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ENERGY ANALYSIS OF A HYBRID SOLAR/GAS SYSTEM FOR WATER HEATING: A CASE STUDY

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Abstract. Solar water heating represents an environmentally clean technology, with an abundant, permanent and renewable energy source, which does not pollute or harm the ecosystem. The correct use of this type of system is translated into a significant reduction in electric energy consumption. This work was conceived due to the difficulties observed in the monitoring, operation and maintenance of a hybrid heating system (solar/gas) of water in a residential building in João Pessoa/PB in Brazil. To fix a problem of excessive pressure increase in hot- and cold-water pipes, the original design configuration (2013), in which the system recirculated the water from the building main plumb when the temperature falls to a certain value, was modified to a configuration where the water from the main plumb is diverted to the building cistern (2019, without recirculation). In addition to this modification, the auxiliary system heating fuel in the original project, which was LPG (liquefied petroleum gas), was replaced by natural gas (NG). The preliminary results, obtained via the *F-Chart* method, show that, as expected, the performance of the system has decreased, causing a higher consumption of hot water and gas (due to the higher demand and lower calorific value of NG in relation to LPG).

Keywords: solar energy, water heating, solar fraction.

1. INTRODUCTION

As an alternative to minimize reliance on fossil fuels, researchers have sought to increase use efficiency and reduce development/use costs of new energy sources. With the trend towards sustainable energy use, the development of technologies that use renewable energy has become a priority (Baddou, 2017).

Regarding solar water heating systems, Herranz (2009) designed and conducted a simplified economic analysis to determine their financial viability in a mixed solar/gas installation to anticipate the hot water demand of a residential building in Zaragoza. Based on technical standards of the European community, it employed the *F-Chart* method to evaluate the annual fraction that the solar source would be able to provide monthly and annually.

Hang *et al.* (2012) evaluated solar water heating systems for typical US residential buildings from energy, economic and environmental perspectives, including flat and evacuated solar collectors, two types of auxiliary systems (natural gas and electricity) and three different locations (Los Angeles, Atlanta and Chicago).

Medeiros *et al.* (2014) conducted a technical and economic feasibility analysis of a solar heating system with recirculation in the same residential building of this study. They showed that it operated with solar fraction between 48-88% and thermal efficiency between 47-73%. They also showed that all the economic parameters were attractive.

Mazarrón *et al.* (2016) analyzed the design, installation and evaluation of a solar water heating system with evacuated collectors and active circulation. The main objective was to determine the useful energy required as a function of the water temperature in the thermal tank that the system is capable of providing and, consequently, its profitability. The results show how the energy that is collected and delivered to the tank decreases with the increase of the required temperature due to the lower performance of the collector and the losses in the pipes. The annual efficiency of the system reached average values of 66%, 64%, 61%, 56% and 55% for the required temperatures of 40 °C, 50 °C, 60 °C, 70 °C and 80 °C.

Ghorab *et al.* (2017) carried out a detailed analysis and performance evaluation of a domestic solar hot water heating system, which used two solar collectors installed on the roof of a house, monitoring data from October/2014 to September/2015.

Aisa (2017) studied in detail the solar thermal energy storage system used for domestic water heating purposes in a typical isolated house in St. John, Newfoundland, Canada. Studies including experimental and simulation models were reviewed, helping to compare previous approaches to the current treatment of the problem. Furthermore, to establish the results of the study, a simulation model of solar thermal energy storage for domestic water use was created with the help of SAM software, as well as various MATLAB software parameters were also taken into consideration to establish the desired design of the system. At the end of the study, it is concluded that the operational performance of the system points to performance results that are significantly above the acceptable range, thus the system proposed in the study offers performance capabilities that rival the other system described in the paper.

Sadiq (2017) presented a cost-benefit analysis of SAS in the residential sector of Islamabad, Pakistan, pointing out that economic evaluation of SAS is an essential tool to conclude the feasibility of this system, and that it can increase public awareness about the benefits associated with its adoption. The results indicate that if SAS replaces electricity or natural gas for water heating, one can save € 430.95 and € 67.81 of energy cost per year per household, respectively.

