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Technical-economical evaluation of a solar water heater with vacuum tubes collector, used in a rural area in Paraná, Brazil

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Solar radiation is a source of energy that can be used directly by residences and industries. In this work, the efficiency of a solar collector type all-glass installed in a rural area in Paraná, Brazil, in the winter period, was evaluated. Two daily showers were simulated in three different scenarios, to measure additional electrical consumption used to boost the heating of water. In the first scenario, the consumption was evaluated leaving the auxiliary heating system connected the entire day and, in the second, only in the afternoon period. This auxiliary heating system, controlled by a thermostat, was only connected when the temperature of the water in the boiler stayed below 40°C. In the third scenario, the auxiliary heating system was disconnected and the heating of the water occurred solely due to the solar heating system. These scenarios were compared with the use of the solar heating system together with an electric shower and with an electric shower alone. It was verified that the mean efficiency of the solar collector in the evaluated period was 51%. The electric shower, when used in conjunction with the solar heater, consumes 6.5 times less electrical energy than when used alone (192.55 kWh and 1240.34 kWh, respectively).

Key words: Renewable energy, vacuum solar collector, solar water heater.

INTRODUCTION

In 2013, the Brazilian electrical consumption per residency was of 124.858 GWh, which represented 27% of the country’s consumption (Brasil, 2014). Of these, 24% were directed to the electric shower of the residency, in other words, 30.000 GWh were intended for the heating of water (Penereiro et al., 2010).

According to Mogawer and Souza (2004), almost all this energy is used during peak hours (between 18 h and 20 h), overloading the electrical system. This demand represents about 12.8% of the total need in this period, which corresponds to approximately 6.800 MW of installed power, almost half of the current 14.000 MW Itaipu Hydroelectric Plant's capacity, Paraná.

Use of conventional sources of energy to meet this

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Figure 1. Solar collector with vacuum tubes type all-glass.

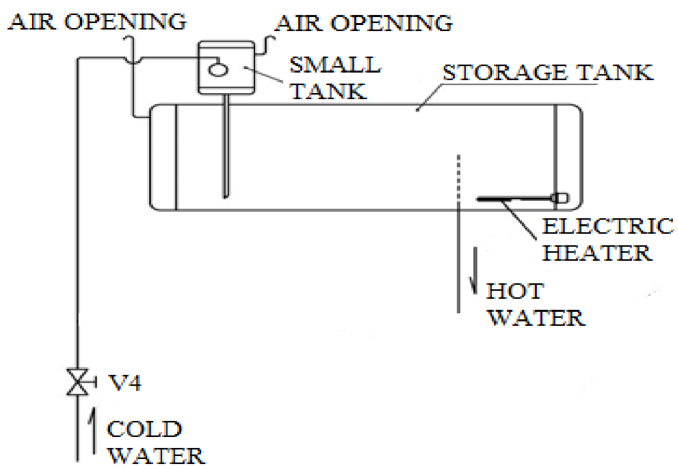


Figure 2. Diagram of thermal reservoir of solar heater. Source: EXXA Solar (2009).

demand causes ecological problems and reduction in supply. A possible solution though is the use of alternative sources of energy (Kousksou et al., 2014). The use of solar energy has intensified in Brazil, taking advantage of its high solar radiation index (Aldabó, 2002).

The South of Brazil has a high usage of electric showers, which means, despite being the region with the smallest solar radiation of Brazil, can contribute with the use of solar heaters, following the example of European countries, that intensely use this technology, despite its solar radiation being a little lower (Pereira et al., 2006).

One of the biggest implementation of this technology is established in India, in an industrial egg processing plant, where 1280 panels heat 110.000 L of water to 85°C, equivalent to a 1 MW power station, generating 78% saving of fuel oil (Nagaraju et al., 1999). Thus, the substitution of conventional heating by solar may be a great economic alternative, in order to reduce peak hour's electrical consumption in the country (Prado, 2007; Naspolini and Rüther, 2011).

