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Research Article

Energy-Environmental One-Year Dynamic Simulation and Ranking Analysis of Using Flat Plate Solar Water Heater to Supply the Heating Demand of an Apartment in the USA: A Comprehensive Review

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Nowadays, owing to the increasing demand for water heating, solar water heaters (SWHs) are an appropriate alternative to heating based on fossil or electric fuels. Solar heating has received a lot of attention due to its reduction of environmental pollution and ensuring future energy security. Moreover, it is cost-effective in the long run. Given the importance of the above, there is a lack of a comprehensive review of the potential for heat supply at the residential scale in different US states. In addition, finding the most suitable place to use SWHs has not been studied so far. Therefore, in the present work, for the first time, the energy-environmental assessment of 50 US state centers during a one-year period has been done using TSOL commercial software. Furthermore, using step-wise weight assessment ratio analysis (SWARA) and weighted aggregated sum product assessment (WASPAS) computational methods, the weighting of criteria and ranking of studied stations were performed, respectively. The results indicated that of the eight parameters studied, the parameters "total solar fraction" and "solar contribution to domestic hot water" have the highest and lowest final normalized weight, respectively. Moreover, the WASPAS method using the decision matrix showed that Phoenix, Santa Fe, and Tallahassee stations are the top 3 stations in terms of using SWHs, respectively, and Juneau, Olympia, and Montpelier stations are three inappropriate stations in this regard, respectively. The VIekriterijumsko KOmpromisno Rangiranje (VIKOR), intelligent transportation system deployment analysis system (IDAS), and technique for order of preference by similarity to ideal solution (TOPSIS) methods also validated the results of the present work, which were completely consistent. The results of the economic analysis revealed that the Santa Fe station with the price of each kW of energy produced at $0.021 has the cheapest solar heat generation.

1. Introduction

Research on renewable energies has become increasingly important since the Kyoto Protocol was signed [1] and, in particular, the development of new solar energy technologies has been considered one of the key solutions for meeting the growing global demand for energy [2]. According to the results of university studies, this organization believes that the US can provide all of its energy requirements by using renewable energy sources, and this goal can be fulfilled by 2050 when wind and solar power supply the major part of renewable energy [3, 4] (Figure 1).

Solar energy is one of the promising sources of renewable energy for thermal applications including solar air

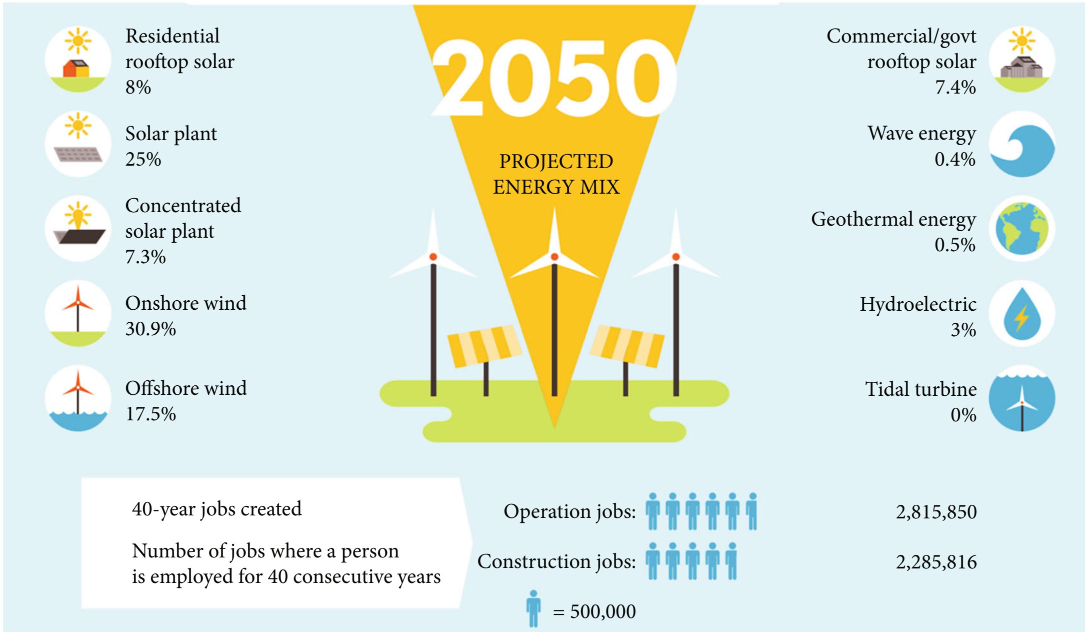


Figure 1: Transition to 100% wind, water, and solar for all purposes (electricity, transportation, and heating/cooling, industry) in the US [5].

heaters, solar stoves, and SWHs [6]. SWHs, especially flat plate collectors, are the best-known technique for using solar energy due to their simpler and economical technology [7, 8]. Solar water heating is generally less common in nonhome use [9]. In general, the widespread use of SWHs can diminish much of the predictable energy used to heat water in homes, businesses, and other institutions [10]. The residential sector is the third-largest consumer of energy in the United States (21 trillion BTU in 2019), which accounts for approximately 22% of the country's total energy consumption [11].

