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Following the balloon temperature of a solar heater installed in Oran, Algeria

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ABSTRACT

The energy consumed for domestic hot water needs is constantly increasing. The use of solar energy can contribute to a share in the energy mix. The study concerns installing an individual solar water heater with forced circulation for the needs of an average family established in the climate of Oran in Algeria. The energy approach used compares the balance of inputs and outputs and the accumulation inside the balloon, which made it possible to present mathematical formulations to determine powers and temperatures. An hourly calculation for a 24-hour day of the different parameters was made, choosing a month of each season. The temperature inside the balloon was monitored, indicating that it can reach peaks of over 50°C without the addition of auxiliary energy; performance results show solar coverage can drop from 18% in January to 66% in July.

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1. INTRODUCTION

The increase in Algeria of the demand for energy for domestic needs follows an ascending curve, added to this a population in clear progression; households consume a significant part of natural gas in cooking and heating equipment. Domestic hot water occupies a relatively high share in this consumption. The use of solar energy in the preparation of domestic hot water can provide part of this energy, knowing that Algeria has a large solar deposit and a very long period of sunshine. Solar water heaters are a solution because of their technical feasibility at a low temperature and their economic feasibility at low cost [1, 2].

The search for solutions to take advantage of renewable energy has always been a challenge, research is carried out to find answers in small hydroelectric installations [3], or in control systems for wind turbines [4], the coupling of two types of energies and their storage has been studied Ebrahim et al. [5, 6], autonomous solutions of photovoltaic systems have been developed by Rekioua et al. [7, 8].

Sahin et al. [9] explained the methods of producing energy from green energies and compared the energy sources. They discussed the issues of energy sources in Turkey and their uses, and new strategies are defined, and recommendations are formulated. Keskin et al. [10] highlighted the construction policies and procedures in Turkey, showing the global sustainability goals of buildings while improving their energy performance by reducing energy consumption and the effects of emissions. Greco et al. [11] compared with TRNSYS 16 software the energy performance of flat plate collectors and evacuated tube collectors applied to domestic water heating under different climatic zones. Khechekhouche et al. [12] studied a solar water heater installed in southern Algeria, calculated the stored water temperature, and assessed the influence of the parameters on the system. Benmenine et al. [13] made an experimental study in the region of Ouargla in Algeria of a solar water heater with a parabolic collector. They found that the installation is efficient for heating the sanitary water of a typical house. Pahlavan et al. [14] simulated with logicians TSOL and MeteoSun a solar water heater supplying a facility with domestic hot water; they observed the use of solar water heaters in 37 stations in Algeria.

Yettou et al. [15] experimented with a test bench for a solar water heater in Batna in Algeria; they designed an electronic card and developed software to manage data set, experimental results are discussed. Sahnoune et al. [16] made a comparative study of the thermal performances of solar water heaters between two Algerian sites, namely Algiers and Adrar; results are presented in the form of tables and graphs. Hakem et al. [17] studied the dimensioning of individual solar water heaters by a computer

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program based on a database of sensors and modelling of solar lighting in Algeria; the results are compared with data from two sites in Algeria. Burch et al. [18] diagnosed the gain of a solar water heater based on the energy balance of the tank and deduced the time derivative of the average temperature. The analyzes are integrated into a tool and validated by experimental measurements from the work of other authors. Mohammed et al. [19] simulated a solar water heater installation for 25 people using a forced circulation solar loop with a ten m² panel and a 600-litre storage tank; the performance of this equipments are tested with TRNSYS, the system analysis shows a maximum auxiliary energy requirement in January and February of around 1000 MJ / month.

Baki [20] has simulated the performance of an individual solar water heater for the needs of a family, in three regions in Algeria, the cities chosen have different climates. Baki et al. [21] simulated with the TRNSYS calculation code an individual solar water heater installed in Oran and followed the performance of the installation, which is composed of a two m² flat collector and a 300-litre tank, hot water consumption is estimated at 240 litres per day, additional electrical energy is added for the months when there is insufficient radiation, the simulation showed that during the hot months, substantial energy is saved and electrical energy is at its lowest. Lazreg et al. [22] studied the effects of parameters on the temperature stratification of a solar water heater balloon, Baki et al. [23] studied the performance of a solar water heater Individual with forced circulation for the needs of domestic hot water for an average family in Algeria, the results show that solar coverage can go from 7% in winter to 57% in summer.

