WATER HEATING SOLAR SYSTEM USING COLLECTOR WITH POLYCARBONATE ABSORBER SURFACE

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Abstract. *It is presented a solar collector to be used in a heating water for bath system, whose main characteristics are low cost and easy fabrication and assembly processes. The collector absorber surface consists of a polycarbonate plate with an area of 1.5 m². The water inlet and outlet are made of PVC 50mm, and were coupled to a 6mm thick polycarbonat plate using fiberglass resin. A 200 liters thermal reservoir will be used. This reservoir is also alternative. The absorber heating system works under thermo-siphon regimen. Thermal parameters will be evaluated to prove the feasibility of the studied solar heating system to obtain bath water for a four people family.*
Keywords*: Solar collector, water heating, solar, low cost.*

1. INTRODUCTION

Over the past ten years the energy alternatives have been in evidence in connection with energy especially in more developed countries. Aware that the world no longer supports such aggression, it's important to seek and find alternative forms of energy generation, which do not produce evils as great as produced by fossil fuels.

The solar water heating, the indirect generation of electricity through the use of solar concentrators and the direct conversion of solar energy into electrical energy through the use of photovoltaic cells represents extremely viable applications and its uses have grown exponentially around the world, mainly in more developed countries.

Brazil is a privileged country in relation to the availability of solar potential. The brazilian northeast has an average potential above 700 W/ m, reaching a peak around 1100 W/m². These potentials place the northeast region as a very viable for deployment of any solar installations, for their various applications.

According to the National Energy Balance (BEN), 2007, 45% of electricity consumption in Brazil is directed to the buildings sector, with 80,0% corresponding to businesses and residences and 12% to public administration, with figures reaching 13, 8% of the country's gross domestic product (www.mme.gov.br). The residential sector accounts for 23% of national consumption of energy and consumption of electric shower is the second largest in a home, accounting for 25%, second only to the refrigerator / freezer that is 30%. Its use affects the peak hours between 06:00pm and 07:00pm, corresponding to 8.5% of national energy demand at this time (Santos, 2008).

These findings indicate that the importance of replacing the power supply by the solar source for obtaining hot water is mainly to reduce the consumption of conventional electric power, relieving the Brazilian energy matrix.

This paper presents the thermal and economic feasibility of a system of solar water heating collector that is built with the use of polycarbonate plates. It is aimed at obtaining hot water for residential purpose to replace the electric shower. Two configurations will be studied, namely: uncoated polycarbonate plate and lined with EPS. The storage tank is alternative and a cost well below the thermal reservoirs used in conventional solar heating systems.

2. BIBLIOGRAPHIC REVIEW

To promote the heating of water conventional and alternative collectors are used. The conventional collectors consists of a box of aluminum or fiberglass profile, glass wool thermal insulation, aluminum plate absorber, copper tubes absorber grid and transparent glass cover, working in 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 as main purpose the socialization of water solar heating. Several generations of alternative collectors using absorbing 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 low cost plastic solar collectors have been studied since the 70s (Santos, 2008).

Santos (2008) presented an alternative water solar heating system consisting 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 using PET bottles, cans of beer and soda and ½ "

PVC tubes. These collectors consist of only three elements: pet bottle, cans and absorber tubes. It was shown the thermal, economic and of material viability of the studied collector.

Souza et al. (2008) had studied a new configuration for the absorber grid of an alternative collector with PVC pipes absorber surface, obtaining a series-parallel grid objectifying an increase in the water temperature, to propitiate the attainment of a bigger temperature of the water in the interior of the thermal reservoir.

Souza et. al (2009) presented in 2009 COBEM a low cost heating system, to promote water heating for bathing in homes, in which the solar collector was manufactured using PVC plates used in coverage of environments. It was demonstrated its thermal, material and economic viability of the proposed collector, whose main innovation is the use of recyclable materials, cans of beer and soft drinks, to increase the temperature of the absorber plate.

Souza et al 2009 presented in 2009 COBEM a heating system using a solar collector built with fibercements tiles for to obtain heat water for bath. The system operates in thermosyphon regimen and will be tested in two configurations: with and without coverage. It will be used a transparent cover of PET bottles. It will be demonstrated the thermal, economic and material viability of the proposed heating system.

