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Research article

The feasibility of using solar heating in Yazd hospital: A case study

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Abstract

The most widespread use of solar energy as an alternative to fossil fuels is for heating. Considering the location of Iran and its location on the global Sunbelt, the aim of the present work is to provide part of the heat needed for the treatment space of Seyed Al-Shohda hospital in Yazd by using a flat plate solar collectors system. A one-year dynamic simulation has been performed using TSOL Pro 5.5 software, and energy-environmental-economic (3E) analyzes have been performed on the proposed system. The difference between the present work and the past works is that the provision of space heating and sanitary spa needed for a treatment space has not been done yet. The results of the investigations showed that about 2 MWh of solar heat is produced, which prevents the annual release of about 630 kg of CO_2 pollutants. Examining the system loss diagram also shows that the bottleneck of energy loss in the system under review is the hot water storage tanks, which have an annual energy loss of about 800 kWh. Financial analysis showed that the price of each kWh of solar heat production and the internal rate of return (IRR) are 0.0021 euros and 2.23%, respectively. The results of the present work indicate the excellent potential of Yazd in the field of using solar water heaters (SWH) for heating treatment spaces. The results of the present work can be used as a roadmap to help energy decision-makers and investors in this sector and accelerate the development of SWHs.

Keywords: Auxiliary boiler; Buffer tank; SWH; TSOL software.

Nomenclature:

N	Project lifetime (year)	T_{cm}	Average temperature of collector (K)
ρ	Collector energy balance (kW)	k_q	Quadratic heat transfer coefficient ($W/m^2.k^2$)
C	Cost of the SWH system ($)	V	Volume of space (m^3)
e	Useful life (year)	$Q_{S,DHW}$	Solar heating for DHW (kW)
n	Number of years (-)	$Q_{S,HL}$	Solar heating for heating load (kW)
d	Rate of decline (%)	K	Coefficient about outside temperature (K)
NPV	Net present value ($)	$Q_{AuxH,DHW}$	Auxiliary heating for DHW (kW)
Q	Space heating load (kcal/hr)	$Q_{AuxH,HL}$	Auxiliary heating for heating load (kW)

A	Floor area (m^2)	AF	Coefficient about height from sea level (m)
3E	Energy, economic, environment (-)	G_{dir}	Part of solar radiation striking a tilted surface (kW)
m_{window}	Surface of window (m^2)	η_0	Collector's zero-loss efficiency (%)
T_A	Air temperature (K)	f_{IAM}	Incidence angle modifier factor (-)
SWH	Solar water heater (-)	G_{diff}	Diffuse solar radiation striking a tilted surface (kW)
R_t	Total revenue ($)	$f_{IAM,diff}$	Diffuse incidence angle modifier factor (-)
η_h	Efficiency of the auxiliary boiler (%)	k_0	Simple heat transfer coefficient ($W/m^2.k$)
$C_{O\&M}$	Total annual operating and maintenance costs ($)	Q_u	Useful energy collected by the solar collectors (kW)
C_0	Total purchase cost ($)	m_{wall}	Surface of external walls (m^2)

1- Introduction

Considering the geographical location of Iran, large areas of the country have very high radiation intensity [1]. Also, with the ever-increasing costs of fossil fuels and electric energy [2], it is time to seriously use unlimited, clean and renewable sources of energy, such as solar energy, like many countries [3]. SWHs are one of the most effective plans for general and easy use of solar energy to provide domestic and industrial hot water [4]. Using SWHs to provide part of the required energy can be a basic solution for Iran's energy problem. Because Iran, having about 300 sunny days per year, is one of the best countries in the world in the field of solar energy exploitation [5].

Every hospital needs to supply large amounts of domestic hot water to develop health care related activities [6]. Therefore, it is necessary to analyze the energy savings that can be obtained by installing solar thermal energy for domestic hot water production in hospitals. These results provide hospital managers with useful information to make decisions about development investments.

Table 1 shows the history of previous studies in the field of solar water heaters. The subject of the present work is the supply of hot water and also the analysis and evaluation of the energy supplied from the technical-energy-economic-environmental point of view by TSOL Pro5.5 application software for a part of a hospital in Yazd city. According to the investigations in Table 1, the use of solar heating in hospitals has not been done in Iran so far. The results of the present work can be used as a road map to help decision-makers in the field of energy in Iran.

