ANALYSIS AND PERFORMANCE THE LCSH SYSTEM

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Abstract. The thermal solar energy, which is obtained by the absorption of solar radiation incidenting on a body in the form of heat, has specific applications and its use is rising in our country, where there are high indices of solar radiation that are determinant to make use of solar energy. This form of energy has been shown not only as a technically and economically feasible solution to the problems concerned to the reduction of the consumption of electric energy in the residential sector, but also acts as a cleaner alternative to the problems of environmental impact caused by other sources of energy. One of the applications of thermal solar energy is to use this energetic potential to heat residential water using solar heaters, which are used to heat a fluid along a collector plate and then store it in a thermally insulated tank.. The conventional solar heater has its collector plate of copper, which is covered by glass, and a reservoir of aluminum or stainless steel with an internal electrical resistance.One of the alternatives to reduce the consumption of electric energy to heat water will be to make popular the use of conventional heaters. This can be done by using the Low Cost Solar Heating (LCSH)), which is a new concept of solar heater to heat water, all made of polymeric materials and without greenhouse effect, with relatively small investment and can be manually built. The ASBC system has the collector plate made of PVC, is not covered with glass and its reservoir can be an ordinary water box or even a plastic drum. The objective of this study is to project a solar heater using a laboratory scale and to analyze the thermal efficiency of the ASBC system with measures of temperature and incident solar radiation, taking into account different variables to project, as absorbed heat in the process, collector inlet and outlet water temperatures for a natural circulation water heater, and thus, estimate the performance presented by this system. The main results showed that the LCSH system satisfies the residential needs consumption, especially in favorable climate regions. Its operation has reached a considerable efficiency, and greater when the water which will be heated is lower temperature. Therefore, its performance is close to the ones observed in conventional solar heaters

***Keywords**: thermal solar energy, performance, collector plate, polymeric materials.*

1. INTRODUCTION

The sun is a source of renewable energy and its use as in the form of heat as the light is one of the most promising energy alternatives to the power supply in the coming years. Working as a fusion reactor, radiates on Earth a remarkable energy potential, incomparable to any other system of energy. Each year, this energy is equivalent to ten thousand times of the consumed energy by the population in the same period at world and this energy captured by the Earth means five to ten times of all known reserves of fuel (BEZERRA, 1998).

Solar energy has contributed significantly to reduce the power consumption of conventional sources, mainly on low temperature applications, presenting economic, social and environmental benefits. For replace hydroelectricity and fossil fuels, each solar thermal installation reduces the once and forever the environmental damage associated with conventional energy sources, for example, produces no emissions of toxic gases that contribute to pollution, has no influence on the greenhouse effect, does not produce radioactive waste and doesn't need turbines or generators to produce electricity. The technology has social benefits such as reducing the electric account and generation a large number of jobs per unit of energy, besides the possibility of marketing certificates of reducing carbon emissions (MATAJS, 2005)

However, has the disadvantage, because this power is not always available and requires their accumulations. It can be used in the following ways: photothermic solar energy, photovoltaic and bioclimatic architecture.

The photothermic effect is directly linked to the amount of energy that a particular body is able to absorb, in the form of heat, from solar radiation incident on the same. The use of this form of energy requires knowledge to capture it and store it and the equipment used for this purpose are known as solar collectors.

Solar heater technology has been used in Brazil since the 60s (www.portalabrava.com.br), when the initial searches has emerged and, according to information of the Brazilian Association of Refrigeration, Air Conditioning, Heating and

Ventilation (ABRAVA) this technology is applied at homes, hotels, motels, hospitals, restaurants and industrial changing rooms and swimming pools.

One of the most widespread applications throughout the world is undoubtedly the domestic water heating that in Brazil needs to be discussed and reviewed on a continuing and intensive form. From this discussion, hopefully, will emerge a better understanding of barriers must be accrued by solar technology, allowing us to refine solutions.

Even the industry showing significant growth rates in recent years, the data available on the National Department of Solar Heating - DASOL shows that Brazil, despite the many favorable conditions for use of this technology, still occupies a modest position in the international market. According to the National Energy Agency (ANEEL), for domestic heating water bathing, was spent about 20 billion kWh of electricity 1998, which could be supplied with solar energy, with enormous socioeconomic and environmental advantages. The consumption of electricity represents 25% of the residential market, where the electric shower has 20% to 35% of spending in homes (Procel, 2005).