Bolera (2010) studied a solar collector for a system for heating bath water. The absorber surface of the collector is formed by twelve 25mm PVC pipe. It was studied eight settings between absorber plate, insulation boards and EPS thermal reservoirs of 150 and 200 liters. The absorber system worked under thermosyphon.

3. MATERIALS E METHODS

The collector of the proposed heating system consists of a sheet of cellular polycarbonate, coupled with two PVC tubes (32 mm) used to place food and water outlet, and a low cost alternative thermal reservoir. The polycarbonate plate has a length of 1.50 m and 1.05 m wide. The collector plate was painted with matte black synthetic enamel for better absorption of solar radiation. It works under thermosyphon regimen, and the heated water volume is 150 liters.

For the union between the plate and polycarbonate tubes for water supply it was made a tear in the tubes, using a drill and metal saw. To seal the union between the two surfaces (plate with the tubes) isophthalic resin was used as an additive powder.

The alternative thermal reservoir **RT 200** was made from a 200 liters polyethylene drum. 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 EPS was placed.

The proposed heating system works under thermosyphon with a volume of water equivalent to 200 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 circulates through the collector, corresponding therefore to a relation between the volume of the reservoir (200 liters) and time to test the system (seven hours).

It was measured the parameters that 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 PVC tube thermal degradation, around 60 ° C (Duffie, 1991, Souza, 2008). The collector was tilted by 15.5 ° S latitude.

It was measured the working fluid inlet and outlet temperature, 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 was also measured the time necessary to standardize the temperature of water in the thermal reservoir.

The fluid temperatures in the inlet and outlet were measured in the period between 08:00 am and 03:00 pm, in intervals of 30 minutes, the temperature of the collector and absorbers tubes were measured from 15 to 15 minutes between 11:00 am and 01:00 pm, period of maximum and constant radiation, which leads to the maximum loss by the 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 cloudiness to allow a more realistic comparison between different days.

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

The system was also evaluated with regard to the number of days in which the system was able to provide hot water in the ideal temperature for bath for a four people residence. The baths were simulated at 07:00 am, 12:00 pm and 06:00 pm, taking up 40 liters of hot water from the reservoir, through a registry located at 2/3 of its height from its base.

The built water heating solar system has been tested for two types of configuration, for a volume of 200 liters storage tank. Figure samples the heating system proposed.

A) SET I: SOLAR COLLECTOR WITHOUT THERMAL INSULATION+ RT200\
B) SET II: SOLAR COLLECTOR WITH THERMAL INSULATION + RT200

FIGURE 1. Proposed solar collector test.

3.1. Determination of thermal parameters

The parameters that best characterize the thermal efficiency of a solar collector are the thermal efficiency, the power loss coefficient and the overall losses.

The heat loss global coefficient is a function of all the thermal exchanges occurring inside and outside the system.

$$U_{loss} = U_{top} + U_{base} \tag{1}$$

Where:
Utop = thermal losses over the sink;
Ubase = thermal losses under the sink.

The loss coefficient for the cover (top) is given by equation (2)

$$U_{top} = \frac{1}{\frac{1}{h_{c(\text{plate-amb})} + h_{r(\,plate\text{-amb})}}}$$

Where:

hc (plate - amb) = convective coefficient between the external surface of the plate and the ambient in W/m².K.

hr (plate - amb) = radiation coefficient between the external surface of the plate in ambient air in W/m².K.

To calculate the coefficient of convective heat transfer between the absorber plate and air, the equations shown below are used.

$$R_{eL} = \frac{V.L}{\upsilon} \tag{3}$$

$$N_{UL} = 0{,}665.R_{eL}{}^{1/2}.Pr^{1/3} \tag{4}$$

$$h_c = \frac{N_{UL}.k}{L} \tag{5}$$

Where:

hc = convective coefficient; R_{EL} = Reynolds number for flow in a horizontal plate, V = air velocity (m / s), L = width of absorber plate; υ = kinematic viscosity of air (m/s²); Nul = Nusselt number, Pr = Prandtl number, k = air thermal conductivity (W/mK).