Domestic energy consumption in the US has increased over the past few decades and now accounts for 22% of the total US energy consumption [12]. Eighteen percent of the country's domestic energy consumption is allocated to water heating [13], and hence one of the measures often taken to replace and/or upgrade energy productivity is in the residential sector. In August 2017, there were more than 300,000 SWH units throughout the US (excluding programs for swimming pools) [14]. In addition to solar technologies for electricity generation, solar thermal technologies that are used to heat space and water and provide the required heat for low-temperature processes are examples of great but overlooked potential. Based on the renewable energy map 2030, solar thermal capacity in the US can be ten times higher than that of today [15]. Figure 2 indicates the amount of global solar radiation in the US. As shown on this map, the southern and, especially, southwestern parts of the country enjoy very good conditions for receiving solar energy and installing solar energy systems.

SWH systems are a simple and cost-effective renewable technology for using solar energy to produce hot water. There are two main types of SWHs: those with flat plate collectors (FPCs) and those with evacuated tube collectors (ETCs) [17]. Of course, ETCs are becoming increasingly more popular due to their considerable productivity [18]. By installing a SWH system, a typical family in the US can provide 50 to 80 percent of the needed hot water. In warm and sunny weather, such as that in Hawaii, a SWH unit can even meet 100 percent of a household's hot water needs [19].

Few articles have been written on the potential use of SWHs in the US. They are discussed below.

In 2018, Mamouri and Benard [20] evaluated the performance of SWHs with vacuum tube collectors for the Michigan climate (among the lowest U.S. states for solar irradiance). A test suite was installed on the campus of Michigan State University, and the amount of useful solar energy received was evaluated using System Advisor Model software. The results indicated that an ETC (with a payback period of at least 8 years) was able to contribute up to 63.8% of the energy required for water heating based on the water consumption profile of a typical American household. Moreover, an ETC system could decrease CO_2-induced air pollution in Michigan by up to 1664 kg per year.

Sanders and Webber [21] examined changes in the way residential water was heated in the US and assessed their effects on CO_2 emissions in 27 locations in the US in 2019. The results indicated that switching from electric heating to natural gas or solar water heating reduced the amount of primary energy supply and CO_2 emissions in most areas of the US. However, this reduction varied depending on the combination of the regional electric grid and solar energy. The scenarios were evaluated by assuming the switching from electric water heaters to natural gas storage water heaters and that from electric water heaters to SWHs with an electric backup system. The results showed that the scenario of replacing 10% of electric water heaters with SWHs led to the greatest reduction in regional CO_2 emissions resulting from water heating. Of course, States such as Ohio and Indiana that consumed large quantities of coal