Several countries, with lower level of sunlight than_Brazil, make intensive use of solar energy through heating systems. In 2002, were produced in the country 310,000 m² of solar collectors, the per capita area of installed solar collectors was 1.2 m^2/100 inhabitants, considerably smaller than those installed in Israel (67.1 m^2/100 inhabitants), Austria (17.5 m^2/100 inhabitants) and China (3.2 m2/100 inhabitants), for example (ABRAVA).

Brazil has an enormous potential for solar energy use: almost all regions get together more than 2,200 hours of sunshine, with an equivalent potential of 15 trillion of MWh, representing 50 thousand times the national consumption of electricity (MATAJS, 2005).Even like that, the Brazilian water heating infrastructure is based on electric showers, equipment of low initial cost, but high electricity consumption over its lifetime, which makes significant demands for capital to the electric sector, and high environmental and social costs.

The electric shower is identified as a strong factor for the lifting of peak demand, 18%, due to its high potency and limited use on short periods, usually at certain times and common for most users. Together with the electric heaters accumulation, the use of electric showers represents about 8% of Brazilian electric power consumption.

According to ABRAVA information, until the year 2000 there was approximately 250,000 solar residential collectors installed in Brazil, which amounted only 0.6% of the approximately 40 million Brazilian households. One of the main barriers to the diffusion of solar water heating technology is the cost to acquiring the equipment and its installation, particularly for low-income households. The price of a conventional solar heater is around R$1200, 00 (tank 100L), while the price of a conventional electric shower is around R$ 25.00 and is widely available. On the one hand the low-cost heater to a low-income households cost around R$ 350, 00 (tank 100L).

2. **THEORETICAL BACKGROUND**

2.1. Solar collectors

The solar collectors are fluid heaters (liquid or gaseous) and are classified as concentrators collectors and plans collectors depending on the existence or not of concentration devices of solar radiation. The heated fluid is kept in thermally insulated tanks until its final use.

The solar water heaters can operate at any weather. The performance depends in part on the location of system, the amount of solar energy available, but also how cold the water is entering into the system.

There are three basic types of collectors (U.S. DEPARTMENT OF ENERGY - ENERGY EFFICIENCY AND RENEWABLE ENERGY, 2004): flat-plate (flat plate), tube - evacuated (evacuated-tube) and concentrating:

Our object of study, the flat-plate collector (Fig. 1), which is the most common type, is an isolated box, protected from weather, with a dark absorbing surface and one or more transparent covers. The flat-plate solar collector are, today, widely used for water heating at homes, hospitals, hotels, etc.

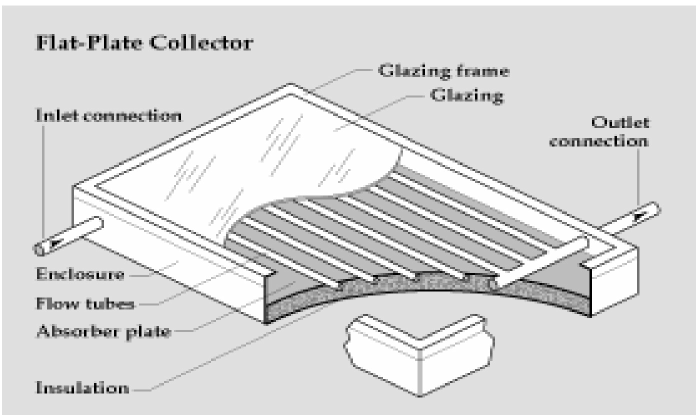

Figure 1. Conventional Flat-Plate Collectors

2.2. Operation principles of solar heaters

The water heaters can be active or passive. An active system uses an electric pump to circulate the fluid, the passive system has no pump. The amount of hot water that the heater produces depends on the type and size of the system, the amount of sunlight available, the appropriate installation and tilt angle and orientation of the collector.

