Acta Mechanica Slovaca **27 (4): 14 - 21,** December **2023**
https://doi.org/10.21496/ams.2023.037

Acta Mechanica SlovacaISSN 1335-2393
www.actamechanica.sk

Influence of the Number of Tanks on the Performance of a Domestic Solar Water Heater

Mohamed Lazreg [1*], Touhami Baki [2], Driss Nehari [3]

[1] Mechanical Department, ENP d'Oran Maurice Audin, Route d'Es Sénia, BP 1523 EL MNAOUER 31100, Oran
[2] Faculty of Mechanics, Gaseous Fuels and Environment Laboratory, USTO-MB, El Mnaouer, BP1505, Bir El Djir 31000, Oran
[3] Laboratory of Intelligent Structures, University, Belhadj Bouchaïb Center, Ain Témouchent, Sidi Bel Abbes Road - BP 284- (46000)

Abstract: A study with the TRNSYS software of solar water heater installations was simulated for the domestic hot water needs of an average family in the Mediterranean climate of the city of Oran in Algeria. Comparisons of systems with one tank and two tanks have shown similarities in the quantities of energy consumed and captured by the solar panels, but differences have been observed in the coverage of auxiliary energies. On the other hand, the two-tank system makes it possible to produce very significant temperature stratification.

Keywords: Solar fraction, solar water heater, tank, stratification, temperature.

1. Introduction

The rapid increase in energy consumption in the world has had negative impacts on the environment, in addition to difficulties in supplying energy resources and congestion in supplies [1]. Currently, technologies can exploit renewable energies; these have a low footprint on the environment and are considered sustainable and environmentally friendly; clean energy for domestic and industrial uses can be obtained from the sun [2]. Due to its geographical position, Algeria has a significant potential in solar energy. The average duration of sunshine in Algeria is 2560 hours in coastal areas, 3000 hours in the highlands, and 3500 hours in the desert; this high potential indicates that Algeria has a considerable capacity for solar water heating systems [3].

Hongbing and others [4] studied a centralized solar hot water system in the residential area of Tianjin, China. They used MATLAB language to describe the calculation procedures of the established model, and they could determine the performance of the system throughout the year based on four parameters, namely the solar fraction, the use of solar energy, the replacement rate, and the dissipation rate. Taher and others [5] have developed and validated a model to assess the performance of a solar water heater with different sensors. An energy, exegetical, environmental, and economic analysis has been drawn up for all the countries of the Middle East and North Africa region, and the maximum values of the solar fraction reached are 60% for flat panels and 83% for vacuum tubes.

Baki and Madjber [6] simulated with TRNSYS an installation composed of thermal solar panels with a storage tank connected to the domestic hot water systems and photovoltaic panels connected to the electrical systems. The thermal and electrical energy needs are covered at 30% by the thermal panels and 70% by the photovoltaic panels. Hamdoun and others [7] numerically studied the thermal and electrical performance of a solar water heater installation for the needs of a house composed of 5 people in the climatic environment of Iraq. A mathematical formulation was developed and compared

*** Corresponding author:** Mohamed Lazreg, ***E-mail address:*** *mohamed.lazreg@enp-oran.dz*

to the experimental data; good agreement of the results was indicated. Baki [8] compared the performance of a solar water heater for the domestic hot water needs of an average family in three different regions of Algeria. The simulation was done with TRNSYS for a solar panel with an area of 4m^2 and a 300-liter storage tank, and the results show significant performance in the south and similar data in the north and the Highlands. Chandra and Matuska [9] analysed the stratification in a domestic hot water storage tank with various temperature distribution models. The models were categorized into linear, stepped, linear continuous, and three-zone ensembles. The decrease of the thermocline and the influencing parameters in idle and dynamic modes were presented, as well as the improvement in performance and its quantification were illustrated. Baki and others [10] have studied the performance of a forced circulation solar water heater for the hot water needs of an average family by mathematical formulations. After taking stock of the inputs and outputs at the level of the tank, the average temperature of the tank was followed, showing that it can exceed 50°C without adding auxiliary energy. Lazreg and others. [11] studied the effect of stratification in a hot water storage tank of a solar water heater, and analysed the temperature inside the tank at nodes at different heights.