The coefficient of radiative heat exchange between the outer surface of the absorber plate and the environment, as Duffie & Beckman, 1991, can be determined using equation (3.13).

$$h_{r(ve-amb)} = 5{,}16.10^{8}.\varepsilon_{plate}\frac{(T_{plate}{}^{4} - T_{amb}{}^{4})}{(T_{plate} - T_{amb})} \tag{6}$$

Where:

Tplate = external temperature of the plate in K; Tamb = ambient temperature in K; ε_{plate} = 0.9

The losses from the sides are considered negligible due to the small thickness of the absorber plate, which has negligible side area. A simplified way to obtain the losses from the base of the collector is to consider the flow of heat coming out of the system by conduction through the insulation and calculate the overall coefficient of heat loss for this situation, according to equation (3.14).

$$U_{base} = \frac{1}{\frac{e_{eps}}{k_{eps}}} \tag{7}$$

Where:
e_{eps} = insulation thickness, m; k_{eps} = thermal conductivity of insulation, W/mK

3.1.2. Determination of thermal efficiency

$$P_u = \dot{m}.c_p.\Delta T \tag{8}$$

$$\eta_t = \frac{P_u}{\mathrm{A.I}} \tag{9}$$

Pu = total power transferred to the useful working fluid, in kW, I = solar radiation in kW/m².
A = area of the collector, in m², m = mass flow in kg / s.
cp = specific heat of the water, KJ / kg º K, ΔT = temperature gradient between inflow and outflow of fluid, K.

4 RESULTS AND DISCUSSION

It will be presented below the general hourly average data for the three days of tests performed for each studied configuration.

4.1. Results of thermal parameters for determining the thermal efficiency of the collector studied.

4.1.1. Configuration I - Uncoated collector + RT200

The following table shows the mean overall three days of tests to setup I - POLYCARBONATE PLATE + RT200

TABLE 1. Hourly average data for testing the configuration I.

Time	Te (°C)	Ts (°C)	ΔT (°C)	Ig (W/m²)	η_t (%)
08:00am - 09:00am	30,2	43,7	13,5	796	35,6
09:00am - 10:00am	31,5	46,5	15	859	36,7
10:00am - 11:00am	32,5	49,5	17	905	39,4
11:00am - 12:00pm	33,7	52,5	18,8	999	39,5
12:00pm - 01:00pm	35,3	53,2	17,9	947	39,7
01:00pm - 02:00pm	37	54,3	17,63	881	42,0
02:00pm - 03:00pm	39,2	53,3	14,07	698	42,3
Average			**16,3**	**844,3**	**39,3**

The outlet temperature of the collector was always above 40 º C, with the highest hourly average recorded of 54.3 ° C. The inlet temperature in the collector in the early tests has always been nearly equal to room temperature.

The collector was able to provide hot water at the end of the day, with temperatures far above the considered ideal for swimming, which is between 34 and 36 º C, thus demonstrating possible in 1 (one) day operation to achieve its goal, and even thermally efficient as conventional collectors.

The average efficiency of the collector in this configuration was approximately 40%, slightly below the conventional collectors, but even above some alternative ones, with thermal efficiency around 30-35%. This level of efficiency was expected because the collector has no transparent cover to minimize convective and radiative exchange with the environment and is not contained in an insulated box.

The average solar radiation for all test days was approximately 850 W / m². It was selected days of low or no cloudiness to the characterization of solarimetric conditions close to every test day.

TABLE 2. Water temperatures at different points of thermal reservoir for the configuration I: Uncoated collector + RT200

Time	T_{Fundo} (°C)	$T_{1/4}$ (°C)	$T_{1/2}$ (°C)	$T_{3/4}$ (°C)	T_{Topo} (°C)
08:00am	28,0	28,6	28,9	32,3	37,2
09:00am	29,1	30,00	31,3	35,1	40,5
10:00am	30,5	31,5	33,00	36,7	40,9
11:00am	32,0	33,3	37,6	39,9	43,0
12:00pm	34,5	37,2	41,0	43,7	46,1
01:00pm	36,5	39,9	43,8	46,5	47,6
02:00pm	39,5	40,5	45,2	46,9	47,7
03:00pm	**40,5**	**41,5**	**45,5**	**47,2**	**47,9**
Water temperature in the storage tank at 03:00pm after mixed = 45.1 ° C					

In relation to temperature levels measured at various points in the thermal reservoir, it is perceived that they were well above average levels required for bath (between 34 and 36 ° C). The difference between the higher temperature level, on top of the tank and the lowest at the low, corresponded to 18%, and the difference between the temperature of the temperature on top and in the middle was around 5.2% which shows that nearly all water in the drum was near uniformity desired.

