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Research article

Techno-enviro assessment and dynamic energy balance simulation of the domestic-scale solar heating system in Lebanon

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Abstract

Statistics show that the residential and service sectors consume a large amount of the total generated energy in every country, most of which is spent for space and water heating. Solar water heater (SWH) as a recently developed technique can be used for supplying most of the energy consumption which is necessary to be considered for social and economic development and continuously improving the quality of life. Practical measures of SWH for space and water heating have not been developed enough and no feasibility study has been conducted on the subject in Lebanon. To do so, using the energy software such METEOSYN and TSOL as very important pre-fabrication tools for the simulation, modelling and analysis of every management applications for energy development-based systems, we study the potential of using domestic-scale SWHs in residential apartments at 2 stations in Lebanon. The results show that Tripoli station, which supplies 37.8% of its total heating needs, is more suitable than Riyaq, which could provide for 32.1% of its total needs. The results also demonstrate that both stations produce 2915.7 kWh for space heating and 5403.7 kWh for water heating annually using SWH. This method prevent the emission of 2.4 tons of CO_2 pollutant gas annually based on fossil fuels.

Keywords: Buffer tank, Gas boiler, Urban network, Water temperature, Heating load.

Nomenclature:

k_t	Hourly clearness index	T_A	Air temperature
I	Total hourly radiation on a horizontal surface (kJ/m^2)	T_{cm}	Average temperature of collector
I_d	Hourly diffuse radiation on a horizontal surface (kJ/m^2)	k_q	Heat transfer coefficient in $W/m^2.k^2$
G_{dir}	Part of solar radiation striking a tilted surface	$Q_{CL;DHW}$	Collector loop heating for domestic hot water
η_0	Collector's zero-loss efficiency	$Q_{S;HL}$	Solar heating for heating load
f_{IAM}	Incidence angle modifier factor	$Q_{Aux;DHW}$	Auxiliary heating for domestic hot water
G_{diff}	Diffuse solar radiation striking a tilted surface	$Q_{Aux;HHL}$	Auxiliary heating for heating load
$f_{IAM,diff}$	Diffuse incidence angle modifier factor	EWH	Electric water heater
k_0	Heat transfer coefficient in $W/m^2.k$	SWH	Solar water heater
α	Tilt angle	ρ	Collector losses
LT	Low temperature	DHW	Domestic hot water

1- Introduction

Due to the increase in global energy demand, there are important concerns for energy producers such as accessibility of and dependence on fossil fuel resources, greenhouse gas emission, the destruction of the environment caused by producing energy from fossil fuels and debates on their future effectiveness [1-3]. Statistics also indicate that the global demand for primary energy will most probably see an extra growth of 37% by 2040 [4]. According to the report by the International Energy Agency, renewable energy will be the biggest contributor in reducing the greenhouse gas emissions by 2050 [5]. Concerns about exhausting fossil fuel resources, growing energy security and environmental problems have caused policy makers all over the world to pay attention to renewable energy resources [6]. The development of solar energy as an alternative approach limits the use of fossil fuels that emit too much greenhouse gas and cause climate change [7]. Solar energy can be considered as a good choice for replacing fossil fuels in the residential sector [8]. Considering its share of the total consumption, domestic water heating is one of the main energy concerns of residential buildings [9, 10]. The energy demand for water heating can be provided through various costly ways such as electricity or fossil fuels costly. SWHs not only can reduce costs, but also have unique advantages like producing clean and sustainable energy [11-13].

Fig. 1 shows that the total solar water heating capacity installed around the world reached 472000 megawatts thermal (MWt) by 2017 [14]. The graph in Fig. 1 also demonstrates SWHs have garnered as much attention in the world as wind turbines. The total SWH capacity (in gigawatt thermal) is approximately 1.17 times the capacity of all solar cells in the world (in gigawatt electric). The growing global trend of installing SWH capacity shown in Fig. 2 indicates that this technology has been able to make inroads into heating systems.

According to the investigations, very few articles, which will be introduced next, have studied the use of SWH in Lebanon. Houri studied the current situation and future outlook of using domestic-scale SWHs in Lebanon in 2006 [16]. He stated that using SWHs is an economical water heating alternative. His study illustrated that only 100,000 of the possible 1,500,000 m^2 was used by solar collectors. His initial approximation indicated a return on investment in 4-5 years, while RETSCREEN software approximated it to be less than 9 years. Government support and reducing taxes were proposed as approaches for increasing SWHs used in Lebanon and increasing the price of fossil fuels will increase the trend of using SWHs. In 2013, Ruble and El Khoury studied Lebanon’s domestic SWH market, as well as its achievements and obstacles [17]. They studied a basic scenario as well as 2 renewable energy-based scenarios (the use of SWH was mandatory for (first) newly built houses and (second) already existing houses). The results for the primary scenario’s electricity consumption for water heating purposes were projected to reach 2430 GWh by 2027; while scenarios based on renewable energy project this amount to be 1550 GWh and 1393 GWh, respectively.