Based on these references, and taking into account the need for a better characterization of the solar/gas heating system of a residential building located in João Pessoa/PB - Brazil, the present work presents a case study, extending the results obtained by Medeiros *et al.* (2014) and aims to show the effects of an operational change of the original design of the solar water heating system (SWHS), in addition to the replacement of the auxiliary heating system fuel [from liquefied petroleum gas (LPG) to natural gas (NG)].

2. PROJECT INFORMATION

2.1 Building characteristics

The SWHS under analysis, in operation since December 2010, is located in a residential building in the city of João Pessoa/PB in Brazil with 27 floors and 52 apartments, 2 per floor. It is estimated that four people inhabit each apartment. The building is located around the geographical coordinates: Latitude $\phi = -7,12^\circ$ ($7,12^\circ$ S); Longitude: $-34,83^\circ$ ($34,83^\circ$ W).

2.2 The solar water heating system

Figure 1 illustrates, schematically, the installation, including the capture of solar radiation by the solar collectors, the storage in two horizontal thermal reservoirs in series, the auxiliary system to complement the solar heating in periods of low solar insolation or high consumption, the water recirculation system of the main plumb (to ensure uniform temperature of the water between the floors) and the outlet for distribution. The deviation of the water from the plumb to the cistern is also illustrated in the figure.

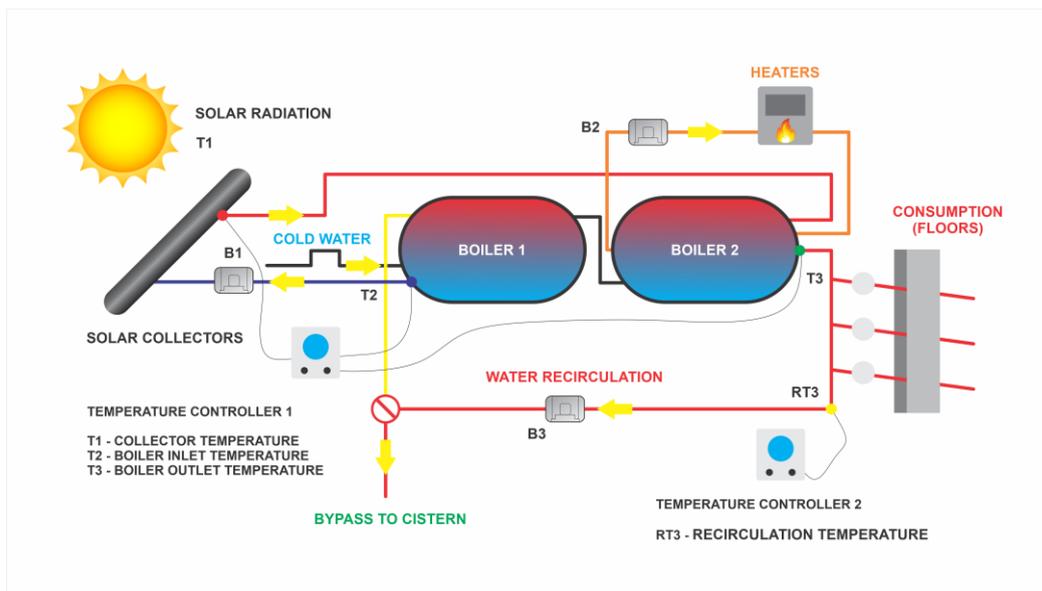


Figure 1. Schematic representation of the SAS studied (Adapted from Medeiros *et al.*, 2014).

The SWHS on the roof of the building under study consists of 47 flat collectors: a left arrangement with 26 collectors without shading and a right one that has 21 collectors, of which eight with partial shading (top side of the arrangement) at certain times and days of the year. The system originally had a water recirculation ring, which was activated to keep

the main plumb of the building at a minimum and uniform temperature between the various floors (35°C to 38 °C). With the occupation of the building, there began to appear an increase in pressure in the hot and cold-water pipes, and in 2015 the system underwent a modification: the recirculation was interrupted and the solution adopted was to redirect the flow of water from the plumb to the cistern when the temperature exceeds 38°C. All the redirected water volume has no specific use. In addition, due to the availability of NG from that year on, LPG, which was used as fuel for the auxiliary system, was replaced by NG.