Table 1: History of studies conducted in the field of solar heating

References	Year	Methodology	Case study	Results
Jahangiri et al. [7]	2018	TSOL software	A residential house in Algeria	If SWH is used, 150160 kWh of thermal energy will be produced for space heating and 99861 kWh for the spa. Also, 56783 kg of CO_2 emissions is avoided annually.
Jahangiri et al. [8]	2018	TSOL software	A residential house located in 10 different Canadian provinces	With the production of 8186 kWh/year of heat, Regina station has been able to supply 35% of its required heat and is the best station in the field of using solar heat. Annually, the emission of more than 2 tons of CO_2 pollutants is prevented in this station.

Riahi et al. [9]	2019	Design Builder software	A residential villa in Saman city located in Chaharmahal and Bakhtiari province	The amount of cooling and heating of the building was optimized by insulating the walls and roof, and it resulted in an annual reduction of 86.9% of energy.
Saberi et al. [10]	2022	TSOL software	A residential apartment located in Shahrekord in Chaharmahal and Bakhtiari province	The total solar fraction for low, medium and high solar scenarios is 19.1%, 28.9% and 41%, respectively. In high solar fraction scenarios, the emission of 4 tons of CO_2 pollutants is avoided. The lowest cost of solar heat generation is $0.028 per kWh.
Tang et al. [11]	2022	TSOL software, GAMS software	A residential house located in 21 different cities in South Africa	The ranking was done using GAMS 24.1 software and the DEA method. The results showed that the vacuum tube solar water heater has 3.23% more total solar fraction than the flat plate, and about 1 ton prevents the emission of more CO_2 pollutants. Top stations are also Beaufort West, Mmabatho and Welkom.
Mortazavi et al. [12]	2022	TSOL software	Buffer tank type effect on the SWH systems performance in Iran	The highest system efficiencies for the three investigated arrangements belonged to Tehran, Shiraz and Tabriz, respectively.
Zarouri et al. [13]	2023	TSOL software	Using SWH for space heating, sanitary water consumption, and swimming pool in different climates of Iran	The "tank-in-tank combination tank" has shown better performance than "indirect water storage tank" in terms of different parameters.
Haghani et al. [14]	2023	TSOL software	Energy assessment of the use of SWH for domestic consumption in 35 stations in Egypt	Sharm el sheikh station is the top station for using SWH systems. Using SWHs in the studied stations generated 134.5 GWh of solar heat and prevented the emission of about 39.2 tons of CO_2 pollutants per year.
Present work	2023	TSOL software	Providing part of the heat for a hospital in Yazd, Iran	The total solar fraction is 26.5%, Preventing the production of pollutants equal to 629 kg/year and solar heat for the investigated system has a price of 0.0021 €/kWh.

2- Problem description

As shown in Fig. 1, the research site of Yazd Seyed Al-Shohada Hospital was selected. Yazd is located at 15 degrees and 53 minutes to 40 degrees and 54 minutes of longitude and 46 degrees and 31 minutes to 15 degrees and 32 minutes of latitude. Little rainfall with intense evaporation, far from the sea, proximity to the dry and vast salt desert, and low relative humidity and heat are many factors that make Yazd one of the driest regions of Iran [15]. The location of Yazd city on the map of Iran is also shown in Fig. 1.

