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SMART STRATEGY FOR SOLAR ENERGY HEATING XXII COBEM

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Abstract. *This study analyzes different configurations of solar water heating systems scenarios, varying the number of thermal reservoirs for the same total volume of the system. Satisfying the same pattern of hot water consumption, under same climatic conditions, the usage of multiple thermal reservoirs shows optimized contribution of solar energy to the system and consequently minimized consumption of electric auxiliary energy.*

Keywords: *Solar water heating system, Multi-tank thermal storage, Water heating, Solar energy.*

1. INTRODUCTION

The energy matrix diversification is increasingly necessary, either to conserve non-renewable resources such as oil, which has become more scarce, or to reduce the matrix vulnerability, or even to mitigate environmental impacts due to use of non-renewable sources. In this scenario renewable energies such as hydro sources, wind, biomass or solar, feature role of increasing relevance.

This study examines aspects of solar energy usage for residential water heating consumption. Two aspects are addressed: the first is the use of daily or monthly mean values of temperature and insolation used by various sizing methods or solar heating systems simulation (S.H.S), and the second is the use of multiple hot water storage tanks rather than a single larger tank.

The use of daily or monthly average data mask weather changes. S.H.S. are then designed to operate on average climatic conditions, disregarding situations such as an entry of a cold front, rain in the middle of the day, a misty morning, etc. Under these conditions the S.H.S operates with lower efficiency and the use of auxiliary heating system is necessary.

The use of a single hot water tank has advantages on design simplification and maintenance, however, on cloudy days or early in the morning, when there is still no significant insolation on the solar collector panels, the auxiliary heating system must act to warm the entire volume of the reservoir. In this weather conditions, if there are multiple smaller volume tanks, the auxiliary heating system would act initially only in one of the tanks, ensuring the supply of hot water, but postponing the heating of the remaining water volume. This postponement can be long enough to ensure that insolation conditions improve allowing the water heating through the collector panels.

2. CLIMATE DATA ANALYSIS

Climate data, more specifically solarimetric data, are easily found on internet. The publications aim to disseminate and facilitate solar energy projects. However, such data usually present daily or monthly mean solarimetric values. Although there are formulas to convert this data to hourly basis, insolation varies expressively each day of the year, and average values are insufficient for a precise S.H.S. simulation.

It was then used data published by National Renwable Energy Laboratory (NREL), which is the main energy efficiency and renewable energy research and development laboratory of United States Energy Department. Entitled Hourly Solar Data for Selected Stations in Brazil (2005). The NREL METSAT model input data were obtained by crossing of satellites information and cloud cover observations. Solarimetric information on hourly basis used in the study contain the years from 1997 to 2001, relating Rio de Janeiro city.

Analyzing this data, there is little variation in the extraterrestrial solar radiation values for each month. However, due to climatic phenomena such as cold fronts, fog, rain and etc, there is a wide variation in direct and diffuse radiation, and also at ambient temperature in all months. If this variation was distributed within each day of the year, i.e. one morning with little insolation compensated for an afternoon of good insolation or an above average insolation around noon that compensates for a morning and afternoon low insolation, then the average day would be a good approach to S.H.S. modeling. It was then required to analyze each daily insolation curve behavior.

For this analysis direct and diffuse radiation values were added for each day, that because a particular day can present low direct insolation due to a high diffuse insolation, as in a fog day, compensating each other. Furthermore, the insolation period was divided in three parts – morning, noon and afternoon – who received three ratings – weak, regular and good.

The morning period covers data recorded between 07 a.m. and 10 a.m., the period named "noon" refers to data of 11a.m. until 02 p.m. and the afternoon refers to 03 p.m. until 06 p.m..

The average insolation of each period (morning, noon and afternoon) was calculated, which was then compared with the average insolation of each period of the average day of its month. I.e., morning, noon and afternoon of a specific day of January is compared with the morning, noon and afternoon of January’s average, and so on for each day and month. If the period is 20% below the average, is classified as weak, 20% above is classified as good and between -20% and + 20% is classified as regular. Each classification is assigned a weight. Weak has weight -1, regular has weight 0 and good +1. So, one day with weak morning, weak noon and weak afternoon receives a total grade of -3. A day with good morning, good noon and good afternoon, grade +3 and one day within the average receives grade zero. Other combinations of periods generate grades between -3 and +3. For each grade was given the following classification: -3, worse day; -2, very weak day; -1, weak day; 0, regular day; 1, good day; 2, very good day; 3, great day. The 1.826 days analyzed were then sorted and distributed in the following table:

Table 1. Qualitative Analysis of Climatic Data

Classification		Worse	Very weak			Weak						Regular							Good						Very good			Great
Grade		-3	-2	-2	-2	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	3
Morning		W	W	W	R	W	W	G	R	R	W	W	W	R	R	R	G	G	G	R	R	W	G	G	R	G	G	G
Noon		W	W	R	W	W	G	W	R	W	R	G	R	W	R	G	R	W	R	G	R	G	W	G	G	R	G	G
Afternoon		W	R	W	W	G	W	W	W	R	R	R	G	G	R	W	W	R	R	R	G	G	G	W	G	G	R	G
January	No. of days	21	3	5	2	-	-	-	9	2	18	-	-	1	27	-	1	1	17	-	8	-	-	-	-	28	4	8
	Monthly %	13,5%	6,5%			18,7%						19,4%							16,1%						20,6%			5,2%
February	No. of days	16	4	6	7	-	-	-	10	-	12	-	2	-	26	-	1	-	6	-	13	-	-	-	-	32	-	6
	Monthly %	11,3%	12,1%			15,6%						20,6%							13,5%								22,7%	4,3%
March	No. of days	24	3	11	7	-	-	-	10	1	9	-	2	-	13	-	2	-	14	-	9	-	-	-	5	13	3	29
	Monthly %	15,5%	13,5%			12,9%						11,0%							14,8%						13,5%			18,7%
April	No. of days	27	4	6	4	-	-	-	5	2	6	-	4	-	21	1	3	-	7	2	8	-	-	1	6	8	7	28
	Monthly %	18,0%	9,3%			8,7%						19,3%							12,0%						14,0%			18,7%
May	No. of days	25	5	12	4	-	-	1	9	2	7	-	3	-	10	1	5	-	8	2	6	2	-	1	2	11	8	31
	Monthly %	16,1%	13,5%			12,3%						12,3%							12,3%						13,5%			20,0%
June	No. of days	24	3	11	7	1	-	1	6	1	8	1	5	-	19	1	2	-	9	3	1	-	1	-	4	5	4	33
	Monthly %	16,0%	14,0%			11,3%						18,7%							9,3%						8,7%			22,0%
July	No. of days	21	3	6	3	1	-	-	4	1	16	1	7	-	23	-	2	-	23	1	5	-	-	-	2	8	5	23
	Monthly %	13,5%	7,7%			14,2%						21,3%							18,7%						9,7%			14,8%
August	No. of days	33	3	10	2	-	-	-	8	-	9	-	3	-	19	-	3	1	3	2	3	1	-	-	2	4	3	46
	Monthly %	21,3%	9,7%			11,0%						16,8%							5,8%						5,8%			29,7%
September	No. of days	36	3	5	7	2	-	-	8	1	4	1	3	-	7	-	-	-	4	6	4	1	-	2	7	3	7	39
	Monthly %	24,0%	10,0%			10,0%						7,3%							11,3%						11,3%			26,0%
October	No. of days	30	8	5	7	1	2	1	8	2	10	2	4	-	5	3	2	-	4	1	5	-	-	5	6	3	6	35
	Monthly %	19,4%	12,9%			15,5%						10,3%												9,7%	9,7%			22,6%
November	No. of days	27	7	8	-	-	-	1	9	-	8	1	7	-	9	1	2	-	17	2	8	-	-	-	2	6	6	29
	Monthly %	18,0%	10,0%			12,0%						13,3%							18,0%						9,3%			19,3%
December	No. of days	39	3	3	3	2	-	-	8	-	6	2	2	-	11	-	3	-	3	6	7	2	-	2	6	5	4	38
	Monthly %	25,2%	5,8%			10,3%						11,6%							12,9%						9,7%			24,5%
Total days		323	49	88	53	7	2	4	94	12	113	8	42	1	190	7	26	2	115	25	77	6	1	11	42	126	57	345
		323	190			232						276							235						225			345
Annual percentage		17,7%	10,4%			12,7%						15,1%							12,9%						12,3%			18,9%

The days are largely distributed among the 7 ratings, confirming the weakness of using daily or monthly average data for a S.H.S. simulations, once it mask a situations like a cold front, rain in the middle of the day, a misty morning, etc. Conditions under which a S.H.S. operates with lower efficiency and use of auxiliary heat system is necessary.