Nevertheless, the high initial cost of this technology can be a negative factor. Moreover, the auxiliary heating for days with low solar radiation can use up a lot of energy, turning the system unviable. The project directly influences the efficiency (Wang et al., 2015), thus, diverse forms of this technology have arrived in the country in the last years, including, the solar water heater with vacuum tube collectors. These tubes have higher efficiency as they make more use of solar radiation, independent of the angle of occurrence of the same (Goerck, 2008). This fact is very important, because the dependence of the angle may be very significant in other systems (Elhab et al., 2012).

The aim of this work was to calculate the efficiency of a solar heating system with vacuum tubes collector, and verify its economic viability using three distinct scenarios.

MATERIALS AND METHODS

This experiment took place during the period of 1st June to 31st August 2013, at State University of Western Paraná, situated in the city of Cascavel, Latitude 24°59' South, Longitude 58°23' west and means altitude of 785 m. In this location, a vacuum tube solar water heater was connected to a boiler EXXA brand, with 1.6 x 2.6 m dimensions. It was installed facing north, with a 28° inclination. The collector shown in Figure 1, of the type all glass is made up of 20 glass tubes, directly connected to thermal reservoir.

This reservoir has 170 L of capacity and an electrical heating system of 1500 W. Above the thermal reservoir there is a small feeder tank, with a floating ball-cock. The water from this tank flows through an internal tube to a boiler, while the water heated by the collector rises by convection to the top of the reservoir. The design of the hydraulic system is highlighted in Figure 2.

Equipment used for measuring and recording data

Datalogger

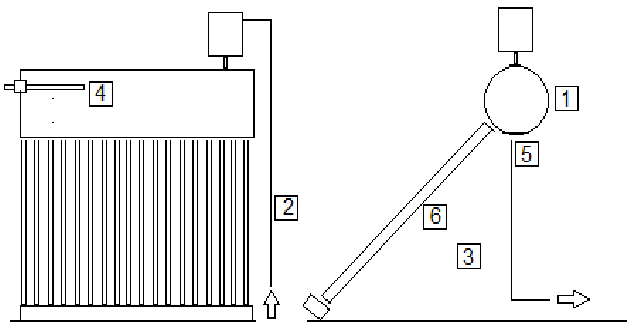
Data regarding temperature, electric current and solar radiation was collected every 10 s using a datalogger CR1 1000 model, of Campbell Scientific manufacture, which has 8 analogue inputs. A 12 V output was also used to power a contact that activates the electrical heating system of boiler when necessary, based on temperature of the water.

Thermocouple

Six thermocouples type J were used to measure temperature, interconnected to the data measuring system. Such thermocouples have mineral insulation with metal protection, allowing for them to be installed and used in direct contact with water. The diagram in Figure 3 shows the location of the temperature sensors in heater.

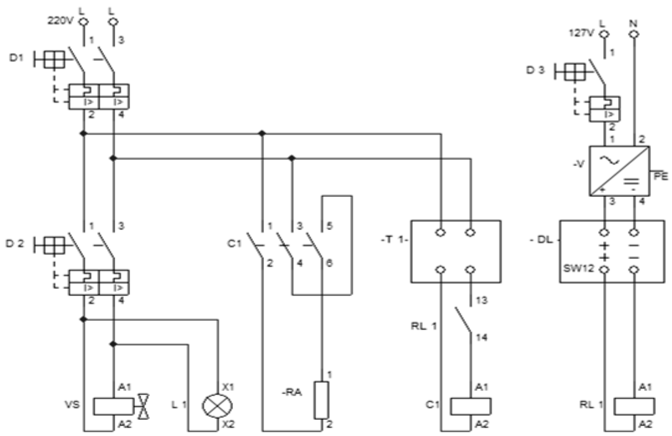
Pyranometer

The measuring of solar radiation was completed using a pyrometer of Kipp & Zonen manufacture; model CMP3, with sensitivity of 15.0 $\mu V\ W^{-1}\ m^{-2}$. It was installed close to the heater, and the values of



1 - Boiler's external sensor
2 - Cold water entry sensor
3 - Ambient temperature sensor
4 - Boiler's internal sensor
5 - Hot water exit sensor
6 - Collector's external sensor

Figure 3. Diagram of location of temperature sensors.