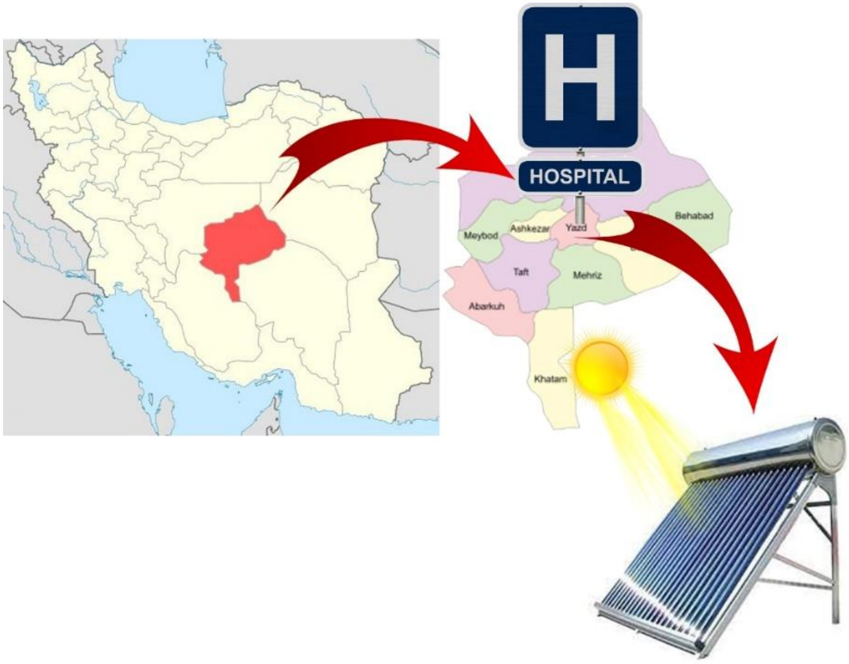


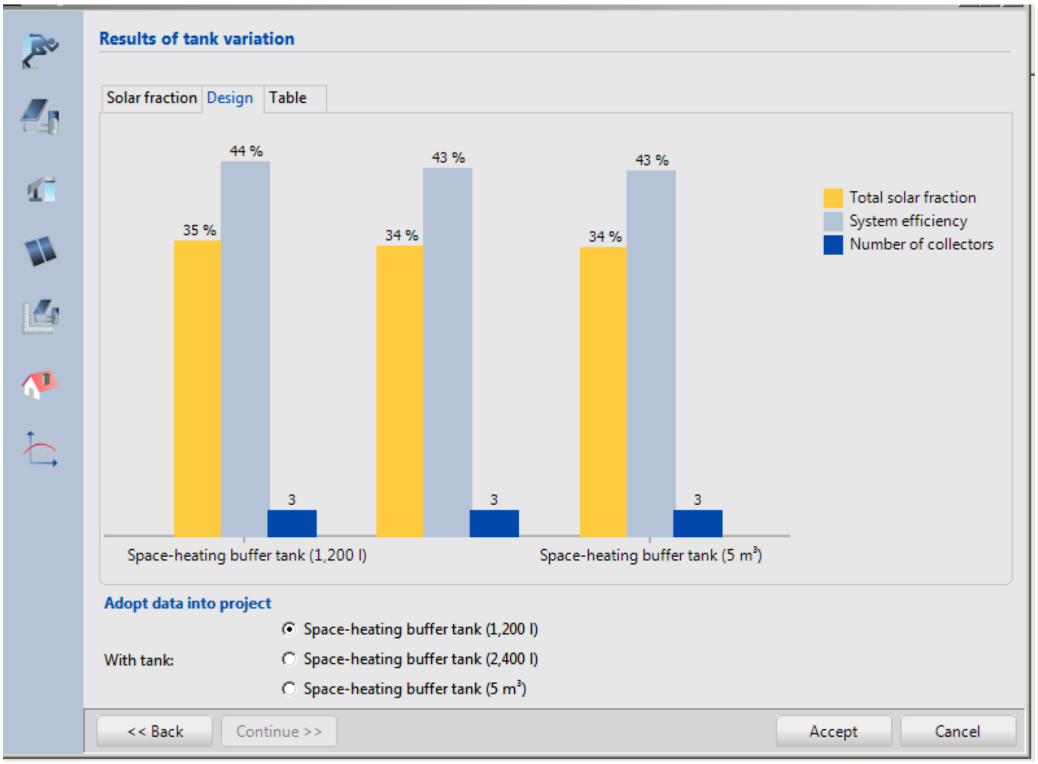
Fig. 1 Location of the investigated hospital.

This hospital with 178 beds, multiple inpatient departments, operating rooms, special service departments, clinics, and emergency and various paraclinical services, welcomes patients from different regions of the country and also some neighboring countries. This hospital has 96,000 m^2 of infrastructure in the main buildings and 26985 m^2 is the foundation of the side buildings and parking lot. The size of the x-ray room that was selected for investigation in the present work is 120 m^2.

3- Methodology

TSOL Pro5.5 simulation software has provided facilities to calculate the accuracy and precision of a solar thermal system for a period of one year and in a completely dynamic way [16]. In fact, TSOL Pro5.5 is a professional simulation program for designing and planning solar thermal systems. This software provides tools and components of solar systems as well as parts related to these systems such as hot water sources, swimming pools, heating processes, buffer tanks, etc., simulation, and calculations for such systems and made it much easier. This makes it possible to optimally design solar thermal systems, simulate temperature and check energy performance by using TSOL software with less time and cost [17].

The results of the preliminary investigations carried out by the software for the investigated location are given in Fig. 2.



Adopt data into project

With tank:
● Space-heating buffer tank (1,200 l)
○ Space-heating buffer tank (2,400 l)
○ Space-heating buffer tank (5 m³)

Fig. 2 Preliminary investigation results for the investigated site.

Based on the results of Fig. 2, the buffer tank of 1200 L has been selected as optimal. The water heater in question has the task of providing sanitary hot water and space heating, and the common type of equipment used for space heating is considered to be a radiator. The amount of water needed daily is 160 L and the ideal water temperature is 50 degrees. Sanitary hot water is needed for all 365 days.