2.3 Main system elements

The solar collector chosen in the original project was the flat plate type, one of the most used in buildings, brand TRANSSSEN, Porto Seguro v2.0 model, of 1.87 m². Its efficiency is $\eta_{coll_fab} = 0,56$ and the parameters of its efficiency curve are given by $F_R(\tau\alpha)_n = 0,741$ and $F_R U_L = 7,969$.

The total area of SWHS collectors is then 87.89 m². To meet the demand without great variations in hot water temperature, 02 TRANSSSEN horizontal accumulators, with a maximum capacity of 5,000 l each, in stainless steel, were used.

Regarding the auxiliary heating system, 04 LPG based heaters were installed, model REU-157 BRS GLP, brand RINNAI. With LPG, this model has a nominal power of 24.3 kW and a performance of 85%. With NG, its nominal power is 24 kW and efficiency of 86%.

The selected pumps are SCHNEIDER brand, bronze rotor, viton mechanical seal. Seven Aquadis ITRON rotary piston volumetric hydrometer are employed: 04 for water circulation through solar collectors, 02 for water circulation through the auxiliary heating system and 01 for water recirculation from the plumb.

3. SYSTEM SIZING AND ANALYSIS

Initially, the theoretical sizing of the system is performed and then the technical evaluation of the installed SWHS, based on actual water demand and temperature measurements, is accomplished. With this, it will be identified if the original project was well dimensioned, besides showing the thermal behavior of the installed system in operation.

3.1 Water demand

Theoretically, the daily demand for hot water (V_{H2O_day}) is evaluated taking into account the average flow rate of a shower (F_{shower}), your time and frequency of use (t_{use}, f_{use}) and the number of persons, $n_{persons}$.

$$V_{H2O_day} = F_{shower} \times t_{use} \times f_{use} \times n_{persons} \quad (1)$$

$$V_{H2O_month} = V_{H2O_day} \times n_{days_month} \quad (2)$$

The NBR 15569 standard (ABNT, 2008) suggests an average showering time of 10 min/person. An average shower flow rate of 3 l/min and 02 baths/day/person is adopted. Thus, considering the 52 apartments, with 04 people each, the total daily water consumption for the whole building (208 residents) will be $V_{H2O_day} = 3 \times 10 \times 2 \times 208 = 12.480$ l/day = 12,48 m³/day. Table 1 compares monthly energy demands based on estimated water demands and actual measurements for each month for the years 2012, 2013 and 2019.

Table 1. Theoretical and real water demand (2012, 2013 and 2019 water consumption data).

Water consumption data - V_{H2O_month}							
Month	n_{days_month}	Theoretical [m ³ /month]	Measurement [m ³ /month]				
			2012	2013	2019		
			V_{apart}	V_{apart}	V_{apart}	$V_{cistern}$	$V_{apart+cistern}$
Jan	31	386,88	228,31	197,95	260,9	191	451,9
Feb	28	349,44	215,26	197,91	325,8	245	570,8
Mar	31	386,88	273,11	196,1	190,1	101	291,1
Apr	30	374,4	223,5	219,69	252,8	173	425,8
May	31	386,88	226,7	228,56	338,6	224	562,6
Jun	30	374,4	248,92	234,1	288,3	262	550,3
Jul	31	386,88	305,59	287,15	375,9	290	665,9
Aug	31	386,88	385,59	306,85	312,9	324	636,9

Sep	30	374,4	290,71	337,88	376,7	284	660,7
Oct	31	386,88	273,9	245,46	295,2	340	635,2
Nov	30	374,4	253,72	270,2	231,3	323	554,3
Dec	31	386,88	186,71	245,31	312,8	198	510,8
<i>V_{H2O_ave}</i>	---	379,6	259,34	247,26	296,78	246,25	543,03
<i>V_{H2O_year}</i> - [m ³ /year]	---	4.555,20	3.112,02	2.967,16	3.561,30	2.955,00	6.516,30