This article studies the evolution of the temperature inside the balloon of a solar water heater used for domestic hot water needs. An analytical approach was made based on the energy balance of the inputs and the outputs and the accumulation inside the balloon, and modelling was deduced, which allowed the determination of the hourly temperature of the water in the balloon for a full day; these calculations were repeated for four months of the year, choosing one month in each season. The performances were calculated by comparing the sun's energy input versus the extra energy in the Oran region of Algeria.

2. DESCRIPTION OF THE STUDIED MODEL

The study concerns an individual solar water heater for the consumption of an average Algerian family made up of six people, a couple, and four children living in Oran's coastal climate.

2.1. Solar Loop

The individual solar water heater is for forced circulation; it is composed of a flat solar panel, and a storage tank, a set of pipes connects the two elements, and a circulation pump in a closed-loop, the supply of water to the city is done by the lower part and the recovery of hot water for sanitary needs by from the upper side, which is injected into the housing network, see Figure 1.

The flat solar panel captures the solar irradiation and heats the liquid in circulation; the solar loop ensures the heating of the water inside the tank thanks to a heat exchanger, an auxiliary hydraulic or electric energy is integrated to fill the deficit and provide heating at the threshold of 60 °C; a control system ensures that the pump is turned on when the panel outlet temperature is higher than the temperature at the bottom of the tank, the tank is fully insulated to minimize losses. The solar panel has a surface of 2 m² and is inclined at 45 ° to the horizontal and oriented to the south. The tank has a storage capacity of 300 liters.

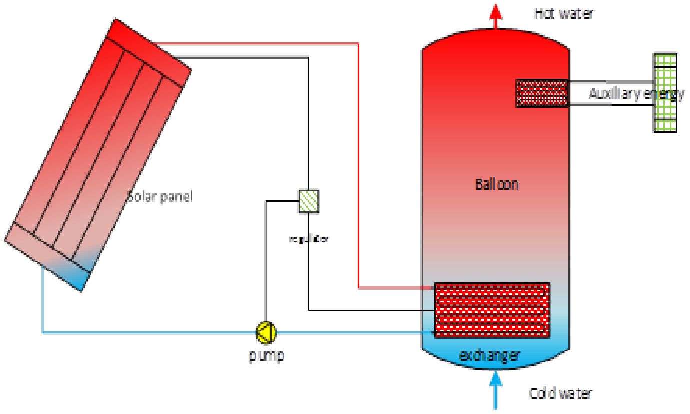

Fig. 1. Installation diagram [20].

2.2. Consumption Profile

The hot water needs are 240 liters per day for an average family of 6 people, the temperature of the hot water leaving the tank is 60°C, the fraction of the hourly consumption of hot water follows the profile shown in Figure 2; This profile shows the variability of the drawing, the consumption is zero between 2 AM and 5 AM, and it is maximum around 8 PM and 10 PM.

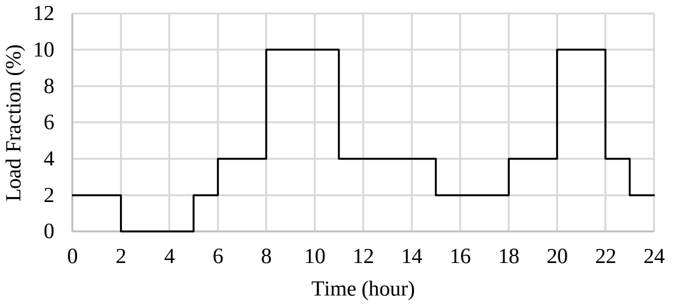

Fig. 2. Domestic hot water consumption daily profile [20].

2.3. Weather Data

The city of Oran is a coastal city in the south of the Mediterranean Sea, classified Csa (Koppen-Geiger); it is located in the northwest of Algeria, its climate is of the warm temperate type; the average annual temperature is 18.3°C, it can reach the limits of 2°C in January and 37°C in July. Figure 3 shows the variation of the monthly average temperature in January, April, July, and October. The curves have the same sinusoidal shape but offset between them, the temperature peaks are reached at around 4 PM, and the minimums before sunrise around 7 AM; Figure 4 shows the average monthly irradiation for the months January, April, July, and October; the curve is of the parabolic type, the irradiation increases, goes through a peak and then decreases; during hot months the duration of sunshine is longer, and the maximum value is more important than winter, going from a value of 500 to almost 1000 W/m² from January to July, the weather data are processed from Meteonorm file of the city of Oran.

