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Potential of Using Residential Scale Solar Heat in Pakistan: Finding the Best Station

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Abstract

The most widespread application of renewable energy is heat production, mainly related to biofuels and solar water heaters (SWHs). Considering that SWHs are essential in energy supply, the present work aims to investigate the heat requirement of a residential apartment in Pakistan using a radiator system in 32 investigated stations. The daily water requirement is 160 L, and the ideal water temperature is 50 °C. It should be considered that hot sanitary water is needed for all 365 days. The investigations were carried out with TSOL Pro 5.5 software to simulate the heat of the desired locations. Also, after the analysis, we found that the selected location's SWH and thermal energy supply have high efficiency. The total heat supply using renewable energies is 18-42% for the investigated stations, and the rest of the required heat is supplied with fossil fuel. Since SWHs are one of the simplest and most economical ways to provide hot water for homes, offices, schools, hospitals, etc., Pakistani people can save a large amount of energy by investing in this field. Considering that Pakistan has good radiation potential, we hope that the present work results will lead to more use of SWHs.

Keywords: System efficiency; Domestic hot water; Sanitary hot water; CO2 emission; Total solar fraction
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1. Introduction

Solar energy is an unlimited, accessible, free, and renewable source [1]. It significantly reduces our dependence on non-renewable energy (fossil fuels) and is an efficient step in protecting the environment, saving energy resources, and will solve the economic problems of the country [2, 3]. Pakistan has all the necessary conditions for implementing heat production projects through sunlight. Therefore, collectors have been installed in dry, waterless, and grassy lands to use solar energy to produce the required heat [4]. On the other hand, the use of solar energy is much cheaper for Pakistani households, and the number of users of this technology in this country is increasing rapidly [5]. In the capital of Pakistan, solar collectors heat some offices, educational centres, and residential areas [6]. Almost 1000 MW of energy is produced and consumed in Pakistan through solar energy [7]. Many experts believe that heat production from renewable energy can save Pakistan from the energy crisis in the future [8]. Due to the geographical location of Pakistan, large areas of the country have very high radiation intensity. Because of the ever-increasing cost of fossil fuels and electric energy, it is time to use unlimited, clean, and accessible renewable energy sources, such as solar energy, like in many countries [9].

SWHs are one of the most effective plans for the general and easy use of solar energy to provide domestic and industrial hot water [10, 11]. The surface temperature of solar energy absorbing collectors increases to about 100 °C, and the temperature of the produced hot sanitary water in high-efficiency models increases to about the boiling point of water [12]. In Table 1, we reviewed the recent studies in Pakistan and evaluated the method of work and the results accurately.

