

# Cost analysis and economic saving of a solar system combined heating and powder for buildings

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**Abstract.** To solve the problems that the gradual depleting of fossil fuels and the increase of CO<sub>2</sub> emission. A solar system combined heating and electric powder in buildings has been proposed and analysed, which contains a solar-thermal subsystem and a photovoltaic subsystem. Taking a family house in Jinan as an example, the area distribution between solar collectors and the PV panels and the operating years were optimized aiming for achieving the cost benefits of the system. Meanwhile, the economic saving of the system is analysed with a solar-thermal system as a reference object. Results show that annual mean cost of the proposed system is much decreased firstly and then the decrease of it slows down, with the increase of the area ratio between PV panels and solar collectors. Meanwhile, that is decreasing with the increase of the operating years. In addition, the proposed system can save more energy than that reference when the heating is assumed the same.

## 1. Introduction

At present, China faces challenges in the energy crisis for a rapid growth of energy consumption. With the increase in energy consumption, the issue of energy shortage brings challenge to sustainable development of economic. Moreover, the sharp increase of gas pollutants has great influences on environmental quality. So, to tackle energy problems and environmental pollution, a portion of fossil fuel powder consumed has been replaced by the new energy resources, which includes solar energy, wind energy, Biomass energy, geothermal energy and so on.

In China, powder consumption in buildings accounts for about one-third of all energy use[1]. And we believed that such a proportion will be greatly increased in the coming decades with the rapid economic growth. Solar energy systems used in the buildings have the advantages of lower cost, reliability and green as compared with traditional energy. In order to make the most of solar resource, the solar energy system in the buildings should contain solar thermal components and photovoltaic (PV) components.

Solar energy development and utilization has a tremendous development around the world. Solar systems which can supply space heating (SH), the production of domestic hot water (DHW) and also the electricity, have been proposed and been performed energy and economic analysis in literatures. In these literatures, some researchers proposed a combined heat and power based on a micro-turbine driven by solar energy which produces electricity and heating energy [2-5]. Other researchers proposed PVT system to generate power [6]. However, none of those installations is fit for providing energy to the buildings, especially for family houses.

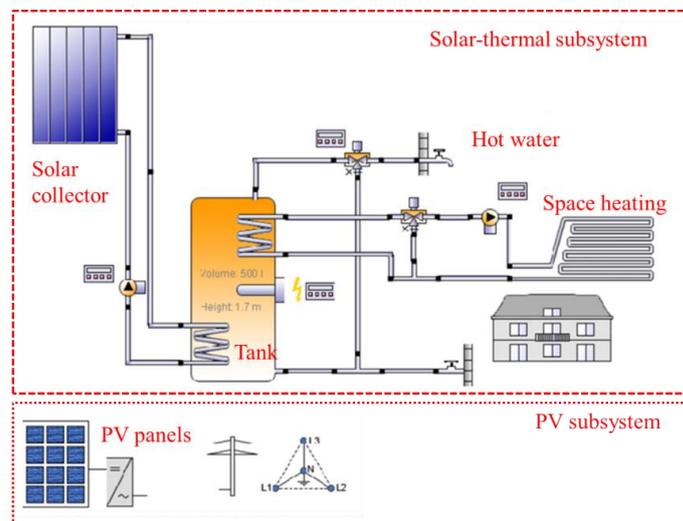


Accordingly, the focus of our researches has been set on a solar system in a family house which could satisfy DHW, SH and electricity needs. The case sites on a suburb in southern Jinan city of Shandong Province in eastern China. This system contains a solar-thermal subsystem and a PV subsystem. The solar-thermal subsystem could supply DHW and SH. The characteristic of the system lies in that the PV subsystem just takes care of the solar-thermal subsystem. If that was not enough, the solar-thermal subsystem obtains electric power from the grid. In our research, we used a software named Polysun for simulation and analysis of system performance. The aim of the analysis is to investigate and optimize the economic performance of the system. Thus, this paper considers a solar system installed in a family house located in Jinan, China, and presents energy and economic analysis based on Polysun.

## 2. The system model in Polysun

Polysun is a software that enables users to effectively simulate solar-thermal and photovoltaic systems. In Polysun, it also contains various system templates which define all of the components and connections, meteorological conditions and also the consumers of the solar energy system. By Polysun, it is possible to simulate each system diagram individually and to visualize the results. Normally different system templates are considered in order to make comparison and optimize [7,8].