They are classified open circuits (open loop, also called "direct") or closed circuit (closed loop or "indirect"). An open system circulates water of household use through the collector. A closed system uses a fluid (heat transfer fluid) (water or antifreeze solution, for example) to collect the heat and a heat -exchanger to transfer the heat to water.

The Thermosyphon Systems is a direct and passive system (natural circulation), which depends on the natural phenomenon of convection, to move the water through the collector to the tank. In this installation type, the tank must be above the collector. This gap is necessary to ensure the movement of water in the collector with difference density between hot and cold water.

As the water in the collector is heated, it becomes lighter and rises naturally to the tank above. Meanwhile, the cold water in the tank seeps in to the tubes to the bottom of the collector, causing movement through the system. The storage tank is connected to the top of the collector so the thermosyphon movement occurs according to Figure 2, available in http://www.volker-quaschning.de/articles/fundamentals4/index_e.html.

These systems are reliable and relatively cheap, but require careful planning construction because the water tank is heavy. They can be protected against freezing by movement of an antifreeze solution through a heat exchanger in closed circuit.

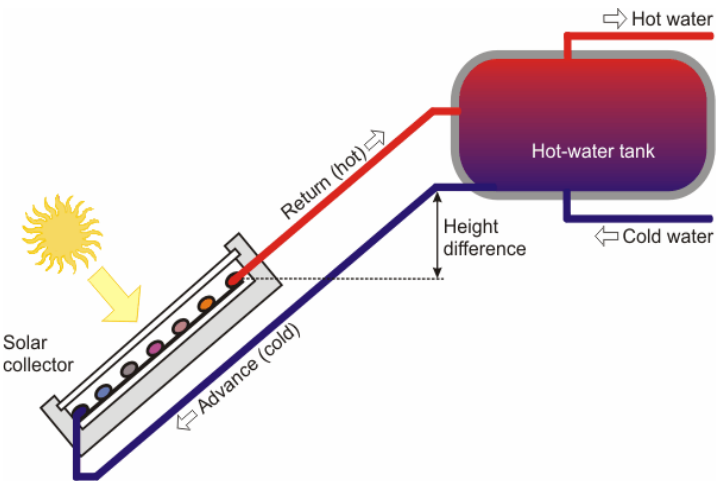

Figure 2. Thermosyphon System (http://www.volker-quaschning.de/articles/fundamentals4/index_e.html)

2.3. The LCSH system

The low-cost solar heater (LCSH) has the same principle of operation of the traditional system of solar water heating, differentiating by type of material used and the possibility of self. Figure 3 has been a picture of LCSH, available in http:// www.sociedadedosol.org.br (Sociedade Do Sol). The collector is made with PVC lining slabs and different from others by not using box and glass cover, which enables the achievement of the greenhouse effect.

Is important the lack of glass cover, because does not allow the water too much warming, affecting the integrity of the PVC components, which has up to temperature (up to 60º approximately).

The reservoir stores heated water during the day has as components typical a buoy - tap attached to a vertical pipe, which carries cold water to the bottom of the box and a “fisherman”, which is designed to lead to final consumption the water that is at higher and warmer layer inside the tank. These components and height of each channel in the water tank are essential to maintain the effect of stratification of the tank.

Besides the traditional water box, other industrialized containers can be used, such as: plastic drum or SPE box internally coated with plastic film (leak-proof).

Independent of the type of container used, everyone receives an external thermal insulation on the sides and lid.

The LCSH system components are:

1. Water Box (1.1 hot water layer, 1.2 transition Layer, 1.3 cold water Layer, 1.4 thermal insulation, 1.5 “ducts piercing” system.
2. Solar collectors
3. Hot water blender
4. System water pipeline - A, B, C, G e H.