Chen and others [12] experimentally studied the influence of the number of water storage tanks for use in air conditioning. They showed that the system can adapt to extreme weather conditions with a rapid temperature rise. They conducted a series of charging and discharging experiments by varying the number of tanks under the same solar radiation conditions. The results indicate the energy quality of the water in the reservoirs by dividing the storage system into multiple reservoirs. Zhou and others. [13] In a comparison between two installations, one with a solar water heater and a tank and another with two tanks, the thermal performances were compared and analysed during experimental tests in the field. The results show that the loss of heat with one tank is less than with two tanks, but the average heat loss is higher. Mather and others. [14] They experimentally and analytically studied liquid water systems for storing the heat of solar origin and compared an individual tank with a multi-tank set interconnected between them, the results show a very effective degree of stratification achieved and a thermodynamic advantage.

In this document, a simulation with TRNSYS has been made to compare an installation of a solar water heater with one tank with that of two tanks. The performances were analysed, and the stratification curves were examined.

2. Choice of installation

The study is a dynamic simulation with the TRNSYS software of a solar water heater installation with a closed loop, primarily using a single tank, installed in the climate of Oran and producing domestic hot water for a family. Average of six people.

2.1 Solar Loop

A schematic diagram of the modelled solar system is shown in Figure 1. It consists of a flat solar panel, a water storage tank, and an auxiliary power source. The circulating water from the collector gives its heat to the water in the storage tank and then returns to the solar collector, where it is heated again. The water arriving from the city's supply circuit is injected at the bottom of the tank, is heated inside the tank, and comes out of the upper part for the sanitary consumption of the dwelling.

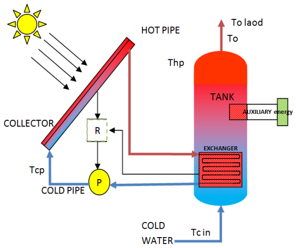

Figure 1: Solar tank system solar loop

2.2 Weather data

The climate of the city of Oran is of the warm temperate type; it is classified as CSA (Koppen-Geiger); the city is located in the west of Algeria on the southern shore of the Mediterranean; rainfall is low; the winter is rainy and mild; and the summer is dry and hot. Figure 2 shows the monthly average temperature during the year; it varies below 10°C in the winter and exceeds 20°C in the summer. The average monthly solar radiation shown in Figure 3 ranges from 600 W/m^2 in winter to 1000 W/m^2 in summer.

2.3 Consumption Profile

Figure 4 shows the evolution of the domestic hot water consumption fraction; it is taken from [6].

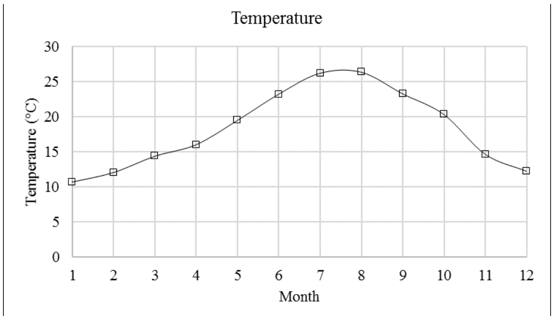

Figure 2: Average temperature

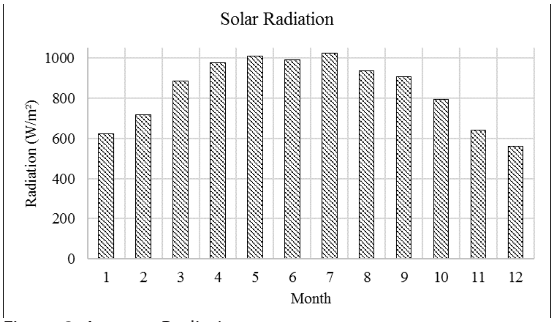

Figure 3: Average Radiation

The load is maximum between 8 and 11 a.m. and between 8 and 10 p.m.; the consumption is zero between 2 and 5 a.m. and varies little the rest of the day; the total load is 240 liters per day for an average family of 6 people, and the temperature set point at the tank outlet is set at 60°C.

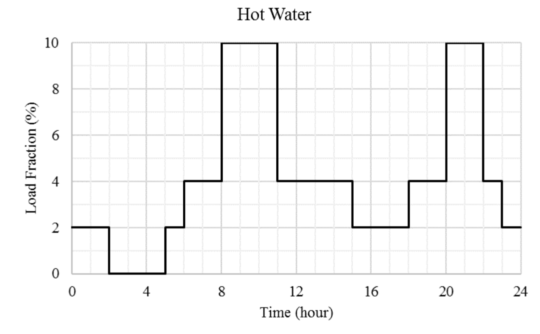

Figure 4: Water consumption profile

2.4 TRNSYS Diagram

A dynamic simulation with a time step of 1 hour was made with the TRNSYS software. The diagram used is shown in Figure 5, and it includes a solar loop consisting of a TYPE60d tank, a TYPE1b thermal solar panel, and a circulation pump TYPE3b. The loop is controlled by the TYPE2b regulator, the consumption profile is integrated into the TYPE14h programmer, the weather is managed by the TYPE109 component, and the results are displayed on files and reading screens.