D1, D2 – Double pole fuse
D3 – Single pole fuse
VS - Solenoid valve
L1 – Indicator light
C1 – Triple pole contactor
SW 12 - 12 VCC exit controlled by internal temperature of boiler
RA - Heating element
T1 – Timer
RL 1 - Relay 12 VCC
V – Datalogger power supply
DL – Datalogger

Figure 4. Electric diagram of power supply of auxiliary heating system and solenoid valve.

radiation measured were stored by the datalogger every 10 s.

Devices used for control and signaling

Solenoid valve

The hot water exit was controlled by a double solenoid valve; model EVA-03 of EMICOL manufacture, controlled by a remote switch. It has 3/4”connection and 220 V power.

Timer, relay and contact

A timer was installed to control the running of the auxiliary heating system of the boiler, of Logica 600 model and Kienzle manufacture, like a relay and a contact controlled by 12V from a datalogger.

Installation diagram

The electrical installation to power the auxiliary heating system and the solenoid valve followed NBR 5410/2004 standards - Electrical installation of low voltage (ABNT, 2004). Its electrical connections are indicated in Figure 4.

Methodology

Daily consumption of hot waters

The daily consumption of hot water during the entire period of the experiment was set to two showers occurring at the end of the afternoon, with temperature of water being around 40°C, and 60 L of volume per shower. As temperatures of hot and cold water vary daily, a mixer of water was simulated for this occurrence. The output of hot water eliminated through the solenoid valve was measured, obtaining the constant amount of 6 L min^{-1}. Thus, through the time variation operating time of this valve, it was possible to obtain the volume of hot water that would be necessarily added to the cold water, to obtain a mixture of water of 40°C temperature. This timing was calculated using Equation 1, developed by the author. The values of hot and cold water used in the equation were obtained directly from recorded measurements in datalogger, moments before each simulation.

$$t = \frac{2400 - 60\,T_f}{Q\,(T_q - T_f)} \quad (1)$$

where:
t - time solenoid valve open (min);
T_f - temperature of cold water (°C);
T_q - temperature of hot water (°C);
Q - volume of hot water output (6 L min^{-1}).

Scenarios for the use of solar heater system

The datalogger was programmed to turn on the auxiliary heating system of the boiler when its temperature fell below 40°C. There were three scenarios for the installed system:
Scenario I - With the timer on "ON position”, the auxiliary heating system stays connected and can be turned on any hour of the day, as needed to heat water.
Scenario II – The timer set in "automatic position” allows connection to auxiliary resistance between 12:00 and 18:00 hours only.
Scenario III – The timer on "OFF position” does not connect to the auxiliary heater at any time and the heating occurs only as a function of solar radiation.
The setting of the timer was changed at the end of each day, to sequence through the scenarios. Other than the scenarios studied, two simulations using an electric shower were used:
Simulation I – The shower is connected to the solar heating system in scenario III, and is used, when necessary, to boost temperature of "preheated" water.
Simulation II – The electric shower works alone, without any solar heating system to preheat the water.

