m^3} . \frac{150.10^{-3}}{7.3600 s} m^3 . 4.180 \frac{J}{Kg.°C} . \Delta T = 24.9x(\Delta T) = 24.9x14.9 = 371.01 Watts$$

$$P_p = 840{,}0 - 371.01 \text{Watts} = 469{,}0 \text{Watts}$$

$$U_{loss} = \frac{469{,}0}{1.4x(42.5 - 30)} = 26{,}8 W/m^2.°C$$

The heat loss global coefficient present significant value, although it has been decreased by placing of plates EPS in its lower surface. Although showing heat loss much larger than the conventional collector, corresponding to around 6.0 W/m² °C, water heating solar system proved to be possible to obtain hot water bath in low-income families, demonstrating its viability.

For a minimization of heat loss could be putting the PVC plate in a box and cover it, but the cost of collector would be increased, rather than to impede the manufacture, complicating the process of technology transfer to communities of low income, in an attempt to increase the use of solar collectors for a reduction of energy consumption by using electric shower.

The test results to evaluate the thermal efficiency of the alternative heat reservoir are presented in Table 4.

Table 4. Results of the test with the alternative proposed thermal reservoir.

TIME(Hour)	T_{water} (°C)	$T_{environment}$ (°C)	$T_{upper\ reservoir}$ (°C)	$T_{medium\ reservoir}$ (°C)	$T_{lower\ reservoir}$ (°C)
16:00	**45,3**	**27,0**	**28,0**	**28,3**	**28.5**
18:00	45,0	26,0	27,0	27,5	28.0
20:00	44,2	25,5	25,1	25,6	26.2
22:00	43,5	25,0	25,1	25,6	25.6
00:00	42,9	25,0	25,1	25,2	25,6
02:00	42,5	24,9	24,9	25,5	25,6
04:00	41,8	25,0	25,0	25,4	25,5
07:00	**40,6**	**28,4**	**28,8**	**29,6**	**28,4**
08:00	40,3	31,9	33,0	33,2	32,0
10:00	40,1	31,9	38,0	36,0	33,6
12:00	40,1	32,0	38,0	35,5	34,0
14:00	40,4	32,4	38,2	36,0	35,0
16:00	**40,7**	**30,0**	**35,0**	**33,0**	**32,0**

The presented data demonstrate the efficiency of thermal alternative heat reservoir proposed. There was a drop in temperature during the 24 hours, corresponding to 4.7 ° C. This is a drop in temperature within the average suggested by the literature for conventional thermal shells, copper or stainless steel, which have values around 5 ° C to the level of temperature tested. It was also the price of the alternative proposed reservoir, much smaller than conventional tanks.

It was observed the temperature of the external surface of the shell was very close to the ambient temperature throughout the night reflecting a low heat loss by the side of the tank. The temperature of the tank just reached values well above the temperature for the period in which the reservoir is now heated by solar radiation absorbed by it, since it was painted with matte black ink. Therefore, the loss was more significant for the bottom and / or lid of the tank.

The resistance mechanics of the considered alternative reservoir did not verify damages to its structure, demonstrating to support the corresponding weight to the volume of water contained in the reservoir. It did not have occurrence of emptying, what it certifies its good prohibition, also gotten through polyester resin.

The cost of manufacture of the collector was around U$43.00 and of the thermal reservoir around U$100.00 Therefore, the total cost of the heating system was inferior the U$150.00, what it represents a sufficiently inferior cost to the necessary one for the manufacture of a system of conventional heating. It is standed out that the studied collector is for being used by low income populations, not being competitive with the conventional system. However, it presents viability of use for the considered end.

To better evaluate the system, it is a simulation of baths taken by a quarter of the volume (approximately 40 liters) of hot water tank at 7:00, 12:00 and 18 hours, using a registry located at the top the tank and then put the same amount of cold water. The result is in Table 5.

Table 5. Results of the parameters for bath simulation test.

DAY	TIME (Hour)	$T_{water\ withdrawal}$ (°C)	$T_{water\ added}$ (°C)	$T_{water\ after\ replacement}$ (°C)	$T_{environment}$ (°C)
1/apr	18:00	45.0	28.8	41.1	27.5
2/apr	***07:00***	***36.5***	*28.2*	*33.5*	*27.0*
2/apr	12:00	49.6	30.1	38.2	28.7
2/apr	18:00	43.3	29.9	40.0	28.3
3/apr	***07:00***	***35.2***	*28.2*	*33.3*	*27.2*
3/apr	12:00	46.9	31.3	42.0	27.7
3/apr	18:00	40.7	29.5	37.5	27.3
4/apr	***07:00***	***33.5***	*29.6*	*32.5*	***28.0***

The dates demonstrate that the system has autonomy to 3 days of use and the critical time at 7:00 pm, as was expected, once during the night is heat loss to the environment. The temperature considered pleasant for swimming is about 34 ° C and in this case, depending on the user would not be necessary to mix the water collector of pre-heated with cold water for bathing.

Souza (2002) studied the PVC tubes degradation when exposed to the sun; proving that a collector with absorbers tube of such material would have a useful life over 10 years. The Society of the Sun, a NGO (non-governmental organization)built collectors which are similar to that presented in this study and concluded that the lifetime of the collector with plate absorber of PVC have more than 10 years of useful life, which demonstrates its economic viability.

The cost of manufacture of the proposed collector was around U.S. $ 43.00 ($ 31.00/m²) and the cost of manufacture of the heat reservoir, is around U.S. $ 100.00.

5. CONCLUSIONS

1. The collector presents feasibility of use for the end proposed;
2. The collector presents easy assembly and manufacturing processes;
3. The heating system has low thermal efficiency, but proved to be capable of providing hot water bath for a family with four people in the region studied;
4. The heat loss of the collector is higher than on the conventional collectors, as was expected;
5. The most important characteristic of the heating system proposed is its low cost;
6. The heating system studied may contribute to the massive use of solar water heating for low-income communities, socializing the use of energy.

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7. RESPONSIBILITY NOTICE