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# Feasibility study of solar water heaters in Algeria, a review

S. Pahlavan[a], M. Jahangiri[b,*], A. Shamsabadi[c], A. Khechekhouche[d]

[a] *Department of Architecture, Sepehr institute of Higher Educational, Isfahan, Iran*
[b] *Department of Mechanical Engineering, Shahrekord Branch, Islamic Azad University, Shahrekord, Iran *Email: jahangiri.m@iaushk.ac.ir*
[c] *Young Researchers and Elite Club, Shahrekord Branch, Islamic Azad University, Shahrekord, Iran*
[d] *Renewable Energy Research unite in Arid Zones, El-Oued University, Algeria*

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**A B S T R A C T**

According to the statistics announced by Algeria's Ministry of Energy and Mine, residential and service sectors account for 40% of total energy consumption of the country of which a huge amount is dedicated to space heating and sanitary hot water. Therefore, using solar water heater (SWH) for providing a major part of this energy demand seems necessary in line with socio-economic development and continuous improvement of standards of living. Applications such as space and water heating are not well-developed in Algeria and no need to say that using energy management software packages is an excellent solution for enhancing management applications of energy development-based systems. Therefore current study uses TSOL and MeteoSyn software packages to investigate the potential of using SWHs for a residential apartment in 37 stations in Algeria. Results indicated that In Salah, Tamanrasset, and Adrar stations that respectively accounted for 85.6%, 81.2%, and 76,7% of total thermal demand provision were the most suitable ones for SWH usage. Also, given the results it can be observed that in case of using SWH in 37 stations, 150160 kWh of thermal energy for space heating and 99861 kWh for sanitary hot water is produced which, due to not using fossil fuels for generating this thermal energy, savings up to 56783 kg in $CO_2$ emissions are obtainable annually.


## 1. Introduction

Due to the increasing growth of world population, limitation of energy sources, and adverse environmental effects of overconsuming fossil fuels, various kinds of renewable energies have gained more attention. SWHs are widely used in private and industrial sectors. According to Renewable Energy Policy Network, it is reported that in 2010, only 70 million houses around the world used SWH systems. SWH is not only environmentally friendly, but also it entails less maintenance and operation costs compared to other uses of solar energy [1].

Algeria is located in the center of North Africa, between Tunisia and Morocco along the Mediterranean coast, between latitudes of 19° and 38° North and longitudes of 8° West and 12° East, with an area of 2381740 km$^2$. The natural resources are: petroleum, natural gas, iron ore, phosphates, uranium, lead, and zinc without forgetting solar energy. More than 86% of the total area of the country is Sahara with duration of sunshine is about 7.3 hours in the north, 8.3 hours in the highlands and more than 10 hours in the southern regions. In general, the duration of sunshine of the whole territory exceeds 3000 hours/year and can reach 3500 hours/year in the Sahara. [2]

Having more than 3000 sunny hours on an annual average basis [2], Algeria enjoys a huge source of solar energy [3]. It has taken many measures for the reduction of and adaptation to climate changes. Since Algeria, similar to other countries, is confronting severe climate events like water shortage and drought, it has formulated a strategy in 2015 which encompasses reduction in GHGs, development of forestry, and sea water desalination [4].

Social and economic development as well as continuous improvement of the standards of living have led to a significant increase in energy consumption in Algeria. This has resulted in Algeria to formulate a comprehensive plan for energy productivity and using renewable energies in most sectors, especially in the construction and transportation. Implementation of these new plans will have a considerable effect on the reduction of GHGs in Algeria [4]. One of the solutions suggested for higher productivity is the installation of 100000 SWH systems during a year in residential buildings [5, 6]. It should be mentioned, however, that these plans and solution require huge investments which is more highlighted due to reduced oil prices, and specially, current economic crisis in Algeria. Other obstacles in this regard include difficulties in deploying new technologies, lack of qualified human sources, low technical coordination between different sectors, etc. [4].

Algeria plays a pivotal role in the world's energy markets and it is the second major natural gas exporter in Europe and Africa and among the top three oil producing countries in Africa [7]. In 2013, Algeria owned 12.2% of world's oil reserves and 4.5% of world's natural gas sources [8]. A major problem that has bothered Algeria in recent years is that, due to reduced sources of natural gas and crude oil, the current energy consumption patterns of Algeria are not compatible with the energy production. Therefore, Algeria inevitably has to use other kinds of energy for meeting its future energy demands [7].

Due to such factors as high radiation potential, density of a large distribution system, lower price of renewable electricity, and enhancement of communication networks, a promising future is predicted for the application of renewable energies in Algeria. Solar energy is most promising energy in Algeria. It is reported that Algeria's radiation potential is 5000 times the current energy consumption of the country and 60 times the current electricity consumption in Europe [7]. Solar radiation potential in Algeria is depicted in Fig.1 [9]. It is obviously clear in this figure that southern parts of Algeria are more suitable in terms of solar radiation compared to other parts.

In 2011, the first hybrid solar-gas 150 MW plant was operated in Algeria with the solar power accounting for 20% of total capacity installed in Hassi R'mel desert [10]. Fig.2 illustrated a view of this power plant [11].

