Study of Applications of Solar Heating Systems with Seasonal Storage in China

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Abstract: In most northern parts of China, it is cold in winter and needs space heating in winter. This paper studies applications of solar heating systems with seasonal storage in China.

A typical residential district was selected, and a solar heating system with seasonal storage was designed and simulated based on various conditions. The results indicate that 1) for many places of China, solar systems with seasonal storage can save conventional energy and can be competitive with gas-fired boiler heating; 2) when the ratio of volume of seasonal storage tank to collector areas is 3~5, the system performance is optimal for many places in China; 3) the obtained solar heat is mainly dependent on the solar irradiance, length of heating period and ambient temperature. Solar heating with seasonal storage in chilly places may also get good performance.

Key words： Solar heating, Seasonal Storage, Application

In many northern parts of China, it is cold in winter and many buildings need space heating during winter. There are about 2/3 areas with annual total horizontal irradiation above 5000MJ/m^2 in China. The resources of solar energy are abundant and there is large potential for solar heating in these areas.

In order to increase the solar fraction of solar heating systems, the concept of seasonal storage was put forward and some demonstration projects have been built in Europe since 1980's[1]. Seasonal storage charges solar heat collected in summer and discharge heat in winter.

1. GENERAL FEATURES OF SYSTEM

In order to study the characteristics of solar heating systems with seasonal storage and the feasibility of applying them to China, a typical residential district in a small town in the suburb of Beijing was assumed, then a solar heating system with seasonal storage was designed. This system is responsible for the space heating and Domestic Hot Water (DHW) of the typical residential district.

There are 8 buildings in the district. Each building has three entrances and 4 stories. There are 2 flats in each floor in each entrance. The flat has three bedrooms, two sitting rooms, one washing room and one kitchen, of floor area ca. 120m^2, with average 3.5 persons in it. The total floor area of the district is ca. 23000 m^2.

1.1 Space Heating Load

The district adopts central space heating system. According the real investigation, the building envelope insulation in most small towns is poor, the design heating index is 50W/m^2， hence the total design heating load is 1124kw.

1.2 Domestic Hot Water (DHW) Load

According to the present living habits in many small towns. DHW is just used for bathing, it constructs a public bathing house in the district, opening from 18:00~22:00. Each bath uses hot water 70L of 60℃ on average，each person has a bath weekly. Therefore hot water usage is 6720L per day, and it needs hot water of 1680L in each hour during opening.

1.3 Solar Collectors

Collectors are placed on the south side of the ridged roof of the buildings. Their tilt angles are 30^o. The total collector area is 1950 m^2.

The efficiency of solar collectors used here is:

$$\eta = 0.7486 - 3.7465x$$

where, *x=(Tw-Ta)/It*

Tw: Collector inlet temperature.

It: Irradiance

1.4 Seasonal Storage Tank

The seasonal storage is a cylindrical steel water tank, standing above ground. The volume of the tank is two times collector area, 3900m^3.

1.5 Heating Networks

The space heating network and solar collecting network are separated, and both are directly buried. Circulation flow rate in solar loop is 50L/(h • m^2 collector area).

1.6 Auxiliary Heating Equipment

Gas-fired boilers were adopted to assist solar collectors.

1.7 Schematic and Operating Mode of Solar Heating Systems

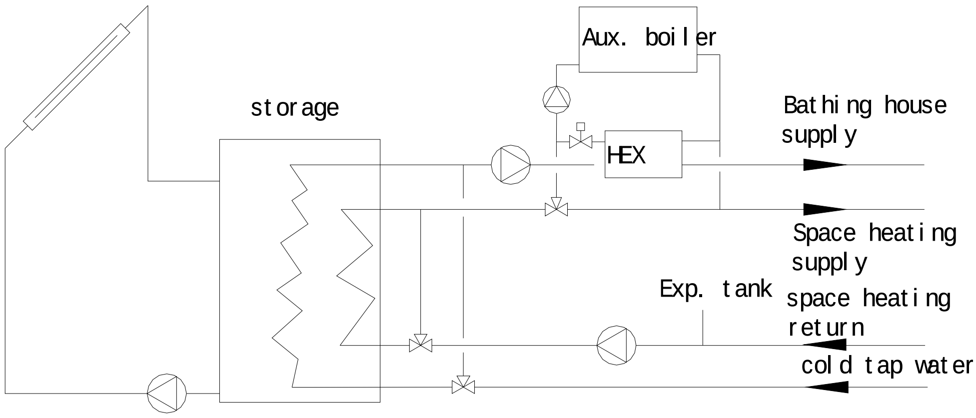

Fig.1 Schematic of solar heating system with seasonal storage

Tab. 1 Distribution of heat consumption

Items	Heat loss by space heating piping	Heat loss by solar network	Heat loss by collector in night	Heat loss by storage	Hot water load	Space heating load	Total
Heat (GJ)	222	93	408	641	497	8320	10200
percentage %	2.18	0.91	4.01	6.30	4.88	81.72	100