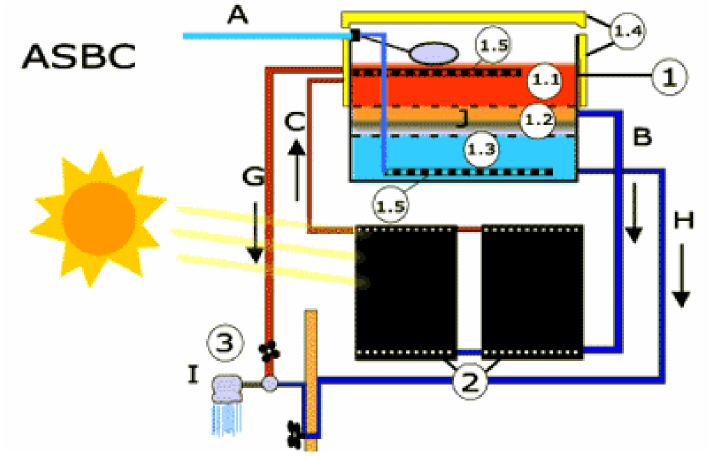

Figure 3. LCSH System (http:// www.sociedadedosol.org.br)

3. DESIGN OF SOLAR COLLECTOR

3.1 Plate collector modelling

For the modeling of the plate collector, the following simplifying assumptions were made:

- The absorbing surface and his basis isolation are the same temperature, called as Tp;
- The plate has no temperature gradients in the direction of flow, neither to cross-flow, then the wall temperature is a function only of time;
- The fluid temperature in the plate only changes along the length of the collector;
- Despise the heat loss at plate side.

The temperature variation at plate collector is associated with the radiant, conductive and convective energy transport, which the last two represent losses to the environment. Thus:

$$\left(mc_p\right)_{fluid}\frac{dT_{plate}}{dt} = AI + AU_L\left(T_{environmente} - T_{plate}\right) + A_{trans}h_f\left(T_{plate} - T_{fluid}\right) \qquad (1)$$

For the Eq. (1) may be noted that the conductive heat exchange between the plate and the fluid was despised, since the plate thickness is small.

The plate areas and tube transverse areas are calculated:

$$A = LW \qquad (2)$$

Where L is the plate length and W is the width.

$$A_{trans} = PLn_c \qquad (3)$$

Where P is the wet perimeter and n_c is the number of plate channels. The overall heat transfer coefficient U_L is the sum of plate bottom and top heat loss.

$$U_L = U_b + U_t \qquad (4)$$

The bottom heat loss relate to the plate and insulation thickness and also with their respective conductive heat transfer coefficients:

$$U_b = \frac{1}{\frac{L_{insul}}{K_{insul}} + \frac{L_{plate}}{K_{plate}}} \qquad (5)$$

The plate top losses depend on the convection and radiation heat transfer coefficients:

$$U_t = \frac{1}{\frac{1}{h_v} + \frac{1}{h_r}} \tag{6}$$

CRISTOFARI et al. (2002) proposed an expression for calculation of *hv*:

$$h_v = 7 + 2{,}1V \tag{7}$$

The value of wind speed of 0.5 ms-1, was given by JURADO (2004).
The energy balance for the fluid considers the convective heat exchange that occurs in the inner surface of the plate:

$$\left(mc_p\right)_{fluid} \frac{dT_{fluid}}{dx} = h_f P\left(T_{plate} - T_{fluid}\right) \tag{8}$$

The wet perimeter of the surface is given by:

$$P = 2n_c\left(d_c + h_c\right) \tag{9}$$

The average heat transfer coefficient due convection of the fluid is calculated using Azevedo and Sparrow' correlations (INCROPERA, 1998) for natural convection in inclined channels with water:

$$\bar{h}_f = \frac{\bar{N}_u}{L_c} K_{fluid} \tag{10}$$

$$\bar{N}_u = 0{,}645\left[R_a\left(\frac{S}{L_c}\right)\right]^{\frac{1}{4}} \tag{11}$$

$$Ra = g\beta\left(T_{plate} - T_{fluid}\right)\frac{S^3}{\alpha v} \tag{12}$$

The value of h_f is 3, 65 W.m-2.K (JURADO 2004).
The thermal diffusivity of water is so calculated:

$$\alpha = \frac{K_{fluid}}{\rho C_{p\,fluid}} \tag{13}$$

The Equations (4.1) to (4.5), together with the equations (4.7) (4.9) and (4.10) were implemented in the Mat Lab software and through an interactive procedure, it was determined the dimensions of the collector plate.
From the collected data, it was possible to determine the collector efficiency for each day was made the experiments, this efficiency can be calculated using the following equation:

$$\eta = \frac{\left(mc_p\right)_{fluid}\left(T_{final} - T_{initial}\right)_{fluid}}{AI} \tag{14}$$

4. MATERIALS AND METHODS

One of the objectives of this study was to determine the dimensions of a collector plate, for the LCSH system, in order to heat 50 liters of water and its final temperature was about 50°C. To that end, it was necessary to use some parameters of the plate materials, the fluid being heated and climatic conditions, which were obtained from JURADO, (2004) and are at Table 1.