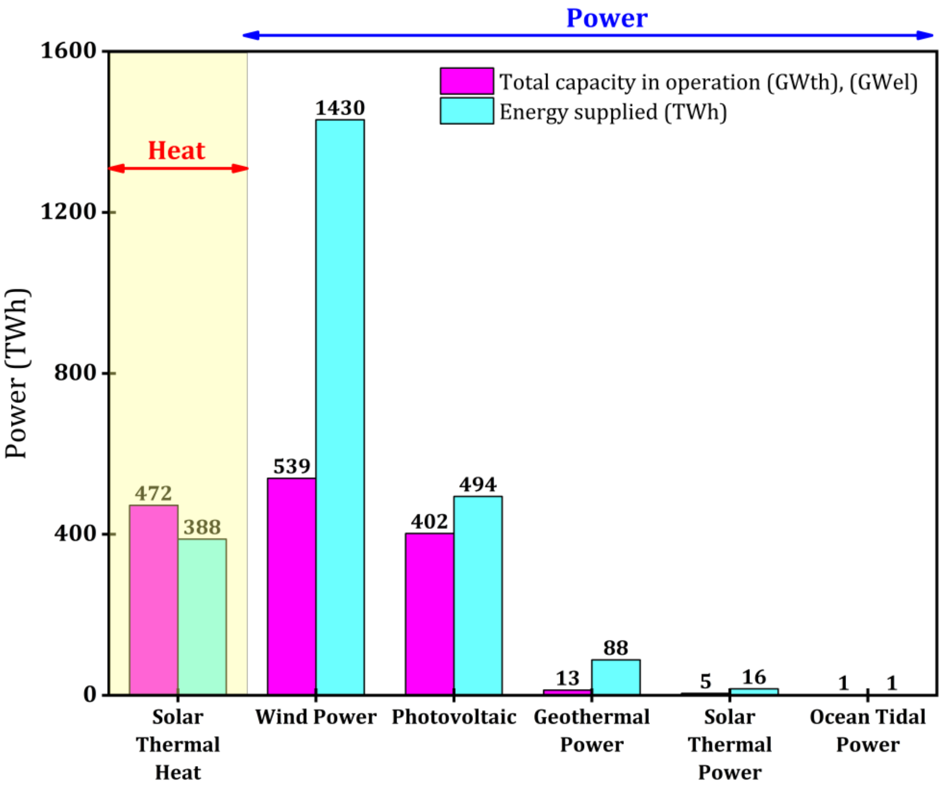


Fig. 1 Global capacity in operation and annual energy yields in 2017 [14].

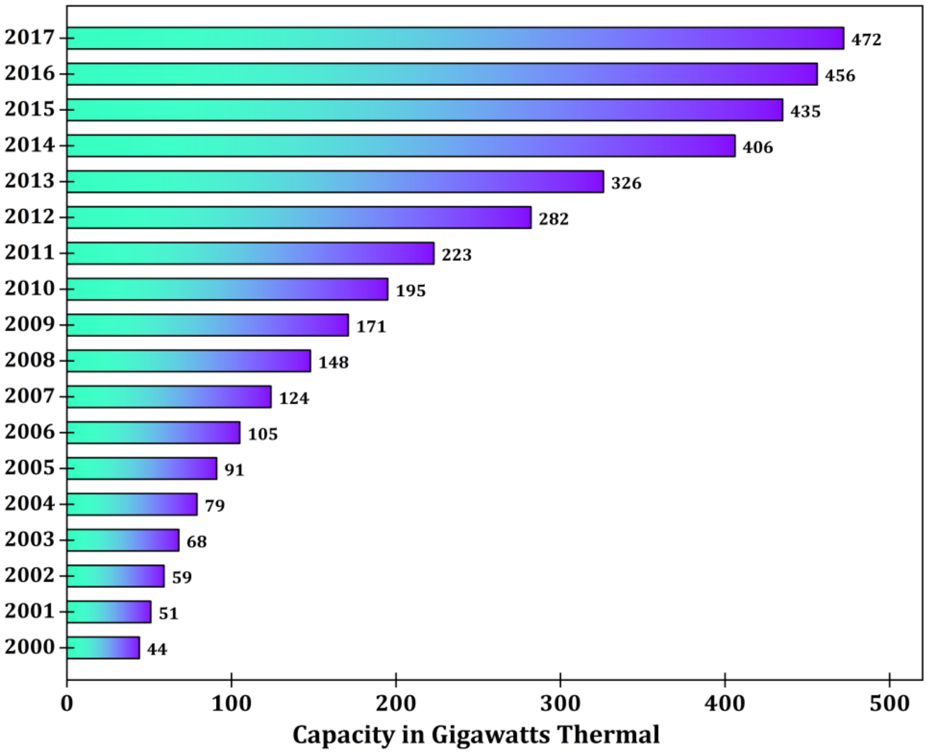


Fig. 2 Global solar thermal capacity in operation 2000 – 2017 [15].

To the best of our knowledge, the use of SWH for providing a residential building’s heating requirements in Lebanon has not been studied. No environmental studies have been conducted on this subject, either. Therefore, in this study, we are going to analyze the behavior of SWHs monthly and annually in two stations located in Lebanon using TSOL software. The parameters under this study include the required heating supply for space heating, heating required for sanitary consumption water, prevention of CO_2 pollutant emissions and the use of auxiliary boilers.

2- The under study stations

Lebanon is a high and mountainous country located on the eastern shore of the Mediterranean Sea. As a Middle Eastern country, Lebanon has a coastal border with the Mediterranean Sea of approximately 225 km. Lebanon's border with Syria is 375 km, while its border with Israel is only 79 km. With an area of only 10452 km^2, Lebanon is one of the smallest countries in the world which is the 162nd country in the world in terms of scale. Many of Lebanon's regions are mountainous, except a narrow coastal region and the Beqaa valley which is an important part of Lebanon's agricultural industry [18]. Lebanon's location on the world map is shown in Fig. 3.