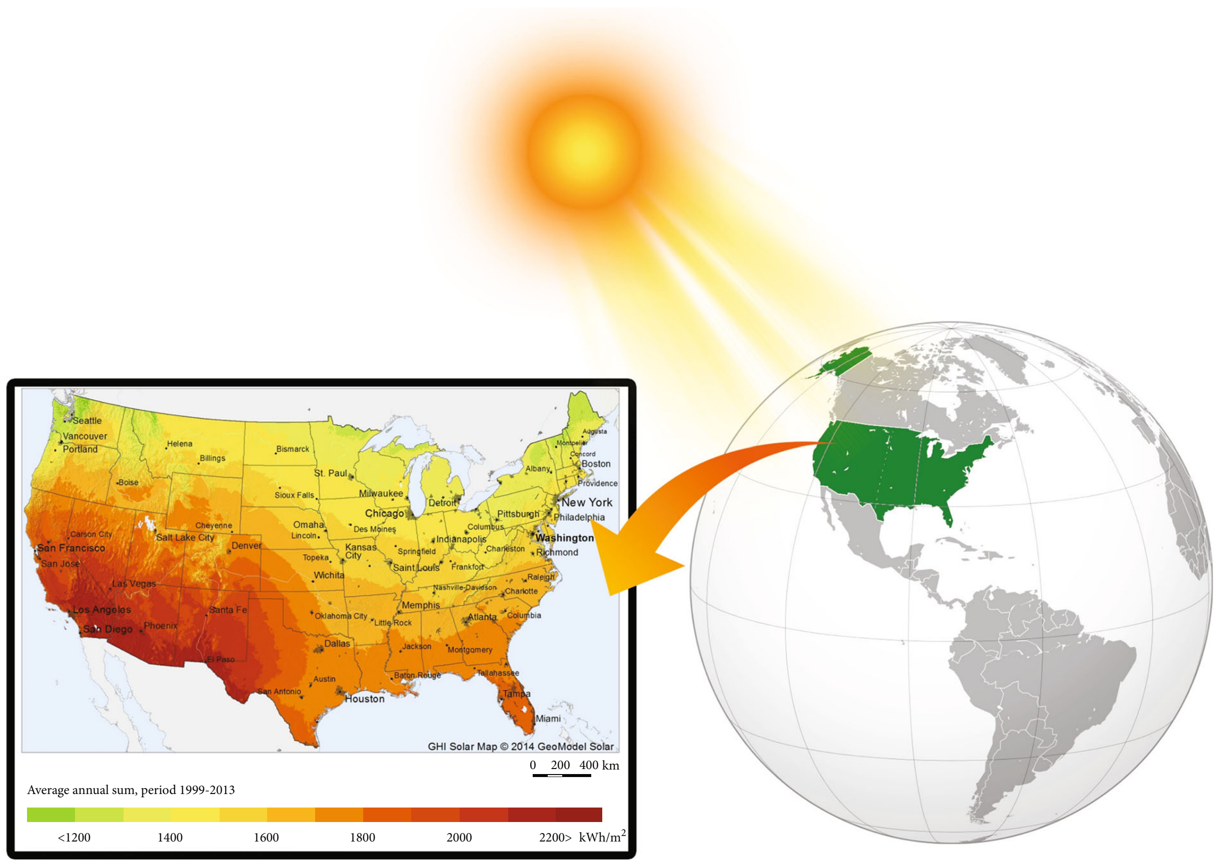


Figure 2: Global horizontal irradiation [16].

Figure 3: Locations of the stations under study on a map of US.

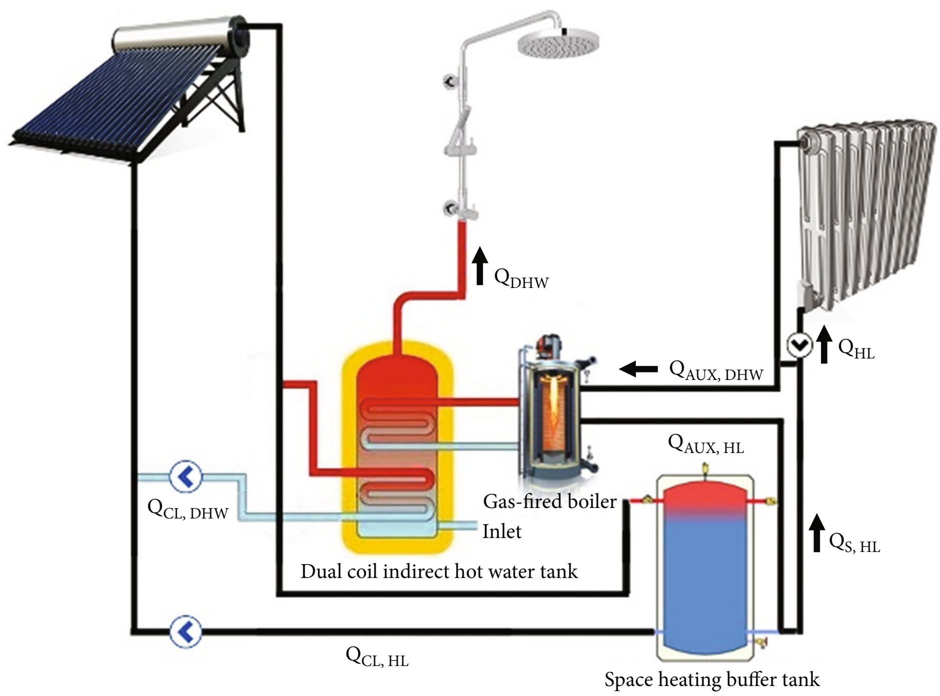


Figure 4: Schematic of the SWH system used.

Table 1: Calculation of the parameters under study by TSOL software.

Parameter	Calculation method
Diffused radiation	$0 \le k_t \le 0•3 : I_d/I = 1•02 - 0•245\,k_t + 0•0123\ \sin\alpha$ $0•3 < k_t \le 0•78 : I_d/I = 1•4 - 1•749\,k_t + 0•177\ \sin\alpha$ $k_t \ge 0•78 : I_d/I = 0•486\,k_t - 0•182\ \sin\alpha$
Energy balance of solar collectors	$\rho = G_{\text{dir}}•\eta_0•f_{\text{IAM}} + G_{\text{diff}}•\eta_0•f_{\text{IAM.diff}} - k_0(T_{\text{km}} - T_A) - k_q(T_{\text{km}} - T_A)^2$
Total solar fraction	$\text{Solar fraction total} = Q_{\text{CL.DHW}} + Q_{\text{S.HL}}/Q_{\text{CL.DHW}} + Q_{\text{S.HL}} + Q_{\text{AuxH.DHW}} + Q_{\text{AuxH.HL}}$
DHW solar fraction	$\text{Solar fraction DHW} = Q_{\text{CL.DHW}}/Q_{\text{CL.DHW}} + Q_{\text{AuxH.DHW}}$
Space heating solar fraction	$\text{Solar fraction heating} = Q_{\text{S.HL}}/Q_{\text{S.HL}} + Q_{\text{AuxH.HL}}$
Economic analysis	$\text{Net present value (NPV)} = \left(Q_u/\eta_h \sum_{n=1}^{N}((1+e)^n/(1+d)^n)\right) - \left(C_0 + \sum_{n=1}^{N}(C_{O\&M} \times (1+e)^n/(1+d)^n)\right)$