The main grid of Algeria is currently dependent upon fossil fuels (natural gas and oil) [3, 4]. It is forecasted that Algeria will produce 22000 MW energy out of renewable sources by 2030 [3, 4, 12] of which around 2000 MW will be taken from solar heat [4].

About 47.6% of Algeria houses are privately-owned or traditional houses which makes them suitable for using SWH systems [13]. At present, the energy requirement of most water heating systems in Algeria is supplied by gas or electricity and the primary energy consumption occurs in residential sector [14]. It is noteworthy that the current average domestic hot water usage in Algeria is 50 L/d [15]. During the last 20 years, SWH installations (Thermosiphon) have been installed by public institutions for providing the sanitary hot water of residential sector. As it could be observed in Fig.3 [15], the total installed capacity is concentrated in northern parts of Algeria where there is a lower need to SWH systems. Being the capital of Algeria, Aljazeera has received the highest number of SWH systems.

Renewable energy development plans in Algeria were launched from 2011 and they are going to continue up to 2030 for rehabilitation of economic growth of the country [16]. Fig.4 shows currently installed capacities and renewables development goals by 2030. At the present, of 11390 MW installed capacity, 228 MW is hydropower and 25 MW is related to CSP while, by 2030, of the total 12000 MW energy generated by renewables, 2000 MW will be by wind energy, 2800 MW solar energy, and 7200 MW from CSP [17].

The average sunny hours in coastal, highland, and desert areas in Algeria are 2560, 3000, and 3500 hours, respectively. This high potential indicates the Algeria's considerable capacity for SWH systems [18] and, as it was previously mentioned, using SWH for domestic usage is both technically and economically cost-effective in Mediterranean countries [19-24]. Regarding installed solar water heater per capita, Cyprus with a total installed capacity of 0.99 $m^2$ per capita hits the world's first rank [25]. In 2012, Tunisia installed 487000 $m^2$SWH which made it the first North African country succeeded in implementing a huge SWH plan and today it is exporting SWH to

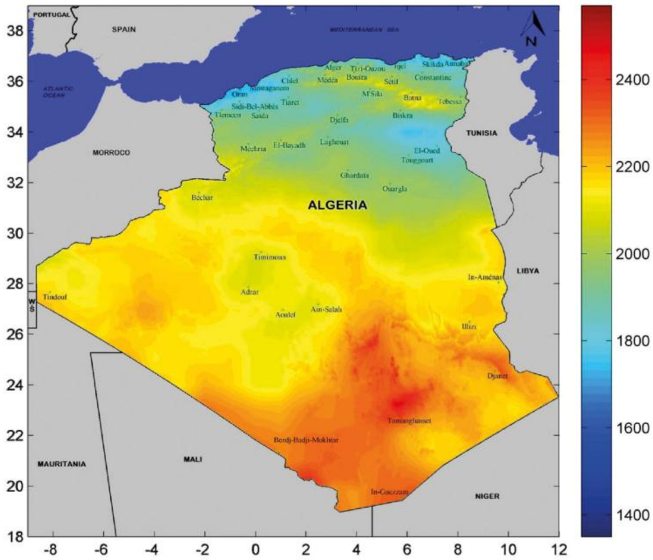


Figure 1. Solar radiation potential in Algeria [9].

Figure 2. Hybrid solar-gas plant in Hassi R'mel desert [11]

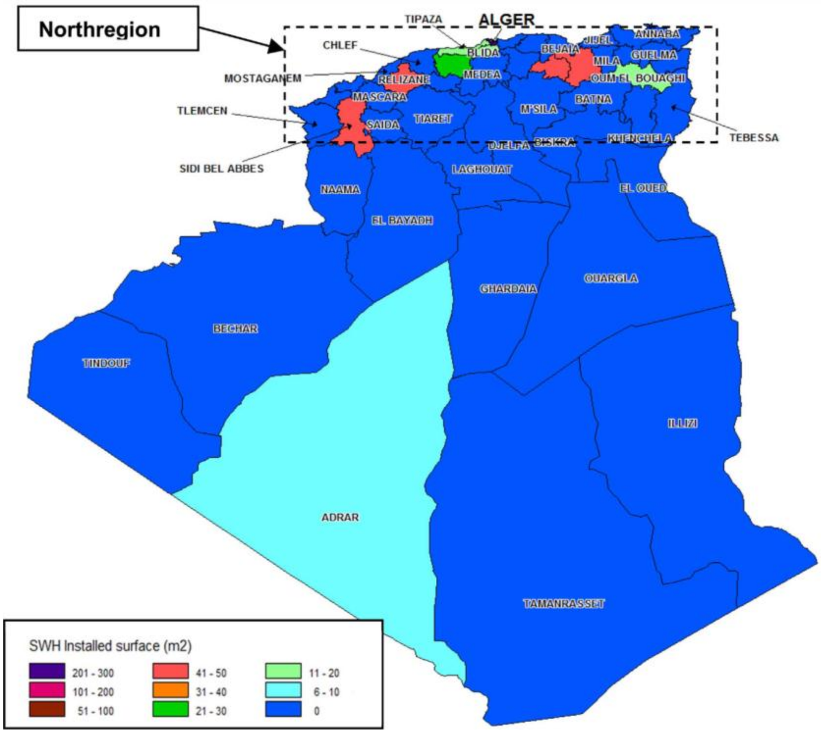


Figure 3. The installed SWH capacity in Algeria [15]