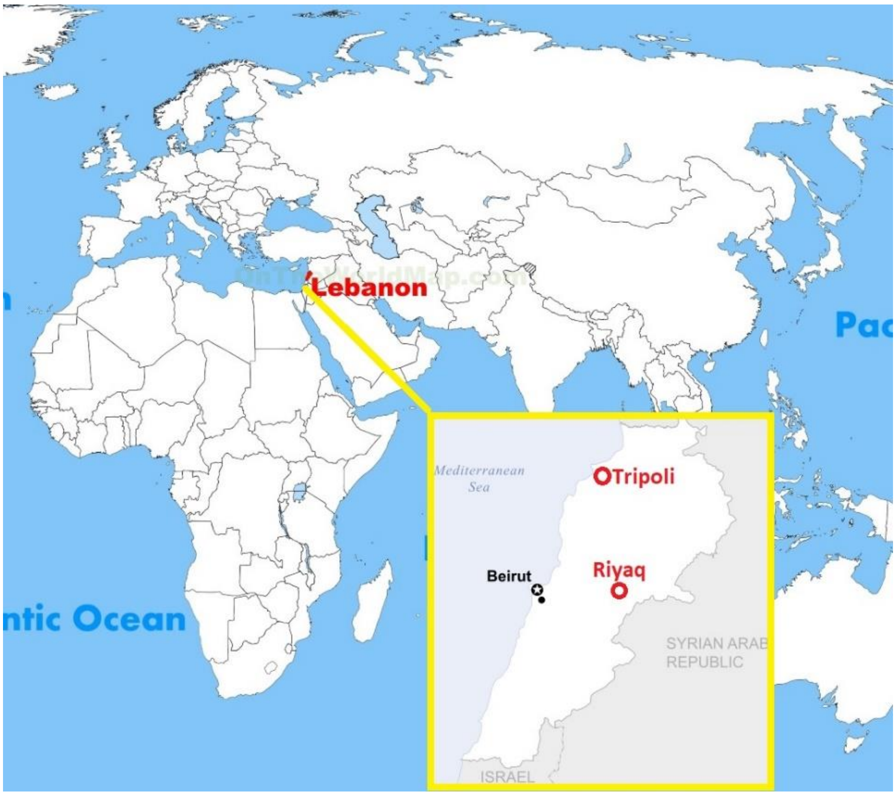
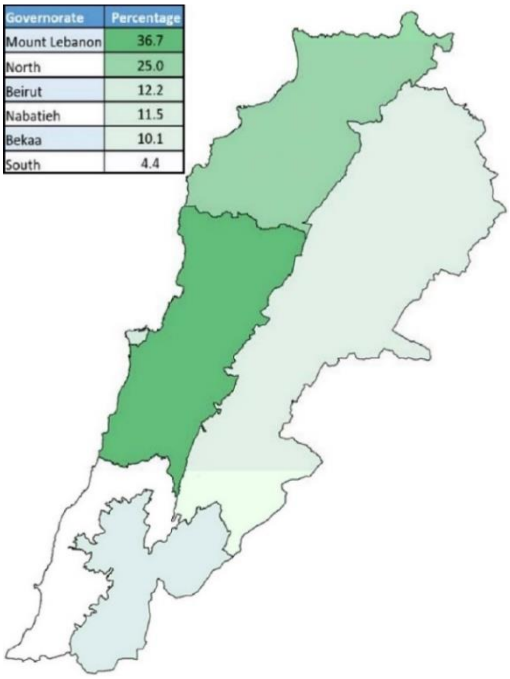


Fig. 3 Lebanon and the stations under study

Lebanon has a Mediterranean climate. The coastal regions are cold and rainy in winter and warm and humid in summer. In higher regions and especially mountains, winters are snowy, and the temperature falls below zero. Other regions have warm and dry summers. Although Lebanon is located on the solar belt of the Mediterranean, it depends on imported fossil fuels for 97% of its energy consumption. This issue has made Lebanon vulnerable to international oil price fluctuations. Therefore, it was announced for the first time in 2010 that Lebanon intends to supply 12% of its total electricity needs from renewable energy by 2020 [17]. About 35% of Lebanon's electricity is consumed in the domestic sector [19], 20% of which is used for water heating [20, 21]. Fig. 4 shows the distribution of Lebanon's SWH use in various regions [22]. This figure illustrates that the Mount Lebanon region has the highest number of installed SWHs, while the South has the lowest.

According to Fig. 5, studies show that 81% of Lebanese households use electric water heaters for providing warm water, while about 13% use solar heating [23]. It is also stated that about 63% of installed water collectors are flat plates and the rest are vacuum tubes. Information required by TSOL for the two stations being investigated are presented in Table 1, and the climate data for both stations have been extracted using Meteonorm, which is installed along with TSOL and used for producing climate files [24]. The locations of under study stations are shown in Fig. 3.



Governorate	Percentage
Mount Lebanon	36.7
North	25.0
Beirut	12.2
Nabatieh	11.5
Bekaa	10.1
South	4.4

Fig. 4 Geographic distribution of using SWH in Lebanon [22]

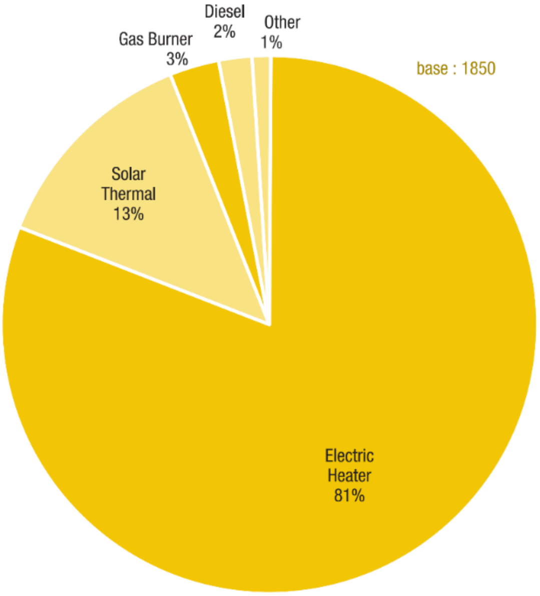


Fig. 5 Domestic water heating methods (Residential users) [23]

Table 1: The information of stations under study

Station	Latitude	Longitude	Total annual global irradiation (kWh/m^2)	Diffuse radiation percentage (%)	Cold water temperature (Feb./Aug.) ºC
Riyaq	33.87	-36	2061.471	38.1	13.5/19
Tripoli	34.45	-35.8	1770.276	42.9	18/21.5

3- Software and the required equations

TSOL is a software for the design and simulation of solar heating systems that makes it possible for the users to calculate the accuracy and precision of a solar heating system for a one-year period by supplying warm water, space heating, pool heating, procedural heating, and large-scale systems. TSOL is designed for simulating solar heating systems of separate and semi-separate homes (with one barrier wall) and makes it possible to present and display the related solar heating systems instantaneously, including revenue and profitability projections [24]. Calculations are performed in TSOL based on balanced energy flow and supplying final demand using hourly meteorology data [25-27].