Table.1.
Literature review of studies conducted in Pakistan

Authors	***Year***	***Topic***	***Results***
Butt et al. [12].	2010	Buildings evaluation as the primary consumer of electrical energy in the summer season in hot and humid areas	When people use solar collectors, energy consumption reduces, and saving up to 50% in energy consumption is possible.
Wakeel et al. [13]	2016	Assessing how to provide sustainable and affordable energy	If a flat plate (FP) collector is used, better results will be obtained. It will also have a higher solar fraction and more efficiency.
Asin et al. [4]	2016	Using TRNSYS to model an absorption chiller	the room temperature in a house can be kept at an average of 26 ºC or less using a vacuum tube collector with an area of 13m^2
Zhou et al. [5]	2017	Assessing public acceptance and interest in the solar home system, investigating people's expectations towards the development of SWH and the problems they face in using SWH	About 81% of people have shown interest in the SWH development, but there are obstacles and problems to using it that need to be solved.
Akhtar et al. [6]	2018	Evaluation of solar reflectors	Materials with more reflective properties such as protectors, and insulators should be used to maximize the efficiency of solar reflectors.
Ashfaq et al. [7]	2018	Assessment of population growth and energy shortage	Solar collectors should be used to save fossil fuel consumption due to the increasing population.
Erfan et al. [14]	2018	Evaluation of environmental entropy and global warming potential and also finding a suitable solution to reduce global warming	SWHs should be used to produce the necessary energy, and fossil fuels should be used along with it. Also, materials should be used that light the house during the day and thus increase the energy produced by solar collectors.
Hussin et al. [15]	2019	Assessing the gap in energy supply and demand	Glazed solar collectors such as FPs or vacuum tube collectors were used to minimize heat loss from the system.
Mehmood et al. [16]	2019	Performance evaluation of solar water heating system by natural gas	Using the desired vacuum tube collector system can reduce fuel consumption and emissions by 23-56%.
Raza et al. [17]	2019	Performance evaluation of solar collectors in rural areas	In rural areas, about 1 MW of energy can be produced by renewable energy
Soomro et al. [18]	2019	Evaluation of the renewable resource's usage	Using renewable energy to reduce the consumption of fossil fuels with air cooling can be a good option for energy production. Also, SWHs can be used for this purpose and to save fossil fuel consumption.
Irfan et al. [19]	2019	Assessment of energy production	Due to the large population and industrialization, fossil energy sources are insufficient, have adverse environmental effects, and are not economically viable. They are also not suitable for providing electricity to remote areas. Finally, there is a need to look for renewable energy sources, of which solar energy is the best option.
Latif et al. [20, 21]	2020	Assessment of security, crisis, demand, supply, and potential of renewable energy	The results showed that a sustainable energy supply is an essential feature for the economic growth of any society. Renewable sources are the best option for reducing the cost of imports and increasing environmental and economic sustainability, and SWHs can be used in this direction.
Touaba et al. [22]	2020	Evaluation of a new FP SWH system using waste motor oil	The investigated system has the best performance because it reaches an acceptable heating temperature of 50 ºC in less than 3 hr, and its efficiency reaches 80%.
Mehmmod et al. [23]	2020	Assessing the ever-increasing population and increasing demand for energy and providing a suitable solution for it	The use of FP solar collectors is not dangerous for the environment and leads to the reduction of pollutants. Also, by changing the angle of these collectors, the percentage of produced energy can be changed.
Tariq et al. [24]	2021	Assessing how to generate more energy	High temperature and performance should be obtained from the collectors in order to use them to produce more thermal energy. Triangular canals are more suitable because all three sides of these canals are exposed to solar radiation.
Uddin et al. [25]	2021	Assessment of energy supply	Renewable energies such as wind and solar should be used to produce energy and save fossil fuel consumption.
Mahboob et al. [26]	2022	Performance evaluation of SWHs	If water containing soluble salts is used, the efficiency and output will be lower than if underground water is used.
Arif et al. [27]	2022	Evaluation of solar water heating system and how to provide sustainable and affordable energy	If people use a FP collector, they obtain better results. This collector also has a higher solar fraction and more efficiency. In winter, wood and gas systems, along with solar collectors, can be used.

According to the detailed review of recent studies on Pakistan and Table 1, we can see that no comprehensive study has been done on the feasibility of using SWHs in all stations of Pakistan. Finding points with suitable potential is significant in renewable energy projects. Therefore, using TSOL Pro 5.5 software, 32 stations located in Pakistan have been evaluated. In each station, we determined how many collectors provided what percentage of the required heat for each station.

2. Investigated place

Figure 1 shows that Pakistan is a country in South Asia, spanning 881913 km2. Islamabad is its national capital. India borders Pakistan to the east, Afghanistan to the west, Iran to the southwest, and China to the northeast. Pakistan has many gas reserves, estimated to be around 24700 billion ft3 [28].

Fig. 1. Location of Pakistan in the world

3. Methodology

We use TSOL Pro 5.5 software for one-year dynamic simulation in the present work. TSOL Pro 5.5 is a simulation program for designing and planning solar thermal systems, which 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. TSOL Pro 5.5 makes it much easier to perform simulations and calculations for solar heating systems. So, we can carry out designing the optimum solar heating systems, temperature simulation, and checking their energy performance with less time and cost [29].