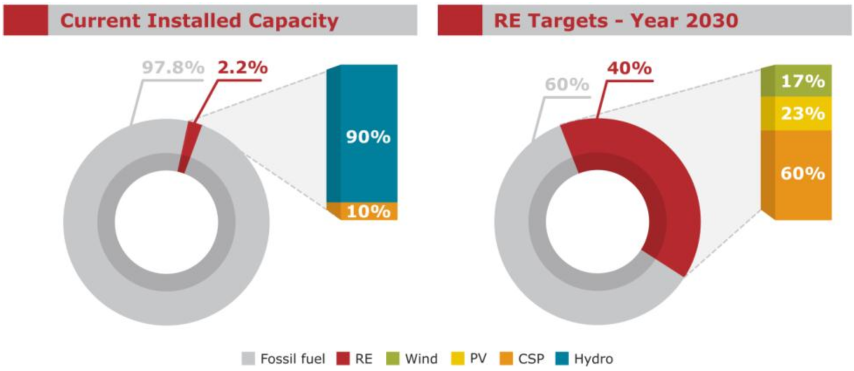

Figure 4. Currently installed capacity and renewable development goals by 2030 in Algeria [17]

its neighbouring countries like Algeria and Libya [26, 27].Extensive studied are required to identify the potential of various regions in Algeria in terms of using renewable energies. Besides, it is important to tap into other countries experiences in this regard so that the best and most efficient approaches will be utilized. Many studies has been conducted so far on using SWHs around the world which are reviewed in the following.

Abou-Zaid and Hawas (1983) performed an economic study on a SWH system in Benghazi City in Libya and they observed that their results were extendable to other regions of Libya [19]. Lewis (1987) evaluated three different methods for estimating the optimal area of SWH systems in Zimbabwe. Results indicated the adequacy of using solar systems [28]. Hawalder et al. (1987) used meteorological data of Singapore and suggested that saving-based approaches led to the optimization of solar collectors' size [29]. Akinoglu et al. (1999) studied the optimal area and storage capacity for several stations in Turkey to find the highest and lowest performance rates of solar collectors [20]. Kablan (2004) conducted an economic comparison between SWH and gas systems in Jordan and suggested that for Jordan's climate, SWH will be cheaper with an increased lifetime [21]. Kalogiru (2009) reported that using SWH in Mediterranean climate can meet a major part of domestic demands and demonstrated a promising future for investing in this sector [22]. Al-Badi (2012) revealed that using SWH in all the cities of Oman could save huge amounts of energy annually which is equal to annual energy generated by a 212 MW power plant and he suggested that the government should offer incentives for using SWH [30]. Studying the long-term performance of SWH, Hazami et al. (2013) showed that using SWH for domestic purposes in Tunisia was highly optimal and profitable [23, 31]. The techno-economic analysis by Nikoofard et al. (2014) revealed that through governmental support, SWH system might become a cost-effective option in Canada saving 2% in GHGs emissions annually [32]. According to the latest Greece regulations on building energy performance, Martinopoulos et al. (2014) undertook a techno-economic evaluation of space and water heating by SWH systems. Their results were indicative of lower costs and pollutants emission [33]. Based on the their feasibility and economic study results, Abd-ur-Rehman et al. (2016) introduced the optimum selection criteria for SWH systems in 10 cities of Saudi Arabia and highlighted the importance of primary costs minimization for cost-effectiveness of the project [34].

Few studies have been undertaken on using solar water heater in Algeria which are reviewed in the following.

Mounir et al. (2012) conducted a techno-economic analysis of a solar water heater for a hospital center in Batna province in Algeria using RETScreen Software [35]. Their results proved that in case of deploying SWH, 1427.1 MWh of energy was produced annually which led to 905.84 ton/y reduction in $CO_2$ emissions. They observed that the main obstacles in the way of implementing projects included very cheap price of fuel and the high costs of installation which demanded governmental subsidies for such projects.

Sellami et al. (2016) studied the market potential and SWH development outlook in Algeria [13]. Their results revealed that no significant development was happening about SWHs in Algeria and they enumerated the access to cheap gas and high initial costs of SWH as the reasons. Also, they recommended domestic production of SWHs according to the industrial capacities of Algeria in order to seen the rapid growth and development of SWH in Algeria. Finally, they expressed that SWHs development would be impossible without a domestic industry for manufacturing SWHs, since the costs of importing are so high relative to citizens' standards of living.

Missoum et al. (2016) studied the energy performance of a SWH for a single-family home in Algerian climate using TRNSYS software [14]. They investigated two storage tank models namely fully mixed and stratified storage systems. In order to determine the desirable size of thermal collector, storage tank, and mass rate, they conducted a parametric study. Results indicated that solar energy accounted for 88% and 96% of total energy supply of the system including the aforementioned tanks.