The amount of radiation incident on the collector's surface, comprising the total of direct and diffused radiations, is a key parameter studied in solar energy-related research. Direct radiation in terms of kJ/m^2 refers to sunlight that reaches the collector directly from the source. This type of radiation arrives directly at the collector's surface from the solar angle and plays a primary role in forming the incident radiation on the collector. Diffused radiation in terms of kJ/m^2 refers to sunlight reaching the Earth's surface that is scattered in the atmosphere and deviates from its direct path. This radiation includes sunlight arriving at the collector's surface from various directions, and thus, geographical location and atmospheric conditions are influential factors in this type of radiation. The total radiation incident on the collector's surface results from the combination of these two types of radiations. This radiation is of significant importance as it affects the collector's ability to absorb and convert solar radiation into energy. There is a direct radiation in the climate files and the amount of diffused radiation directly hitting the collector's surface with an angle of α and hourly air quality index of k_t is calculated using the following equations [26]:

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

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

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

Where "I" is hourly total radiation on a horizontal surface (kJ/m^2) and I_d represents hourly diffuse radiation on a horizontal surface. It's worth mentioning that a part of radiation hitting the collector is wasted. In TSOL software, the collector loss is calculated as follows [25]:

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

where G_{dir} is a part of solar irradiation striking a tilted surface, η_0 is the zero-loss collector efficiency, f_{IAM} is incident angle modifier, G_{diff} is the diffuse solar irradiation striking a tilted surface, $f_{IAM,\ diff}$ is the correction coefficient for the diffused radiation angle, k_0 is the heat transfer coefficient in terms of $\frac{w}{m^2-k}$, T_{km} is the average collector temperature, T_A is the air temperature and k_q is the heat transfer coefficient in terms of $\frac{w}{m^2-k^2}$.

The software applied the prevented factor of CO_2 pollutant emission with 5.14355 grams per each kJ of energy produced from natural gas [25]. The amount of energy supplied by collectors is calculated by dividing the energy supply sent from the solar heating system to the standby tank by the total energy supplied to the standby tank (solar system+auxiliary heating) as follows [27]:

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

Fig. 6 shows the schematic view of our heating system in which the equations of such system for the design and simulation are organized as follows [25]:

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

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

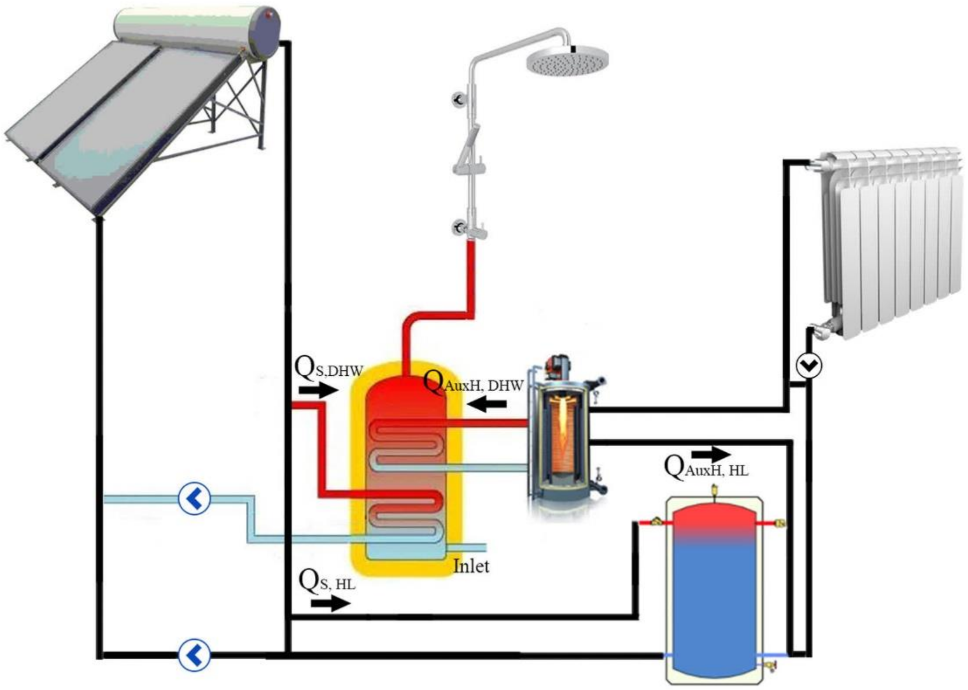


Fig. 6 Schematic of solar system with bivalent storage tank (internal heat exchanger)

4- The required data for simulations

Thermal information, geographic position, water temperature of urban network, and annual global radiation (presented in Table 1) are necessary for simulations. The stations studied here are shown in Fig. 3. The average volume of sanitary hot water for daily use is 110 liters with the temperature of 60°C. The period of time required for sanitary hot water is the whole year. In addition, the thermal load used for space heating is 10 kW, the space temperature and the built-up area being heated are 21°C, and 80 m^2, respectively. Windows are double glazed and the area of north, east, south, and western windows are 1.6, 4, 8 and 5.6 m^2, respectively. The heat produced by heating equipment inside the building is considered to be 5 W/m^2. The building heating requirement is invariable (except from May to September that are equal to zero). The building's wall materials are the “medium” type. The SWHs and other auxiliary equipment such as buffer tanks, pipe length, used boiler, etc. are the same for both stations. The type of used water heater has 14 m^2 area with flat plate and the azimuth angle of zero degree. As shown in Fig. 6, the buffer tanks for sanitary hot water consumption and space heating are two- and one-coil types and have 300 liters and 1000 liters capacity respectively. The boiler is gas-fueled with a nominal capacity of 9 kW. The intermediate fluid is 40 to 60 propylene glycol-water and the flow for each square meter is 40 liters per hour. In case of urgent need for space heating, the difference between outlet and inlet temperature is considered to be 20°C, and 15°C in other conditions. The complete schematic of the simulated system is presented in Fig. 6. It’s worth mentioning that the solar collectors’ placement angle is set based on the region’s latitude.