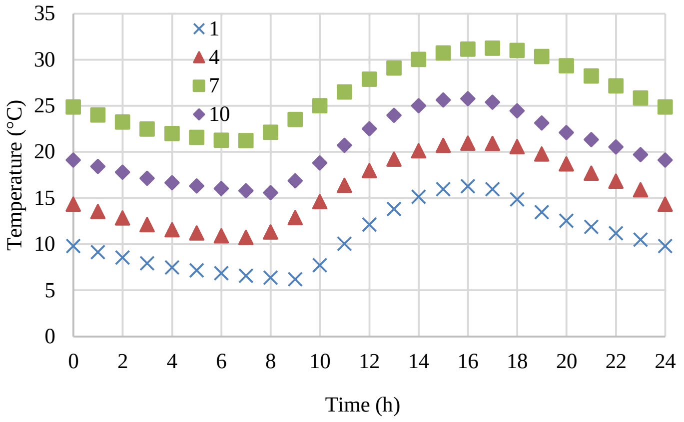

Fig. 3. Monthly average temperature.

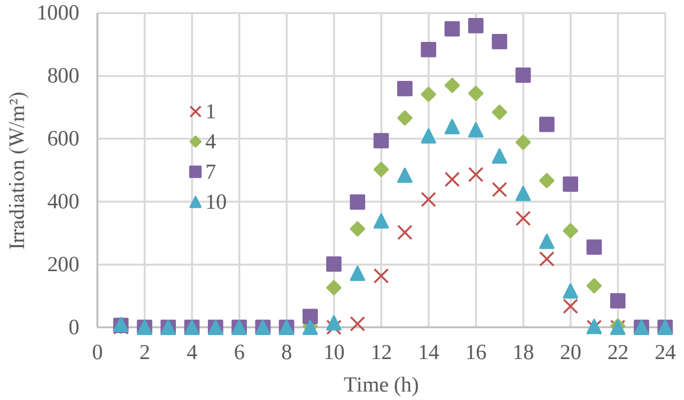

Fig. 4. Monthly average of irradiation

3. MATHEMATICAL FORMULATION

The energy balance of the tank highlights all the data of the installation. The tank absorbs the amount of heat coming from the solar panel, which via an exchanger will heat the water accumulated in the tank, the water cold enters below, and hot water exits from the high side for domestic consumption, the tank is wrapped in an insulating jacket to minimize losses; the injected auxiliary power heats the water in case of conditions unfavorable weather conditions. Figure 5 shows the energy approach to the balance of system inputs and outputs.

The energy balance at the level of the balloon gives in:

$$P_{useful} - P_{loss} - P_{cons} = P_{acc} \tag{1}$$

$P_{auseful}$ is the valuable power of the solar panel; it is determined from the characteristics of the collector and is worth:

$$P_{useful} = \eta . G . A_p \tag{2}$$

The yield is calculated by:

$$\eta = \eta_0 - a_0 \frac{T_{mean} - T_{ambient}}{G} - a_1 \frac{(T_{mean} - T_{ambient})^2}{G} \tag{3}$$

P_{loss} represents the losses through the walls of the tank; this value is determined by:

$$P_{loss} = U . S . (T_{in} - T_{out}) \tag{4}$$

The consumption of the hot water drawing is:

$$P_{cons} = \dot{m} cp (T_{in} - T_{water}) \tag{5}$$

And the accumulation at the level of the balloon:

$$P_{acc} = Mcp \frac{(T_{in+1} - T_{in})}{\Delta t} \tag{6}$$

The resolution of these equations will allow the determination of the average temperature inside the balloon T_{in+1} at time $t + 1h$, knowing all the parameters at time t; the calculation makes over a 24-hour day period with a time step of 1 hour, and repeats for January, April, July, and October.