Sami et al. (2018) studied the integration of SWHs in high-energy-performance-residential buildings in Algeria [18]. Their studied locations were houses in four different climates in Algeria. Monthly meteorological data were used for investigations. Results suggested that, depending on the location, 45%-100% of the required energy could be provided through SWH system. Also, an energy consumption reduction of 46% and 57% was observed for northern and southern areas respectively which led to a reduction in total costs by 51% and 69%. According to the literature on Algeria, no extensive potentiometric study has been done so far on using SWH systems for simultaneous provision of space heating and sanitary hot water of a residential building at various climate zones of Algeria. Therefore, since these kind of studies are a necessary prerequisite for investing on any solar project so that they could be technically and economically guaranteed, this study uses MeteoSyn and TSOL software packages to investigate the potential of using solar water heaters in Algeria. The aim of this work is to evaluate each station's potential and locate the best place for using SWH systems. Such parameters as total solar fraction, the required space heat supply, the required sanitary hot water supply, savings in $CO_2$ emissions, and the heat supplied by boiler were studied in order to determine the best station in Algeria.

## 2. The Studied Area and Stations

Algeria is situated in a semi-tropical [18] region in North Africa on Mediterranean Sea coastline. It is surrounded by Morocco in the northwest, Tunisia to the northeast, Libya to the east, Niger to the southeast, Mali to the southwest, Mauritania and Western Saharan to the west [36]. As it could be seen in Fig.5, Algeria is located on the geographical coordinates of 17˚.96' to 37˚.5' N and 9˚.5' W to 12˚.36' E. Algeria has a varied climate from the North to the South and from the east to the west [36].

With an area of 2381740 km$^2$, Algeria is one of the vast countries of the world [13]. More than 90% of Algerian people, which is the largest coastal country in Africa, live in coastal areas [36]. The vastness of country, the population residing in the remote and desert areas, and difficulties and costs of connection to the main gas grid have created a large market potential for development and using SWH systems [13]. The 2010 statistics of Algerian gas and electricity organization show that there are 6.5 million electricity subscribers and 3.4 million natural gas subscribers [37]. Accordingly, it can be inferred that a large part of population connected to the main grid are still deprived of natural gas which is the main source of heating. Thus, SWH systems have to be developed even in the northern populated areas. Table 1 summarizes the required data for 39 studied stations to be used in TSOL which are also shown in Fig.5. These data are extracted from Meteonorm software which is installed along with TSOL software and it is responsible for creating climate files.

## 3. The Software and Relations Used

In studying the SDHWS performance there is a need to use dynamic analysis tools to accurately describe the system responses to rapid changes in environmental conditions. T*SOL Pro 5.5 is one of these tools, a professional simulation program for the design and planning of solar thermal systems [38]. It has facilitated the simulation and calculation process in these systems by providing tools and components of solar systems and also the relevant components such as hot water supply, swimming pool, heating process, buffer tanks, etc. This software enables the optimal design of solar thermal systems, temperature simulation, and their energy performance at lower cost and time [39]. In T*SOL Pro 5.5, calculations are preformed based on the balance of energy flows and provides yield prognoses according to the hourly meteorological data provided [39]. The total radiation received on a collector surface is a summation of direct and diffuse radiation. Direct radiation is available in the supplied climate files and the calculations of diffuse radiation striking collector surface are performed using α angle and hourly clearness index $K_t$ according to the following relations [40]:

| Table 1. The data of the studied stations | | | | | |
|---|---|---|---|---|---|
| Station | Latitude | Longitude | Total annual global irradiation (kWh/m²) | Cold water temperature (Feb./Aug.) $°C$ | Diffuse radiation percentage (%) |
| Adrar | 27.8 | 0.2 | 2252.7 | 22.5/29.5 | 31.8 |
| Ain sefra | 32.6 | 0.60 | 2159 | 16/22.5 | 37.1 |
| Annaba | 36.8 | -7.8 | 1757.5 | 16/19.5 | 41.3 |
| Batna | 35.6 | -6.2 | 1989.9 | 13/18.5 | 40.5 |
| Bejaia | 36.7 | -5.1 | 1716 | 16/20 | 44.1 |
| Beni-Saf | 35.3 | 1.4 | 1901.5 | 18/21 | 37.8 |
| Beni Abbes | 30.1 | 2.2 | 2285.7 | 19.5/26.5 | 31.7 |
| Biskra | 33.1 | -6.1 | 2115.3 | 19/26 | 31.3 |
| Bordj Bou Arreridj | 36.1 | -4.80 | 1923 | 13/19 | 38.6 |
| Bou-Saada | 35.3 | -4.20 | 1989.6 | 18.5/25 | 34.5 |
| Chlef | 36.2 | -1.30 | 18635.7 | 16/20 | 38.0 |
| Constantion | 36.3 | -6.60 | 1885.5 | 13.5/18.5 | 39.7 |
| Djanet | 24.6 | -9.5 | 2226.2 | 21/16.5 | 40.9 |
| Djelfa | 34.7 | -3.3 | 2001.3 | 13.5/19.5 | 40.5 |
| EL Bayadh | 33.7 | -1.0 | 2109 | 12.5/19 | 39.5 |
| EL Borma | 31.7 | -9.2 | 2215.9 | 21.5/28 | 29.9 |
| EL Golea | 30.6 | -2.9 | 2278.1 | 19.5/26.5 | 32.4 |
| EL Oued | 33.5 | -6.8 | 2086.2 | 19/26 | 32.0 |
| Ghardaia | 32.4 | -3.8 | 2210.7 | 19.5/26 | 30.3 |
| Hassi Messaoud | 31.7 | -6.5 | 2205.7 | 20.5/27.5 | 31.2 |
| Illizi | 26.5 | -8.4 | 2321.6 | 22/28.5 | 34.3 |
| In Amenas | 28.0 | -9.6 | 2301 | 20/26.5 | 32.7 |
| In Salah | 27.3 | 2.51 | 2232.9 | 24/30.5 | 32.3 |
| Jijel | 36.9 | 5.8 | 1722.7 | 17/20.5 | 44.0 |
| Mecheria | 34.9 | 0.4 | 1955 | 14.5/21 | 41.5 |
| Miliana | 36.3 | -2.2 | 1848.7 | 16/21 | 39.7 |
| Oran | 35.6 | 0.60 | 1893.8 | 16/20 | 37.9 |
| Ouargla | 31.9 | -5.40 | 2186.9 | 20/27 | 30.3 |
| Setif | 36.2 | -5.40 | 1914.5 | 12/17.5 | 40.7 |
| Skikda | 36.9 | -6.90 | 1765.9 | 16.5/20 | 41.9 |
| Tamanrasset | 22.8 | -5.5 | 2345.9 | 20.5/25 | 40.8 |
| Tebessa | 35.5 | -8.1 | 1940.2 | 13.5/19.5 | 39.3 |
| Tiaret | 35.3 | -1.4 | 1942.3 | 12.5/18 | 41.3 |
| Timimoun | 29.3 | -0.3 | 2270.4 | 21/28 | 31.0 |
| Tindouf | 27.7 | 8.1 | 2246.6 | 21/26.5 | 33.2 |
| Tlemcen | 35.0 | 1.5 | 1910.6 | 16/20 | 37.5 |
| Touggourt | 33.1 | -6.1 | 2115.3 | 19/26 | 31.3 |

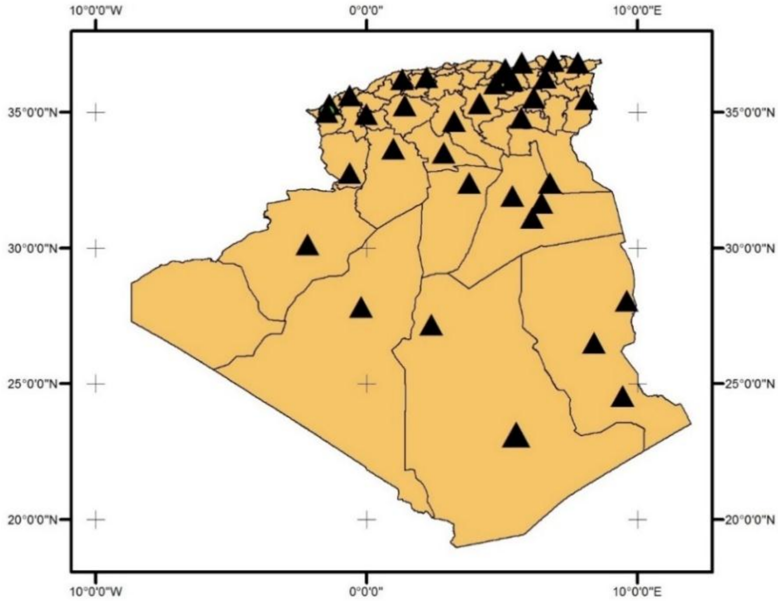


Figure 5. The geographical position of Algeria and the location of the studied stations.

**3. The Software and Relations Used**

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$$0 \le k_t \le 0 \cdot 3 \ : \ \frac{I_d}{I} = 1 \cdot 02 - 0 \cdot 245\, k_t + 0 \cdot 0123 \sin\alpha \quad (1)$$

$$0 \cdot 3 < k_t \le 0 \cdot 78 \ : \ \frac{I_d}{I} = 1 \cdot 4 - 1 \cdot 749\, k_t + 0 \cdot 177 \sin\alpha \quad (2)$$

$$k_t \ge 0 \cdot 78 \ : \ \frac{I_d}{I} = 0 \cdot 486\, k_t - 0 \cdot 182 \sin\alpha \quad (3)$$

Where I is the total hourly radiation on a horizontal surface (KJ/m$^2$) and $I_d$ is the hourly diffuse radiation on a horizontal surface (KJ/m$^2$). It is noteworthy that some incident radiation on the collector surface is wasted. The software calculates collector losses by [39]:

$$\rho = G_{dir} \cdot \eta_0 \cdot f_{IAM} + G_{diff} \cdot \eta_0 \cdot f_{IAM.diff} - k_0(T_{km} - T_A) - k_q(T_{km} - T_A)^2 \quad (4)$$

Where $G_{dir}$ is the part of solar radiation striking a tilted surface, $\eta_0$ is the collector's zero-loss efficiency, $f_{IAM}$is the incidence angle modifier factor, $G_{diff}$ is the diffuse solar radiation striking a tilted surface, $f_{IAM,diff}$ is the diffuse incidence angle modifier factor, $k_0$ is the heat transfer coefficient (in $\frac{w}{m^2-k}$), $T_{cm}$ is the average temperature of collector, $T_A$ is the air temperature, and $k_q$ is the heat transfer coefficient (in $\frac{w}{m^2-k^2}$).