The heat load is estimated to be 6 kW, which is obtained from the average number calculated by the following empirical formulas (based on the opinion of Iranian technical experts) [18].

$$Q=151.2\times A\times AF\times K \qquad (1)$$

where Q is in kcal/hr, AF is a coefficient that depends on the height from sea level, K is a coefficient that depends on the temperature of the outside environment, and A is the floor area of the building in m^2.

$$Q=3.5\,(3.3\,V+10\,m^2_{wall}+100\,m^2_{window}) \qquad (2)$$

where V is the volume of the space in m^3, m^2_{wall} is the surface of the external walls in m^2, and m^2_{window} is the surface of the window in m^2.

$$Q=(0.035\sim0.05)\times V \qquad (3)$$

where Q is in kW, and V is the volume of the space in m^3, which means the volume that needs heating, and according to the insulation of the building, it will be multiplied by a number between 0.035 and 0.05. For the better insulation of building, the chosen number will be closer to 0.035, and for the weaker it will be closer to 0.05.

The desired area is 120 m^2 with 6 people. The thickness of the walls is considered medium and the east and west walls have no windows. The percentage of the window area to the floor area on the south and north sides is 10 and 2, respectively. The type of windows is double-glazed. According to the investigated location, space heating is not needed in the months of July and June. The type of flat plate SWHs is considered, which is the common type. The type of fluid inside the pipes is considered to be ethylene glycol-water, the percentage of ethylene glycol is 40%.

Fig. 3 shows the schematic of the investigated system. As it is known, a storage tank is considered for each part of space heating and sanitary water heating. Also, for times when solar heating is not enough, an auxiliary gas boiler is used. The governing equations of the problem, which are total solar fraction [19], energy balance [20], and financial calculations of the system [21, 22], are given in equations 4 to 8, respectively.

$$\text{total solar fraction} = \frac{Q_{S,DHW}+Q_{S,HL}}{Q_{S,DHW}+Q_{S,HL}+Q_{AUXH,DHW}+Q_{AUXH,HL}} \quad (4)$$

$$\rho = G_{dir}.\eta_0.f_{IAM} + G_{diff}.\eta_0.f_{IAM.diff} - K_0(T_{cm}-T_A) - K_q(T_{cm}-T_A)^2 \quad (5)$$