Processing of data

Efficiency of solar heater calculation

The mean efficiency of the solar heating system was calculated from data gathered between 6:00 and 18:00 h each day, and is given in Equation 2 (Duffie and Beckman, 2006).

$$\eta = \frac{Q}{A_c \sum S + Q_a)} 100\ \% \quad (2)$$

where:
η - efficiency of system (%);
A_c - area of solar collector (1,61 m²);
S - incidence solar radiation (Wh m^{-2});
Q_a - auxiliary electrical energy (Wh);
Q - energy needed to heat water (Wh).
The energy needed to heat the water (Q), was calculated using Equation 3 (Duffie and Beckman, 2006).

$$Q = m\ C_p\ (T_1 - T_2) \quad (3)$$

where:
m - mass of water in thermal reservoir (kg);
C_p - thermal coefficient of water (1.1628 Wh kg^{-1} $°C^{-1}$);
T_1 - maximum temperature of reservoir at the end of the period (°C);
T_2 - minimum temperature of reservoir at the beginning of the period (°C).

The area of the collector was calculated using Equation 4:

$$A_c = N\ D\ L \quad (4)$$

where:
A_c - area of collector (m^2);
N - number of tubes in collector (20);
D - diameter of internal tube (47x 10^{-3} m);
L - superficial length of absorbing surface of inner tube (1.713 m).

Calculation of energy balance of the system

The energy balance of the system was calculated using Equation 5, so that energy gained were due to incidence of solar radiation and the functioning of the auxiliary electric heating; and the losses of energy were due to losses through the walls of the boiler and replacement of cold water (Duffie and Beckman, 2006).

$$m\ C_p\ (T_s^+ - T_s^-) = Q_s\ \Delta t + Q_a\ \Delta t - (UA)_s\ \Delta t\ (T_s^- - T_a) - m_c\ C_p\ (T_c - T_f) \quad (5)$$

where:
m_c - mass of water consumed (kg);
T_s^+ - water temperature afterwards (ºC);
T_s^- - water temperature beforehand (ºC);
T_a - ambient temperature (ºC);
T_c - temperature of water used (ºC);
T_f - temperature of cold water (ºC);
Δt - time interval considered in simulation (1 h);
Q_s - solar energy transferred to fluid (Wh);
Q_a - electric energy transmitted to fluid (Wh);
U - global coefficient of heat transfer between reservoir and the air (W m^{-2} $ºC^{-1}$);
A - external area of thermal reservoir (m²).

The term Q_s expresses the useful thermal energy produced in the solar collector, and can be expressed in accordance with Equation 6.

$$Q_s = A_c\ F_R\ [S - U_L(T_{pm} - T_a)] \quad (6)$$

where:
F_R - extraction factor of heat of solar collector (adimensional)
S - incidence of solar radiation (W m^{-2})
U_L - global heat transfer coefficient between collector and the air (W m^{-2} $ºC^{-1}$)
T_{pm} - surface temperature of heat absorber of collector (ºC).
Equations 5 and 6 were used to obtain the coefficients U and F_R, from the simulations made with real data collected in field research.

RESULTS AND DISCUSSION

Analysis of efficiency of solar heater

The efficiency of the collector was calculated using Equation 2, resulting in a mean value of 51%. Goerck (2008) evaluated a solar water heater with vacuum tubes collector with heat pipe in the region of Taquari (Rio Grande do Sul), estimating its efficiency to 43%.

Extraction factor of the collector (F_R) and thermal coefficient of boiler (U)

The factors UA and F_R were determined from Equation 5, using simulations performed with the Matlab 2012 software. The optimum value obtained for the F_R (extraction factor of collector) was of 0.62 with values ranging between 0.50 and 1.0 in increments of 0.01. For UA (product of thermal coefficient of the boiler by its external area), the optimum value was of 3.5, with values varying from 2 to 10, in increments of 0.5. Sabs (2009) has found the coefficient of 3.878 for various reservoirs exposed to open air. The optimum values obtained were the ones that presented the best fit of temperature measured data and of solar radiation to equation of energy balance.

Functioning of heater evaluation

Table 1 compares the performance and consumption of energy from the heater in the three scenarios. The third column of the table details the days in which the temperature remained above 40°C. In scenario 1, the consumption of electrical energy measured in 46 days,

Table 1. Comparison of consumption of electrical energy between the three scenarios reviewed.