The software considers solar system's $CO_2$ emissions savings of 5.14355 g per KJ of energy generated [39]. The energy supplied by collectors is obtained by dividing the energy transferred from solar system to the standby tank by total energy supply of standby tank (solar system + auxiliary heating) according to the following relation [39]:

$$\text{Solar fraction. total} = \frac{Q_{CL.DHW} + Q_{S.HL}}{Q_{CL.DHW} + Q_{S.HL} + Q_{AuxH.DHW} + Q_{AuxH.HL}} \quad (5)$$

Other relations used in simulations, shown schematically in Figure 3, are as follows [39]:

$$\text{Solar fraction DHW} = \frac{Q_{CL.DHW}}{Q_{CL.DHW} + Q_{AuxH.DHW}} \quad (6)$$

$$\text{Solar fraction heating} = \frac{Q_{S.HL}}{Q_{S.HL} + Q_{AuxH.HL}} \quad (7)$$

**4. Simulation Data**

Information on the temperature, geographical position, municipal water temperature, and total annual global radiation for the studied stations is presented in Table 1.

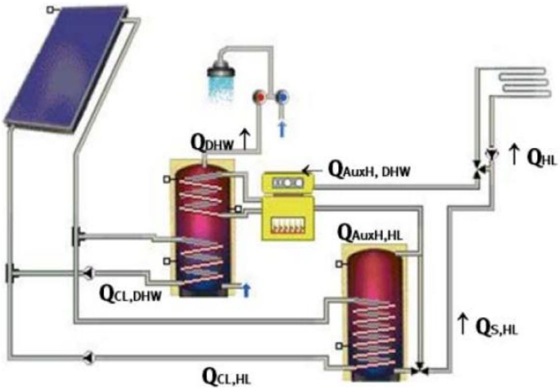


Figure 6. Schematic of solar system with bivalent storage tank (internal heat exchanger).

These stations are also shown in Figure 5. Daily average sanitary hot water consumption of 110L, sanitary hot watertemperature of 60 ˚C, and operating period of the whole year were considered. Furthermore, the space heating load of 10 kW, space temperature of 21 ˚C, and heated useable area of 80 m$^2$ were applied. Double glazed windows with an area of 1.6, 4, 8, and 5.6 m$^2$ were considered for north, east, south, and west facing windows, respectively. 5 W/m$^2$ heat gain due to internal heat sources was also considered. By the way, heating load requirements of the building were assumed as constant throughout the year (except June & July). Also, “thick” wall type was considered. Solar water heater and other accessory equipment such as buffer tanks, piping's, boiler, etc. were all the same in stations for comparison purposes. The used solar water heater was of a standard flat-plate type with an area of 19 m$^2$ and 0 ˚ azimuth angle. Double coil buffer tanks for sanitary hot water and space heating were used having 300 L and 1000 L capacities, respectively (As shown in Figure 6). Also, a gas boiler with rated capacity of 9 kW was utilized. Water/polypropylene glycol in 60/40 ratio and a rate of 40 L/m$^2$ was used as the intermediate heat transfer fluid. In case of high requirement for space heating, in/outlet temperature difference of 20 ˚C and for other cases 15 ˚C were considered. The general schematic of the simulated system is shown in Figure 7. It should be noted that the solar panels tilt angle was equal to the latitude of the studied area [41].

**5. Results**

From the results presented in Table 2 it can be seen that In Salah, Tamanrasset, and Adrar stations providing respectively 85.6%, 81.2%, and 76.7% of the required heat for space heating and sanitary hot water are the most suitable stations in terms of using SWH. Regarding the space heating, El Bayadh (3652 kWh), Batna (3549 kWh), El golea (3546 kWh) stations provide the highest rate of heat. However, In Salah, Tamanrasset, and Adrar stations with respectively 72.3%, 68.1%, and 62.9%, have provided the highest percentage of space heating demand through SWH systems. El Bayadh (2912.34 kWh), Batna (2885.27 kWh), and Djelfa (2859.48 kWh) stations have produced the highest solar heat to be used for sanitary hot water. It should be mentioned that in terms of meeting the sanitary hot water demand, 16 stations namely Adrar, Beni Abbes, Biskra, EL Borma, El Golea, EL Oued, Gharadaia, Hassi Messaoud, Illizi, In Amenas, In Salah, Ouargla, Tamanrasset, Timimoun, Tindouf, Touggourt, have been able to provide 100% of their demand by SWH. With regard to savings in $CO_2$ emissions (kg/y) due to higher share of SWH systems for providing the required heat, EL Bayadh (1732.59 kg), Batna (1704.53 kg), and Ain Sefra (1696.1 kg) stations are the most suitable stations.