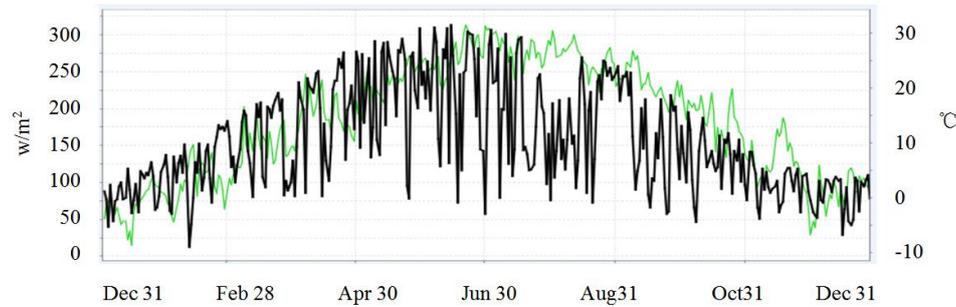
The template of the proposed system is shown in Figure 1. This is a solar system which contains a solar-thermal subsystem and a photovoltaic subsystem. For the solar-thermal subsystem, the solar collector is the key parts which is a kind of heat exchangers. Solar collector absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid flowing through it. In the day time, the thermal energy applied by the solar collector can be used for heating, while in the evening or rainy days, the electric heater of the tank can supply thermal energy. The PV subsystem is connected to the grid. It means that during the day, the electricity generated by the PV system can either be used immediately for the solar-thermal subsystem or can be fed into the grid. In the evening, when the PV system is unable to produce the electricity, power can be bought back from the grid. So, the PV system does not need battery storages, for the grid is acting as an energy storage system.



**Figure 1.** The template of the system in Polysun

Solar collectors produce thermal energy and PV panels generate electricity most depending on global irradiation and outdoor temperature. Figure 2 shows the outdoor temperature and global irradiance time series over a one-year period of Jinan. The green line is the temperature curve and the black is irradiance time series. It can be seen that the months with the highest outdoor temperature is June, and with the highest global irradiance are May, June and July. The hybrid system provides

domestic hot water and space heating for a two-floor building with the total area of 140m<sup>2</sup> in Jinan. The domestic hot water need is 200 L/d of water at 50°C. The heating set temperature in building is 21°C. It is assumed that the building space heating operates for 24 hours a day. The duration of the heating period is selected taking into account the Chinese normative, which is from early November until late January.



**Figure 2.** The average outdoor temperature and global irradiance over a one-year period of Jinan

### 3. Cost analysis and economic saving

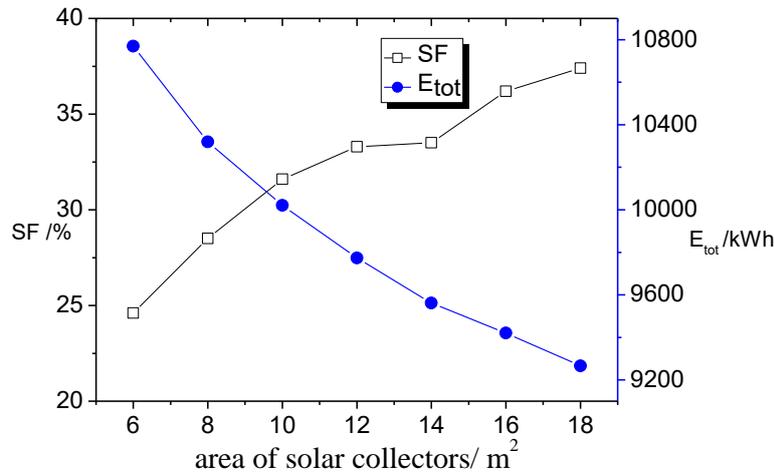
The performance of the system is evaluated in terms of cost analysis and economic savings, performing a comparison between the investigated system (IS) and a reference one (RS). In particular, RS is just a simple solar thermal system, the structure of which is just the same with the solar-thermal subsystem of IS, and for both IS and RS are assumed the same SH and DHW. The costs of both the two systems are depended on the first investment, annual operating cost and total operating years. The first investment contains the cost of solar collectors, PV panels, the tank, controller, pump, pipelines and other gadgets. And the powder consumption (fuel and electricity) is the operating cost.

#### 3.1. Solar friction

Solar friction ( $SF$ ) is percentage of energy to the system supplied by the sun which is expressed by formula (1). In particularly, the higher the  $SF$  is, the smaller the sum of consumed powder over a one-year period ( $E_{tot}$ ) will be.

$$SF = \frac{\text{solar energy to the system}}{\text{solar energy to the system} + \text{auxiliary energy to the system}} = \frac{Q_{sol}}{Q_{sol} + Q_{aux}} \quad (1)$$

Figure 3 shows the impacts of solar collectors' area for the  $SF$  and  $E_{tot}$ . It can be seen that the area of solar collectors affects both the  $SF$  and  $E_{tot}$ .  $SF$  is much increased with the increase of the area of solar collectors, while  $E_{tot}$  is just the opposite. In particularly, the larger area of solar collectors, the more first investment and less  $E_{tot}$ .