3. SIZING OF THE SOLAR HEATING SYSTEM

The solar heating system sizing obeyed the NBR 15569 - Solar Water Heating System in Direct Electric Circuit : Design and Installation (ABNT, 2008) and the Technical Quality Regulation for Energy Efficiency – Residential Buildings - RTQ-R (Inmetro, 2010). The methodology used in these publications is the F-Chart (Beckman et al. 1977).

The S.H.S was scaled to a single-family residence with a capacity of 4 hot baths per day with duration of 10 minutes and flow rate of 10 liters per minute, being this the most commonly found configuration of S.H.S.. The scaling resulted in S.H.S with a hot water storage tank of 300 liters, three flat-plane Solar Collector of 1.01 m² each, $F_R U_L$ equal to 4,22 , FR($\tau\alpha$)n of 0,76 and Solar Fraction of 73,25%.

4. SIMULATOR MODELING

4.1. Insolation on Tilted Plane

Insolation values provided by NREL refers to an area of 1 m² in the horizontal plane. It is necessary to convert these data to a tilted plane. According to Duffie et al. (1977), the diffuse radiation I_d, reflected by the clouds, the ground or the buildings next to the area of data collection, can be considered the same for horizontal and tilted plane, because they do not have defined origin. As for the beam radiation I_b, comes directly from the Sun to the horizontal plane and therefore needs to be calculated for the tilted plane by a reason R_b (beam ratio). R_b is given by:

$$R_b = \frac{\cos(\emptyset + \beta) . \cos\delta \ . \cos\omega + \ sen(\emptyset + \beta) . sen \ \delta}{\cos\emptyset . \cos\delta \ . \cos\omega + \ sen \ \emptyset \ . \ sen \ \delta} \quad (1)$$

ø: Latitude at S.H.S. location. Angular location north or south of the equator, north positive and south negative, -90º ≤ ø ≤ 90º (degrees);

β: Collector plane's tilt in relation to the horizontal plane, 0º ≤ β ≤ 180º (degrees);

δ: Solar declination – solar angular position at noon to the plane of the equator, -23.45° ≤ δ ≤ 23.45° (degrees);

ω: hour angle – Sun's angular displacement in relation to the local Meridian. Equivalent to 15° per hour, in the morning is negative, in afternoon is positive, and equal to 0º at noon (degrees).

With R_b it is found the radiation on the tilted plane by the formula:

$$I_t = I_b . R_b + I_d \quad (2)$$

I_b: Direct radiation, (Wh/m²);

R_b: Tilled plane and horizontal plane ratio;

I_d: Diffuse radiation, (Wh/m²).

4.2. Flat-plane Solar Collector

For simulation of solar collectors operation, three groups of input data are needed: the parameters of the collector, the weather parameters and the S.H.S. parameters. The collector's parameters are obtained with Inmetro tables of the Brazilian labeling program. There are the optical properties $F_R(\tau\alpha)_n$ (dimensionless), representing collector's energy gains; the thermal properties $F_R U_L$ (in W/m². K), which represent the collector's thermal losses; and the collector's useful area A_c (m²). The weather parameters are irradiation over the collector I_t (Wh/m²), and the ambient temperature T_{amb} (°C), data from NREL. Finally the S.H.S parameters, which are the water temperature at the entrance of the collector T_{in} (°C) and the mass flow rate of water through the collector (kg/s) (Not to be confused with the consumption flow). The values are used to find water's temperature in the collector output T_{out} (°C) by the equation:

$$T_{out} = \frac{F_R(\tau\alpha)_n . A_c . I_t}{\dot{m} \ . \ C_p} - \frac{F_R U_L \ . \ (T_{in} - T_{amb}) . A_c}{\dot{m} \ . \ C_p} + T_{in} \quad (3)$$

C_p being the specific heat of water, (W.s/kg.K).

