IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Optimal sizing of a solar thermal system in building based on simulation results of Polysun

To cite this article: F F Fu and F Li 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **188** 012006

IOP Conf. Series: Earth and Environmental Science **188** (2018) 012006 doi:10.1088/1755-1315/188/1/012006

Optimal sizing of a solar thermal system in building based on simulation results of Polysun

F F Fu[1,2] and F Li[1]

[1]School of Physics and Technology, University of Jinan, Jinan, 250022, China

Email: sps_fuff@ujn.edu.cn

Abstract. Due to a series of environmental pollution and energy crisis, much attention is focused on developing clean renewable energy. Many institutes in different nations have interesting in studying the usage of solar heaters into buildings. In China, solar energy heat usage technology in buildings has a big potential market and has been rapidly developed. So, in this paper, a solar thermal system in building used for space heating and domestic hot water production has been studied. A simulation calculation method is put forward by Polysun for finding the optimal size of three main components for the solar thermal system, including the tilt angle of collectors, volume of the buffer and area of the collectors. Moreover, the relative impact of those three parameters on the optimizing indexes (*SF*, E_{tot} and *f*) is investigated where all indexes are most affected by the area of the collectors while the tilt angle of collectors and the volume of buffer both present a relatively small influence.

Introduction

Now China faces challenges in shortages of energy and environmental crisis. Currently, Fossil fuel contributes to 75% of primary energy consumption, followed by the fossil fuel gradual exhaustion and the green-house effects and air pollution.

A global research in the field of new energy resources and systems is carried out during the past fifty years [1-4]. Energy conversion systems based on new energy technologies seem to be less expensive compared to the high cost of fossil fuel. Meanwhile, new energy systems can have a beneficial influence on the environmental. China has rich solar energy resources. More than 60% of areas of the country receive annual total radiation above 5860 kJ/cm^2 with more than 2200h of sunshine [5]. So, utilization of solar energy has huge development potential in China. Solar energy thermal utilization technologies started in half a century ago in China. By the persisting work for decades, solar energy thermal technologies have been rapidly developed and its application has been rapidly expanded.

Due to the low cost, easy operation and minimal need for maintenance, solar thermal system has been wildly installed in buildings. And thus, the integration of solar water heaters into buildings has been studied by many universities, which can supply SH (space heating) and also provide the production of DHW (domestic hot water) [6-11]. Accordingly, the focus of our researches has been set on a solar thermal system installation that simultaneously satisfies DHW and SH needs. In previous research we just only focused on the system construction and operation features of different modes of solar thermal system in building, due to lack of effective research strategies. While now, the software Polysun provides the possibility of intense researches, for the Polysun product range includes all the tools you will ever need to design, enhance and simulate your systems in the field of renewable energies [12]. Thus, this paper focuses on a solar thermal system installed in a single-family house located in city of Jinan, China, and presents a simulation calculation method by Polysun for finding the optimizing size of the main components of the solar thermal system.

Solar thermal system model in Polysun

The simulation software Polysun provides a comfortable and attractive graphical user interface, in which different system model could be created. Even more it permits a comfortable and clear input of all system parameters and the analysis and design of energy systems. It runs with time steps from 1 s to 1 h, thus simulation can be more stable and exact [12].

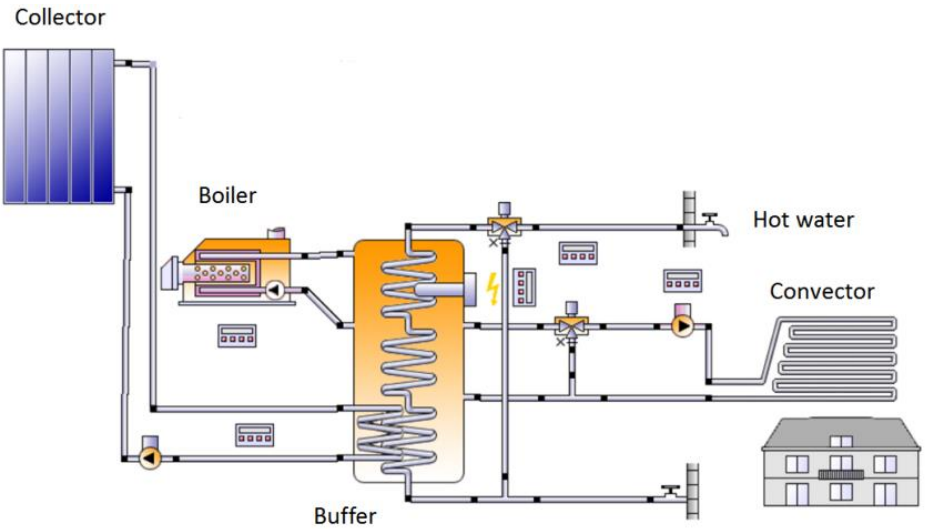

Figure 1. A solar thermal system designed using Polysun.