5- Results and discussion

Simulation results presented in Table 2 demonstrate that the Tripoli station provides 37.8% of its total space heating and sanitary water heating needs. This station is more suitable than Riyaq station, which supplies 32.1%. Therefore, the Tripoli station is a better choice for using SWH.

Regarding the necessity of space heating supply, the Riyaq station produced 1911.87 kWh which is more than the Tripoli station’s that was 1003.85 kWh. On this subject, the Riyaq station supplied 16.2% of its space heating needs through SWH, compared with the Tripoli station’s that was 14.8%.

The Riyaq station could produce 2820.32 kWh of solar heating for the use in sanitary water, higher than the Tripoli station’s 2583.4 kWh. It’s worth mentioning that both stations could supply more than 95% of their sanitary hot water needs through SWHs.

By using SWHs for supplying required heating, the Riyaq station prevented the emission of 1323.59 kg of CO_2 pollutants per year, compared to the Tripoli station’s (1111.02 kg). Since SWHs cannot supply all the heating needs of a residential apartment, there was a need in both stations for auxiliary boilers. As the results show, the Riyaq station needs 9990 kWh annually, which is the highest supplied by the auxiliary gas boiler.

Table 2. Results of the 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)
Riyaq	32.1	1911.87	16.2	2820.32	97.4%	1323.59	9915	75
Tripoli	37.8	1003.85	14.8	2583.40	95.8%	1111.02	5801	112

Fig. 7 compares the energy produced by solar collectors with the total heating energy required by the residential building. As can be observed in this figure, the Riyaq and Tripoli stations don’t need auxiliary heating from boilers for 5 and 6 months of the year respectively, because the solar collectors were able to provide for 100% of their heating needs. Since there was no need for space heating in the warm seasons of the year (May to September), the collectors only had to supply hot water for sanitary consumption, which also indicates that the Tripoli station has a warmer climate than Riyaq. Results also show that most of the need for the auxiliary gas boiler was through the cold season starting December through March. Although, solar heating produced at Riyaq station is 1.32 times that produced at Tripoli station, the total solar deficit for Tripoli is higher than Riyaq, because the heating needs of Tripoli is about 0.65 of Riyaq. Also, the most critical state for the stations occurs in January, when about 800 and 650 kWh of heating should be supplied by the gas boilers at Riyaq and Tripoli, respectively.