Calculated the outlet temperature T_{out} is also possible to calculate the efficiency of the collector η (dimensionless) with the equation:

$$\eta = \frac{\dot{m} . C_p . (T_{out} - T_{in})}{A_c \ . \ I_t} \quad (4)$$

About the collector efficiency, applying the equation 3 in 4 you get the equation:

$$\eta = F_R(\tau\alpha)_n - \frac{F_R U_L.(T_{in} - T_{amb})}{I_t} \tag{5}$$

By the equation above, the lower the water's temperature entering the collector, the greater the efficiency of the collector. Thus, the importance of a stratified temperature profile inside the thermal reservoir.

The formula 3 is, in fact, an approximation valid only for working temperatures. So, as the water temperature in the collector's entry increases, the formula generates temperatures too high and discrepant from reality. A non-linear formula is than needed for the calculation of T_{out}. According to Cooper and Dunkle (1981) equation 3 can be rewritten as follows:

$$T_{out} = \frac{F_R(\tau\alpha)_n \,.\, A_c \,.\, I_t}{\dot{m} \,.\, C_p} - \frac{a \,.\, (T_{in} - T_{amb}).\, A_c}{\dot{m} \,.\, C_p} - \frac{b \,.\, (T_{in} - T_{amb})^2.\, A_c}{\dot{m} \,.\, C_p} + T_{in} \tag{6}$$

Notice that if *a* is equal to $F'_r.U_L$ and *b* equal to zero, the equation 6 becomes again on the linear equation 3. Therefore, *a* is a value around $F'_r.U_L$ and *b* has a value greater than zero.

For the calculation of *a* and *b* would be necessary to know various parameters of each collector, like material used, number of tubes, internal diameter of the pipes, etc. As these values are not reported in Inmetro's tables, *a* and *b* were adjusted until the efficiencies of the collector for working temperatures were similar in equations 3 and 6, and that the maximum temperature was not greater than 85 °C. The values of *a* and *b* were estimated at 3.0 and 0,1715, respectively.

Forced circulation was chosen instead of variable flow, for two reasons: the F-Chart was developed for forced circulation systems, although there are works that adapt the F-Chart for natural circulation (Malkin, 1985). As a second reason, the parameters measured by Inmetro, $F_R(\tau\alpha)_n$ and $F_R U_L$, vary in function of the flow, being valid only for the flow used in tests (worth 1L/(min m²), 1 litre per minute per square meter of collector area).

4.3. Hot Water Tank

In order to study the most efficient operating conditions, we opted for the simulation of vertical tanks. We opted for the Hottel-Whilier-Bliss equations for the multiple nodes one-dimensional model, which is characterized by the subdivision of the tank in *n* equal and fixed volumes, as if they were overlapping disks. Each node displays uniform temperature. Its initial temperature is represented by $T_{i,0}$, temperature of the node i at time zero (in °C), with i ranging from 1 to *n*. Each node exchanges heat with its neighbors (i + 1 and i - 1) and with the external environment by the side walls of the tank. Yet the node 1 and node n Exchange heat with only one neighboring node, and exchange energy with the side of the tank and the top cover or bottom of the tank.

Oliveski (2000) compares the one-dimensional model of multiple nodes with a two-dimensional model, nonlinear, transient and experimental data, demonstrating that the one-dimensional model successfully simulates the heat exchange of a hot water storage tank. Duffie et al. (1977) claim that 8 is a sufficiently large number of nodes to ensure accuracy of results and small enough to optimize its computation.

For the calculation of heat exchanges with the external environment we have:

$$T_{i,t+1} = \left[\frac{UA_{lateral}.\left(T_{amb,t} - T_{i,t}\right).\Delta t}{m_i \,.\, C_p}\right] + T_{i,t} \tag{7}$$

$T_{i,t+1}$: is the temperature at node i in t + 1 iteration, in °C;
$UA_{lateral}$: is the heat exchange coefficient by the side of the tank, in W/K;
$T_{amb,t}$: is the room temperature at time t, in °C;
Δt: is the time elapsed between each iteration, in seconds;
m_i: the mass of water contained in the node i, in kg;
C_p: is the specific heat of water, 4.190 W.s/(kg.K)
$T_{i,t}$: is the temperature of the node i in t iteration, in °C.