**Figure 3.** Impacts of solar collectors' area for the  $SF$  and  $E_{tot}$

### 3.2. Cost and economic savings

The annual mean cost of the RS (ACRS) can be expressed as:

$$ACRS = \frac{A_s * P_{sa} + P_{ic} + E_{tot} * P_e * N}{N} \quad (2)$$

Where,  $A_s$  is the area of the solar collectors.  $P_{sa}$  is the price of per square meter of the solar collectors.  $P_{ic}$  is the installation cost but the solar collectors.  $P_e$  is the price for electricity per kWh.  $N$  is the operating years. While, for IS, we should also take into account the installation cost and energy production of PV panels. So, the annual mean cost of the IS (ACIS) can be expressed as:

$$ACIS = \frac{A_s * P_{sa} + A_{pv} * P_{pv} + P_{icpv} + (E_{tot} - E_{acp}) * P_e * N}{N} \quad (3)$$

Where,  $A_{pv}$  is the area of the PV panels.  $P_{pv}$  is the price of per square meter of the PV panels.  $P_{icpv}$  is the installation cost but the solar collectors and photovoltaic panels.  $E_{acp}$  is the yield energy production of PV panels. The annual mean energy saving (AMES) and the annual mean energy saving ratio (AMESR) achieved by IS with respect to RS are expressed as:

$$AMES = AC_{RS} - AC_{IS} \quad (4)$$

$$AMESR = \frac{AC_{RS} - AC_{IS}}{AC_{IS}} \quad (5)$$

It worth noting that the total area of the solar collectors and PV panels are at most 50m<sup>2</sup>, for the utilization of the building's rooftop is 70%. We considered seven area distributions between  $A_{pv}$  and  $A_s$ , which are showed in Table 1. The relevant factors for the count of ACIS and ACRS are showed in Table 2. Figure 4 shows the result of ACIS. It can be seen that along with the increase of the area ratio, ACIS is much decreased with the increase of the area ratio firstly, and then the decrease of it slows down. Meanwhile, the ACIS is decreasing with the increase of the operating years. So, the ACIS for 15 operating years is the smallest, under the considered 5,10 and 15 operating years. Also, it can be seen that the ACIS has an obvious reduction between 5 and 10 operating years. Figure 5 shows the

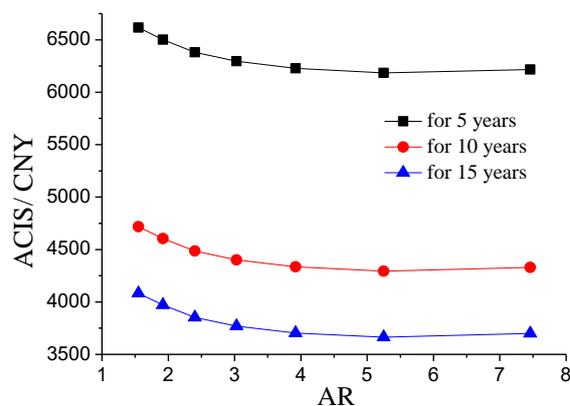
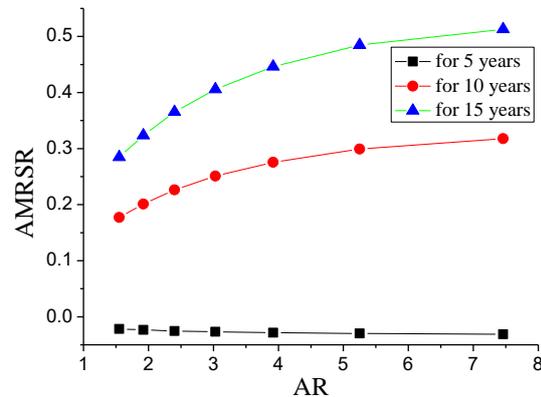
result of AMESR. It shows that for 5 operating years, AMESR is negative, which means the ACIS is larger than ACRS. While, the AMESR for 10 years is positive which is between 18% and 32%. For 15 years, that is between 28% and 51%. So, the AMESR is increasing with the increased of operating years.

**Table 1.** AR considered

$A_{PV}/m^2$	$A_S/m^2$	Area ratio
28	18	1.55
30.8	16	1.92
33.6	14	2.4
36.4	12	3.03
39.2	10	3.92
42	8	5.25
44.8	6	7.46

**Table 2.** Relevant factors for the ACIS and ACRS

Item	Value	Unit
Solar collector	500	CNY/m <sup>2</sup>
Tank	4	CNY/L
Electricity	0.5	CNY/kWh
PV panel	350	CNY/m <sup>2</sup>

**Figure 4.** ACIS results**Figure 5.** AMRSR results

#### 4. Conclusion

A solar system which could satisfy DHW, SH and electricity needs for a family house has been proposed and analysed. This system contains a solar-thermal subsystem and a PV subsystem. The solar-thermal subsystem supply DHW and SH. The PV subsystem takes care of the solar-thermal subsystem. The performance of the system is evaluated in terms of cost analysis and economic savings, performing a comparison between the investigated system and a reference one which is a solar thermal system with no PV component. The most important conclusion of the study can be summarized as follows:

1. Annual mean cost of the proposed system is much decreased firstly and then the decrease of it slows down, with the increase of the area ratio between PV panels and solar collectors. Meanwhile, that is decreasing with the increase of operating years.

2. The hybrid system can save more energy than that reference, in this case that both the two systems are assumed the same SH and DHW.

### Acknowledgments

This research was financially supported by the National Natural Science Foundation of China (No. 51506074).

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