The value for the solar radiation and duration of the day were withdrawn from the RADIASOL Programme, available in http://www.ufrs.br (UFRS). The system incorporates a database containing information of over 2000 weather stations around the world, of which about 200 in Brazil. These values come from Uberaba station.
With these parameters and equations of modeling, it was necessary to take the inlet water temperature would be

23°C and, until the system is at steady state, the difference between outlet water temperature of the tank and inlet temperature of the plate was 1.5 ° C. Thus, had begun the construction of the solar heater prototype. Using the Mat Lab software and through an interactive procedure, it was determined the dimensions of the plate collector, 1.1 x 0618 m, to the required fluid final temperature, 50ºC.

The system was positioned in relation to the geographic North with an inclination of 28º, with 18º on the latitude of Uberlândia and the other 10º to compensate for variations of the Earth's axis throughout the year in relation Ecuador.

Table 1 – Constants adopted for the design of the LCSH system.

Parameter	Value	Parameter	Value
g	9,8 m/s^2	V	0,5m/s
Cp_{fluid}	4183 J/kgºC	L_{insul}	0,025m
ρ	1000 kg/m³	K_{insul}	0,038 W/mºC
k_{fluid}	0,61067 W/mºC	L_{plate}	0,0006m
I	5480Wh/m2	K_{plate}	0,16 W/mºC
$T_{environmente}$	23º	Cp_{plate}	1200 J/kgºC
d_c	0,009m	h_f	3,65 W/m²K
h_c	0,0204m	n_c	40

5. RESULTS AND DISCUSSIONS

It had started the measures of temperature, through the day, water that would be used for consumption. On the first day, the tank was emptied and filled again, and every one hour, was measured the temperature. This was done from 8:30 until 18:30 hours and twenty-four hours after start, the temperature for consumption was measured again to check the thermal losses during the night (which was rain and wind). This can be found in Fig.4.

On the second day the tank was emptied and filled again and started up the measurements to 8:00 am. On the third day the tank was not emptied and the measurements started at the 8:00 am. On the fourth day did the homogenization of water that already was in the tank with a quantity that had to be added to collect it volume. The measurements were begum at 8:00 in the morning.

On the fifth day the tank was emptied and filled again. Started up the measurements 8:00 am. The Fig. 4, 5, 6, 7 and 8 show the behavior of the temperature in the reservoir for these five days of measurement.

For Figure 4, twenty-four hours after had started the measurements, the water temperature in tank was measured. There was a heat loss in about 1673200 Joules.

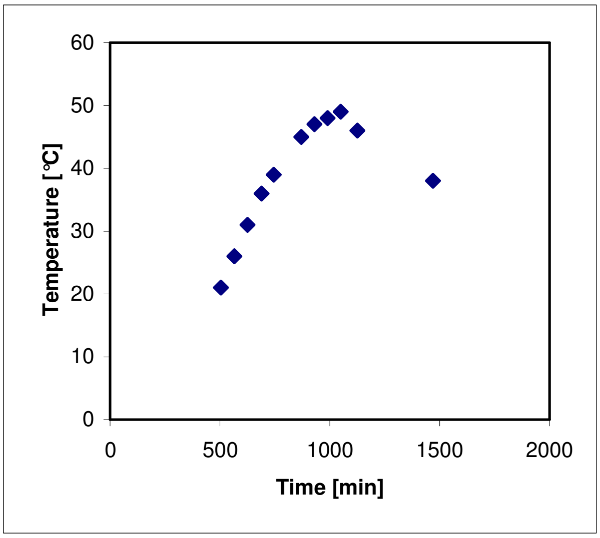

Figure 4. Measurement first day.