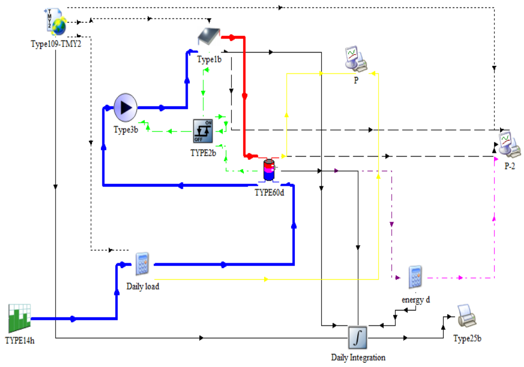

Figure 5: TRNSYS scheme

3. Results and Discussion

An analysis of the thermal performance will be made for an installation of a solar water heater with a tank and another installation with two tanks. A comparison between the two systems will follow.

3.1 Installation with a tank

Parameters will be studied before the final choice of the chosen installation; among these parameters is the surface of the solar collector and the volume of the tank.

3.1.1 Panel surface effect

A change in the surface of the solar collector certainly affects the thermal efficiency, which is fully reflected in the results of the solar fraction. Figure6 depicts the evolution of the solar fraction as the collector's surface increases; the more the surface increases, the more the solar fraction is important, then tends to a limited value, so our choice will be made on a surface of 4m^2, where the solar fraction is greater than 0.6 and, beyond that, the temperature inside the flask is close to boiling, as indicated by Baki and others. [15]

3.1.2 Tank volume effect

Figure 7 shows the influence of the volume of the tank on the solar fraction; we have varied the volume from 100 to 500 liters in steps of 100; the solar fraction varied little, but the maximum was obtained at 300 liters, and the fraction was then higher at 0.6. Given the results above, the installation studied will be made with a solar panel of 4m^2 and a storage tank of 300 liters.

3.1.3 Monthly Solar Fraction

The monthly fraction is shown in Figure 8. We

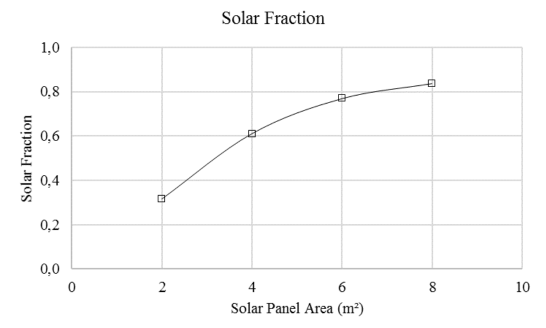

Figure 6: Solar Fraction VS Panel Area

acknowledge that there is a large dispersion from one month to another; in the winter months, the fraction has around 0.4. Its value limited to 0.9 in the summer. Between winter and summer, it gradually increases, then it decreases; the annual average is 0.61.

3.1.4 Useful energy recovered from the panel

What Figure 9 shows is the energy acquired by the solar panel, and what we notice is an increase until the seventh month, approximately 285 kWh, after which the curve begins to descend. And those results were an entire year. The lowest value recorded in the last month was December, with an estimated value of around 134 kWh.