The diagram of the solar thermal system used in this paper is shown in figure 1. In this system, the main equipments are solar collectors, the buffer and the boiler. The solar collector is a kind of heat exchangers which is the key parts of the system. Solar collector absorbs the light falling on its surface, converts it into heat energy, and transfers this heat to the working fluid flow in solar collectors.

The boiler and the solar collectors are connected to the buffer in the centre of the picture, which are both the energy supplies to the system. Solar collectors produce thermal energy most depending on global solar irradiation and outdoor temperature. The higher the global irradiation level, the better efficiency, and higher thermal performance of collectors. If the temperature is increased, collector heat loss decreases. In table 1, the average outdoor temperature and global irradiance time series are list over a one-year period.

Table 1. The average outdoor temperature and global irradiance.

month	average outdoor temperature/℃	average direct irradiance/kWh	average scattering irradiation/ kWh	average global irradiance/ kWh
Jan	-0.1	60.1	37.9	98
Feb	3.4	72	45	117
Mar	9.4	89.1	68.7	157.8
Apr	16.4	88.1	85.1	173.2
May	21.8	111	94.5	205.5
Jun	26.1	96.5	101.3	197.8
Jul	27.8	67.1	94.3	161.4

Aug	26	72.3	86.5	158.8
Sep	21.9	84.3	72.6	156.9
Oct	15.7	87	57.8	144.8
Nov	8.2	63.9	39.7	103.6
Dec	1.9	57	32.9	89.9

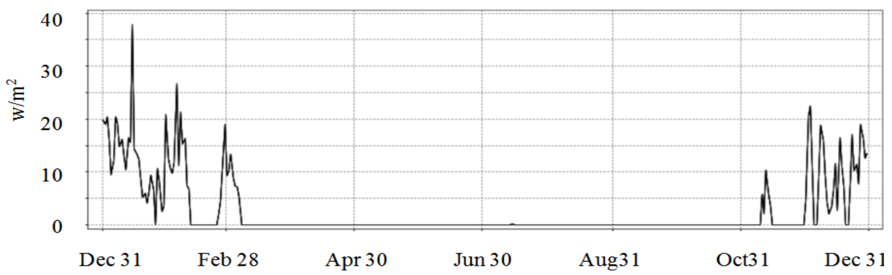

Figure 2. Yearly SH requirements for space heating in a mid-sized single-family house.

The system provides a DHW and a SH demand. The domestic hot water need is 200 L/d of water at 50℃. Energy for space heating is depended on local environmental temperature and building insulation. The heating set temperature is 19℃ during the day and night in the heating period from mid-November until mid-March the next year. The resulting simulated SH demand is shown in figure 2. Other simulation relevant parameters include the heated area of the building is 150 m^2 and the collector is oriented toward South. The output of the boiler is 5 kW and the efficiency is 0.74.

Optimization results

The goal of the optimization is to maximize the *SF* (solar frication) or to minimize the cost. *SF* is percentage of energy to the system supplied by the sun. A larger *SF* means the percentage of fuel energy and electricity consumed by auxiliary heating devices and pumps (E_{tot}) is smaller. The values of *SF* and E_{tot} presented in this section both are obtained by the software Polysun when simulating the model presented in Section 2. The main components in this model are the solar collectors and the buffer. So the optimizations for the tilt angle of solar collectors, the volume of buffer and total gross area of collectors are presented in this section.

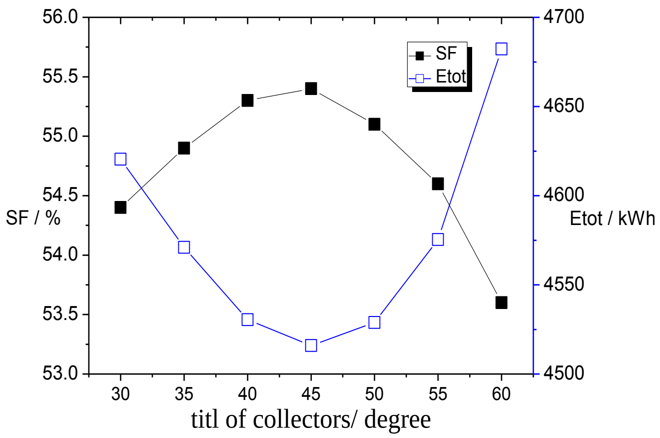

Figure 3. Relationship between tilt angle of collectors and *SF*, E_{tot}. (Area of solar collectors is 10 m^2, volume of buffer is 800 L).