Operation of auxiliary heating scenario	Total (days)	Temperature of boiler above 40 °C (days)	Measured consumption (kWh)	Daily mean (kWh)
Scenario 1	46	46	436	9.48
Scenario 2	15	15	38.9	2.59
Scenario 3	28	14	0	0

Table 2. Daily consumption of electrical energy for the heating of water for showering.

Days in Scenario 3 below desirable temperatures	Temperature of water (°C)		Addition of energy (kWh)	
	Preheated	Cold (Natural)	With preheated water	With cold water
11/06/2012	37.78	21.96	0.31	2.51
20/06/2012	33.55	20.55	0.90	2.71
05/07/2012	37.27	22.17	0.38	2.48
08/07/2012	37.50	16.65	0.35	3.25
10/07/2012	30.29	18.59	1.35	2.98
13/07/2012	36.14	16.13	0.54	3.33
17/07/2012	18.89	16.62	2.94	3.26
20/07/2012	37.60	15.27	0.33	3.45
23/07/2012	29.70	20.88	1.43	2.66
26/07/2012	23.96	22.00	2.24	2.51
29/07/2012	27.70	23.01	1.71	2.37
01/08/2012	35.83	20.77	0.58	2.68
16/08/2012	36.52	23.42	0.49	2.31
28/08/2012	25.96	19.31	1.96	2.88
Total (kWh)	-	-	15.51	39.38
Daily mean (kWh)	-	-	1.11	2.81

due to the operation of the auxiliary heating system, was of 436 kWh (average of 9.48 kWh day^{-1}). In the days in which the heater operated in Scenario 2, the temperature of the boiler also remained above 40°C at the end of the afternoon. The measured consumption of electrical energy was of 38.9 kW (mean of 2.59 kWh day^{-1}). It is noted that the insertion of the timer in the circuit in scenario 2, to limit the operation of the auxiliary heater only to the afternoon period, reduced in 72.68% the mean daily consumption in relation to scenario 1. In scenario 3, in 14 days (of a total of 28), the temperature of the boiler at 17 h was lower than the set temperature.

Evaluation of the use of solar collector as a preheater for an electric shower

The results obtained in Scenario 3 were used to make Table 2, which simulates the energy that would be consumed by an electric shower to heat water up to the required temperature for showers, from the preheated water by the solar heater, and from the natural water (cold). The results of the fourth and fifth column were calculated considering a water mass equal to 120 kg at 40°C (2 showers).

In the fourth column are the values calculated to complement the thermal energy needed to reach the set temperature of consumption from the temperature of water preheated by solar energy. This energy would be supplied by an electric shower with variable power that would consume a daily average of 1.11 kWh (Simulation I).

The last column shows calculated values of energy that would be consumed in the same days by a shower, also electrical, to raise the temperature of the cold water to 40°C (Simulation II). The daily mean consumption of 2.81 kWh of the shower would be, in this case, about, 1.5 times the consumption obtained when the preheated water with solar energy is used by the shower supply.

Of the five ways of operating the solar heater analyzed (Scenario I, II and III; Simulation I and II), the best result would be the one that meets the requirements of showers every day, with the least consumption of electrical energy.

Table 3. Determination of saving obtained using water preheated by solar energy to feed an electric shower.

Month	Daily mean global radiation (Wh $m^{-2}day^{-1}$) (Tiba and Fraidenraich, 2000)	Mean temperature of preheated water (°C)	Energy consumed by shower for preheated water to reach desired temperature (kWh)	Mean temp. of cold water (°C) (Lima, 2012)	Energy consumed by shower for cold water to reach desired temperature (kWh)
Jan	5556	52	0	19	90.84
Feb	5000	48	0	19	82.05
Mar	5000	47	0	18	95.16
Apr	3333	37	14.62	17	96.28
May	3333	33	31.90	13	116.79
Jun	2778	28	50.34	12	117.21
Jul	2778	28	50.34	12	121.12
Aug	3333	33	31.90	13	116.79
Sept	3889	37	13.46	14	108.84
Oct	4444	42	0	16	103.81
Nov	5556	50	0	17	96.28
Dez	6111	54	0	18	95.16
Annual consumption (kWh)	-	-	192.55	-	1240.34
Annual cost of consumed energy (US$)	-	-	36.90	-	237.73
Annual saving (US$)	-	-	200.83	-	-