The measured values show that the temperature levels of the absorber plate on the top surface exposed to solar radiation for this configuration were very far from the critical level for initiation of thermal degradation, around 60 ° C.

4.1.2. Configuration II – Coated collector +RT200

Followig table shows the average results of three test days for **configuration II.**

TABLE 14. Hourly average test configuration IV Data: Coated collector +RT200

Time	Te (°C)	Ts (°C)	ΔT (°C)	Ig (W/m²)	η_t (%)
08:00am - 09:00am	30,5	45,1	14,6	796	38,5
09:00am - 10:00am	31,5	49,2	17,7	859	43,3
10:00am - 11:00am	33,1	53,2	20,1	905	46,6
11:00am - 12:00pm	34,5	55,3	20,8	999	43,7
12:00pm - 01:00pm	36,2	57,3	21,1	947	46,8
01:00pm - 02:00pm	38,5	57,5	17,63	881	42,0
02:00pm - 03:00pm	40,5	56,3	14,07	698	42,3
Average			**18,0**	**844,3**	**43,3**

The outlet temperature of the collector was always above 45° C, with 57.3 °C being the highest recorded hourly average. The inlet temperature in the collector in the early tests has always been nearly equal to room temperature.

The collector was able to provide hot water at the end of the day, with temperatures far above the considered ideal for swimming, which is between 34 and 36 º C, thus demonstrating possible in 1 (one) day operation to achieve its goal, and even thermally efficient as conventional collectors.

The average efficiency of the collector in this configuration was approximately 40%, slightly below the conventional collectors, but even above some alternative ones, with thermal efficiency around 30-35%. This level of efficiency was expected because the collector has no transparent cover to minimize convective and radiative exchange with the environment and is not contained in an insulated box.

The average solar radiation for all test days was approximately 850 W / m². It was selected days of low or no cloudiness to the characterization of solarimetric conditions close to every test day.

TABLE 13. Average temperatures in various parts of the thermal reservoir for the test Configuration II - Coated collector +RT200

Time	T_{Bottom} (ºC)	$T_{¼}$ (ºC)	$T_{½}$ (ºC)	$T_{¾}$ (ºC)	T_{Top} (ºC)
08:00am	30,1	30,5	31,0	33,3	36,2
09:00am	31,1	31,8	34,7	38,6	40,5
10:00am	32,5	33,5	35,50	39,4	42,9
11:00am	34,2	35,3	39,6	43,1	45,3
12:00pm	36,5	40,1	43,0	46,4	48,8
01:00pm	38,4	41,5	45,6	48,5	49,4
02:00pm	39,6	42,3	46,5	49,1	49,2
03:00pm	**41,0**	**43,1**	**47,5**	**49,1**	**49.2**
Water temperature in the storage tank at 03:00pm after mixed = 47.0 º C					

The measured levels of temperature at various points in the thermal reservoir were much higher than average levels required for bath (between 34 and 36 ° C). The difference between the temperature level higher, on top of the tank and the lowest at the low, corresponded to 20%, and the difference between the water temperature at the top and middle was around 3.5% which shows that nearly all water in the drum was near uniformity desired.

The temperatures of the external surfaces of the upper and lower absorber plates were measured to assess susceptibility to degradation by thermal and ultra violet radiation. Figure 4.1 shows its values for SETUP I.

4.3. COMPARISON BETWEEN MEASUREMENT CONFIGURATIONS

The Table shows main results for the two general configurations studied: polycarbonate plate with and without thermal insulation.

TABLE 14. Generals results for the two configurations studied.