Since SWH cannot meet 100% of the residential apartment’s demands, there is a need for auxiliary boiler in all stations. From the results it is obvious that the gas-fired boiler is mostly needed in Setif (12713 kWh), Tiaret (12010 kWh), Constantion (11629 kWh) stations, respectively. It is noteworthy that all three stations mentioned have the lowest total solar fraction with 32.3%, 34.1%, and 33.1%, respectively.

As a general conclusion it can be suggested that the average total solar fraction for Algeria is 53%, the average and aggregated heat provision for space heating are respectively 2842 kWh (38.2%) and 150160 kWh, the average and total heat provision for sanitary hot water are respectively 2699 (99%) and 99861 kWh, the average and total annual savings in $CO_2$ emissions are respectively 1535 and 56783 kg, and the average heat provided by gas-fired boiler for space heating and sanitary hot water are respectively 5908 and 29.5 kWh.

| Table 2. The results of studied parameters. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Station | Total solar fraction (%) | Solar contribution to heating (kWh) | Heating solar fraction (%) | Solar contribution to DHW (kWh) | DHW solar fraction (%) | $CO_2$ emissions avoided (kg) | Boiler energy to heating (kWh) | Boiler energy to DHW (kWh) |
| Adrar | 76.7 | 2659 | 62.9 | 2517.04 | 100.0 | 1479.61 | 1569 | 0 |
| Ain sefra | 52.0 | 3463 | 37.4 | 2807.27 | 99.8 | 1696.10 | 5792 | 5.0 |
| Annaba | 38.8 | 2223 | 22.5 | 2697.17 | 97.0 | 1382.56 | 7666 | 85 |
| Batna | 37.9 | 3549 | 25.2 | 2885.27 | 98.9 | 1704.53 | 10525 | 32 |
| Bejaia | 37.5 | 2041 | 20.6 | 2713.62 | 97.2 | 1361.81 | 7581 | 80 |
| Beni-Saf | 53.2 | 1881 | 31.7 | 2744.87 | 99.9 | 1378.64 | 4056 | 18.3 |
| Beni Abbes | 64.5 | 3225 | 49.9 | 2648.29 | 100.0 | 1627.08 | 3234 | 0 |
| Biskra | 56.9 | 3073 | 41.3 | 2672.42 | 100.0 | 1593.82 | 4359 | 0 |
| Bordj Bou Arreridj | 34.0 | 3204 | 21.6 | 2818.45 | 97.5 | 1606.04 | 11622 | 72 |
| Bou-Saada | 52.0 | 2586 | 34.7 | 2683.43 | 99.9 | 1477.43 | 4865 | 2.4 |
| Chlef | 41.3 | 2802 | 26.3 | 2769.49 | 98.7 | 1542.49 | 7868 | 38 |
| Constantio n | 33.1 | 3032 | 20.7 | 2727.45 | 96.6 | 1555.07 | 11629 | 99 |
| Djanet | 65.2 | 2097 | 46.0 | 2571.49 | 99.0 | 1363.56 | 2465 | 27 |
| Djelfa | 37.3 | 3288 | 24.2 | 2859.48 | 98.8 | 1640.37 | 10229 | 34 |
| EL Bayadh | 38.7 | 3652 | 26.0 | 2912.34 | 99.3 | 1732.59 | 10398 | 20 |
| EL Borma | 71.6 | 2549 | 55.7 | 2572.40 | 100.0 | 1471.61 | 2030 | 0 |
| EL Golea | 65.1 | 3546 | 51.6 | 2649.81 | 100.0 | 1561.21 | 3328 | 0 |
| EL Oued | 57.2 | 2925 | 41.1 | 2671.73 | 100.0 | 1561.21 | 4095 | 0 |
| Ghardaia | 61.5 | 3038 | 46.0 | 2661.51 | 100.0 | 1588.95 | 3568 | 0 |
| Hassi Messaoud | 63.0 | 3033 | 47.8 | 2604.93 | 100.0 | 1573.92 | 3306 | 0 |
| Illizi | 75.4 | 2550 | 60.5 | 2547.43 | 100.0 | 1468.29 | 1665 | 0 |
| In Amenas | 65.7 | 3059 | 50.7 | 2635.28 | 100.0 | 1586.37 | 2972 | 0 |
| In Salah | 85.6 | 1942 | 72.3 | 2462.90 | 100.0 | 1316.36 | 743 | 0 |
| Jijel | 38.6 | 1935 | 21.1 | 2658.10 | 96.8 | 1325.52 | 7217 | 87 |
| Mecheria | 38.3 | 2902 | 24.2 | 2757.72 | 97.7 | 1541.72 | 9065 | 64 |
| Miliana | 36.3 | 2424 | 21.5 | 2660.12 | 96.5 | 1416.51 | 8835 | 98 |
| Oran | 48.0 | 2898 | 31.9 | 2813.80 | 99.4 | 1577.55 | 6174 | 16.6 |
| Ouargla | 64.7 | 3073 | 49.7 | 2627.82 | 100.0 | 1588.37 | 3114 | 0 |
| Setif | 32.3 | 3242 | 20.3 | 2853.21 | 97.2 | 1614.89 | 12713 | 77 |
| Skikda | 39.9 | 2171 | 23.0 | 2700.00 | 97.3 | 1382.67 | 7264 | 75 |
| Tamanrass et | 81.2 | 2602 | 68.1 | 2648.48 | 100.0 | 1508.44 | 1219 | 0 |
| Tebessa | 37.0 | 3136 | 23.8 | 2809.24 | 97.9 | 1592.99 | 10058 | 60 |
| Tiaret | 34.1 | 3421 | 22.2 | 2838.29 | 97.6 | 1651.62 | 12010 | 71 |
| Timimoun | 70.3 | 3028 | 56.1 | 2583.77 | 100.0 | 1573.44 | 2366 | 0 |
| Tindouf | 75.4 | 2741 | 61.2 | 2610.05 | 100.0 | 1536.39 | 1740 | 0.88 |
| Tlemcen | 46.7 | 3199 | 32.0 | 2793.29 | 99.0 | 1633.03 | 6801 | 30 |
| Touggourt | 55.9 | 2971 | 40.0 | 2672.60 | 100.0 | 1570.65 | 4461 | 0 |