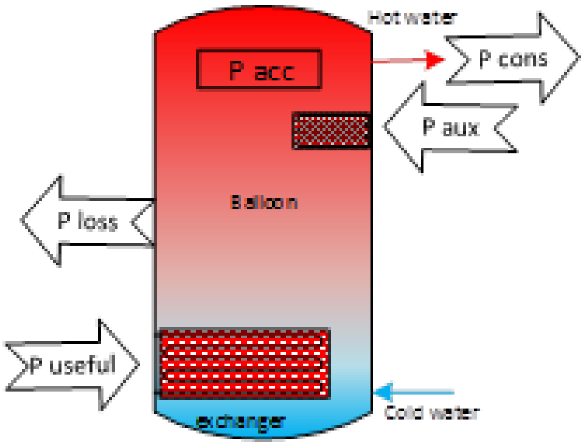

Fig. 5. Energy balance of the storage balloon.

4. RESULTS AND DISCUSSIONS

The calculation was made with a time step of one hour, the results found were presented in the form of graphs and tables, including their comments above.

4.1. *The Yield of the Solar Panel end the Useful Power*

The yield of the solar panel calculates with Equation 3 by introducing the parameters of the collector recovered from the study by Gherib, L. [24], namely the optical efficiency is 0.7, the coefficient $a_0 = 4.13 \mathrm{W/m^2.K}$, and the second coefficient $a_1 = 0$. The average temperature of the panel is given by Kefti, O. *et al.* [25]. It is valid for the summer season for July at 70°C; we subtract 10°C for each season and determine the average temperatures of the selected months. In October, it is 60, April 50 and January 40°C.

Figure 6 shows the hourly yield during the solar irradiation of the day in January, April, July, and October. The result varies from 0.2 to less than 0.5 in January, and it is around 0.5 or higher for the other months; the operating time of the panel increases depending on the season.

Figure 7 shows the power supplied by the panel in January, April, July, and October. The maximum power recovered during July when it reaches a peak of 1000 W for a significant period. The powers in April and October are similar, and that of January is weak. The numerical values of graphics are given in Appendix.

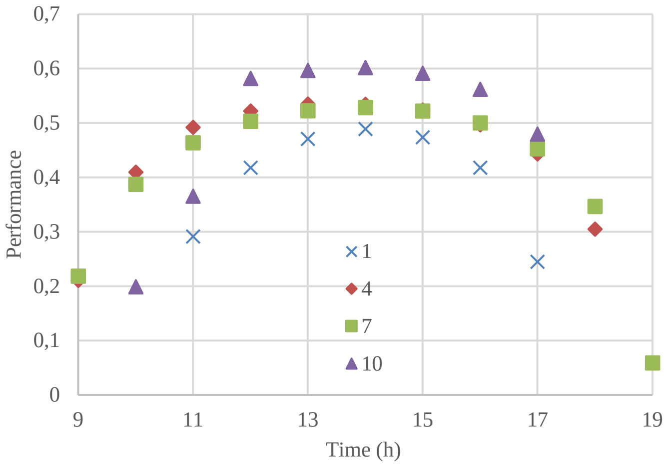

Fig. 6. The hourly yield of the panel performance.

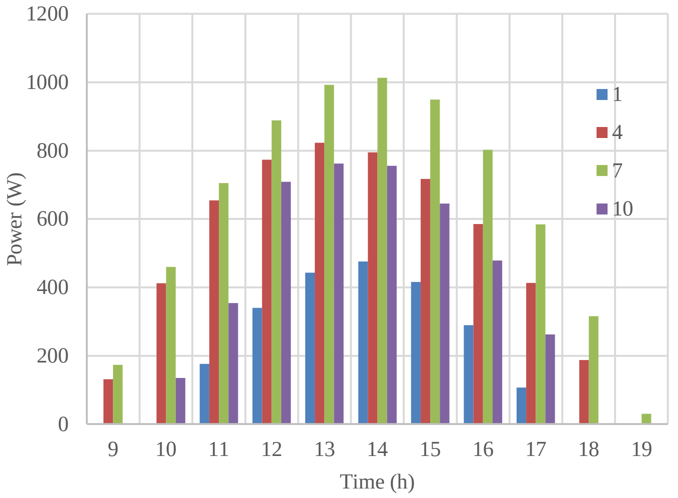

Fig. 7. Useful power supplied by the panel.

4.2. Balloon Temperature

The determination of losses makes by assuming that the balloon is an assembly of a cylindrical part and two spherical caps, a thickness of 100 mm of glass wool covers the balloon. The internal and external exchange coefficients are calculated by assuming inside the balloon an internal flow in forced convection and natural convection outside. The overall exchange coefficient by the surface has been determined and is $U.S = 1.059W/K$. The tank's internal temperature is calculated by Equation (6), and by making the balance of entries and exits, the update is made every hour.