3.2 Energy demand

The monthly energy demand can be evaluated from the energy balance in the SWHS boilers:

$$ED_{month} = V_{H_2O_{month}} \rho_{H_2O} c_{pH_2O} (T_{H_2O_{out}} - T_{H_2O_{in}}) \quad (3)$$

The water inlet temperature in boiler 1, $T_{H_2O_{in}}$, was adopted as the ambient air, minus 2 °C. The temperature of the water at the outlet of boiler 2, which will be mixed with the that in the boiler 1, was fixed at $T_{H_2O_{out}} = 52$ °C, the value normally imposed on control systems, and sufficient to maintain the average temperature in the reservoirs close to 45 °C.

Adopting the temperatures in Celsius and the water demand in (m³/month), the energy demands (MJ/month) are given by ($\rho_{H_2O} = 1.000$ kg/m³, $c_{pH_2O} = 4,184$ KJ/kg/°C):

$$ED_{month} = \frac{V_{H_2O_{month}} \times \rho_{H_2O} \times c_{pH_2O} \times (T_{H_2O_{out}} - T_{H_2O_{in}})}{1.000} \quad \left[\frac{MJ}{month} \right] \quad (4)$$

Table 2 compares the monthly energy demands based on estimated water volume and actual water measurements for each month. There is a high energy demand in 2019 due to the redirection of water from the main plumb to the cistern. It is important to note that this demand is not consumption-independent or fixed because, since the system is dynamic, when the consumption of the apartments grows, the effect of the water deviation from the cistern on the thermal demand also grows.

Table 2. Energy demands, theoretical and real (water consumption data 2012, 2013 and 2019).

ENERGY DEMANDS – ED _{month}										
Month	T _{H2O_out}	Theoretical		2012		2013		2019		
		T _{H2O_in}	ED _{month}							
	[°C]	[°C]	[MJ/month]	[°C]	[MJ/month]	[°C]	[MJ/month]	[°C]	[MJ/ month]	[MJ/ month]
Jan	52	25,5	42.896	25,5	25.314	26,2	21.368	26,4	27.945	48.403
Feb	52	25,6	38.598	25,6	23.777	26,6	21.033	26,1	35.306	61.855
Mar	52	26,1	41.924	26,1	29.596	26,9	20.594	26,3	20.441	31.302
Apr	52	25,1	42.139	25,9	24.407	25,9	23.991	26	27.501	46.320
May	52	24,6	44.353	25	25.610	25,3	25.533	25,9	36.976	61.437
Jun	52	23,7	44.332	23,7	29.474	24	27.425	23,9	33.896	64.699
Jul	52	23	46.942	23,4	36.568	23	34.842	23,4	44.981	79.683
Aug	52	23,2	46.619	23,2	46.463	23,7	36.333	23,7	37.050	75.414
Sep	52	24	43.862	24	34.057	24,2	39.301	24,4	43.501	76.297
Oct	52	24,8	44.029	24,8	31.171	25,4	27.318	25,1	33.225	71.492
Nov	52	25,5	41.512	25,7	27.919	25,5	29.959	26	25.162	60.299
Dec	52	26	42.086	26,1	20.233	26	26.686	26,2	33.766	55.139
<i>Average</i>	---	24,8	43.274	24,9	29.549	25,2	27.865	25,3	33.312	61.028
<i>ED_{year}</i>	---	---	519.291	---	354.589	---	334.382	---	399.748	732.340

3.3 Solar radiation

In order to define the size of the SWHS that meets, at least partially, the energy demand, an evaluation of the amount of solar energy available at the installation site of the system must be made. The monthly solar radiation evaluation (in the inclined plane of the collector, \bar{H}_T) follows the methodology described by Duffie and Beckman (2013), being obtained through the method of Liu and Jordan (1960), which is used with good precision for surface azimuthal angles < 30°.