TSOL software is a simulation software for solar heat supply that can dynamically simulate the system 365 days a year for different purposes of hot water consumption. One of the advantages of this software is the possibility of connecting to Meteonorm software and not needing climate data separately. this software has chosen for the present work due to the high accuracy of this software in analyzing the results and its wide use for different purposes.

In Figure 2, the schematic of the TSOL software performance is shown. The required information for space heating provided by the user, and the climate data provided by Meteonorm 7.1 software, as the input data to the software, will ultimately lead to the output, which is the total solar fraction.

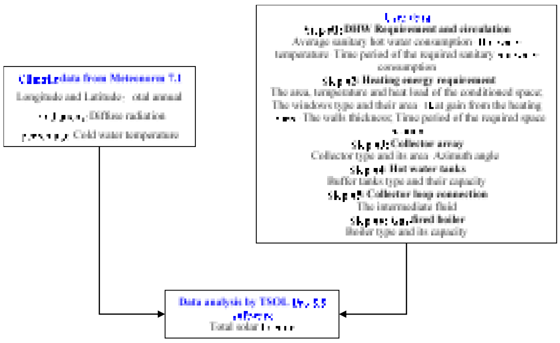

Fig. 2. Schematic of the TSOL software performance

Stations have selected in Pakistan to check their potential, whose climatic information, such as the intensity of solar radiation, air temperature, etc., are available in the database of Meteonorm software. For this reason, 32 stations have been selected.

4. Data for simulation

This work aims to supply the required heat for a one-story residential building without a basement and skylight windows in Pakistan using SWHs. Other characteristics of the investigated structure are:

– Area: 120 m^2
– Ceiling height: 3.3 m
– Area of external walls: 194 m^2
– Size of windows: 18 m^2

The heat load is estimated to be 8 kW, which is obtained from the average number calculated by the following empirical formulas (based on the opinion of technical experts),

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

where Q is in kcal/hr, AF is a coefficient 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.

$$Q=3.5\ (3.3\ V+10\ m_{wall}^2+100\ m_{window}^2) \quad (2)$$

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

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

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 the 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 intended for six 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 ten and two, respectively.

The fluid inside the pipes is water and ethylene glycol. The percentage of ethylene glycol is 40%. Figure 3 shows the schematic of the investigated SWH system and the desired location with an area of 120 m^2. The outer part of the solar system, including the solar collector, is installed on the roof of the desired location, and the heating process starts when the sun comes up. Figure 3 shows the needed equipment to simulate the solar heating system. Also, the number of residents, required water temperature, type of heating system under investigation, plumbing information, etc., are given in Table 2.

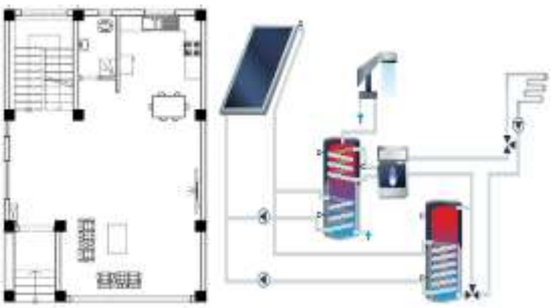

Fig. 3. Schematic of the SWH system and the investigated space

Table.2.
Software inputs

Parameters	*Data*
No. of people to be supplied	4 people
What is the target temperature for DHW	60 ºC
February and August cold water temperature	8 ºC and 12 ºC
How large is the area to be heated	120 m^2
Use which type of heating	Radiators
Heating energy requirements	8 kW
At which tilt angle should the collectors be set	30
What directors are the collectors facing	South
One-way length of inside piping	16 m
One-way length of outside piping	2 m

The required hot water temperature is 60 ºC , and a 2-tank system is considered. We used heat formulas to calculate the required heat, and the final heat of 8 kW was calculated. The initial estimates made by the software were checked and among the volume of the suggested tanks, the best and most economical, 1200 L, is considered.