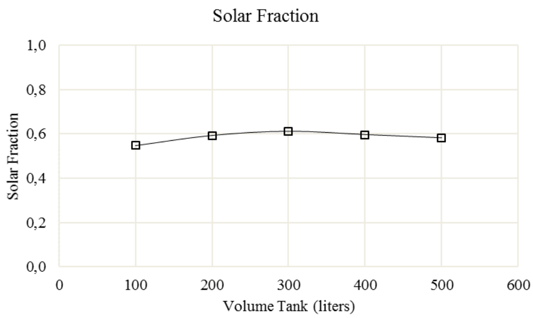

Figure 7: Mean Fraction VS Tank Volume

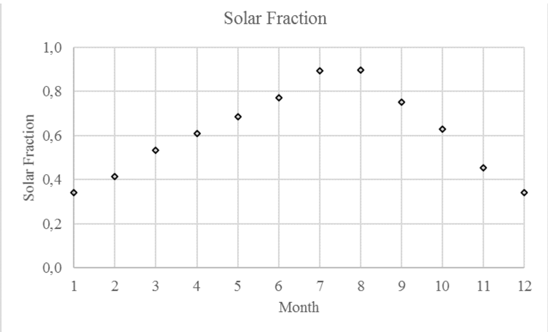

Figure 8: Monthly solar fraction

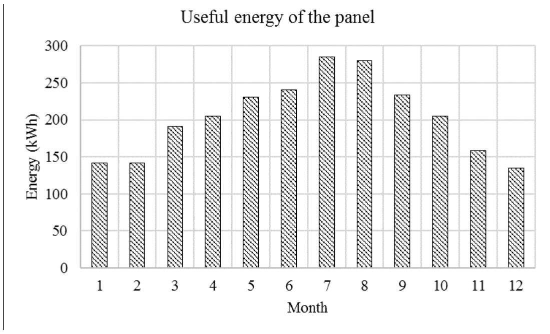

Figure 9: Useful energy recovered from the panel

3.1.5 Energy consumed

As for the energy consumed, we recorded a fluctuation in the level of energy between the months of the year, and we also recorded the maximum value in the month of July, which is estimated at around 273 kWh and the highest value low recorded in the second month of February is about 240 kWh. See Figure 10.

3.1.6 Auxiliary energy

To fill in energy needs during the winter, the auxiliary energy is snaps to reach a temperature of 60 °C at the outlet of the tank, in summer as the energy recovered from the panel is high, the demand for auxiliary energy is low, see Figure 11.

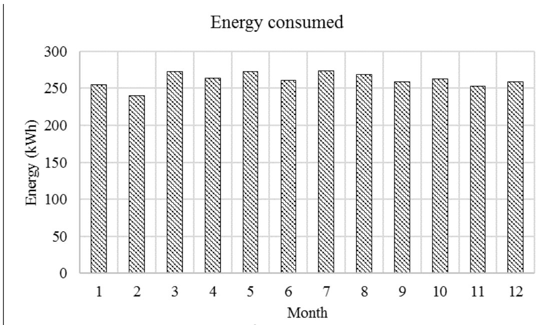

Figure 10: Energy Consumed

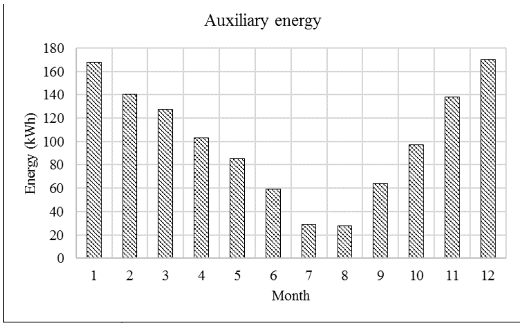

Figure 11: Auxiliary energy

3.1.7 Temperature stratification in the tank

Figures 12 and 13 show the evolution of the temperature inside the tank at the top, middle, and bottom on the chosen days of June 21 and December 21. The curves show a separation of the temperature strata during the morning, then the curves meet in the afternoon. Beyond midday, the consumption decreases, as indicated in the consumption profile in Figure 4, and the energy captured by the panel increases. In summer, the peak is close to 80 °C; on the other hand, in winter it is around 60 °C.

When looking at Figures 14 and 15, we see the evolution of temperature in the absence of additional energy. When energies are captured at sunrise, the temperature curves meet at the top and bottom middle. Temperatures remain the same throughout the day and until dusk. In summer, it barely exceeds 60°C, and in winter, it is just below 50°C.