$UA_{lateral}$ is the inverse of thermal resistance of the side of the tank (R_l) given by:

$$R_l = \frac{\ln\left[\frac{(r+e_{met})}{r}\right]}{2.\pi.{}^{H}/_{n}.k_{met}} + \frac{\ln\left[\frac{(r+e_{met}+e_{isol})}{(r+e_{met})}\right]}{2.\pi.{}^{H}/_{n}.k_{isol}} + \frac{1}{h_{ar}.2.\pi.(r+e_{met}+e_{isol}).{}^{H}/_{n}} \tag{8}$$

r: is the radius of the tank in metres;
e_{met}: is the thickness of the sheet metal on the side of the tank, in metres;
e_{isol}: thick side of the thermal insulation coating, in meters;
H: is the height of the tank in metres;
n: is the number of nodes;
k_{met}: is the thermal conductivity of metal, in W/m.K;
k_{isol}: is the thermal conductivity of the insulation, in W/m.K;

h_{ar}: is the heat transfer coefficient of the air, in W/m².K.

The equations are replicated in the algorithm for up to three tanks, each with volumes of 100 L, 200 L, 300 L, all equipped with timer (which can be active or inactive), with thermostat (with minimum temperature of 48 °C and maximum of 50 °C) and internal electric heater of 3 kW. The tanks are connected in series, i.e. in the case of three tanks, the tank A supplies the shower, the tank B supplies A, C supplies B, and C tank is filled with cold water (considered with constant temperature of 20 °C) by the water tower. If the simulation requires only two tanks, reservoir C is annulled and water tower supplies the last remaining tank, in this case B. So it is possible to simulate a S.H.S with one or even three reservoirs. Each tank is connected to the solar collector set used in the simulation. In a real situation, those connections would be controlled through electrovalvules so that at any given time, only certain tank is connected to the collector set. A schematic summary for a S.H.S with three reservoirs is shown below:

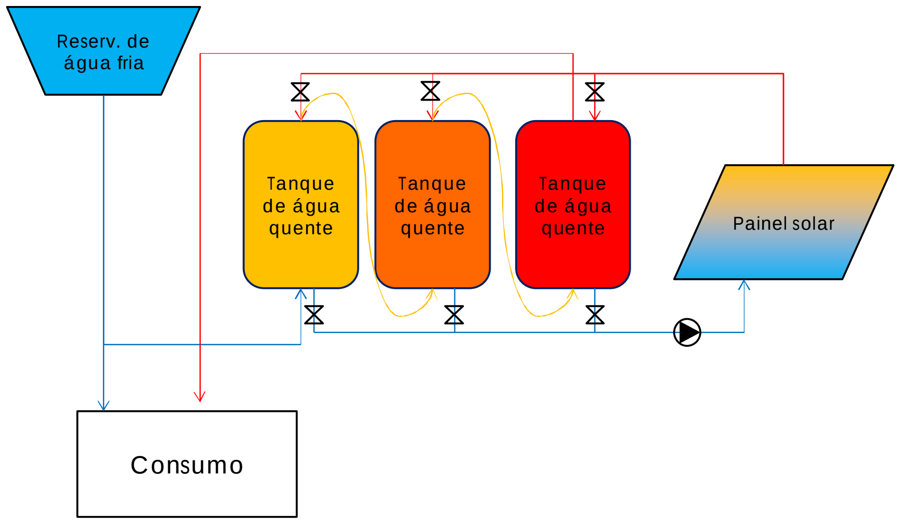

Figure 1. Schematic summary - 3 tanks S.H.S.

4.4. Hot water consumption

According to the stipulated for the sizing of S.H.S, a daily consumption of 400 liters of water at 40 °C was set, the equivalent of four baths, 10-minutes long, with 10 L/min flow. However, it is necessary to define the distribution of these showers throughout the day, because if all the baths occurs in the morning, or during the night , the behavior will generate different results on simulations. It was considered a standard consumption – With a distribution that emulates the curves of residential consumption of electricity, that is, with an average peak consumption started at 6 a.m., a small peak around noon and a higher spike starting from 7 p.m..