Figure 8 shows the evolution of the average water temperature in the balloon for a day in January, April, July, and October. The temperature decreases from 0 to 10 hours because of the losses and the drawing, then it increases since the solar contribution becomes more and more critical, at sunset the temperature drops; the curve of January remains weak compared to the others, that of April and October are similar, and that of July is the most important, the temperature exceeds 50 °C from 16 to 20 hours.

4.3. Auxiliary Power

Figure 9 shows the auxiliary power required to supply water at 60 °C, in January, April, July, and October. This power follows the shape of the consumption profile, but in the interval between 12 PM and 4 PM, heating is provided by the energy supply from the solar panel. The auxiliary power is minimal; in July, we have the same trend, but the solar energy supply is more critical, and the extra energy is zero in the interval from 12 AM to 6 PM; between 2 AM and 6 AM consumption is zero, the auxiliary power compensates the losses.

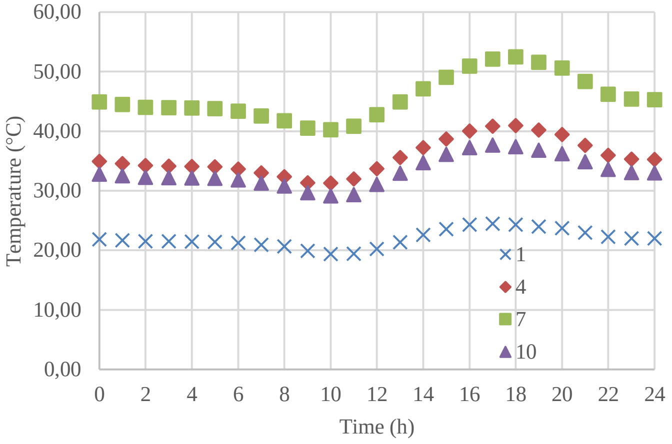

Fig. 8. The internal temperature of the balloon.

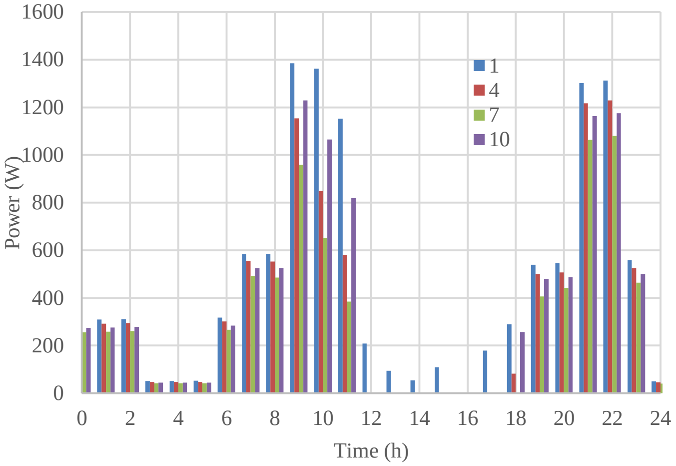

Fig. 9. Auxiliary power consumed by resistance

4.3. Solar Energy Coverage Rate

Analysis of the monthly data in Table 1 shows that the solar energy coverage goes from 18% in January to 66% in July. April and October cover less than half of the needs, i.e., 46 and 36%.

Table 1. Monthly comparison of energy intake.

Month	*P_useful (Wh)*	*P_loss (Wh)*	*P_cons (Wh)*	*P_aux (Wh)*	*Coverage (%)*
1	2247,81	1238,27	12709,60	11706,05	18
4	5492,94	1136,48	11913,58	9119,49	46
7	6915,74	999,63	10471,48	7633,44	66
10	4102,80	1077,36	11327,54	9518,51	36

5. CONCLUSION

The study of an individual solar water heater with forced circulation was drawn up, based on the energy balance of the balloon, from which mathematical formulations are obtained for the calculation of temperatures and powers; Hourly temperature and performance analysis was obtained for January, April, July and October. The temperature of a solar water heater tank has been monitored, indicating that it can reach the desired values. By adding extra energy, we can meet an average family's domestic hot water consumption needs with substantial savings. The study of energy consumption performance has been carried out and has shown that solar energy coverage can reach 66% with a minimum of 18% in January for a single panel. The efficiency of such an installation is proven in the typical Oran climate.