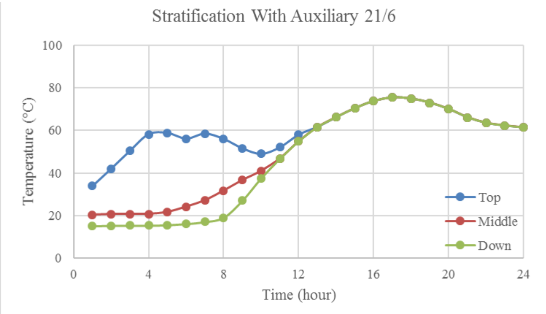

Figure 12: Temperature inside the tank at 21/6 with auxiliary energy

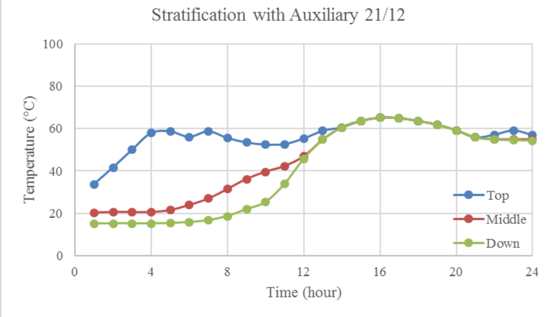

Figure 13: Temperature inside the tank at 21/12 with auxiliary energy

3.2 Installation with two tanks

The installation of the solar water heater will be modified by adding a second tank to the circuit; the quantity of water stored will be divided between the two tanks; the solar loop will be the same with a 4m^2 solar panel, and the consumption will also be the same with 240 liters per day distributed according to the profile shown in Figure 4.

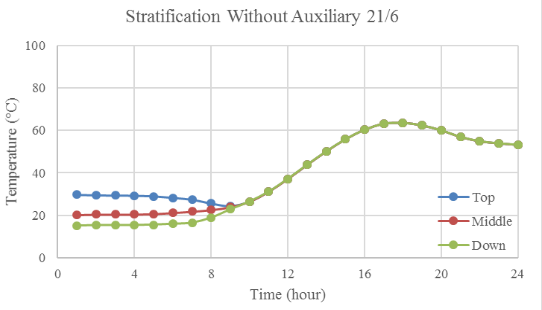

Figure 14: Temperature inside the tank at 21/6 without auxiliary energ

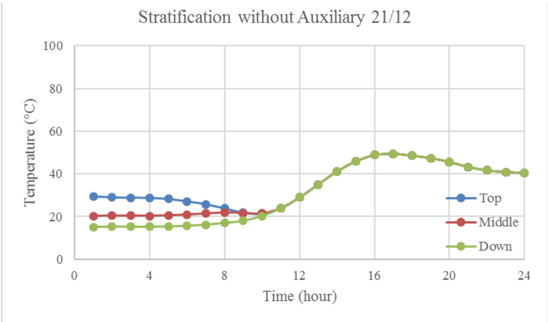

Figure 15: Temperature inside the tank at 21/12 without auxiliary energy

As for auxiliary energy, it is considered an important element in the energy cycle that we have, and here we wanted it to be within the first cycle only of the system, that is, within the first reservoir only, and this is in our attempt to conserve energy.

3.2.1 TRNSYS diagram

In the simulation diagram of Figure 16, the same elements will be maintained, and by adding a second tank, the connections of the exchanger will be connected to the inlet and outlet of the first tank. A second pump makes it possible to circulate the fluid between the two tanks at 50°C.

The scientific objective of studying a two-tank system is to try to exploit the wasted energy from the first cycle of the system. This is in light of the complete need to exploit every source of energy and not allow it to be wasted in any way.

3.2.2 Choice of tanks volume

The influence of the tank volume on the solar fraction is shown in Figure 7. To choose the best cases, we vary the volumes of the two tanks to be 200, 300, and 400 liters, and we choose the best combination. Table 1 shows the results of the comparison and the combination possibilities between tank1 and tank2.

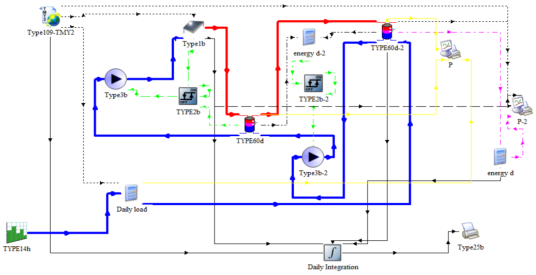

Figure 16: TRNSYS schematic for a two-tank system

The maximum fraction is for the cases of 200 and 400, where the fraction value is 0.48. We choose the second case, where the first tank has a volume of 200 liters and the second has a volume of 300 liters. For a lesser quantity of stored water, we obtain a fraction of 0.45. The difference is minimal between the second case and the third.

Table 1: Comparison of tank volumes.

N°	Tank 1 (liter)	Tank 2 (liter)	Solar Fraction
1	200	200	0.39
2	200	300	0.45
3	200	400	0.48
4	300	200	0.28
5	300	300	0.32
6	300	400	0.31
7	400	200	0.22
8	400	300	0.23
9	400	400	0.21

3.2.3 Useful energy recovered from the panel

Figure 17 shows the energy recovered from the panel in the case of two tanks; the evolution remains similar to the curve in Figure 9 for an installation of one tank, with a slight reduction in energies due to changes in the temperature of the tank. Second system.