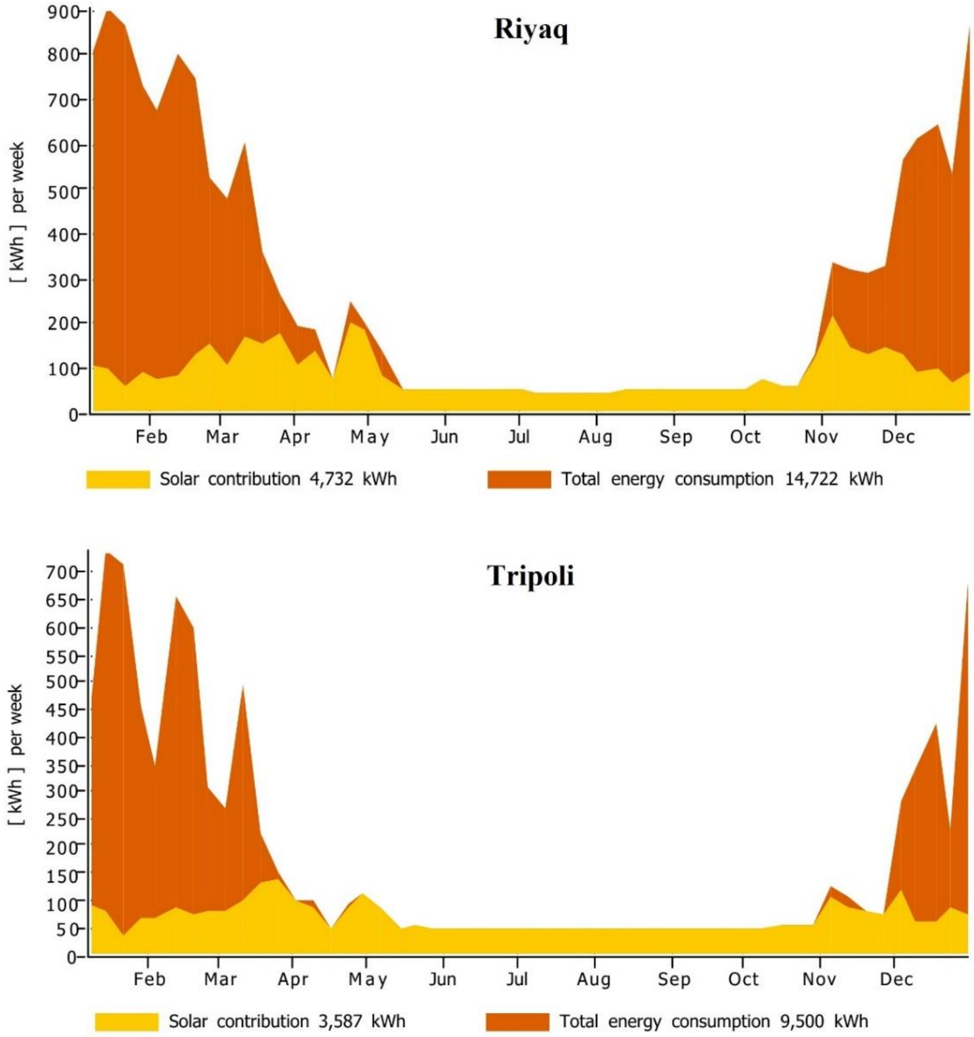


Fig. 7 Solar energy consumption as percentage of total consumption

Fig. 8 shows the maximum daily temperature of solar collector plates for each station in 12 months of a year. The results show that the temperature of Riyaq station's collector plates was more than 100°C in about 6 months of a year (May to October), and reached 130°C in some months. This causes more heat to be produced by Riyaq station's solar collectors compared to Tripoli, which is consistent with the results of Fig. 7. The collectors getting hotter at Riyaq station compared to Tripoli station leads to more heat waste. The results from Fig. 8 also illustrate that the least collector surface temperature was about 30°C in December, January, and

February at Riyaq and about 20°C in December and January at Tripoli.

Fig. 9 represents the energy balanced schematic for the solar water heating system's components at both stations. The results show that Riyaq's and Tripoli's solar collector plates received 32 and 27 MWh of radiation, respectively, which indicates a better radiation condition at Riyaq station. It should of course be mentioned that the collectors' optical and heat wastes at these stations were 24 and 20 MWh, respectively, which mean that the SWHS of Riyaq and Tripoli station produced 8 and 7 MW of pure heat annually. Also, it made clear by the system energy balance schematic is that most of the system's wastes are first at the tank-level and then the piping system. Such wastes were 2822 and 1249 kWh, respectively at Riyaq, and 2813 and 1179 kWh, respectively at Tripoli.