TYPE	ΔT (ºC)	I (KW/m^2)	ηt (%)	T_{bottom} (ºC)	$T_{1/4}$ (ºC)	$T_{1/2}$ (ºC)	$T_{3/4}$ (ºC)	Ttop (ºC)	$T_{mixture}$ (ºC)
WITHOUT INSULATION + RT200	*16,3*	*0,845*	*39,3*	40,5	41,5	45,5	47,2	47,9	45,1
WITH INSULATION + RT200	*18,0*	*0,844*	*43,3*	41,0	43,1	47,5	49,1	49.2	47,0
WITHOUT INSULATION / WITH INSULATION	*0,9*		*0,8*	*0,99*	*0,96*	*0,96*	*0,96*	*0,97*	*0,96*

The figure shows the levels of average temperature of the fluid at points inside the storage tank for the two studied configurations at the end of the test, at 03:00pm.

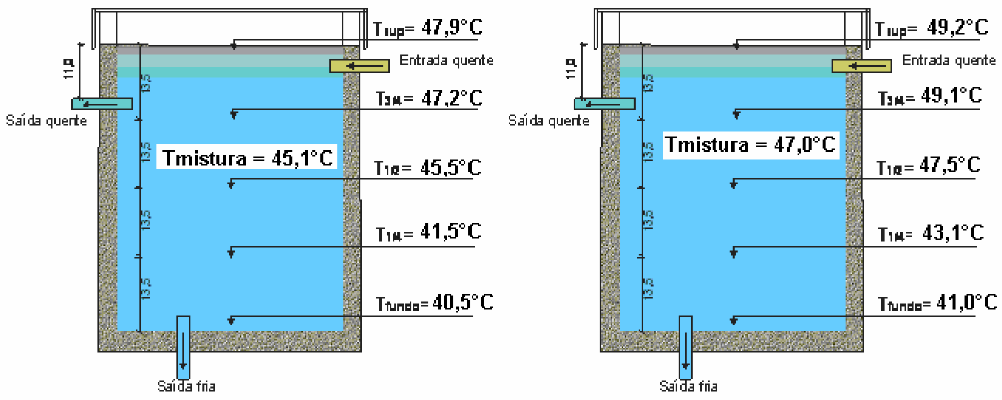

FIGURE 2. Levels of average temperature of the fluid at points inside the storage tank.

The entire volume of water in the tank is far above the thermal optimum temperature for bathing, for the two configurations studied, demonstrating the viability of the proposed solar collector to provide hot water for a four people family. It should be noted that withdrawal of water occurs through the upper reservoir which is at a temperature higher than that contained in the tank bottom.

The configuration with isolation showed a better thermal performance and considering that the cost for placing the insulation is negligible, about $ 12, is therefore the configuration that offers the best cost benefit. Although the configuration with insulation has shown better performance, the other configuration that was also studied had results that were only 4.0% lower. Therefore, the two configurations studied have potential use for this purpose.

With regard to surface temperatures and lower outer plate of polycarbonate, the table shows the values for both configurations.

The temperatures of the external surfaces of the upper and lower absorber plate were measured to assess susceptibility to degradation by thermal and ultra violet radiation. Table 15 presents their values to the configurations I and II.

TABLE 15. Average temperatures at various points on the surface of absorber plate.

TYPE	T_{mps} ***(C)***	T_{mpi} ***(C)***	T_{amb} ***(C)***
WITHOUT INSULATION + RT200	***42,6***	***41,7***	***32***
WITH INSULATION + RT200	***47,03***	***39,0***	***33***
WITHOUT INSULATION / WITH INSULATION	***0,9***		***0,8***

The results of the measured temperatures on the polycarbonate board evidenced that the initiation of thermal degradation process has not been reached and that the insulation provided better heat transfer between fluid and plate stock. Degradation by UV is softened by the matte black paint applied to the plate.

Because the insulated configuration showed a higher thermal efficiency, it was chosen for the simulation test facilities.

4.4 Bath Simulation

To evaluate the system in its real condition of operation, a simulation was proceeded through the withdrawal of a certain volume of hot water at the following times: 07:00am, 12:00pm and 06:00pm. For this, it was used a record set at ¾ of the tank from the base, it was withdrawn 50 liters of water and then the same amount of cold water was dropped in the reservoir. Table 16 shows the obtained data during the bath simulation tests.