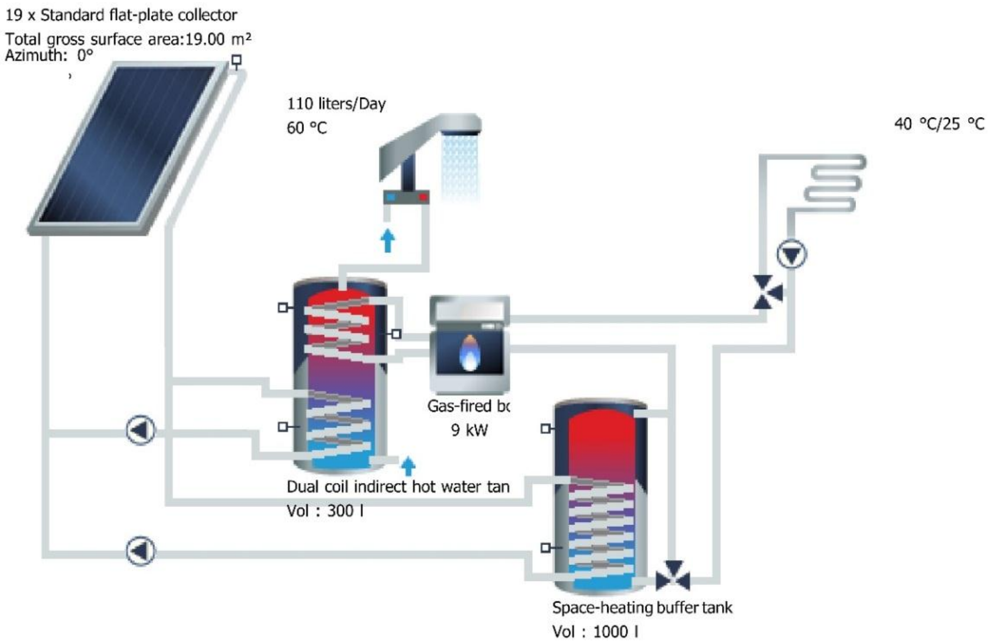


Figure 7. The specifications and components of simulated system.

## 6. Conclusion

Water heating accounts for 20% to 30% of total energy consumption in a house. SWHs are one of the most effective initiatives for public and easy utilization of solar energy for providing domestic hot water. SWHs can provide 70% of energy required for water heating annually [42]. Although SWHs have a good market potential in Algeria, their development and commercialization has been blocked by such obstacles as lack of a specialized domestic industry and incentive regulations [13]. Therefore in the current study, TSOL and MeteoSyn software are used to investigate the feasibility of using SWHs for meeting the heating demands of a 80 $m^2$ residential building in 37 station in Algeria. Results indicated that:

- Regarding the simultaneous provision of heat required for space heating and sanitary hot water, In Salah station is the most suitable one in which SWH system accounted for 85.6% of total thermal energy required.
- In terms of heat production to be used for space heating and sanitary hot water, EL Bayadh station is the best one with generating 3652 kWh and 2912.34 kWh of heat by SWH, respectively.
- For 16 stations of Adrar, Beni Abbes, Biskra, EL Borma, EL Golea, EL Oued, Gharadaia, Hassi Messaoud, Illizi, In Amenas, In Salah, Ouargla, Tamanrasset, Timimoun, Tindouf, Touggourt, SWH system has been able to provide 100% of the heat required for sanitary hot water.
- Saving 1732.59 kg of $CO_2$ emissions annually, EL Bayadh station is the most environmentally-friendly station.
- The highest need to gas-fired boiler which is associated with the lowest total solar fraction (32.3%) is related to Setif station which requires 12713 kWh of heat to be produced by boiler annually.

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