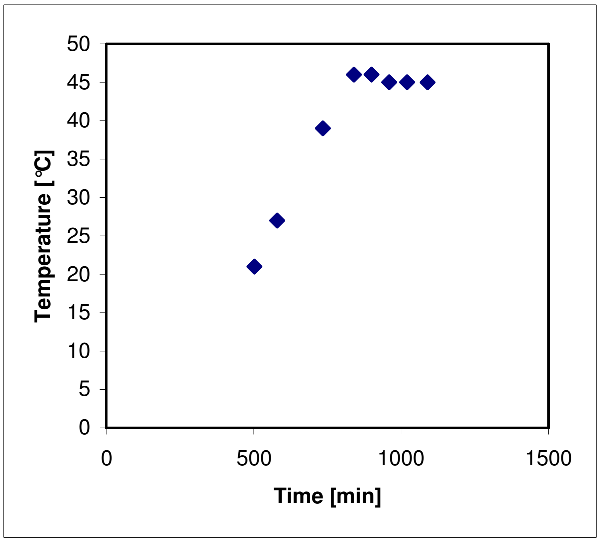

Figure 5. Measurement second day.

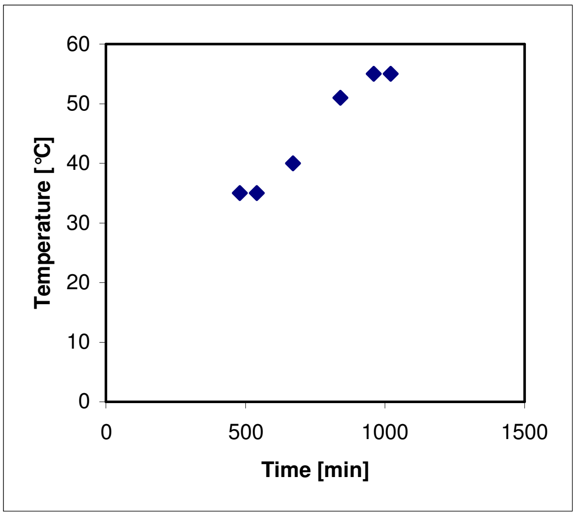

Figure 6. Measurement third day.

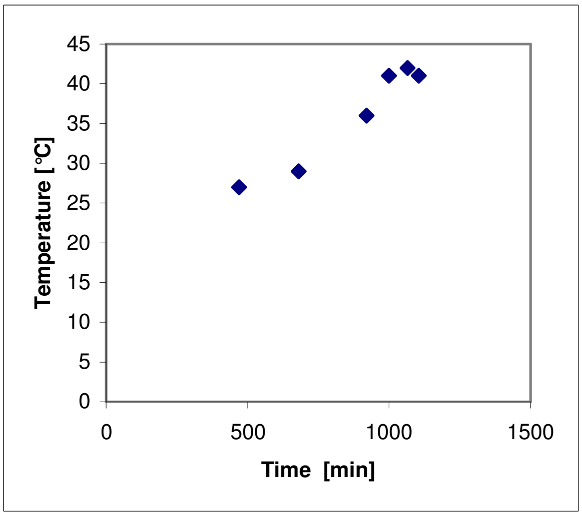

Figure 7. Measurement fourth day.

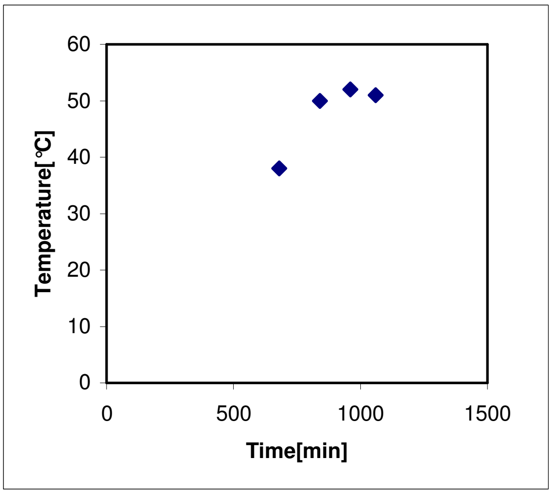

Figure 8. Measurement fifth day.