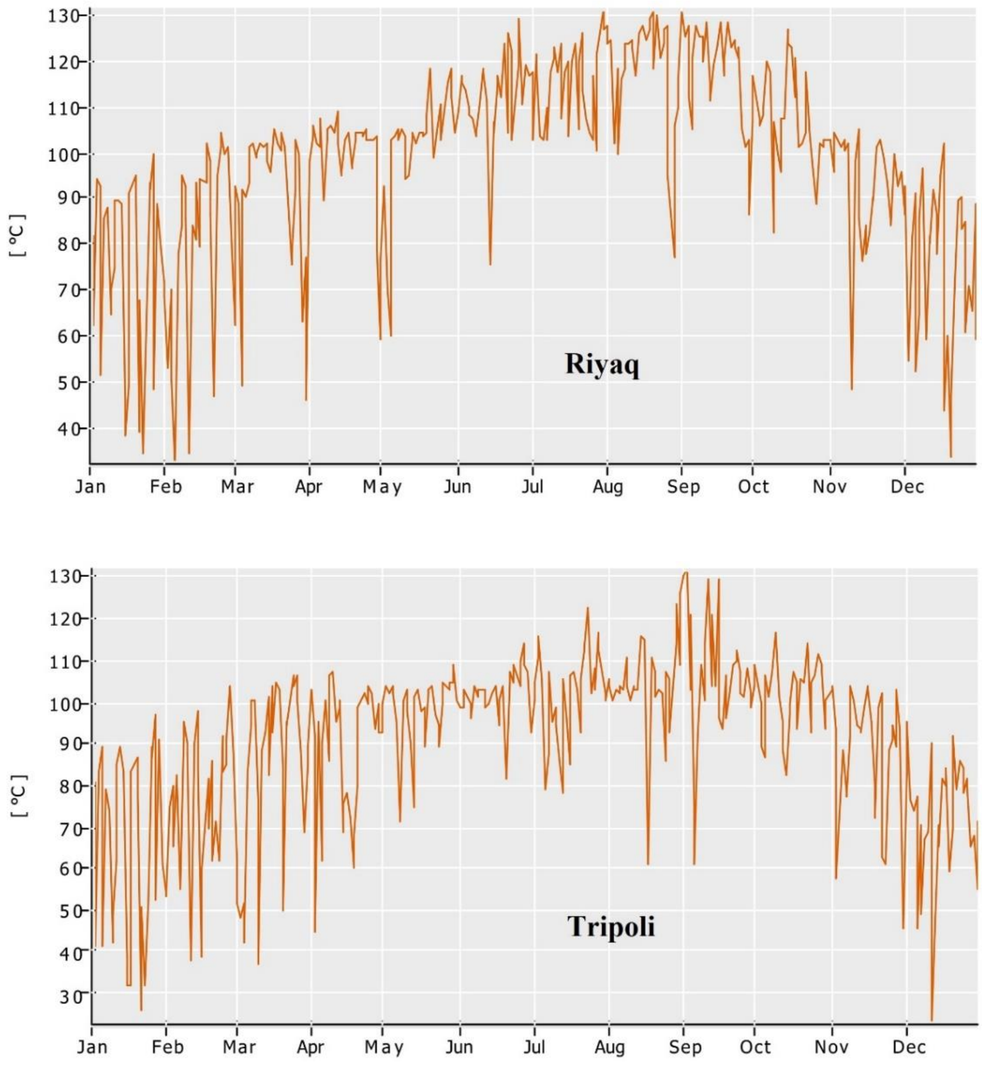


Fig. 8 Daily maximum collector temperature

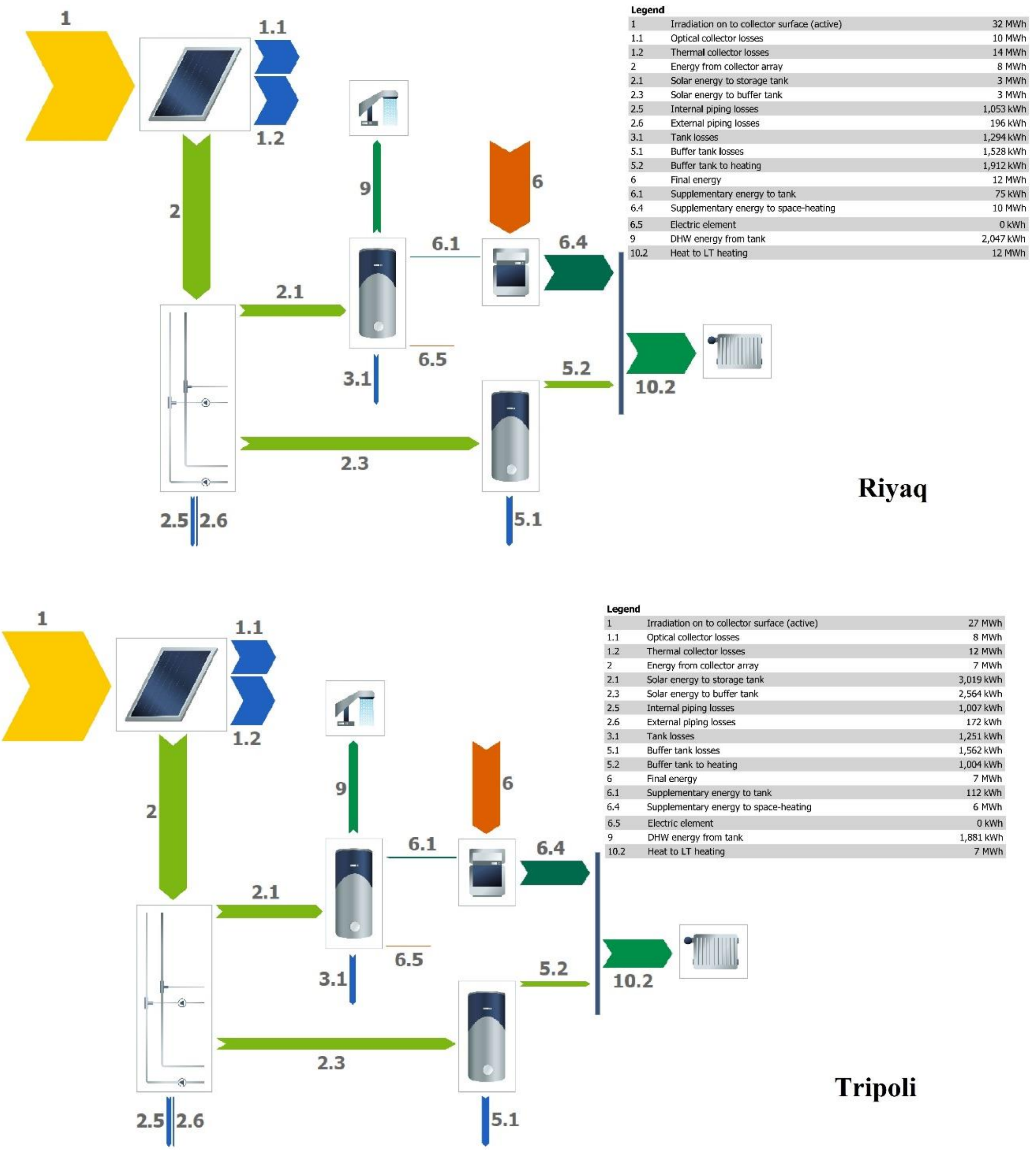


Fig. 9 Energy balance schematic

6- Conclusion

Solar water heating is a mature and cost-effective technology that has a growing trend in popularity all over the world. Despite this, the growth rate of SWH is still low in many countries, like Lebanon. Therefore, the current study used TSOL to study and evaluate the performance of SWH in supplying the hot water needs of a residential apartment in 2 stations, Riyaq and Tripoli, in Lebanon. The objective is supplying 110 liters of 60°C hot water for an apartment with 80 m^2 of built-up area and using a gas boiler whenever necessary. The main results are organized as follows:

- 2915.7 kWh of space heating was produced in total using SWH during a year at both stations.
- 5403.7 kWh of sanitary hot water was produced in total using SWH during a year at both stations.
- About 2.4 tons of CO_2 pollutant emission was prevented in total during a year at both stations.

- The need for gas boilers for supplying the required heat was 15903 kWh in total during a year at both stations.
- The average percentage of heat supply needed during a year for space heating and hot consumption sanitation water was 15.5 and 96.6% of the total, respectively, for both stations.
- During a year, solar collectors' optical and heat wastes were higher in Riyaq than in Tripoli.

References

[1] Mostafaeipour, A., Qolipour, M., Rezaei, M., Jahangiri, M., Goli, A., & Sedaghat, A. (2021). A novel integrated approach for ranking solar energy location planning: a case study. *Journal of Engineering, Design and Technology*, *19*(3), 698-720.

[2] Riahi Zaniani, J., Taghipour Ghahfarokhi, S., Jahangiri, M., & Alidadi Shamsabadi, A. (2019). Design and optimization of heating, cooling and lightening systems for a residential villa at Saman city, Iran. *Journal of Engineering, Design and Technology*, *17*(1), 41-52.

[3] Jahangiri, M., Mostafaeipour, A., Rahman Habib, H. U., Saghaei, H., & Waqar, A. (2021). Effect of emission penalty and annual interest rate on cogeneration of electricity, heat, and hydrogen in Karachi: 3E assessment and sensitivity analysis. *Journal of Engineering*, *2021*, 1-16.