to heat water, which led to more CO_2 emissions, had the largest CO_2 emission reductions resulting from the execution of the scenarios (1722 kg of CO_2 per home per year). Meanwhile, California had the smallest reduction in CO_2 emissions (527 kg of CO_2 per home per year).

Siampour et al. [22] conducted a technical-environmental study of the use of 2 types of flat plate and evacuated tube collectors in 45 stations in Turkey. Then, using the method of data envelopment analysis, they ranked the investigated stations. TSOL Pro5.5 software was used for one-year dynamic analysis, and GAMS 24.1 software was used for ranking analysis. The results indicated the superiority of evacuated tube collectors over flat plate collectors in such a way that they produced 96209 KWh of heat more annually and prevented the release of 25 tons of CO_2 pollutants more annually. The results also showed that Sinop station is the most inappropriate in terms of using SWHs.

Tang et al. [23] conducted a technical and environmental analysis of the use of solar heating in South Africa using TSOL Pro5.5 software. The investigated places were 21 cities in different places in the country, and 2 data envelopment analysis models were used to rank the results, using GAMS 24.1 software. The total solar fraction in the investigated stations was 95.93% if a flat plate collector was used and 99.16% if an evacuated tube collector was used. The rate of preventing CO_2 emission when using flat plate and evacuated tube collectors was 23.5 tons/year and 24.4 tons/year, respectively. Meanwhile, Beaufort West, Mmabatho, and Welkom stations were the most suitable cities for using SWHs.

Esfeh and Dehghan [24] worked on the technoeconomic design of a hybrid solar system in a residential building in Tehran (Iran). They considered different configurations of solar systems and then determined the optimal design variables using artificial neural networks and genetic algorithm

Table 2: Data required for thermal and economical calculations.

Data	Type/amount
Heat requirement for space heating	10 kW
Heated usable area	80 m^2
Indoor temperature	21°C
Building type	Average wall thickness
Internal heat gain	5 W/m^2
Window type	2 panes of insulating glass
Space heating operating times	Jan. to May & Sept. to Dec.
Hot water consumption	110 lit/day
DHW temperature	60°C
DHW operating times	All months
DHW tank	300 lit
Space heating tank	1000 lit
Collector area	20 m^2
Azimuth angle	0°
Tilt angle	Equal to latitude [38]
FP conversion factor	78%
Life span	25 year
Specific fuel cost	\$0.038/m^3 [39]
Running cost	0.5%/year
Price	\$200/m^2 [40]
Subsidy	22% [41]
Interest on capital	5% [42]
Reinvestment return	2.5%
Cost escalation rate	Energy 3% running cost 1.5%

methods. The results showed that the optimal system has an improvement of 3.7% in the total solar fraction. This optimal system, which includes 17.91 m^2 of evacuated tube collectors with an angle of 50 degrees, can provide 94% of the required sanitary hot water and 23% of the required space heating. In addition, this system prevents the annual release of 1806 kg of CO_2 pollutants.

According to the aforementioned studies, it can be seen that so far no comprehensive work has been done to assess the potential use of SWHs in all parts of the US. Therefore, in the present work, for the first time, an energy-environmental assessment of the use of home-scale SWHs for the centers of the 50 US states has been performed. Finding the right place to make an investment decision is one of the most important issues, showing the need to use the ranking methods of different stations in a country [25]. For this reason, the present work is the first to rank the potential use of SWHs in the US. For this purpose, parameters of total solar fraction, domestic hot water (DHW) solar fraction, space heating solar fraction, CO_2 emission avoided, and supply heat by auxiliary boiler were first calculated by TSOL software and formed a decision matrix. Then, the criteria were weighed by the SWARA method, and finally, the WASPAS method was used for ranking, and the results were validated with the results of the VIKOR, TOPSIS, and IDAS methods.

The results of the present work can be used for stations with similar weather conditions in other parts of the world. The present work method and analysis of the results and weighting and ranking methods of the present work can also be used for any other part of the world and come to the aid of decision-makers and investors in the field of solar heating.