Beyond irradiation ($H: J/m^2$), irradiance information is required ($G: W/m^2$), the energetic power, which takes into account the average number of hours of sunshine during a given day, $h_{sunshine}$. For more details on how to evaluate $h_{sunshine}$, one should consult Silva Júnior (2020).

$$\bar{G}_T = \frac{10^6 \times \bar{H}_T [MJ/m^2/day]}{h_{sunshine} \times 3.600 [s/hour]} [W/m^2/day] \quad (5)$$

The monthly radiation data for the studied site in the inclined plane of the collectors are illustrated in Table 3. The irradiance was evaluated by taking the monthly historical values of hours of sunshine obtained from “Atlas Solarimétrico do Brasil” (2000) and the database from INMET (2020) for each year.

Table 3. Average radiation data for the studied location, $\phi = -7, 12^\circ$; $\beta = 17^\circ$

Month	$h_{sunshine}$	\bar{H}_T	\bar{G}_T
	[h/day]	[MJ/m ² /day]	[W/m ² /day]
Jan	11,5	17,4	420,55
Feb	11,7	19,24	457,04
Mar	11,9	19,48	453,13
Apr	11,8	18,86	442,4
May	11,7	20,05	477,03
Jun	11,6	17,19	411,99
Jul	11,6	18,2	434,76
Aug	11,8	20,75	489,66
Sep	12,0	20,63	479,06
Oct	11,8	21,86	515,77
Nov	11,5	21,33	513,19
Dec	11,4	19,99	485,74
Avarage	11,7	19,58	465,03

Although the auxiliary heating system is designed to complement the thermal energy demand, its dimensioning must take into account the possibility of all heating demand being met by it alone, in case of failure of the solar system. For the selection of heaters, the energy demand must be specified in terms of power, so that the time of use to meet the demand must be considered, $h_{warming}$.

In the present work, it was considered that, in case of SWHS failure, the heater provides all the daily thermal demand in at most 5 hours. This value is an estimate for the worst operational scenario of the system, when the water must be heated from the SWHS boilers inlet temperature to the outlet temperature. The number of heaters is calculated by the rounded-up ratio between the highest monthly power demanded and the power of a heater (*CEILING* and *INT* are Excel functions). Therefore:

$$Pot_{heater_min} = MAX_{val} \left[\frac{DE_{month} [MJ/month] \times 10^3}{h_{warming} \times 3600 [s/hour] \times n_{days}} \right] [kW/month] \quad (6)$$

$$N_{heaters} = CEILING \left[0,5 + INT \left(\frac{Pot_{heater_min}}{Pot_{1heater}} \right) \right] \quad (7)$$

Table 4 shows the monthly power required and the highest heating power for each year. Based on this heating power, the number of heaters to meet the total daily demand in that time interval is showed in the last row. The results indicate that, for normal operation, 04 heaters would be required to meet it in the required time. However, in 2019, 06 heaters would be necessary. This behavior shows how harmful was the operation intervention to the SWHS.

Table 4. Monthly power required for the gas heaters.

Monthly power required – Pot_{heater} [kW/month]							
Month	n_{days}	h_{heater} [h/day]	Theoretical	2012	2013	2019	
						Apart.	Apart. + Cistern
Jan	31	5	76,87	45,37	38,29	50,08	86,74
Feb	28	5	76,58	47,18	41,73	70,32	122,73
Mar	31	5	75,13	53,04	36,91	36,63	56,1
Apr	30	5	78,03	45,2	44,43	50,93	85,78

May	31	5	79,48	45,9	45,76	66,27	110,1
Jun	30	5	82,1	54,58	50,79	62,77	119,81
Jul	31	5	84,13	65,3	62,44	80,61	142,8
Aug	31	5	83,55	83,27	65,11	66,4	135,15
Sep	30	5	81,23	63,07	72,78	80,56	141,29
Oct	31	5	78,9	55,86	48,96	59,54	128,12
Nov	30	5	76,87	51,7	55,48	46,6	111,66
Dec	31	5	75,42	36,26	47,82	60,51	98,82
Pot_{max}	---	---	84,13	83,27	72,78	80,61	142,8
N_{heaters}	---	---	4 (3,46 LPG) / (3,51 NG)	4 (3,43 LPG)	3 (3,00 LPG)	4 (3,36 NG)	6 (5,95 NG)