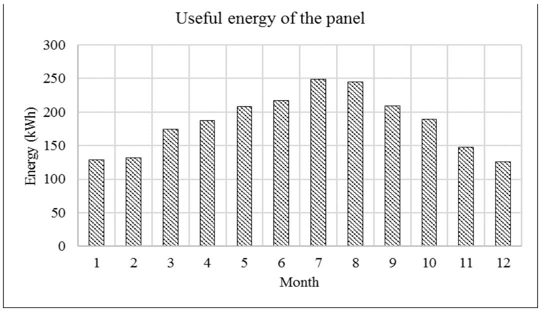

Figure 17: Energy recovered from the panel

3.2.4 Energy consumed

The energy consumed indicated in Figure 18 remains identical to that of Figure 10. As for energy, changing the system to one tank or two tanks does not affect the evolution of consumption; the total consumption is around 250 kWh per month.

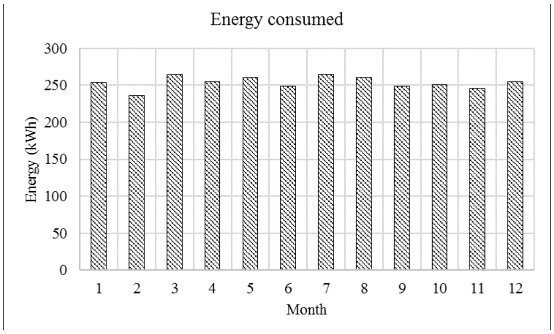

Figure 18: Energy consumed

3.2.5 Auxiliary energy

Figure 19 shows the evolution of the auxiliary energy needs to fill the energy deficit, relatively compared to the installation with a single tank, the energy is much greater, since at the level of the two tanks there are losses, the monthly energy is almost twice the energy for a tank.

3.2.6 Lost energy

The largest energy losses are at the level of the tank; the losses are due to the temperature difference between the inside of the tank and the room. Figure 20 shows the quantities lost during the months of the year for the two tanks separately; tank 1 has a volume of 200 liters and a lower surface than tank 2, whose volume is 300 liters; the losses of the installation with a tank will have the same losses as that of tank 2.

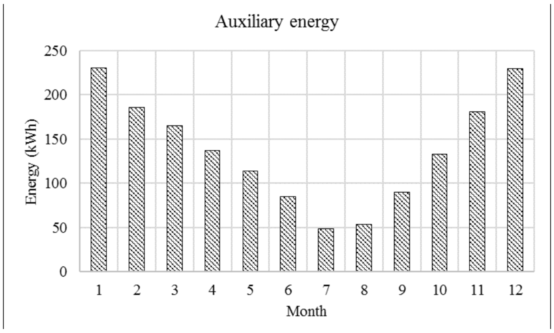

Figure 19: Auxiliary energy

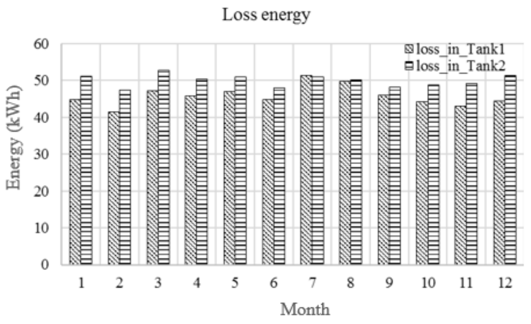

Figure 20: Energy losses

3.2.7 Temperature stratification in the tank

Figures 21 and 22 show the evolution of the temperature inside the two tanks at the top, middle, and bottom levels on the chosen days of June 21 and December 21. The curves show a separation of the temperature strata during the morning, then the curves meet at sunrise. The peaks obtained are relatively high, particularly in the first tank. On the day of June 21, the second tank reaches and even exceeds 80°C after 4 p.m. The same observation was made for the day of December 21, but with peaks lower than those of the summer of 20°C. The temperature curves evolve in the same way, with a lower offset when the auxiliary energy is not functional. A comparison of the stratification curves between the installations of one tank and two tanks shows a better evolution of the temperatures in the case of two tanks, since the peaks reached are much greater in all situations, namely in summer, in winter, and with or without auxiliary energy.