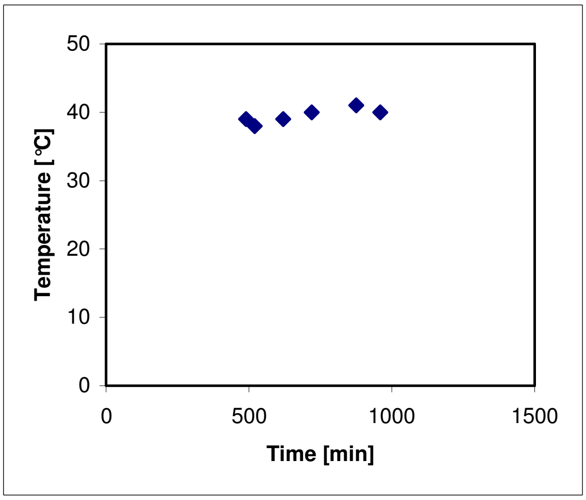

Figure 9. Bath in the morning simulation.

After these measurements, a bath was simulated. A temperature of water consumption was measured before it occurs in 39 ° C. The bath was estimated at 2 minutes and rate 2.85 liters.min^{-1}. After this period, it was observed that the temperature dropped to 38 ° C, however after one hour of the last measure, it already had returned to 39 º C. This is displayed in Figure 9 where the first point of the graph is the point where it was the bath.

With the measured data, and with Equation (14), is possible to obtain collector efficiency in each one of these days. The results are shown in Table 2.

To do so, obtained the average solar radiation of the day for the month of February in the RADIASOL software and was considered that the tank was always full. It is adopted 1g.cm-3 for the value of the density of water.

Table 2 - Stored heat in each one of these days

$T_{initial}$ (°C)	T_{final} (°C)	Q_{stored} (J)	η(%)
21	46	5228750	42,112
21	45	5019600	36,096
35	55	4183000	30,080
27	41	8575123	21,056
38	51	2718950	19,552
39	40	209150	1,504

Using the Maple software, made up the simulation of behavior the plate temperature (Tp), the mean fluid temperature (Tm) and the plate inlet fluid temperature (Te), in a one hour, from environment temperature (25ºC) in $t_i = 0$ to $t_f = 36000$s. The results can be seen in Fig. 10 to follow.

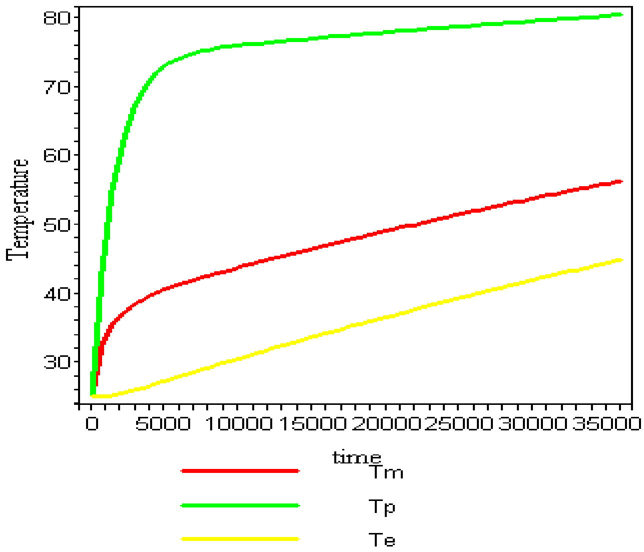

Figure 10. Collector Modelling

It was observed there is a distribution of temperature through the day, and after approximately 1,5h, the heating system already has reached a consumption suitable temperature.

6. CONCLUSION

Solar heaters produce hot water the ideal temperature for human consumption, replacing the use of electric showers, especially in a country like Brazil, which has a tropical climate throughout the year.

The development of low-cost heaters allows an available alternative to the low income people.

The construction of this type of heater is relatively simple, as well as their maintenance, and its operation reaches a considerable efficiency, even on a cloudy weather and not very strong sunshine. Therefore, its performance is close to that observed in conventional solar heaters.

The collector efficiency proved to be greater when the collector inlet water temperature is lower.

The efficiency of a collector proved to be greater when the water temperature in the collector is lower.

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