3.4 Hot Water Accumulators

The calculation of the hot water storage volume follows the ABNT NBR 15569 standard (2008), which guides that the boiler must have a volume \geq at 75% of the daily consumption volume:

$$V_{acc} = 0,75 \times V_{H2O_day} \quad (8)$$

$$V_{acc} = 9.360 \text{ l} = 9,36 \text{ m}^3 \quad (9)$$

The number of hot water storage tanks can be calculated by the rounded-up ratio between the calculated volume and the volume of a tank selected from some supplier (rounded up, to the nearest even number):

$$N_{acc} = CEILING \left[0,5 + INT \left(\frac{V_{acc}}{V_{1acc}} \right) \right] \quad (10)$$

$$N_{acc} = 2 \text{ accumulators} \quad \begin{cases} \text{Brand: TRANSSEN 5.000} \\ \text{Capacity: 5.000 l} \end{cases} \quad (11)$$

3.5 Solar fraction

In solar collectors dimensioning, the solar fraction, the ratio between the energy supplied by the solar source and the total energy demand, f , is the main design parameter, being normally employed in two ways:

(a) f is pre-established: the total area of the solar collector is calculated in function of the minimum specified fraction that meets the need for heating by the solar source;

(b) f is evaluated through methods such as *F-Chart*: from an estimated area of collectors (area of the previous method, or the roof of the building), the solar fraction is calculated to verify the feasibility of the project. If the fraction is smaller than an acceptable value, and there is an available area in the building, a new area is assumed, and the calculations redone until the minimum is met. This is the method employed in the present work.

In the *F-Chart* method, the main variable is the collector area, and the secondary variables are the storage capacity, the collector type, the collector load and size, and fluid flow. The solar fraction depends on two adimensional variables "X" and "Y", which take into account the specific thermal characteristics of each collector, the monthly heating load, the average daily solar radiation incident on the collector plane and the average daily ambient temperature. The empirical function describing this relationship is given by Duffie & Beckman (2013):

$$f = 1,029 \times Y - 0,065 \times X - 0,245 \times Y^2 + 0,0018 \times X^2 + 0,0215 \times Y^3 \quad (12)$$

Parameter X, dimensionless, represents the ratio between the monthly energy lost by the collector and the monthly heating load required, and is expressed by the following equation:

$$X = F_R U_L \times \frac{F_R'}{F_R} \times (T_{ref} - \bar{T}_{env}) \times \Delta t \times \frac{A_{coll}}{ED_{month}} \quad (13)$$

$F_R U_L$ is the heat loss removal factor of the collector [W/m²/°C], F_R'/F_R is the thermal correction factor [dimensionless]. T_{ref} is the reference temperature [100 °C]. \bar{T}_{env} is the average monthly environment temperature [°C]. Δt is the insolation time of the month, A_{coll} is an estimate of the total area of collectors to be installed [m²] and ED_{month} is the monthly heating demand [J/month].

The heat loss removal factor of the collector ($F_r U_L = 7,969$) is supplied by the manufacturer when the technical specifications of the selected collector are met. The thermal correction factor (F_R'/F_R) corrects the performance of the collector against the boiler. When the value of this factor is not provided, the value of 0,95 is adopted, as in the present work.

Parameter Y , also dimensionless, represents the ratio of total solar energy absorbed by the total heating load, or demand, during the same period. This variable is expressed by the following equation:

$$Y = F_R(\tau\alpha)_n \times \frac{F_R'}{F_R} \times \left[\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n} \right] \times \bar{H}_{T_month} \times \frac{A_{coll}}{ED_{month}} \quad (14)$$

$F_R(\tau\alpha)_n$ is the normal transmittance-absorbance product [dimensionless] and $(\overline{\tau\alpha})/(\tau\alpha)_n$ is the slope correction factor of the collector [dimensionless]. \bar{H}_{T_month} is the monthly average of the daily radiation in the plane of the collector [MJ/m²/month].