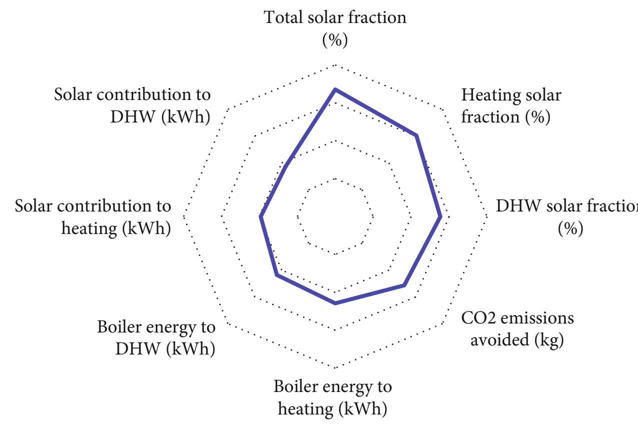


Figure 5: Compare the final weight of the criteria.

2. Stations under Study

The US has a diverse climate due to its different latitudes. Figure 3 shows the locations of the stations under study on a map of the US. The stations under study are the 50 US state capitals.

Geographical coordinates, climatic information, and water temperature of the pipeline network for the studied stations are extracted from Meteonorm software. When installing TSOL software, Meteonorm software is automatically installed with it, which has the task of generating climate data for analysis. Meteonorm software is a global and reliable software that has information on 8325 weather stations in all countries of the world through 5 meteorological satellites during a 30-year period and can provide users with various weather parameters. It also has advanced interpolation models for information calculations at points outside its database. The information used for the simulations was extracted from Meteonorm software.

In the calculation of the cold water temperature in each month (T_s) in the software, it is assumed that the sinusoidal profile of the cold water temperature is calculated from the following equation [26]. It is assumed that the maximum and minimum temperatures occur in the months of August and February, respectively.

$$T_s = \frac{T_{\min} + T_{\max}}{2} - \frac{T_{\max} - T_{\min}}{2} h \cos\left(2\pi \frac{n-2}{12}\right). \quad (1)$$

In the above equation, h is equal to one for the northern hemisphere and -1 for the southern hemisphere, and n is the number of the month.

Table 3: Results of station ranking by WASPAS method.

Station	WASPAS WPS_i	Rank
Montgomery	0.363	4
Juneau	0.160	50
Phoenix	0.462	1
Little Rock	0.291	22
Sacramento	0.332	12
Denver	0.348	6
Hartford	0.260	39
Dover	0.276	29
Tallahassee	0.393	3
Atlanta	0.340	9
Honolulu	0.334	11
Boise	0.293	21
Springfield	0.279	27
Indianapolis	0.262	37
Des Moines	0.269	33
Topeka	0.304	19
Frankfort	0.277	28
Baton Rouge	0.326	13
Augusta	0.228	47
Annapolis	0.266	35
Boston	0.264	36
Lansing	0.238	45
Saint Paul	0.231	46
Jackson	0.347	7
Jefferson City	0.285	25
Helena	0.274	31
Lincoln	0.290	24
Carson City	0.363	5
Concord	0.254	41
Trenton	0.283	26
Santa Fe	0.411	2
Albany	0.250	43
Raleigh	0.320	15
Bismarck	0.270	32
Columbus	0.244	44
Oklahoma City	0.305	18
Salem	0.252	42
Harrisburg	0.258	40
Providence	0.266	34
Columbia	0.342	8
Pierre	0.290	23
Nashville	0.295	20
Austin	0.338	10
Salt Lake City	0.306	17
Montpelier	0.221	48
Richmond	0.320	16
Olympia	0.214	49
Charleston	0.275	30
Madison	0.261	38
Cheyenne	0.326	14

Table 4: Validation of station ranking results with IDAS, TOPSIS and VIKOR methods.