3.1. Tilt angle of collectors

Tilt angle of collectors is the angle between the plane of the solar collector array and the horizontal plane. Optimizing the tilt angle of collector is a way to improve the utilization ratio of solar energy resources. As showed in figure 3, along with the increase of tilt angle of collector, *SF* is firstly increasing and then decreasing, existing an maximum value, in addition, the higher *SF*, the smaller consumed fuel energy and electricity (E_{tot}). As show in this figure, the best tilt angle of collectors is 45 degree.

3.2. Volume of buffer

The buffer is connected to a piping network, though which the medium transfers either to the solar collectors which it can be heated or to the buffer which it can be cooled. Different volume of buffer will result in different temperature of water inside and that medium during the running process of the system. As the medium flowing into the solar collector, the inflow temperature could influence the efficiency of solar energy photo thermal conversion and available heat gains of solar collectors and hence the *SF*. As showed in figure 4, an increase of the volume of buffer has a positive effect on the *SF*, while has a negative effect on the E_{tot}. Considered that the cost of buffer is ignored compared with such a reasonably sized system, the optimal volume of buffer is 1200 L in the range of value.

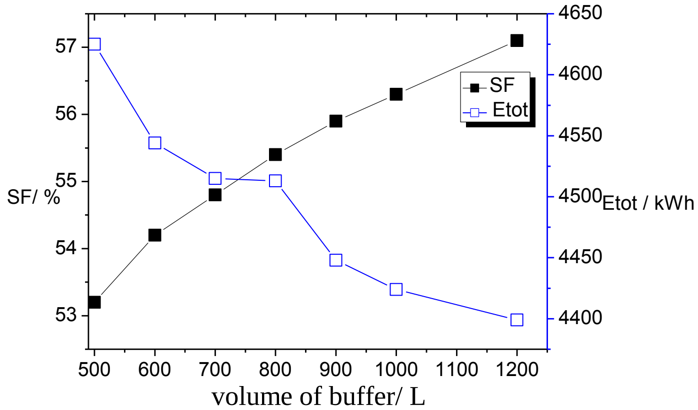

Figure 4. Relationship between volume of buffer and *SF*, E_{tot}. (Area of solar collector is 10 m^2, tilt angle of collectors is 45 degree).

3.3. Area of solar collectors

As showed in figure 5, firstly *SF* significantly increases with the increase of solar collectors' area, then, the increase is slow down when it increases to a certain value, while E_{tot} is just the opposite. In this case, solar collectors' area affects both the cost of the installation and operating cost of the system. That is, the larger area of collector, the more cost of installation and less operating cost of the system. So, the objective of this optimization is to minimize the total cost of the system.

According to equation (1), the total cost of the system *f* is as follows,

$$f = M + E_{tot} \cdot P_e \cdot n \tag{1}$$

Where *M* is the cost of the installation, P_e is the electricity price per kWh, *n* is the operating years of the system, so $E_{tot} \cdot P_e \cdot n$ presents the operating cost of the system. The market prices used for the total cost of the installation are listed in table 2. More remarkable, the electricity price per kWh is increasing every year, thus an annual increase of 5% at the price is considered for the purpose of this study. Table 3 and figure 6 shows the total cost of the system with different operating years. As showed in figure 6, along with the increase of solar collectors' area, total cost of system is firstly decreasing and then increasing, existing a minimum value. So the optimalarea of collector is 8 m^2 when the operating years is 5, 10 or 15.

Table 2. Relevant factors for the installation pricing.

Item	Value	Unit
Collector	500	CNY/m^2
Buffer	4	CNY /L
Boiler	200	CNY /kW
Electricity	0.5	CNY /kWh

Table 3. Total cost of the system with different operating years.