TABLE 16. Data simulation facilities in the Setting - Coated collector +RT200

Day	Temperature of hot water coming out (°C)	Temperature of Cold Water that enters (°C)	Time	Ambient Temperature (°C)	Solar Radiation (W/m²)
17/03	47,5	41,6	18:00	27,2	___
18/03	36,8	33,5	07:00	26,7	262
18/03	47,6	44,1	12:00	32,8	988
18/03	40,8	38,5	18:00	28,3	___
19/03	36,1	33,2	07:00	26,8	124
19/03	39,5	37,0	12:00	31,8	980
19/03	41,3	39,7	18:00	28,0	___
20/03	34,6	33,2	07:00	28,8	148
20/03	41,2	39,1	12:00	32,4	758
20/03	40,9	38,7	18:00	28,9	___
21/03	34,1	33,0	07:00	28,1	195
21/03	41,1	38,8	12:00	32,1	654
21/03	40,5	37,9	18:00	28,8	___
22/03	34,1	32,8	07:00	29,2	108
22/03	41,7	39,9	12:00	32,6	1019
22/03	39,7	37,2	18:00	28,9	___
23/03	33,8	31,9	07:00	29,5	200

The data shows that with the exception of march 23 that showed a temperature of 33.8 ºC at 07:00 am, in all other days and times the levels of water temperature were compatible for the bath thus exhibiting autonomy to 5 (five) days. These results were important, mainly because of the low cost of the studied heating system, emphasizing again that this system has significant behavior for a collector without collection boxes and glass coverage.

Using the equations presented previously it was calculated the global coefficient of thermal losses, Uloss, being an amount equal to 16 W / m². K, much higher than the ones found on conventional collectors available on the market, around 6.0 / m². K. But it does not preclude the use of the proposed collector. It highlights the option for a low cost, no box store and transparent cover collector as a way to socialize the use of solar energy for residential water heating.

4.5 Costs of heating system

For the manufacture of the proposed system the main materials used were: plate alveolar lining polycarbonate, PVC pipes of 1 ½ "and ½" knees ½ "connections, glue, PVC, EPS, plastic adhesive, matte black enamel paint, isophthalic resin and others. The manufacturing cost of the collector was R $ 152.00.The manufacturing cost of each thermal reservoir built was around $ 300.00 (Santos, 2008). The total cost of the alternative water heating system was R$ 452.00. It was not tallied the working cost.

5. CONCLUSIONS AND SUGGESTIONS

1. The solar heating system proved to be viable for residential heating water for a family of four people. Its manufacturing cost is around £ 350.00 (U $ 175.00) and below in relation to conventional collectors commercially available;
2. The system was easy to manufacture and assembly, with low weight and easy handling of the collector;
3. The two configurations studied proved to be viable for the proposed end, but the setup with isolation was more efficient;
4. The heating system tested has a low cost advantage and can contribute significantly to the socialization of the use of heated bath water using solar energy;
5. The alternative thermal reservoir showed itself to be feasible for suits used in heating systems. The temperature at the bottom of the barrel was close to the upper level, which demonstrates the significant degree of heating provided by the alternative proposed heating system;
7. The temperature of the PVC absorber plate was below the critical level for initiation of the thermal degradation. With regard to degradation by UV such effect is mitigated by the matte black paint that covers the absorber tubes. It contains black pigments that absorb ultraviolet radiation;

8. The studied heat loss is much higher than on conventional collectors, but it can be emphasized that the collector has no transparent cover, which significantly reduces heat exchange between the sink and the environment;

9. The insulating material placed on the lower surface of the absorber plate was efficient, but it is necessary to study a way to reduce its exposal to minimize their environmental degradation processes without altering the basic characteristics of the collector, low cost and easy manufacturing process and assembly;

10. One problem encountered in the fabrication of such collector is to avoid leaks. It was studied some options for the coupling between the Polycarbonate and the PVC plates, which must still be optimized;

11. The heating system showed significant autonomy, which can be increased with the construction of a collector or even a larger area with the use of another collector in series. It will also be studied the connection in parallel for better heating rate, without significantly increasing the cost of the system, since the cost of the plates is low;

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