Station	IDAS		TOPSIS		VIKOR	
	AS_i	Rank	C_i	Rank	Q_i	Rank
Montgomery	0.766	5	0.594	3	0.246	4
Juneau	—	50	0.089	50	1.000	50
Phoenix	0.999	1	0.734	1	—	1
Little Rock	0.542	20	0.462	19	0.461	16
Sacramento	0.634	13	0.505	14	0.402	14
Denver	0.664	12	0.513	12	0.378	11
Hartford	0.401	39	0.370	39	0.626	39
Dover	0.466	30	0.411	30	0.556	30
Tallahassee	0.873	2	0.671	2	0.113	2
Atlanta	0.698	9	0.556	8	0.302	7
Honolulu	0.786	4	0.586	5	0.532	26
Boise	0.496	23	0.425	25	0.527	25
Springfield	0.475	28	0.417	27	0.538	27
Indianapolis	0.418	36	0.380	36	0.594	35
Des Moines	0.440	31	0.395	31	0.582	31
Topeka	0.550	18	0.459	20	0.477	19
Frankfort	0.469	29	0.415	29	0.548	29
Baton Rouge	0.673	11	0.549	10	0.314	8
Augusta	0.289	47	0.286	47	0.725	47
Annapolis	0.436	32	0.394	32	0.590	33
Boston	0.429	33	0.389	33	0.589	32
Lansing	0.334	45	0.319	45	0.677	45
Saint Paul	0.308	46	0.300	46	0.701	46
Jackson	0.716	7	0.566	7	0.294	6
Jefferson City	0.490	25	0.427	23	0.517	22
Helena	0.426	34	0.380	35	0.594	34
Lincoln	0.495	24	0.427	24	0.520	24
Carson City	0.698	8	0.527	11	0.360	10
Concord	0.378	41	0.354	41	0.645	41
Trenton	0.476	27	0.416	28	0.541	28
Santa Fe	0.831	3	0.590	4	0.235	3
Albany	0.364	43	0.345	42	0.660	44
Raleigh	0.618	15	0.501	15	0.398	13
Bismarck	0.419	35	0.378	37	0.597	36
Columbus	0.361	44	0.340	43	0.657	43
Oklahoma City	0.557	17	0.465	17	0.465	18
Salem	0.366	42	0.339	44	0.654	42
Harrisburg	0.399	40	0.368	40	0.627	40
Providence	0.416	37	0.380	34	0.613	38
Columbia	0.698	10	0.553	9	0.315	9
Pierre	0.504	22	0.432	22	0.502	20
Nashville	0.545	19	0.463	18	0.464	17
Austin	0.726	6	0.584	6	0.247	5
Salt Lake City	0.533	21	0.444	21	0.506	21
Montpelier	0.277	48	0.280	48	0.736	48
Richmond	0.623	14	0.507	13	0.385	12
Olympia	0.223	49	0.238	49	0.802	49
Charleston	0.477	26	0.420	26	0.518	23
Madison	0.409	38	0.371	38	0.598	37
Cheyenne	0.593	16	0.474	16	0.439	15

3. Methodology

3.1. TSOL Software. TSOL simulation software provides the user with the ability to calculate the performance of a solar heating system for a one-year period and quite dynamically [27]. Using this software, with less time and cost, energy experts and specialists will be able to optimally design solar heating systems, simulate temperature, and evaluate energy performance in them [28]. Investigating the amount of domestic hot water supply, space heating, pool heating, and process heating are among the items that are conducted in this software [29].

The schematic of the system under consideration is shown in Figure 4. As it is shown, the purpose is to provide space heating and DHW using SWH, which has a gas boiler as a backup.

Direct radiation data is available in the Meteosyn software database, which provides climate data for TSOL software. Diffuse radiation data are also calculated from the equations in Table 1 based on the value of the air clearness index [30]. By adding direct and diffused radiation to the collector surface, the total contact radiation to the collector surface is calculated. Parameters and other supplementary information on the below equations are given in reference [31].

3.2. SWARA Method. In multicriteria decision-making methods, a set of criteria is used to rank the options, which one of the methods for weighting the criteria is the SWARA method, which was developed by Kersuliene et al. in 2010 [31]. One of the reasons for using the SWARA method is that the process of implementing these methods can be simple (compared to methods such as the analytic hierarchy process, which requires a lot of pairwise comparisons). Furthermore, these methods lead to more stable comparisons. This means that it gives more reliable answers than other weighting methods. The reason is less use of comparative data, which avoids inconsistent comparisons by decision-making experts, and better acceptance by experts who have time constraints [32, 33].

The process of determining the weights in this method can be shown as follows:

Step 1: The criteria are sorted with the expert's opinion based on significance.

Step 2: The relative importance of each criterion (S_j) is determined by each of the experts.

Step3: The relative importance of each criterion will be calculated according to

$$K_j = S_j + 1. \tag{2}$$

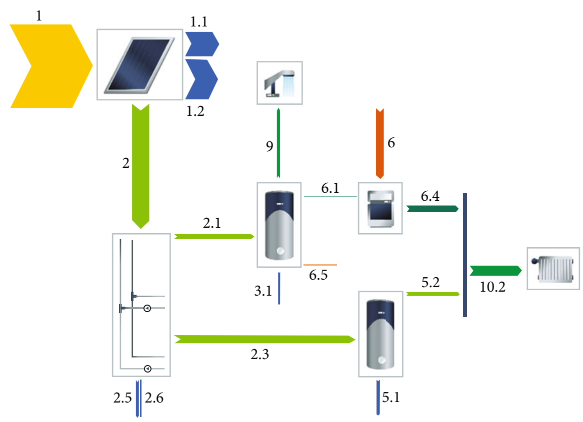
Step 4: the initial weight of each criterion is calculated through equation (3). The weight of the most important criterion is considered to be equal to 1.

$$q_j = \frac{q_{j-1}}{K_j}. \tag{3}$$

Step 5: in this step, the weight of the criteria is normalized in the previous step, and the final normal weight of

Table 5: Economic analysis performed for the studied stations.