[4] World Energy Outlook. Executive summary, 2014. *http://www.worldenergyoutlook.org* [Accessed 17 December 2023]

[5] IEA. *Energy technology perspectives* 2015. Paris: IEA; 2014.

[6] Mostafaeipour, A., Goudarzi, H., Sedaghat, A., Jahangiri, M., Hadian, H., Rezaei, M., & Karimi, P. (2019). Energy efficiency for cooling buildings in hot and dry regions using sol-air temperature and ground temperature effects. *Journal of Engineering, Design and Technology*, *17*(3), 613-628.

[7] Zaniani, J. R., Dehkordi, R. H., Bibak, A., Bayat, P., & Jahangiri, M. (2015). Examining the possibility of using solar energy to provide warm water using RETScreen4 software (Case study: Nasr primary school of pirbalut). *Current World Environment*, *10*(Special Issue), 835-841.

[8] Tabrizi, A. A., Saghaei, H., Mehranpour, M. A., & Jahangiri, M. (2021). Enhancement of absorption and effectiveness of a perovskite thin-film solar cell embedded with Gold nanospheres. *Plasmonics*, *16*, 747-760.

[9] Alayi, R., Jahangiri, M., & Najafi, A. (2021). Energy analysis of vacuum tube collector system to supply the required heat gas pressure reduction station. *International Journal of Low-Carbon Technologies*, *16*(4), 1391-1396.

[10] Almutairi, K., Mostafaeipour, A., Baghaei, N., Techato, K., Chowdhury, S., Jahangiri, M., & Issakhov, A. (2021). Techno-economic investigation of using solar energy for heating swimming pools in buildings and producing hydrogen: a case study. *Frontiers in Energy Research*, *9*, 680103.

[11] Mortazavi, M., Yaghoubi, S., & Jahangiri, M. (2022). Investigating the effect of buffer tank type on technical and environmental performance of solar heating systems in Iran. *International Journal of Smart Electrical Engineering*, *11*(2), 55-61.

[12] Haghani, A., Jahangiri, M., Riahi, R., Golali Jonaghani, M., & Baharizadeh, A. (2023). One-year Dynamic Study of the Use of Solar Water Heater for Domestic Consumption in Egypt: An Energy Assessment. *Iranian (Iranica) Journal of Energy & Environment*, *14*(3), 263-270.

[13] Babaei, M., Jahangiri, M., Riahi, R., Raeiszadeh, F., & Habib, H. U. R. (2023). Potential of the use of solar heat on a residential scale in Pakistan: Finding the best station. *International Journal of Smart Electrical Engineering*, *12*(3), 201-207.

[14] International Energy Agency (iea). Solar Heat Worldwide Edition 2018. *https://www.ises.org/sites/default/files/webinars/SHC%20Market%20and%20Industry%20Trends_WWeiss.pdf* [Accessed 17 December 2023]

[15] Statista. Capacity of solar water heating (SWH) systems worldwide from 2000 to 2017 (in gigawatts thermal). *https://www.statista.com/statistics/260688/forecast-capacity-of-csp-plants-worldwide-until-2050* [Accessed 17 December 2023]

[16] Houri, A. (2006). Solar water heating in Lebanon: current status and future prospects. *Renewable energy*, *31*(5), 663-675.

[17] Ruble, I., & El Khoury, P. (2013). Lebanon's market for domestic solar water heaters: Achievements and barriers. *Energy for Sustainable Development*, *17*(1), 54-61.

[18] Geography of Lebanon, *Wikipedia*, https://en.wikipedia.org/wiki/Geography_of_Lebanon [Accessed 17 December 2023]

[19] Mourtada, A. (2008). Energy efficiency in the building sector: Lebanese experience. National experiences in the field of energy conservation with a focus on building sector. *Round Table MedENERGAIA2008*.

[20] Chedid, R., Ghaddar, N., Chaaban, F., Chehab, S., & Mattar, T. (2001). Assessment of energy efficiency measures: the case of the Lebanese energy sector. *International journal of energy research*, *25*(4), 355-374.

[21] Ruble, I., & Karaki, S. (2013). Introducing mandatory standards for select household appliances in Lebanon: A cost-benefit analysis. *Energy policy*, *52*, 608-617.

[22] Gebrayel T. (2017), The Evolvement of the Solar Water Heaters Market in Lebanon. *Beirut: Lebanese Center for Energy Conservation (LCEC).*

[23] United Nations Development Programme (UNDP), (2014). *Lebanon's First National Survey Study of the Solar Water Heaters Market*. Including an Insight on the Solar Photovoltaic Market, Beirut: Ministry of Energy and Water- Beirut, Lebanon.

[24] Zarouri, A., Yaghoubi, S., & Jahangiri, M. (2023). Simultaneous Production of Heat Required for Space Heating, Sanitary Water Consumption, And Swimming Pool in Different Climates of Iran. *Journal of Solar Energy Research*, *8*(2), 1393-1409.

[25] Siampour, L., Vahdatpour, S., Jahangiri, M., Mostafaeipour, A., Goli, A., Shamsabadi, A. A., & Atabani, A. (2021). Techno-enviro assessment and ranking of Turkey for use of home-scale solar water heaters. *Sustainable Energy Technologies and Assessments*, *43*, 100948.

[26] Jahangiri, M., Akinlabi, E. T., & Sichilalu, S. M. (2021). Assessment and modeling of household-scale solar water heater application in Zambia: technical, environmental, and energy analysis. *International Journal of Photoenergy*, *2021*, 1-13.

[27] Rezapour, S., Jahangiri, M., Shahrezaie, A. G., Goli, A., Farsani, R. Y., Almutairi, K., & Techato, K. (2022). Dynamic simulation and ranking of using residential-scale solar water heater in Iran. *Journal of Environmental Engineering and Landscape Management*, *30*(1), 30-42.