The product $F_R(\tau\alpha)_n = 0,741$ is also supplied by the collector manufacturer. The collector slope correction factor $(\overline{\tau\alpha})/(\tau\alpha)_n = \eta_{opt}$, when not specified, is generally estimated, and in the present work the value 0,96 is adopted.

Finally, after evaluating the solar fraction for each month, the annual solar fraction is easily evaluated as:

$$f_{annual} = \frac{\sum_{12} CE_{month}}{ED_{year}} = \frac{\sum_{12} f_{month} \times ED_{month}}{ED_{year}} \quad (15)$$

Table 5 presents the results for the expected solar fraction, monthly and annual, by the *F-Chart* method, using the installed area of the original project ($A_{coll} = 87.89 \text{ m}^2$) and the specific energy demands.

Considering the extra demand, due to the deviation of the volume of water from the main plumb to the cistern^(a), in the year 2019, the annual solar fraction is strongly reduced ($f = 40\%$), that is, the SWHS is not able to meet the energy demand in this situation, so the consumption of gas should be strongly accentuated, as, in fact, the measures have shown.

The results of the solar fraction for the years 2012 (68%) and 2013 (71%) indicate, on the other hand, that the SWHS would be oversized for the consumption profile of those years. Thus, the results of gas consumption for those years should be the lowest, if the hybrid SWHS and its control system were working properly. In red are highlighted the lowest monthly solar fractions.

Table 5. Solar fraction evaluated by the *F-Chart* Method.

Solar fraction – f															
$A_{coll} = A_{project} = 87,89 \text{ m}^2 - N_{coll} = 47$ collectors															
Month	Theoretical			2012			2013			2019					
	$ED_{month_theor.}$			ED_{month_2012}			ED_{month_2013}			ED_{month_2019}			$ED_{month_2019}^a$		
	X	Y	f	X	Y	f	X	Y	f	X	Y	f	X	Y	f
Jan	3,17	0,79	0,48	5,37	1,33	0,69	6,30	1,58	0,76	4,81	1,21	0,65	2,77	0,70	0,44
Feb	3,18	0,87	0,54	5,16	1,42	0,74	5,75	1,60	0,79	3,45	0,95	0,57	1,97	0,54	0,37
Mar	3,22	0,90	0,55	4,56	1,28	0,70	6,48	1,83	0,85	6,58	1,85	0,85	4,3	1,21	0,68
Apr	3,14	0,84	0,52	5,36	1,45	0,75	5,46	1,47	0,75	4,75	1,29	0,70	2,82	0,76	0,48
May	3,10	0,88	0,54	5,35	1,52	0,78	5,34	1,52	0,78	3,66	1,05	0,62	2,20	0,63	0,42
Jun	3,04	0,73	0,45	4,58	1,09	0,60	4,90	1,18	0,63	3,97	0,95	0,55	2,08	0,50	0,33
Jul	3,00	0,75	0,47	3,83	0,96	0,56	4,04	1,01	0,58	3,11	0,78	0,48	1,76	0,44	0,30
Aug	3,01	0,86	0,54	3,02	0,87	0,54	3,84	1,11	0,65	3,76	1,09	0,64	1,85	0,53	0,37
Sep	3,06	0,88	0,55	3,94	1,14	0,66	3,41	0,98	0,60	3,07	0,89	0,55	1,75	0,51	0,35
Oct	3,12	0,96	0,60	4,41	1,36	0,75	4,99	1,55	0,81	4,12	1,28	0,72	1,91	0,59	0,41
Nov	3,17	0,96	0,60	4,70	1,43	0,77	4,39	1,34	0,74	5,19	1,59	0,81	2,17	0,66	0,45
Dec	3,21	0,92	0,57	6,67	1,92	0,87	5,06	1,45	0,76	3,99	1,15	0,66	2,44	0,70	0,46
f_{annual}	---	---	0,53	---	---	0,68	---	---	0,71	---	---	0,63	---	---	0,40

4. CONCLUSIONS

In general, the energy analysis developed for a hybrid heating system, solar/gas, installed in a building in the city of João Pessoa/PB, Brazil, showed that the *F-Chart* method is an interesting calculation tool for the sizing and evaluation of SWHS projects, detailing, month by month, its behavior.