$$NPV = R_t - C, \quad (6)$$

$$C = C_0 + \frac{\sum_{n=1}^{N} C_{O\&M}\times(1+e)^n}{(1+d)^n} \quad (7)$$

$$R_t = \frac{Q_u}{\eta_h} + \sum_{n=1}^{N}\frac{(1+e)^n}{(1+d)^n}, \quad (8)$$

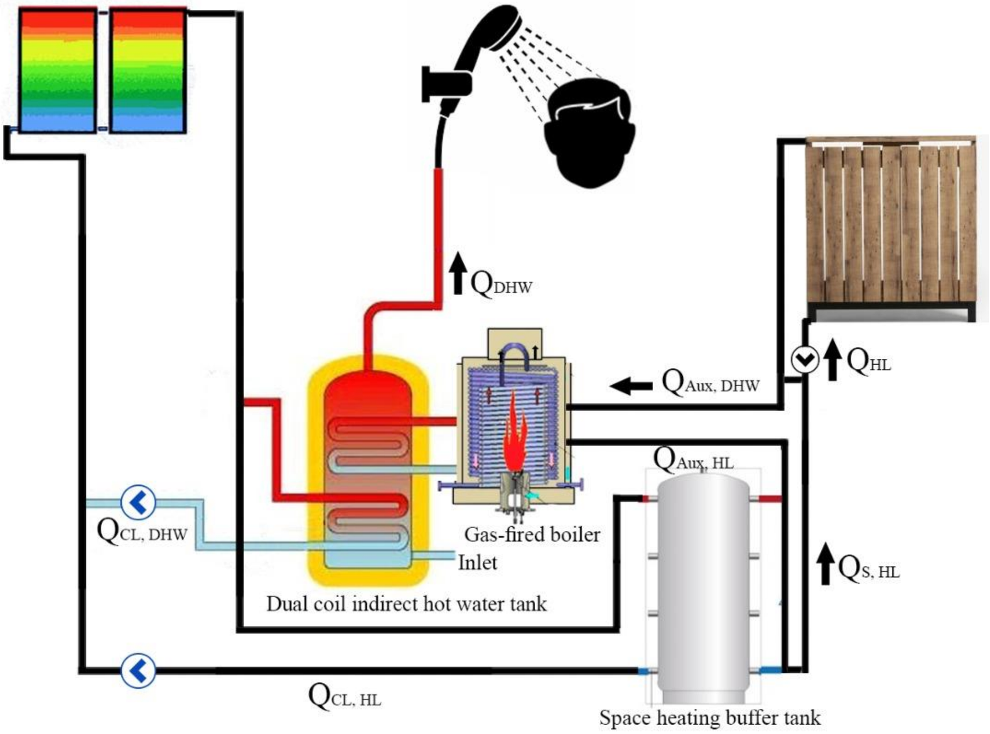
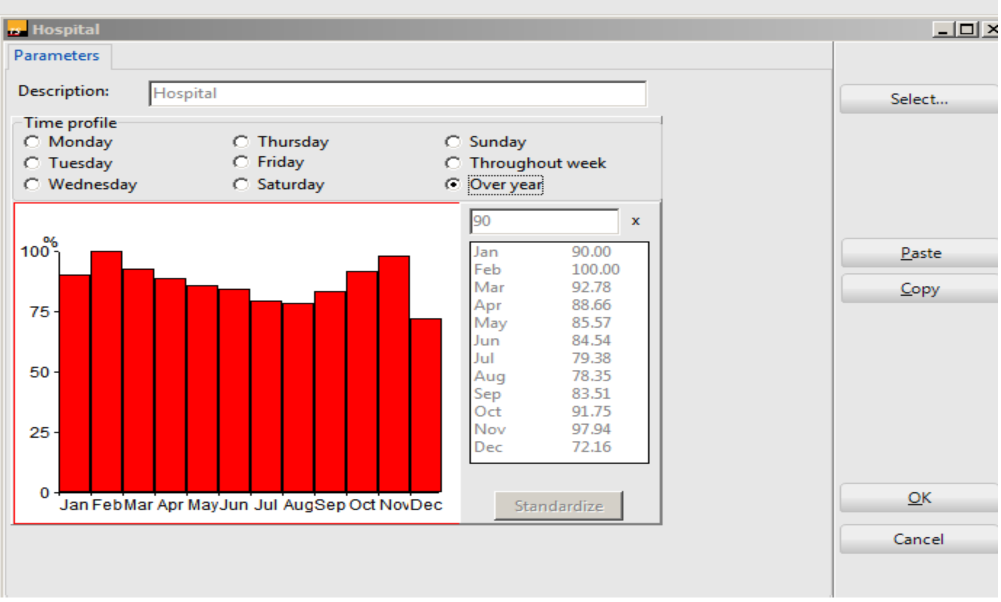


Fig. 3 Schematic of the investigated system.

According to the detailed information entered from the components of the SWH, as well as the location of the desired place (latitude 31.5 North and longitude 54.2 East and the angle of the sun's radiation 30 degrees) and the amount of water consumed 160 L with the desired temperature of 50 °C, the maximum heating load of the investigated place was calculated to be 6 kW. Fig. 4 shows the required heat profile for a hospital from the software database, which is the basis of the calculations of the present work.

The useful life of the project is 25 years, the price of each m^3 of natural gas is equal to 0.001 euro, the price of each m^2 of used flat plate solar collector is 206.4 euro, the subsidy is 50%, maintenance costs are 0.5% of the total annual costs, allowance is equal to 0.001 euro in during 25 years and interest on capital equal to 18% was included in the calculations [22].



Description: Hospital

Time profile
○ Monday
○ Tuesday
○ Wednesday
○ Thursday
○ Friday
○ Saturday
○ Sunday
○ Throughout week
● Over year

90

Jan	90.00
Feb	100.00
Mar	92.78
Apr	88.66
May	85.57
Jun	84.54
Jul	79.38
Aug	78.35
Sep	83.51
Oct	91.75
Nov	97.94
Dec	72.16

Fig. 4 Energy profile required in different months of the year.

4- Results

It can be seen from Fig. 5 that out of 7320 kWh of required energy, 1937 kWh were produced by SWHs for the radiography department of the hospital. In other words, the total solar fraction for this problem is 26.5%. Based on Fig. 5, it can be seen that from May to October, i.e. 5 months of the year, solar heat meets the thermal needs of the desired space. According to Fig. 5, the highest demand for gas-fired auxiliary boilers is in January.