– *Temperature stratification in the two tanks with auxiliary energy (Fig. 21,22,23,24)*

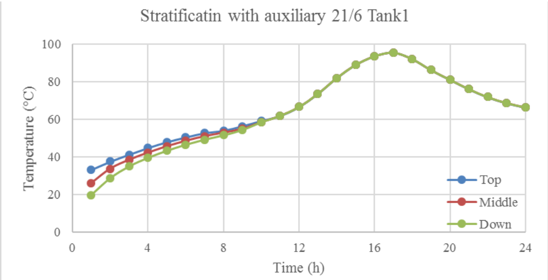

Figure 21: Tank 1 au 21/6

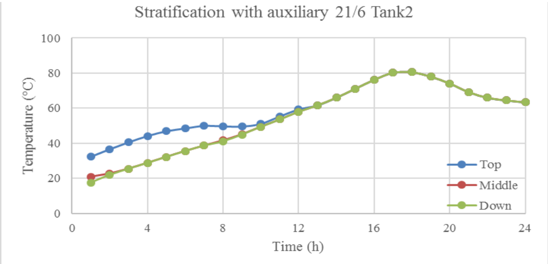

Figure 22: Tank 2 au 21/6

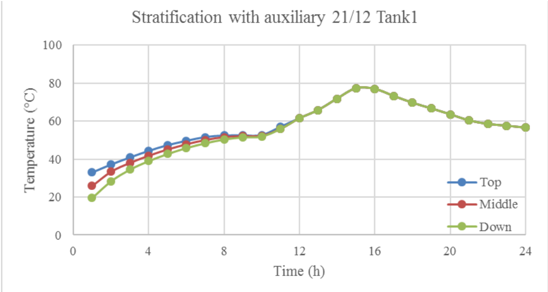

Figure 23: Tank 1 au 21/12

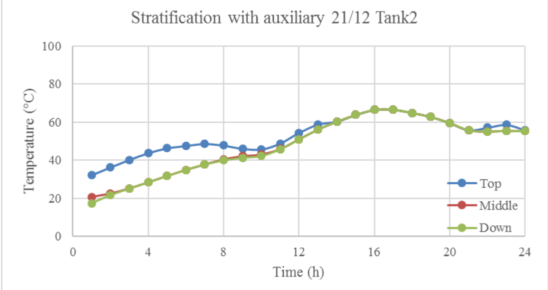

Figure 24: Tank 2 au 21/12

– *Temperature stratification in the two tanks without auxiliary energy (Fig. 25,26,27,28)*

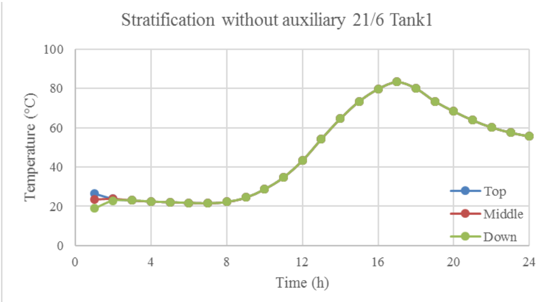

Figure 25: Tank 1 au 21/6

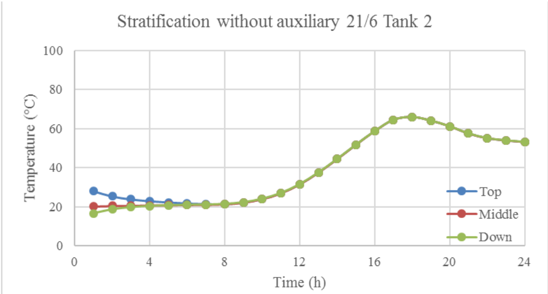

Figure 26: Tank 2 au 21/6

4. Conclusions

A study of the performance of a solar water heater installation has been made. Important points have been drawn from this simulation, which are:

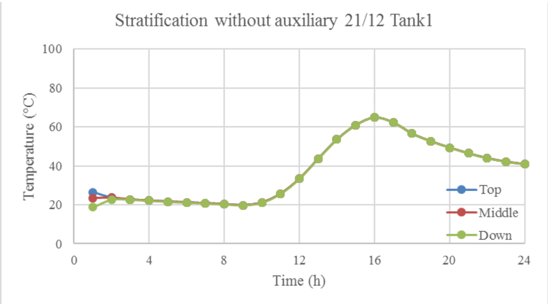

Figure 27: Tank 1 au 21/12

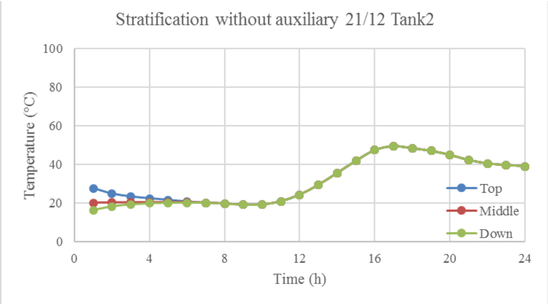

Figure 28: Tank 2 au 21/12

A solar water heater with a $4m^2$ solar panel and a 300-liter tank can cover the domestic hot water needs of an average family of 6 people living in the climate of Oran; the average annual solar fraction obtained is 0.61.