Aera of collectors /m^2	SF /%	E_{tot} /kWh	Total Cost of 5 years/ CNY	Total Cost of 10 years/ CNY	Total Cost of 15 years/ CNY
2	17.5	8,345	27,662	48,525	69,387
4	30.9	7,112	26,469	45,138	63,807
6	42	5,921	25,119	41,439	57,759
8	54.7	4,609	23,138	36,476	49,815
10	49.8	5,107	26,318	41,837	57,356
12	57.8	4,300	25,519	39,238	52,957
14	60.2	4,071	26,437	40,075	53,713
16	62	3,896	27,504	41,208	54,912
18	63.6	3,744	28,629	42,458	56,288
20	64.7	3,638	29,909	44,018	58,127

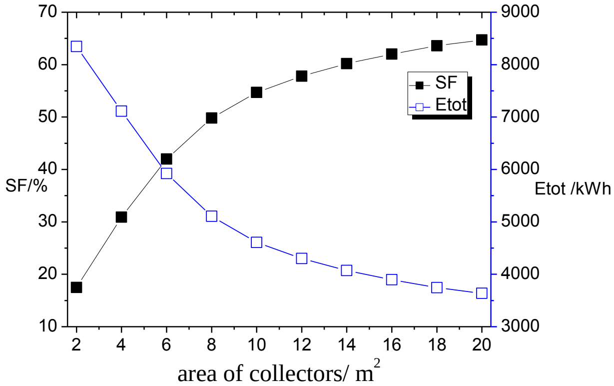

Figure 5. Relationship between area of collectors and *SF*, E_{tot}. (Volume of buffer is 1200 L, tilt angle of collectors is 45 degree).

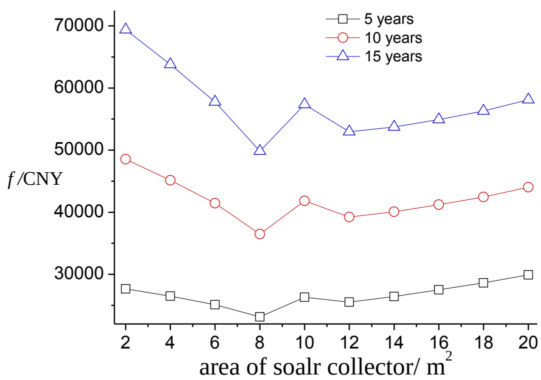

Figure 6. Total cost of the system with different operating years. (Volume of buffer is 1200 L, tilt angle of collectors is 45 degree).

Conclusion

In this paper the optimal sizing of a solar thermal system installed in a single-family house in city of Jinan, China has been presented. A optimization analysis has been carried out by the Polysun software, with the purpose of maximizing the *SF* or minimizing the cost. The analysis shows that the area of the collectors has the greatest influence on *SF*, E_{tot} and the total cost of system. The tilt angle of collectors and the volume of buffer both have a relatively small influence on *SF*, E_{tot} and the total cost of system. And tilt angle of collectors as 45 degree, collector area as 8 m^2, a buffer volume of 1200 L are the optimal sizes for the system's main components.

Acknowledgments

This research was financially supported by the National Natural Science Foundation of China (No.

51506074).

References

[1] Kevin L 2014 Critical review of China's rapidly developing renewable energy and energy efficiency policies *Renew. Sust. Energ. Rev* **29** 508-16
[2] Lysen E 2003 Photovoltaics: an outlook for the 21st century *Renew. Energ. World* **6** 43-53
[3] Li J F, Wan Y H and Ohi J M 1997 Renewable energy development in China: resource assessment, technologystatus, and greenhouse gas mitigation potential *Appl. Energ.* **56** 381-94
[4] Mekhilefa S, Saidurb R and Safari A 2011 A review on solar energy use in industries *Renew. Sust. Energ. Rev* **15** 1777-90
[5] Chao F X, Hui L L, Run S T and Hao Z 2004 Solar thermal utilization in China *Renew. Energ.* **29** 1549-56
[6] Soltau H 1992 Testing the thermal performance of uncovered solar collectors *Sol. Energ.* **49** 263-72
[7] Riffelmann K J, Fend T H and Pitz-Paal R 2000 Parabolic trough collector efficiency improvement activities. *10th SolarPACES International Symposium on Solar Thermal Concentrating Technologies* (Sydney, Australia) 121-9
[8] Lund P 2005 Sizing and applicability considerations of solar combisystems *Sol. Energ.* **78** 59-71
[9] Jordan U and Vajen K 2001 Influence of the dhw load profile on the fractional energysavings: a case study of a solar combi-system with trnsys simulations *Sol. Energ.* **69** 197-208
[10] Jiang Y, Wu H Y, Zhang J N and Zhang Z 2012 Simulation calculation and experimental study on solar radiant floor heating system *Gas & Heat* **32** 17-9
[11] Wei L 2013 The calculation of solar heating performance and the solar guaranteed rate *Refrig. and Air Condit.* **27** 381-3
[12] Polysun 2000 *User's Manual for Polysun,* (Switzerland) http://www.velasolaris.com