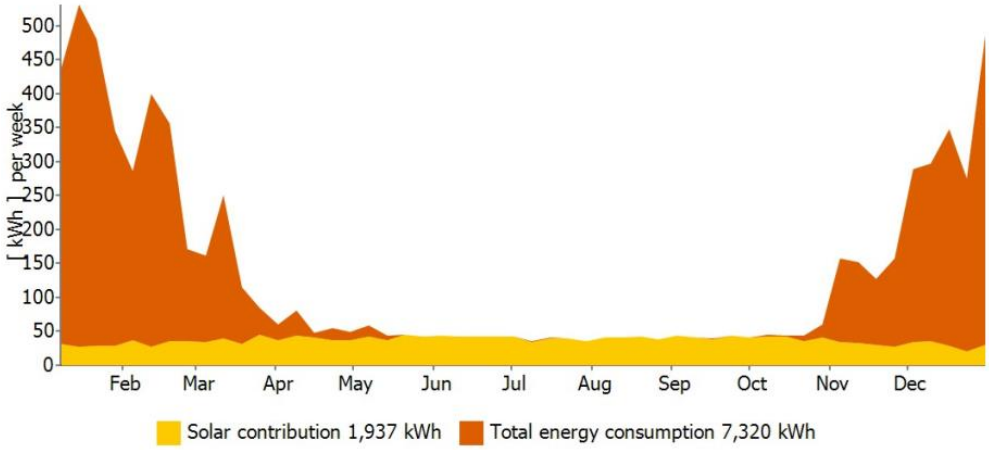
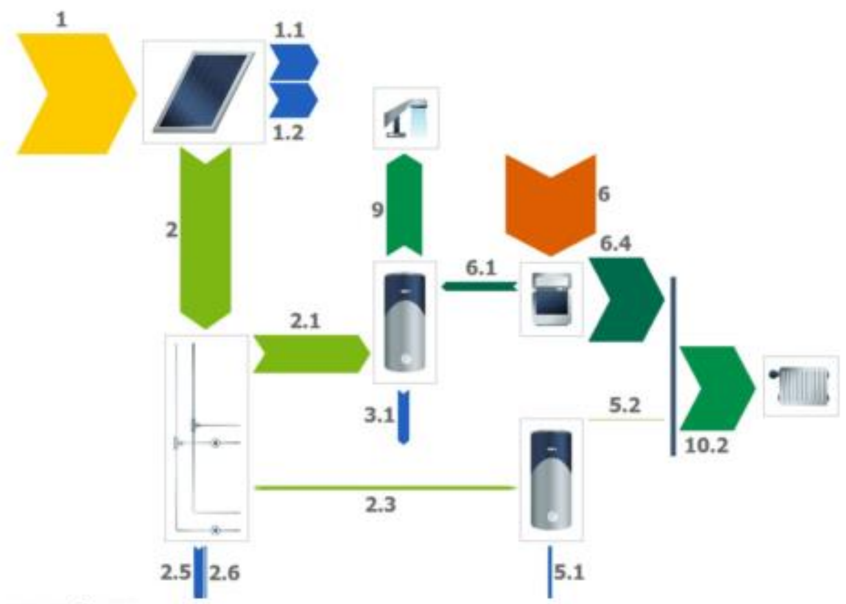


Fig. 5 Solar fraction and total heat demand for investigated hospital.

Fig. 6 shows how much energy is exchanged between different parts and actually balances the energy of the propulsion system. The losses that occur, including external and internal piping losses (about 580 kWh), tank losses (about 800 kWh), and optical and thermal losses (4056 kWh), are shown in Fig. 6.



Legend

1	Irradiation on collector surface (active)	6,940 kWh
1.1	Optical collector losses	2,089 kWh
1.2	Thermal collector losses	1,967 kWh
2	Energy from collector array	2,885 kWh
2.1	Solar energy to storage tank	2,142 kWh
2.3	Solar energy to buffer tank	162 kWh
2.5	Internal piping losses	521 kWh
2.6	External piping losses	59 kWh
3.1	Tank losses	640 kWh
5.1	Buffer tank losses	162 kWh
5.2	Buffer tank to heating	0 kWh
6	Final energy	5,231 kWh
6.1	Supplementary energy to tank	498 kWh
6.4	Supplementary energy to space-heating	4,886 kWh
9	DHW energy from tank	2,000 kWh
10.2	Heat to LT heating.	4,886 kWh

Fig. 6 Energy balance diagram of the investigated system

Fig. 7 shows the solar fraction in different months and the amount of prevention of CO_2 emissions. Based on the results of Fig. 7, it can be seen that in the months of May to October, almost all the heating needs are met and the total solar fraction is about 26%. Also, the maximum amount of CO_2 emissions is prevented in the months of May and August, when the maximum amount of solar heat is produced. The total prevention of the release of pollutants during the year is 629 kg. The reason that the solar fraction is low in the cold months of the year (November to February) is that the heat demand is higher in these months, which is all related to space heating.