The average monthly energy fluctuates around 250 kWh, and the auxiliary energy is maximum in the winter at 150 kWh and minimum in the summer at around 30 kWh.

A comparison was made between installing a single-tank solar water heater and a two-tank solar water heater installation. It was found that the difference in power consumption and useful energy recovered from the panel is very small, about 4%. This is for July, but on the other hand, the auxiliary energy may be divided.

A second pump was added to the two-tank system. If we talk about energy consumption per liter, it is about 38 kWh/liter for the two systems. The difference lies in the auxiliary power, which rises from 4 kWh/liter in the first system to 7 kWh/liter, and this is within the month of July.

References

[1.] Pérez-Lombard, L., Ortiz, J., & Pout, C((2008).A review on buildings energy consumption information. Energy and buildings. 40(3), 394-398.

[2.] Evangelisti, L., Vollaro, R. D. L., & Asdrubali, F(2019). Latest advances on solar thermal collectors: A comprehensive review. Renewable and Sustainable Energy Reviews, 114, 109318.

[3.] Sami, S., Semmar, D., Hamid, A., Mecheri, R. and Yaiche, M, (2018). Viability of integrating Solar Water Heating systems into High Energy Performance housing in Algeria. Energy.149, 354- 363.

[4.] Hongbing, C., Yutong, G., Haoyu, N., Xiaoli, Y., &Xilin, C (2019). Optimization and performance study of residential centralized solar domestic hot water system. Energy Procedia.158, 6431-6437.

[5.] Taher, M. B., Benseddik, Z., Afass, A., Smouh, S., Ahachad, M., &Mahdaoui, M(2021).Energy life cycle cost analysis of various solar water heating systems under Middle East and North Africa region. Case Studies in Thermal Engineering,.27, 101262.

[6.] Baki, T., Madjber, H(2022).Assessment of the Thermal and Electrical Energy Needs of an Autonomous Single-Family House. Journal of Electrical and Electronics Engineering.15(1), 9-14.

[7.] Hamdoon, O. M., Alomar, O. R., & Salim, B. M(2020). Performance analysis of hybrid photovoltaic thermal solar system in Iraq climate condition. Thermal Science and Engineering Progress,.17, 100359.

[8.] Baki, T(2021). Comparison of the performance of a domestic solar water heater in different climates in Algeria. Present Environment & Sustainable Development,.15(1), 143-151.

[9.] Chandra, Y. P., & Matuska, T. (2019). Stratification analysis of domestic hot water storage tanks: A comprehensive review. Energy and Buildings, 187, 110-131.

[10.] Baki, T., Tebbal, M., & Berrebah, H(2021).Following the balloon temperature of a solar heater installed in Oran, Algeria. Turkish Journal of Electromechanics & Energy, 6(2), 73-79.

[11.] Lazreg, M., Baki, T., & Nehari, D (2019). Effect of Parameters on the Stratification of a Solar Water Heater. In ICREEC (pp. 117-125). Springer, Singapore. (2020).

[12.] Chen, L., Jin, S., & Bu, G(2017). Experimental investigation of a novel multi-tank thermal energy storage system for solar-powered air conditioning. Applied Thermal Engineering,.123, 953-962.

[13.] Zhou, Z., Wang, L., Li, C., & Ebert, A(2016).Performance Analysis of a Collective Solar Domestic Water-Heating System in the Temperate Zone of Yunnan Province, China. Journal of Engineering Science & Technology Review. 9(3)

[14.] Mather, D. W., Hollands, K. G. T., & Wright, J. L(2002). Single- and multi-tank energy storage for solar heating systems: fundamentals. Solar Energy. 73(1), 3-13.

[15.] Baki, T., Sandid, A. M., & Nehari, D(2022).Sizing of an Autonomous Individual Solar Water Heater Based in Oran, Algeria. Slovak Journal of Civil Engineering. 30(3), 9-16.