For its optimized application, however, water consumption information and data from the manufacturer of solar system components (as informed in the present work) are fundamental for the continuous evaluation of the heating system.

The year 2019 showed high consumption rates if compared to the biennium 2012/2013. As previously mentioned, there were two reasons for this increase: the first was the measure taken to solve the problem of internal pressure in the pipes, and the second was the increase in occupancy in the apartments. Thus, it was observed that both gas consumption and the amount of water diverted to the cistern were higher in 2019.

Specifically, by the analysis of the results, the technical solution adopted to solve the problem of pressure elevation in the solar system tubes was not adequate, so that a more in-depth study of it is recommended and the search for a more adequate solution that makes the heating system operate in a functional way again.

5. REFERENCES

- Aisa, A. M. (2017). Modeling and simulation of solar water heating system with Thermal storage. *Master's Thesis. Faculty of Engineering and Applied Science Memorial University of Newfoundland, Canada.*
- ABNT - Associação Brasileira de Normas Técnicas, (2008). NBR 15.569: Sistemas de aquecimento solar de água em circuito direto - Projeto e instalação (in portuguese), Rio de Janeiro.
- Atlas Solarimétrico do Brasil (2000). Banco de Dados Solarimétricos (in portuguese). Ed. Universitária da UFPE.
- Baddou, Y. (2017). Solar thermal systems for domestic water heating applications in residential buildings. Efficiency and economic viability analysis of monitored plants. *Master's Thesis UEMF-Morocco/UPC-Barcelona-Spain.*
- Duffie, J.A. and Beckman, W.A., (2013). *Solar Engineering of Thermal Processes.* Ed. John Wiley & Sons, New York.
- Ghorab, M.; Entchev, E. and Yang, L. (2017). Inclusive analysis and performance evaluation of solar domestic hot water system (a case study). *Alexandria Engineering Journal.*
- Hang, Y.; Qu, M. and Zhao, F. (2012). Economic and environmental life cycle analysis of solar hot water systems in the United States. *Energy and Buildings. Vol. 45, pp.181-188.*
- Herranz, D. S. (2009). Design of a solar water heating system in a residential building. *Master's Thesis. University of Gavle.*
- INMET- Instituto Nacional de Meteorologia. (2020). *BDMEP: Banco de Dados Meteorológicos para Ensino e Pesquisa* (in portuguese). Available at: <http://www.inmet.gov.br>. (Visit: 15/05/2020)
- Liu B.Y.H. and Jordan R.C. (1960). The Interrelationship and Characteristic Distribution of Direct, Diffuse e Total Solar Radiation. *Solar Energy. Vol. 4 (3), 1-19.*
- Mazarrón, F. R.; Porrás-prieto, C. J.; García, J. L.; Benavente, R. M. (2016). Feasibility of active solar water heating systems with evacuated tube collector at different operational water temperatures. *Energy Conversion and Management. Vol. 113, pp. 16–26.*
- Medeiros, J.M., Félix W.M., Medeiros M.J. and Braga A.H.G. (2014). Analysis of a solar water heating system in a residential building. *VIII National Congress of Mechanical Engineering - Uberlândia*
- Sadiq, M. (2017). Solar water heating system for residential consumers of Islamabad, Pakistan: A cost benefit analysis. *Journal of Cleaner Production. Vol. 172. P. 2443-2453.*
- Silva Júnior, O.E. (2020). Energy and economic analysis of a hybrid solar/gas system for water heating in a building in João Pessoa. *Master's Thesis (in portuguese). PPPGER/CEAR. Federal University of Paraíba, João Pessoa.*

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