The radiation received by the collectors is equal to the sum of direct and diffused radiation. We calculated direct radiation from Meteonorm 7.1 software, and for the diffused radiation colliding with the surface of the collectors, there are the following relationships based on the air smoothness coefficient (kt), where α is the angle of the solar collector [30, 31]:

$$0 \le k_t \le 0.3 \ : \ \frac{I_d}{I} = 1.02 - 0.245\, k_t + 0.0123 \sin\alpha \tag{4}$$

$$0.3 < k_t \le 0.78 \ : \ \frac{I_d}{I} = 1.4 - 1.749\, k_t + 0.177 \sin\alpha \tag{5}$$

$$k_t > 0.78 \ : \ \frac{I_d}{I} = 0.486\, k_t - 0.182 \sin\alpha \tag{6}$$

In the above equations, I is the total radiation on a horizontal surface in terms of $\frac{kj}{m^2}$ and Id is the diffused radiation on a horizontal surface in terms of $\frac{kj}{m^2}$. Since some of the received radiation is dissipated by the collector, the energy balance is expressed by the following equation [32, 33]:

$$\rho = G_{dir} \cdot \eta_0 \cdot f_{IAM} + G_{diff} \cdot \eta_0 \cdot f_{IAM.diff} - k_0\,(T_{cm} - T_A) - k_q\,(T_{cm} - T_A)^2 \tag{7}$$

In the above equation, G_{dir} is the direct incident radiation on the collector surface, G_{diff} is the diffused radiation incident on the collector surface, η_0 is the collector efficiency, f_{IAM} is the direct radiation correction factor, $f_{IAM.diff}$ is the diffused radiation correction factor, k_0 is the first order losses factor, k_q is the second order losses factor, T_{cm} is the average temperature of the collector and T_A is the air temperature.

The total solar fraction parameter is obtained by the following equation, its parameters are given in the references [34, 35]:

$$\text{Total solar fracion} = \frac{Q_{S.\ DHW} + Q_{S.HL}}{Q_{S.\ DHW} + Q_{S.HL} + Q_{AUXH.DHW} + Q_{AUXH.HL}} \tag{8}$$

5. Results

First, we checked all three types of heating, i.e., floor heating, radiators, and a combination of them, in Badin station. Then the system with better efficiency was selected. Finally, it was checked for all stations in Pakistan. According to investigations, all types of heating systems have the same results. For all three systems, an investigation has been done for 2 m2 collectors with an efficiency of 38% and a 1200 L tank. Because the results are the same for all three types of heating systems, we considered the radiator type heating system, the most common type. The entered information and the simulation results for all stations in Pakistan are given in Table 3.

The radiation potential for various parts of Pakistan is shown in Figure 4 to compare the radiation of different stations. The stations close to each other on the radiation map (Figure 4) have the same amount of received radiation. As a result, their solar fraction value is close to each other. Therefore, the difference in solar fraction changes their efficiency and the number of required collectors. For example, according to the radiation map (Figure 4), two stations, Sukkur and Peshawar, are in the same color scheme, so their solar fraction percentages are close. This slight difference is due to the small difference in solar radiation. It can be seen from the results of Table 3 that the more the total radiation of the station, the more the solar fraction of that station. This result is the same as the result we got from the radiation map of Pakistan. Badin has the highest solar deficit, 42%, followed by Nawabshah and Nokkundi, Panjgur, Parachinar, and Padidan, 39% because they are geographically located in a place that benefits from more sunlight. The lowest solar fraction (18%) is related to Balakot because it has less radiation. The minimum number of collectors (one) is required in stations with 47% efficiency. After that, Hyderabad, Jacobabad, and Badin stations need two collectors each. At the Murree station, the highest number of collectors, twelve, is required, and in this station, the efficiency is 22%, and the solar fraction is 30%. The stations with the highest efficiency (lowest collector) have a solar fraction of 27%, the lowest solar fraction. Stations that require three collectors have a solar fraction of 39% and an efficiency of 35%. In the stations where four collectors are needed, the solar fraction is 31%, and the efficiency is 30%. The minimum required number of collectors is one, and the maximum is twelve. The average solar fraction in Pakistan is 30%, and the average number of collectors in the investigated stations is three.