4.5. Simulated Cases

- Boiler - With Timer: For that simulation was considered a single hot water tank with internal electrical resistance. Solar energy was not used for water heating. The timer was used so that the fluid was heated before consumption only, and not at any time. This case is used to check how much energy a system dependent on electric power consumes to provide the required hot water volume.
- Base Case - Internal resistance without Timer: This is the basic S.H.S model. It has a single hot water tank connected to the solar collectors. Has electrical internal resistance without timer, i.e. whenever the thermostat is below the minimum temperature, electrical resistance is on.
- Base Case - Internal resistance with Timer: Similar to the previous case, but with the advent of the timer, which stipulates at what times the internal resistance can be on.
- Case 01 - Internal resistance with Timer: it has two reservoirs (A and B). The tank A is 100 L, with internal resistance and timer. B tank has volume of 200 liters, without inner resistance. Both tanks are connected to the collector set.
- Case 02 - Internal resistance with Timer: Has three reservoirs (A, B and C). The three tanks have volume equal to 100 L. Only tank A has internal resistance and timer. All the tanks are connected to the collector set.
- Base Case – Pass through heater: it has a single hot water tank connected to the solar collectors. Has no internal resistance, but an external pass through electrical heater. The pass through heater checks the water’s temperature coming out of the tank, if it’s under the stipulated temperature of 40 °C, the heater provides energy required to obtain such temperature.

- Case 01 – Pass through heater: it has two reservoirs (A and B). The tank A has a volume of 100 L and B 200 L, both without internal resistance, but an external pass through electrical heater connected to the tank A. Both tanks are connected to the solar collector set.

- Case 02 - Pass through heater: Has three reservoirs (A, B and C). The three tanks have volume equal to 100 L. No internal resistance, but an external pass through electrical heater connected to the tank A, all tanks are connected to the solar collector set.

Also two special cases were simulated. The first is a simplification of the S.H.S project with two tanks. Instead of the two tanks (A and B) be connected to the solar collectors, only the tank B is connected to the panels. In this case you don't need the electrovalvules to control which tank is connected to the solar collectors. This special case was named as Simplified. The second case is an adaptation of a pre-existing S.H.S., i.e. the base cases received another tank, installed between the original tank and the shower. Only the additional tank has internal resistance, and the one inside the old tank is disabled. This special case was named as Adapted.

The information above was summarized in the table:

Table 1. Studied cases

Case	Tank			Internal Resistance (Tan. A)	Timer	Pass through heater	Connected to the solar collector
	A	B	C				
Boiler	300 L	-	-	Yes	Yes	-	-
Base Case - Internal resistance without Timer	300 L	-	-	Yes	-	-	A
Base Case - Internal resistance with Timer	300 L	-	-	Yes	Yes	-	A
Case 01 - Internal resistance with Timer	100 L	200 L	-	Yes	Yes	-	A and B
Case 02 - Internal resistance with Timer	100 L	100 L	100 L	Yes	Yes	-	A, B and C
Base Case – Pass through heater	300 L	-	-	-	-	Yes	A
Case 01 - Pass through heater	100 L	200 L	-	-	-	Yes	A and B
Case 02 - Pass through heater	100 L	100 L	100 L	-	-	Yes	A, B and C
Case 01 – Simplified	100 L	200 L	-	Yes	Yes	-	B
Base Case - Adapted - 100 L	100 L	300 L	-	Yes	Yes	-	B

5. SIMULATION RESULTS

In the following tables are presented the results obtained in scenarios simulations of the cases exposed earlier. The values represent the daily average of 1.826 days simulated. Only the values for electricity costs are monthly basis (was considered cost of R$ 0,50 per kWh).

The first column "Shower demand" is the daily energy consumption of the baths considering the cold water at the temperature of 20 °C and the bath temperature of 40 °C. The column "Provided shower" shows how much energy on average was provided daily to the baths. The column "% Not provided" shows that all cases provided satisfactorily the energy demanded. The column "Ambient loss" shows the thermal losses from the reservoir to the environment. You can see that the greater the number of tanks in a case, the greater the loss. The column "% Losses" shows the participation of loss to the environment in total loss of the system (Hot water discharge by consumption plus losses by heat transfer to the environment). "Solar Heater" and "Electric Heater" shows, respectively, the energy provided by solar heating system and electric heating. "Solar Fraction" is the reason of solar energy provided by total energy supplied to the system (solar + electrical). "R$/Month" is the only column that is not on a daily basis, but monthly. This column shows how much you pay monthly by electrical energy consumed in each case. The columns "% Gain" shows how much you're saving in terms of monthly costs of electricity, in relation to one of the first three cases. "% Gain 1" shows how much you save by choosing a particular case rather than opt for the Boiler. "% Gain 2" refers to the economy made by choosing a case compared to the Base Case - Internal resistance without Timer. In "% Gain 3" the cases are compared to the Base Case - Internal resistance with timer.