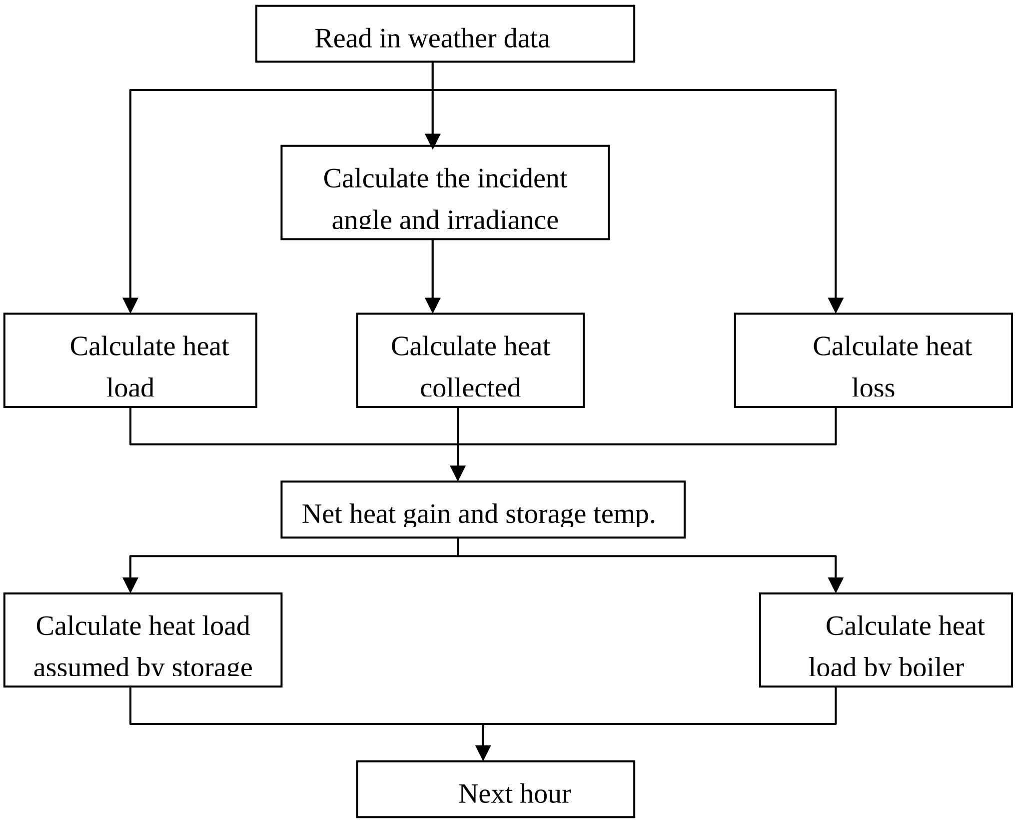

Fig. 2 Computation process

Fig.1 shows the schematic of the solar heating system with seasonal storage. The practical diagram will be much complex than this. The space heating supply temperature is set to 60℃, the operating strategies for space heating are as below:

(1) When storage temperature is higher than 60 ℃, space heating load and heat loss of piping are assumed by storage.

(2) When storage temperature is lower than 60℃ and higher than return water temperature, heat is extracted from the storage, and then supply water is heated to 60℃ by boiler.

(3) When storage temperature is lower than return water temperature, the storage is bypassed and all space heating load and heat loss of piping are assumed by boiler.

The DHW operating strategies follows:

(1) When storage temperature is higher than 60℃, tap water is heated by storage.

(2) When storage temp. lower than 60℃, tap water is preheated by storage, and then heated by heat exchanger to 60℃.

2. SIMULATION METHODORLOGY

There is no existing solar heating system with seasonal storage at present. In order to study the characteristics of such systems and the feasibility of applying them to China, a typical residential district in a small town in Beijing was assumed, and a solar heating system with seasonal storage was designed. Some computer routines were made, and many simulations were conducted hour by hour for many different parameters and conditions based on TMY weather data. The computation process of the main routine is described in Fig.2. The life cycle of the system was assumed as 15 years. The computation takes account of the dynamics of capital.

Some important results will be discussed in the following sections.

3. ANALYSIS OF THE BASIC CASE

The parameters of the basic case are described in section 1 of this paper. Its performance was studied by simulation.

3.1 Energy Balance

The distribution of the heat consumption was listed in Table 1. It indicates that the fraction of DHW is much lower than that in Europe. This is adverse to the cost-effectiveness of the whole system[2].

Table 2 lists the distribution of the heat production.

Tab. 2 Heat production

Items	Solar heat	Hot water by boiler	Space heating by boiler	Total
Heat(GJ)	3470	61	6640	10200
Percentage %	34.09	0.60	65.31	100

Table 1 and Table 2 verify that Heat consumption is equal to heat production.

3.2 Monthly Variation of Solar Heat and Auxiliary Heat

Solar fraction is defined as:

$$solar\ \ fraction = \frac{solar\ heat\ \text{collected} - heat\ \text{loss by solar loop} - heat\ \text{loss by storage}}{heat\ \text{load} + heat\ \text{loss by heating network}}$$

Table 2 shows that the solar fraction is 34%. It is hard to achieve so high solar fraction in multi-storey buildings without seasonal storage[3].