Station	Cost of solar energy ($)	NPV ($)
Montgomery	0.030	-2971
Juneau	0.051	-3280
Phoenix	0.030	-2954
Little Rock	0.035	-3066
Sacramento	0.027	-2926
Denver	0.025	-2879
Hartford	0.033	-3061
Dover	0.033	-3045
Tallahassee	0.031	-2977
Atlanta	0.031	-3006
Honolulu	0.060	-3211
Boise	0.029	-2996
Springfield	0.033	-3047
Indianapolis	0.035	-3080
Des Moines	0.033	-3049
Topeka	0.030	-2992
Frankfort	0.033	-3052
Baton Rouge	0.035	-3053
Augusta	0.037	-3134
Annapolis	0.034	-3068
Boston	0.034	-3073
Lansing	0.037	-3120
Saint Paul	0.038	-3132
Jackson	0.031	-2982
Jefferson City	0.033	-3046
Helena	0.030	-3023
Lincoln	0.031	-3012
Carson City	0.024	-2850
Concord	0.033	-3071
Trenton	0.032	-3031
Santa Fe	0.021	-2738
Albany	0.034	-3078
Raleigh	0.031	-2991
Bismarck	0.031	-3030
Columbus	0.037	-3113
Oklahoma City	0.030	-2994
Salem	0.034	-3082
Harrisburg	0.034	-3067
Providence	0.032	-3044
Columbia	0.031	-2984
Pierre	0.031	-3025
Nashville	0.034	-3049
Austin	0.038	-3069
Salt Lake City	0.027	-2948
Montpelier	0.039	-3156
Richmond	0.031	-3007
Olympia	0.039	-3150
Charleston	0.036	-3087
Madison	0.034	-3078
Cheyenne	0.026	-2913



Legend

1	Irradiation on to collector surface (active)	46,956 kWh
1.1	Optical collector losses	14,214 kWh
1.2	Thermal collector losses	23,122 kWh
2	Energy from collector array	9,620 kWh
2.1	Solar energy to storage tank	3,108 kWh
2.3	Solar energy to buffer tank	4.596 kWh
2.5	Internal piping losses	1,638 kWh
2.6	External piping losses	277 kWh
3.1	Tank losses	1,430 kWh
5.1	Buffer tank losses	2,104 kWh
5.2	Buffer tank to heating	2,502 kWh
6	Final energy	3,909 kWh
6.1	Supplementary energy to tank	17 kWh
6.4	Supplementary energy to space-heating	3,303 kWh
6.5	Electric element	0 kWh
9	DHW energy from tank	1,698 kWh
10.2	Heat to LT heating	5,805 kWh

Figure 6: Energy balance schematic for Phoenix.

the criteria is calculated.

$$w_j = \frac{q_j}{\sum q_j}. \quad (4)$$

3.3. WASPAS Method. The WASPAS method is one of the new decision-making techniques for ranking options that was introduced in 2012 by Zavadaskas et al. [34]. This method is based on a combination of the WSM method (weighted sum model) and WPM method (weighted production model), which is useful in complex decision-making problems, and its output is highly accurate. This method has a special ability in single and multiple optimization problems, is used in the real world, and can be used successfully in decision-making problems [34]. The WPS_i value is calculated, and the options are ranked accordingly:

$$\mathrm{WPS}_i = 0.5 \sum_{j=1}^{m} Q_i + 0.5 \sum_{j=1}^{m} P_i, \quad (5)$$

where Q_i is the optimal function value for the WSM model and P_i is the optimal function value for the WPM model.

3.4. Validations Model. Three IDAS, TOPSIS, and VIKOR models have been used to validate the WASPAS model results in the present work. The analysis equations of the models used are given in references [35–37]. The purpose of presenting these three models is to check whether the results of the WASPAS model are accurate or not. Finally, the average rank of each station from the four investigated methods will be considered the final rank of that station. If the top stations are the same, the accuracy of the WASPAS model results will be confirmed.

4. Data Used

The data required to calculate the required space heating and DHW consumption are given in Table 2. The information of SWHs used and information of economic analysis are also given in Table 2.

5. Data Analysis

5.1. Weighing the Criteria by SWARA Method. In consistent with the SWARA method, the experts of the decision-making team, which included experts with an average of 8 years of activity in the field of renewable energy, were asked to arrange the criteria according to their preferences in consultation with each other. Then, each of the experts completed a questionnaire on the SWARA method, and based on the steps of this method, the weights of the criteria were calculated, and the results are listed in Figure 5. Total solar fraction (%), heating solar fraction (%), and DHW solar fraction (%) criteria with normalized weights of 0.1676, 0.1510, and 0.1385, respectively, were the most important among the criteria, which are compared in Figure 5. Also, the parameters' solar contribution to DHW, solar contribution to heating, and boiler energy to DHW have the lowest normal weight with values of 0.0927, 0.0983, and 0.1091, respectively.