Table 2. Simulation results

Case	Energy Withdrawal from the System (kJ/day)					Energy Provided to the System (kJ/day)						
	Shower demand	Provided shower	% Not provided	Ambient loss	% Losses	Solar Heater	Electric Heater	Solar Fraction	R$/Month	% Gain 1*	% Gain 2*	% Gain 3*
Boiler	33.520	33.517	0,01%	-1.025	2,97%	0	34.547	0,00%	R$ 143,95	0,00%	-	-
Base Case - Internal resistance without Timer	33.520	33.520	0,00%	-6.189	15,58%	30214	9.512	76,06%	R$ 39,63	72,47%	0,00%	-
Base Case - Internal resistance with Timer	33.520	33.517	0,01%	-5.622	14,36%	34326	4.828	87,67%	R$ 20,12	86,02%	49,24%	0,00%
Case 01 - Internal resistance with Timer	33.520	33.516	0,01%	-7.913	19,10%	39505	1.941	95,32%	R$ 8,09	94,38%	79,60%	59,80%
Case 02 - Internal resistance with Timer	33.520	33.515	0,01%	-9.334	21,78%	41229	1.637	96,18%	R$ 6,82	95,26%	82,79%	66,10%
Base Case – Pass through heater	33.520	33.520	0,00%	-4.994	12,97%	37289	1.239	96,78%	R$ 5,16	96,41%	86,98%	74,34%
Case 01 - Pass through heater	33.520	33.520	0,00%	-7.519	18,32%	40285	771	98,12%	R$ 3,21	97,77%	91,90%	84,03%
Case 02 - Pass through heater	33.520	33.520	0,00%	-8.932	21,04%	41818	651	98,47%	R$ 2,71	98,12%	93,15%	86,51%
Case 01 – Simplified	33.520	33.517	0,01%	-9.209	21,55%	40741	2.002	95,32%	R$ 8,34	94,20%	78,95%	58,53%
Base Case - Adapted - 100 L	33.520	33.517	0,01%	-10.375	23,64%	42016	1.901	95,67%	R$ 7,92	94,50%	80,02%	60,63%

6. CONCLUSIONS AND SUGGESTIONS

It can be concluded, by the results presented, that although dividing a tank into two or more smaller tanks increase the thermal losses, it also enhances the collector gains. But these increases do not occur at the same rate, so there is an optimum number of tanks where the proportion of gains is greater than the losses.

Another important issue is verified in the results improvement when using the timer function, restricting the hours of the internal resistance is on. Even more significant improvements are observed when the internal resistance is disabled to for use of the pass through heater. Auxiliary heating, when internal to the tank, is not merely supplemental, but is also a concurrent to solar heating. Every time the internal resistance provides energy, it increases the water's temperature which will also go through the collectors, and as already seen, a higher temperature reduces the efficiency of solar collectors. The higher the injection of heat energy of electrical source inside the tank, lower the system's ability to absorb solar energy.

Finally, it can be concluded that, in cases where the S.H.S have two tanks, it is preferable to use the simplified version (version where only the tank B is connected to collectors). The results are almost identical to those cases in which both tanks are connected. Also, simplified version don't need electrovalvules to control the connections between tanks and collectors, so it has installation, operation and maintenance less complex. It should be noted that much more meaningful than a larger system stratification (increasing the number of tanks) is more beneficial to separate the solar energy supply from the electric supply, by isolating the electrical supply in the tank A and the solar in tank B, or else removing the internal resistance of the tank to use a pass through heater.

The results suggest that for designing a new S.H.S, it's preferable the use of the pass through heater instead of internal tank resistance. However, this equipment requires specific electrical installations that many houses are not prepared for, since their power is greater than 10 kW, demanding higher installation costs. It then becomes more interesting a S.H.S with two tanks A and B, being A the smallest in volume than B and with internal electric resistance, and B being the only tank connected to collectors. As the internal resistance usually have power of 3 kW, usually the electric installation is simpler, reducing its installation cost.

It was also verified that, in order to improve the performance of a S.H.S. already installed, you can add a new reservoir of lower volume between the existing tank and the consumption, disabling the internal resistance of the old tank and using only the internal resistance of the new tank, taking advantage of the existing electrical installations.

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8. RESPONSIBILITY NOTICE

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