Annual saving of combined use of electric shower with solar heater

Table 3 shows a simulation of annual saving obtained when using an electric shower of variable power to heat water from an initial temperature (cold or preheated by solar heater) up to the desired temperature for a shower (about 40°C). Figure 5 shows a comparison between the energy consumed by shower using preheated water, with the energy consumed by shower using cold water, to reach the desired temperature. These data were obtained from columns 4 and 6 of Table 3.

The simulation shown in Table 3 indicates an annual saving of US$ 200.83, obtained by reduction of consumption of electric energy of a shower fed with water preheated by solar energy (annual cost of US$ 36.90), when compared with a shower fed with cold water from supply network (annual cost of US$ 237.73). The cost of US$ 0.1916 per kWh of electrical energy is applied to consumers in residential category (COPEL, 2013).

The temperature of the preheated water, in the third column of the table, was estimated based on potential heating of solar collector when exposed to the mean monthly radiation in the West of Paraná (Pereira, 2002).

The values of additional energy, in the fourth column, are of thermal energy necessary for the water, already preheated by the solar collector, to reach 40°C. There is a greater need of extra electrical energy between May and August, because these months coincide with smaller values of ambient temperature and solar radiation. However, in the month of April, a lower radiation is compensated by higher ambient temperature, while in September the opposite occurs.

The table was created taking into account that the water stored is at ambient temperature. Therefore, the constant temperature of the cold water in the fifth column was considered equal to the lowest average ambient temperature registered in the city of Cascavel between 1972 and 2009 (Lima, 2012).

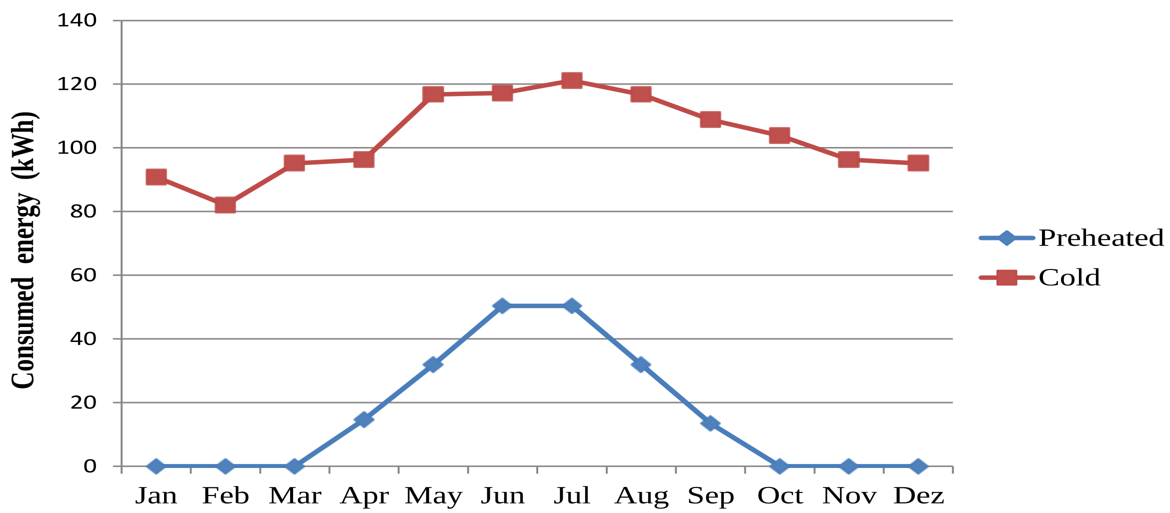


Figure 5. Comparison of the energy consumption between the preheated and cold water.