5.2. Ranking of US Stations. At this stage, stations in the US are ranked using the WASPAS method. Then, in order to validate and verify the results, IDAS, TOPSIS, and VIKOR techniques are used for ranking. The identified stations were ranked according to the WASPAS technique steps. The ranking results of the stations are presented in Table 3. The ranking results indicate that Phoenix, Santa Fe, and Tallahassee stations were selected as the most suitable stations in the WASPAS method. Also, Juneau, Olympia, and Montpelier stations are the three stations that are the most inappropriate in terms of using SWHs.

5.3. Validation of Ranking Results. The IDAS, TOPSIS, and VIKOR techniques were used to validate the station ranking results, which are shown in Table 4. The ranking results with the WASPAS, IDAS, TOPSIS, and VIKOR techniques showed that Phoenix station was recognized as the most suitable station in all methods. The station ranking results are compared with the WASPAS, IDAS, TOPSIS, and VIKOR methods. If the final ranking of each station is considered the average of the 4 calculated methods, the top 3 stations are Phoenix, Tallahassee, and Santa Fe, respectively.

This issue indicates that, despite the fact that the top station selection model is different in different methods but the top 3 stations are definitely the same in all methods, and the validation of the results of the WASPAS model with very high accuracy is acceptable.

5.4. Economic Analysis. The results of the economic analysis done for all the studied stations are shown in Table 5. According to the results, it can be seen that for all stations, the value of the NPV parameter is negative, which means that there is no return on investment for them. This is due both to the cheapness of natural gas in the US and to the fact that emissions penalties do not apply to the domestic scale in the US. Moreover, the average price per kW of solar heat produced for all stations surveyed is $0.033. The Santa Fe station with the price of each kW of energy produced at $0.021 has the cheapest solar heat and the Honolulu station with the price of each kW of energy produced at $0.06 has the most expensive solar heat.

5.5. Energy Analysis for Best Station. Figure 6 shows the energy balance schematic for the SWH system for the Phoenix station, which was ranked as the best station. The results of Figure 6 indicate that the total amount of solar energy that hits the surface of the collectors, about 80% of it is wasted due to optical and thermal losses of solar collectors. In addition, with the amount of 3534 kWh/year, the losses of hot water storage tanks are in the second rank of the highest losses of the system. Piping system losses with 1915 kWh/year are the third-highest losses. According to the energy balance diagram, it seems that the use of solar collectors with higher efficiency and insulation of hot water storage tanks and piping are among the solutions to boost solar heat production in the present work.

6. Conclusion

Today, water heating, after the energy spent on heating and cooling homes, is the second-largest part of energy consumption in homes. SWHs are relatively inexpensive, have no environmental pollution, and can greatly help reduce energy consumption in the residential sector by saving on fossil fuels. Given these cases, and since the study of the potential of different regions of a country to find the most suitable and unsuitable places to use SWHs is very helpful to energy decision-makers, the need for a comprehensive study for each country is clearly felt. Therefore, the present work evaluates for the first time the potential of 50 state centers in the US using flat-plate SWHs. TSOL software was used for one-year dynamic analysis, and SWARA and WASPAS numerical methods were used to weighing the parameters and ranking of potential stations, respectively. The main results of the present work are

(i) For the stations under study, on average, about 30% of the total required heat is supplied by SWHs

(ii) A total of about 235 MW of heat per year is generated for the stations under study by SWHs

(iii) About 63 tons/year of CO_2 emissions have been prevented for the studied stations due to the use of SWHs

(iv) For the stations under study, because the SWHs cannot meet all the thermal needs, about 592 MW of heat per year is produced by gas-fired boilers

(v) SWARA method showed that the "total solar fraction" has the highest weight among the 8 parameters studied

According to the results of the WASPAS method, the most suitable and unsuitable stations are Phoenix and Juneau, respectively.

(i) There is a very good agreement between the results of the WASPAS method used in the present work with the results of the VIKOR, IDAS, and TOPSIS methods

(ii) The average price per kW of solar heat produced for all stations surveyed is $0.033

The results of the present work are associated with challenges. One is that the cost of preventing the emission of pollutants has not been seen as a positive effect on the results. Also, the effect of fossil fuel price increases on the results has not been observed. In addition, in some cases, it is not possible to access fossil fuels, and it is necessary to use SWH. Due to these mentioned issues, it is necessary for the decision-makers in the energy field and the investors of this sector to have an estimate of the price of each kWh of solar heat produced, so that if needed, they can make a decision regarding the use or non-use of SWH with a more open vision in the future.

Data Availability

All data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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