Appendix

Data of Figure 6: The hourly yield of the panel performance.

Time (h)	*January*	*April*	*July*	*October*
9	-	0,21	0,22	-
10	-	0,41	0,39	0,20
11	0,29	0,49	0,46	0,37
12	0,42	0,52	0,50	0,58
13	0,47	0,53	0,52	0,60
14	0,49	0,53	0,53	0,60
15	0,47	0,52	0,52	0,59
16	0,42	0,50	0,50	0,56
17	0,24	0,44	0,45	0,48
18	-	0,30	0,35	-
19	-	-	0,06	-

Data of Figure 7: Useful power supplied by the panel.

Time (h)	*January*	*April*	*July*	*October*
9	0,00	131,77	173,89	0,00
10	0,00	412,13	459,81	135,04
11	176,13	654,62	704,93	353,87
12	340,14	773,46	889,03	708,92
13	443,24	823,29	992,52	762,34
14	475,97	794,98	1013,61	755,87
15	415,77	717,06	949,14	645,23
16	289,96	585,25	802,81	478,95
17	106,61	413,24	584,39	262,58
18	0,00	187,14	315,53	0,00
19	0,00	0,00	30,09	0,00

Data of Figure 8: The internal temperature of the balloon.

Time (h)	*January*	*April*	*July*	*October*
0	21,85	34,95	44,93	32,80
1	21,69	34,58	44,48	32,52
2	21,53	34,22	44,03	32,25
3	21,50	34,16	43,96	32,20
4	21,47	34,09	43,89	32,16
5	21,44	34,03	43,82	32,11
6	21,26	33,66	43,36	31,82
7	20,95	32,98	42,54	31,30
8	20,64	32,34	41,76	30,80
9	19,94	31,32	40,52	29,70
10	19,36	31,27	40,28	29,16
11	19,43	31,99	40,82	29,37
12	20,25	33,72	42,75	31,10
13	21,37	35,56	44,94	32,94
14	22,58	37,27	47,13	34,72
15	23,58	38,71	49,06	36,12
16	24,29	40,03	50,91	37,23
17	24,46	40,82	52,09	37,70
18	24,30	40,95	52,48	37,39
19	24,01	40,19	51,59	36,81
20	23,70	39,43	50,62	36,23
21	22,98	37,64	48,35	34,86
22	22,29	35,97	46,23	33,58
23	22,01	35,31	45,38	33,07
24	21,99	35,25	45,32	33,03

Data of Figure 9: Auxiliary power consumed by resistance

Time (h)	*January*	*April*	*July*	*October*
0	306,60	290,01	255,05	274,10
1	308,87	292,61	257,98	276,41
2	310,98	294,90	260,47	278,49
3	51,48	47,43	41,94	44,78
4	51,80	47,72	42,21	45,03
5	52,01	47,91	42,42	45,21
6	316,87	301,40	266,98	284,43
7	583,20	555,82	491,68	524,89
8	584,48	552,21	486,21	526,05
9	1385,02	1154,22	958,38	1228,53
10	1362,46	848,78	650,92	1065,26
11	1152,39	580,74	384,15	818,99
12	208,20	0,00	0,00	0,00
13	94,43	0,00	0,00	0,00
14	53,46	0,00	0,00	0,00
15	108,43	0,00	0,00	0,00
16	0,00	0,00	0,00	0,00
17	178,41	0,00	0,00	0,00
18	288,90	82,16	0,00	256,48
19	539,84	500,43	405,91	480,03
20	545,69	507,15	442,08	486,40
21	1301,82	1216,42	1063,65	1163,71
22	1311,93	1229,08	1079,32	1175,01
23	558,61	524,26	463,42	500,98
24	50,17	46,26	40,68	43,72

Symbols

a	Coefficient
Ap	Panel Surface (m^2)
cp	Massic heat ($J\ kg^{-1}\ K^{-1}$)
G	Solar irradiation ($W\ m^{-2}$)
$\dot{m}$	Mass flow ($kg\ s^{-1}$)
M	Ballon mass (kg)
P	Power (W)
S	External surface of the balloon (m^2)
t	Time (s)
T	Temperature (K)
U	Overall exchange coefficient ($W\ m^{-2}\ K^{-1}$)
η	Yield

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