Table 5. Comparative economic analysis for the 5 options presented.

Options	Annual consumption of electrical energy (kWh)	Annual cost of electrical energy (US$)	Initial cost of equipment (US$)	Annual cost (US$)	Total annual cost (US$)	Pay back compared with simulation 2 (years)	Meets the requirements of hot water?
Scenario 1	2412.50	462.15	1141.25	117.51	579.65	(NA)	Yes
Scenario 2	238.28	45.65	1141.25	117.51	163.15	7.23	Yes
Scenario 3	0.00	0.00	1141.25	117.51	117.51	5.59	No
Simulation 1	192.55	36.89	1182.92	121.80	158.68	7.16	Yes
Simulation 2	1240.34	237.60	41.67	4.29	241.89	Reference	Yes

(NA)= Not applicable since payback is negative.

The values in the last column show the necessary energy for a shower to reach the set temperature for showering, when fed with cold water from supply network.

Economic analysis of investments

Table 4 shows data used to make financial analysis of investments. Table 5 presents a comparative economic analysis for the five options of heating water for showering. Analyzing Table 5, it can be noted that option "Scenario 1" has the highest annual cost (US$ 579.65), followed

Table 4. Outlay of financial analysis of investment.

Purchase cost of solar heater analyzed (US$)	974.58
Material and labour cost for installation of heater (US$)	166.67
Cost of electric shower (US$)	41.67
Cost of kWh (US$)	0.1916
Useful lifetime of heater considered (years)	15 years
Annual interest rate (%)	6.00

by option 'Simulation 2" (US$ 241.89). Option "Scenario 3" has the smallest annual cost; it however, does not meet the water temperature requirements in the coldest months. The options "Scenario 2" and "Simulation 1" are practically the same, since the latter has an annual cost a little less than the former. Column 4 shows return time of investment (*payback* completion), in accordance with Newnan et al., (2011).

CONCLUSIONS

The mean efficiency found for the model of solar heater in study was of 51%. Three scenarios with solar heater were evaluated and 2 simulations with an electric shower were made. In scenario 1, the daily average energy consumption was of 9.48 kWh (auxiliary heating system connected without time restriction). In scenario 2 (working hours of auxiliary heating system restricted to the afternoon period), the daily average consumption was of 2.59 kWh, in other words, 72.68% lower than the previous.

In scenario 3 (auxiliary heating system turned off), 14 of the 28 days that the heater functioned, the water temperature at the end of the afternoon was lower than set, which makes this form of operation unviable. Simulating the energy that would be necessary for an electric shower to boost the temperature of water in these 14 days in Scenario 3, a daily mean consumption of 1.11kWh can be observed (Simulation I) against 2.81kWh (Simulation II), which would have been used by the same shower, if it were directly fed with cold water from network supply.

The annual costs of these ways of operating were calculated and compared, revealing that simulation I presents smaller cost and is more interesting due to flexibility of operating times of hot water. Finally, it was established that the return of investment in the installation of a solar heater connected to an electric shower, for an interest rate of 6% per year, occurs in about 7 years, when compared with using an electric shower alone.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

ABNT (2004). NBR 5410- Instalações elétricas de baixa tensão. Rio de Janeiro.

Aldabó R (2002). Energia Solar. São Paulo. Artiliber Editora.

Brasil, Agência (2015). Consumo de energia elétrica cresceu 3.5% em 2013. Rio de Janeiro. 2014. Available at. < http://agenciabrasil.ebc.com.br/print/901884>. Accessed on Mar/25.

COPEL (2013). Taxas e tarifas. Available at .<copel.com/hpcopel/root/nivel2.jsp?endereco=%2Fhp copel%2Ftarifas%2Fpagcopel2.nsf%2Fverdocatual%2F23BF37E672 61209C0325748800 5939EB >, 2012.Accessed on Nov/22.