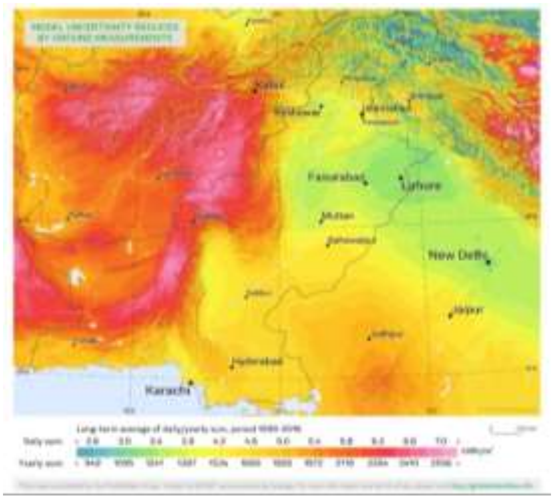

Fig. 4. Pakistan's radiation potential [36]

Table.3.
Entered information and simulation results

Location	***Total solar fraction***	***System Efficiency***	***collectors***	***Lat***	***Long***	***Total radiation (kWh/m²)***
Badin	42%	38%	2	24.6	-68.9	1978
Bahawalnagar	33%	34%	3	30 C	-73.3	1845.4
Balakot	18%	32%	3	34.4	-73.4	1751.3
Bar khan	36%	29%	5	29.9	-69.7	2000.7
Chhor	36%	29%	5	25.5	-69.8	1975.3
Chitral	29%	22%	9	35.9	-71.8	1871.7
Dalbandin	37%	31%	4	28.9	-64.4	2199.0
Deraismail	37%	31%	4	31.8	-70.9	1725.9
Dir	35%	23%	10	35.2	-71.9	1948.9
Drosh	30%	24%	9	35.6	-71.8	1807.4
Hyderabad	38%	38%	2	25.4	-68.4	1951.5
Islamabad	29%	31%	4	33.6	-73.1	1716.5
Jacobabad	33%	39%	2	28.3	-68.5	1943.2
Jhelum	29%	31%	4	32.9	-73.7	1689.3
Jiwani	27%	47%	1	25.1	-68.1	1956.3
Karachi	27%	47%	1	29.9	-67	1832.7
Khanpur	27%	47%	1	28.7	-70.7	1944.4
Khuzdar	27%	47%	1	27.8	-66.6	2115.3
Lahore	27%	47%	1	31.5	-74.4	1715.6
Multan	27%	47%	1	30.2	-71.4	1862.2
Murree	30%	22%	12	33.9	-73.4	1753
Nawabshah	39%	35%	3	26.3	-68.4	1984.5
Nokkundi	39%	35%	3	28.8	-62.8	2133.3
Padidan	39%	35%	3	26.9	-68.1	1968.9
Panjgur	39%	35%	3	27	-64.1	2147.9
Parachinar	39%	35%	3	33.9	-70.1	1822.5
Peshawar	31%	30%	4	34	-71.5	1874.5
Quetta	31%	30%	4	30.2	-67	2040.9
Rohri/Sukkur	31%	30%	4	27.7	-68.9	1942.1
Sialkot	31%	30%	4	32.5	-74.5	1665.2
Sibi	31%	30%	4	29.6	-68.9	1975.7
Zhob	31%	30%	4	31.4	-69.5	2013.4

6. Conclusion

Using SWHs in residential buildings will significantly reduce the energy consumption of any country. Based on the investigations, no comprehensive potential measurement has been done for the Pakistan stations to find each point's potential and the optimal point. Therefore, in this work, for the first time, using TSOL Pro5.5 software, the performance of 32 stations in Pakistan has been evaluated. Based on the results, the most suitable and unsuitable stations are Badin (with 42% of the total heat needs supplied by SWH) and Balakot (with 18% of the total heat needs provided by SWH), respectively. The reason for this difference is high radiation in Badin and low radiation in Balakot. According to the carried-out investigations in the present work, further research on the price of each kWh of solar heat is suggested in future studies.

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