Fig. 8 shows the amount of gas-fired auxiliary boiler used in providing the required heat for space heating and for sanitary spa use. From the results of Fig. 8, it can be seen that in the months of May to October, the use of the boiler is almost zero because all the required energy is provided by solar collectors. In the mentioned months, there is no need for space heating and the only heat requirement is the need for a sanitary spa. Based on the results of Fig. 8, 498 kWh of energy required for the sanitary spa is provided by the gas-fired auxiliary boiler and 4886 kWh of heat required for space heating is provided by the gas-fired auxiliary boiler. For the cold months of the year when there is a need to heat the space, the use of the gas auxiliary boiler is much more. According to the results of Fig. 8, the highest demand for gas-fired auxiliary boilers is about 1700 kWh for the month of January.

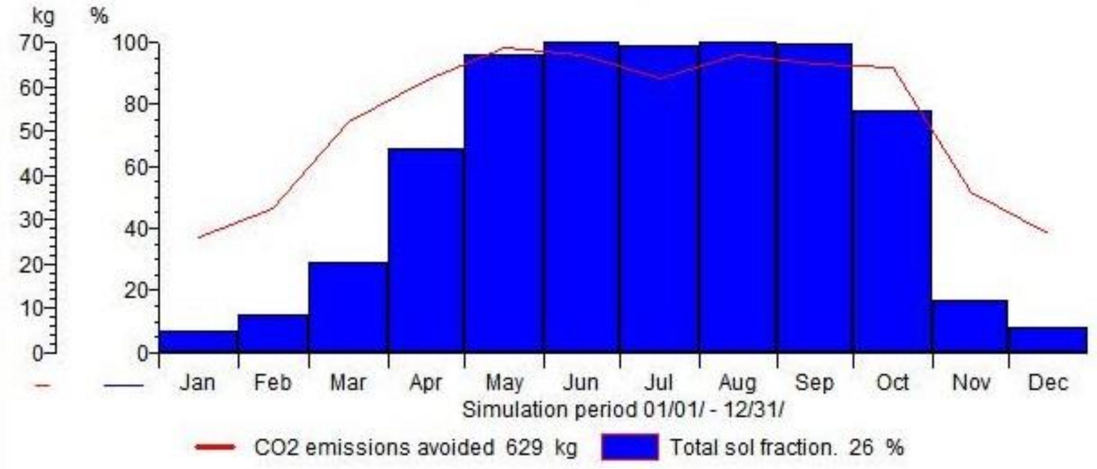


Fig. 7 Solar fraction and CO_2 emissions prevention rate in different months for investigated system.

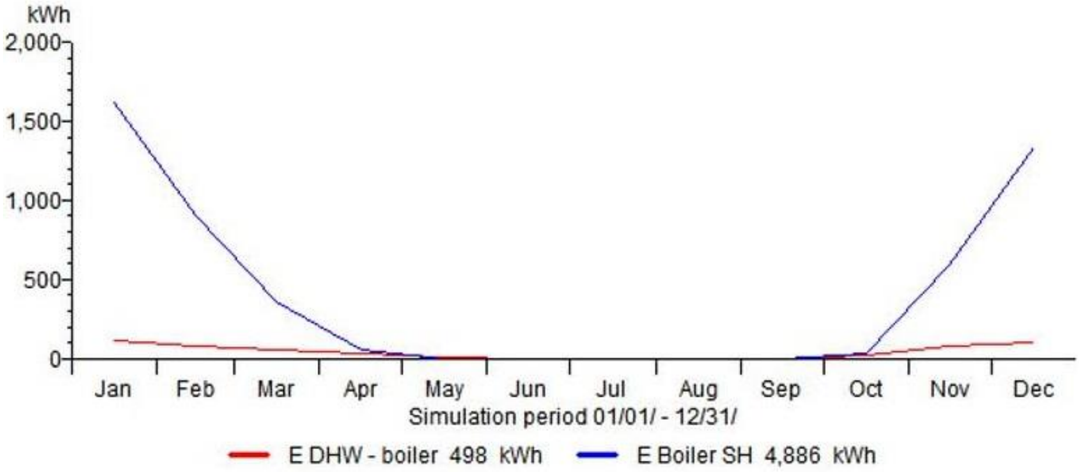


Fig. 8 Energy provided by the boiler and by solar energy for space heating of investigated hospital.

Fig. 9 shows the financial analysis performed for the present work during the 25-year useful life of the project. Based on Fig. 9, it can be seen that the remaining investment and profit at the end of 25 years are 310 euros and 247 euros, respectively. Also, the cost of each kWh of heat production was calculated as 0.0021 euros, which led to a return on investment of 19 years. Net present value and IRR were also calculated for the present work - 220 euros and 2.23%, respectively.