Duffie JA, Beckman WA (2006). Solar engineering of thermal processes. 3ª ed. New Jersey. Wiley.P. 928.

Elhab BR, Sobian K, Mat S (2012). Optimizing tilt angles and orientations of solar panels for Kuala Lumpu, Malaysia. Solar Energy Research Institute (SERI), Level 3. Malaysia.

EXXA SOLAR (2009). Sistema de aquecimento solar - tubos a vácuo. Manual de Instalação.

Goerck M (2008). Determinação do potencial energético de um coletor solar foto térmico na região do vale do Taquari – RS Brasil. Lajeado. Centro Universitário Univates. Dissertação (Mestrado em Ambiente e Desenvolvimento). P. 92.

Kousksou T, Bruel P, Jamil A, Rhafiki EI, Zeraouli Y (2014). Energy storage: Applications and challenges. Solar Energy Materials and Solar Cells. France.

Lima CB (2012). Análise da variação das temperaturas mínimas para Cascavel – PR. Revista Brasileira de Energias Renováveis, 1:1-21.

Mogawer T, Souza TM (2004). Sistema Solar de Aquecimento de Água para Residências Populares. In. V Encontro de Energia do Meio Rural. Campinas. Anais eletrônicos. Available at. <http://www.proceedings.scielo.br/scielo.php?pid=MSC00000000220 04000200050& script=sci_arttext&tlng=pt>. Accessed on Jan/03, 2013.

Nagaraju J, Garud SS, Kumar KA, Rao MR (1999). 1 MWth Industrial solar hot water system and its performance. Solar Energy. [S.l.], 66(6):491-497.

Naspolini HF, Rüther R (2011). The impacts of solar water heating in low-income households on the distribution utility's active, reactive and apparent power demands. Solar Energy. Federal University of Santa Catarina. Florianópolis, Santa Catarina.

Newnan D, Eschenbach T, Lavelle J (2011). Engineering Economics Analysis. 11ª edição. Oxford University Press.

Penereiro JC, Melo LP, Coradi TB (2010). Construção de um aquecedor solar de baixo custo sem cobertura: análise experimental da eficiência térmica para vários ensaios. Revista de ciência & tecnologia. Nova Iguaçu - Rio de Janeiro. 10:1 (Jun-2010). Gráfica Universitária.

Pereira AB (2002). Estimativa da radiação solar global diária em função do potencial de energia solar na superfície do solo. Scientia Agricola, 59(2):211-216, Apr./Jun.

Pereira EB, Martins FR, Abreu SL, Ruther R (2006). Atlas Brasileiro de Energia Solar. 1ª. ed. São José dos Campos. INPE.

Prado RTA (2007). Levantamento do estado da arte: Energia solar. Projeto tecnologias para construção habitacional mais sustentável. São Paulo Projeto FINEP 2386/04.

Sabs Commercial (Pty) Ltd (2013). Test report SANS 6211-1:2003.

Pretória. 2009. Available at http://kayema.co.za/sitefiles/wp-content/uploads/2010/01/Kayema-SANS-6211-1-Report-09S001b - Kayema-200lt-indirect-system.pdfhttp://kayema.co.za/sitefiles/wp-content/uploads/2010/01/ Kayema-SANS-6211-1-Report-09S001b-Kayema-200lt-indirect-system.pdf. Accessed on Jan/16.

Tiba C, Fraidenraich N (2000). Atlas Solarimétrico do Brasil. Grupo de Pesquisas em Fontes Alternativas de Energia, Departamento de Energia Nuclear. Recife - PE.

Wang H, Sivan VP, Mitchell A (2015). Highly efficient selective metamaterial absorber for high-temperature solar thermal energy harvesting. Solar Energy Materials and Solar Cells. School for Engineering of Matter, USA.