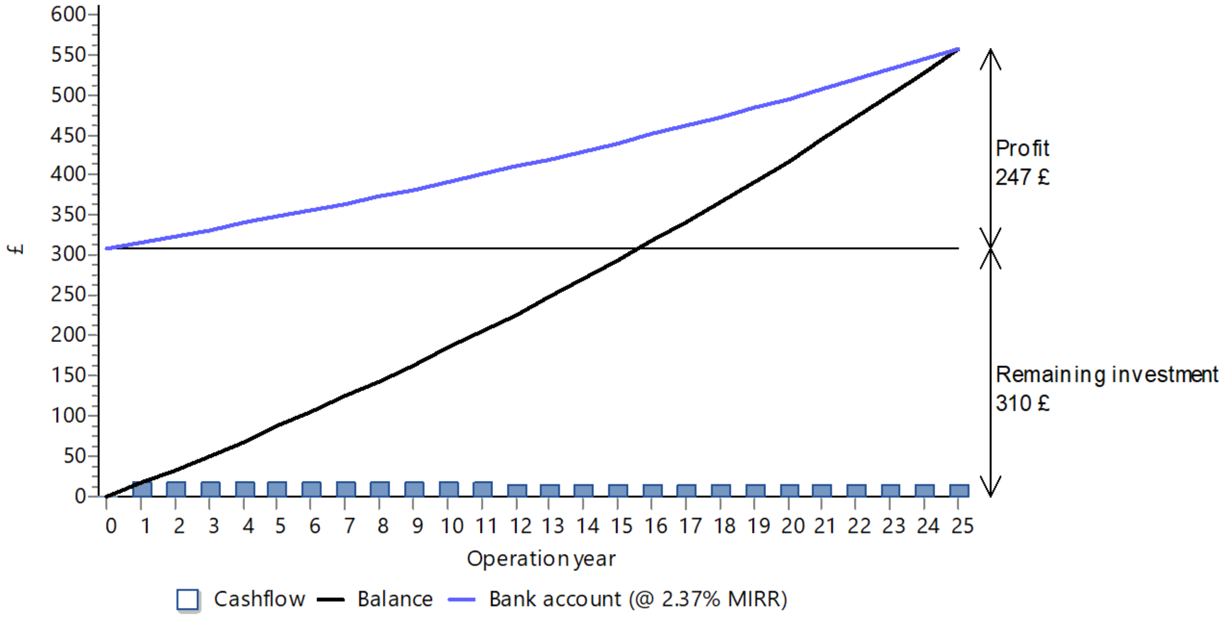


Fig. 9 Financial analysis of the investigated system.

5- Conclusion

Providing heat for treatment spaces is a point that has not been addressed so far. Due to the need for sustainable energy for treatment spaces and the importance of using solar energy and due to Iran's good potential in this field, a hospital for first time in Yazd has been selected. One-year analysis of the SWH system thermal performance was performed using TSOL Pro5.5 software. Performing technical, energy, economic, and environmental analyzes during the 25 years of the project lifetime, along with the analysis of the losses of different parts, makes the results comprehensive and usable for decision-makers in the energy sector and even investors in this sector. It should be noted that the collectors used in the present work are flat plates, and for emergency situations, a gas-fired auxiliary boiler is used as a backup. The main results are as follows:

- Based on preliminary estimates, considering 3 m^2 of SWH, the 1200 L storage tank is more suitable than other options due to its higher efficiency.
- The total solar fraction for the examined treatment spaces is equal to 26.5%, which is caused by the production of 1937 kWh/year of solar heat.
- The total losses of the investigated solar thermal system are equal to 5436 kWh/year, and optical and thermal losses are the major part.
- Due to the use of SWHs, the production of 629 kg/year pollutants is avoided.
- Due to the non-supply of the total required heat by SWHs, gas-fired auxiliary boilers produce 5384 kWh of heat annually.
- Each kWh of solar heat for the investigated system during the 25-year system lifetime has a price of 0.0021 €.

In continuation of the present work, the following can be done:

- Use evacuated tube solar collectors that have higher efficiency.
- The working fluid in the present work is a combination of water and ethylene glycol. Nanofluids can be used in future works.
- Sensitivity analysis has not been done on the influencing parameters. In future works,

sensitivity analysis can be done on effective parameters, especially financial parameters.

- The present work is a case study for Yazd. It is possible to do the present work for several places in other climates and observe the effect of the climate.

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