Fig.3 shows the monthly fraction of solar heat and auxiliary heat. The solar heat contributes much more in November than in other months due to the seasonal storage.

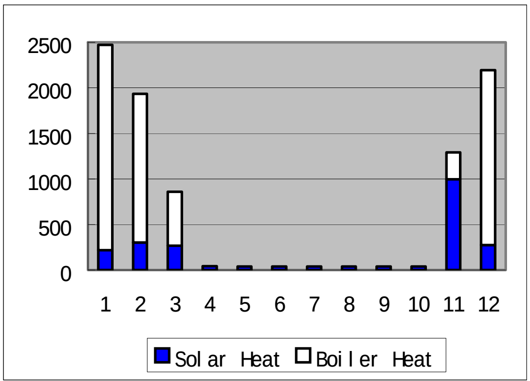

Fig.3 Monthly Aux. heat and solar heat (GJ)

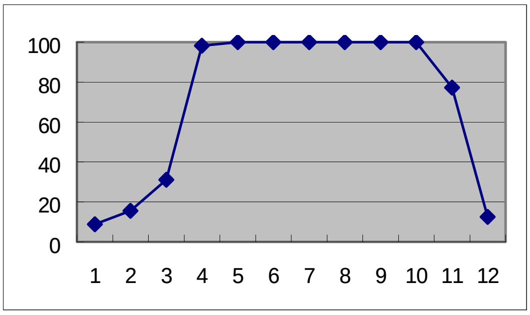

Fig.4 Monthly Solar Fraction (%)

Fig. 4 shows the monthly solar fraction in a whole year. In the months from April to October, the solar fraction is nearly 100%, the boiler can be shut down and hence avoid of operating at low efficiency due to partial load.

4. EFFECTS OF STORAGE VOLUME

The volume of seasonal storage is an important parameter for the solar system. According to the usual routine[1], this paper uses the ratio of storage volume to collector area (Rv) to study its effects on the whole system.

Fig.5 gives the yearly temperature changes for different volume of tank. Rv is from 0.5 to 5. From Fig.3 we can see that the temperature in the tank rise to high level in short period when Rv is smaller than 3. If the Rv is more than 5, the temperature in the tank rises slowly, the temperature is still in low level until winter coming and the available temperature difference of storage is small.

The larger the volume of the tank, the more the solar energy can be collected (shown in Fig. 6) as long as the Rv is lower than 10. When Rv is more than 10, solar fraction begin to reduce, and there is adverse effects to increase the storage volume.

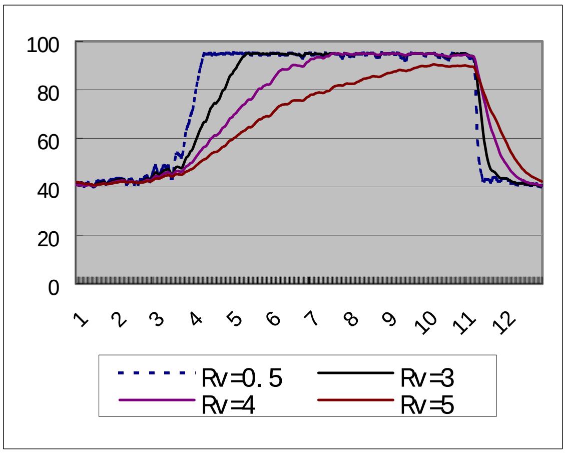

Fig.5 Annual temperature of storage water temperature (°C)

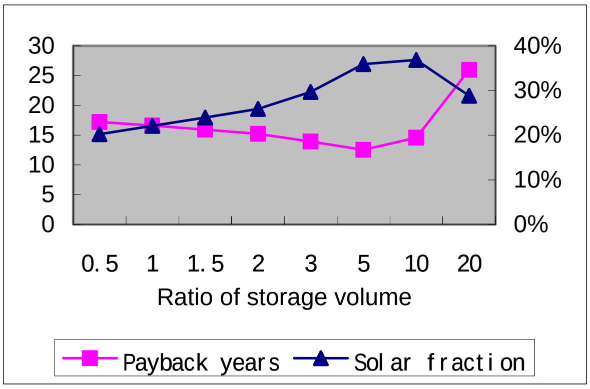

Fig.6 Solar fraction & payback years for some storage volumes

Fig. 6 indicates that when the Rv is near 5, the payback year is shortest.

The European experience indicates that optimal Rv is among 2-3[4], while the optimal Rv is Beijing is near 5, this is due to the following factors:

(1) The lower cost of construction of such a large tank in China than in Europe.

(2) The longer summer time and shorter heating periods.

(3) The poor performance of the building envelope and higher U-value.

(4) The lower DHW fraction of the load of this system.

5. COMPARISON AMONG DIFFERENT PLACES

It is necessary to study the effects of weather conditions on the system performance. Five typical places (Beijing, Shanghai, Harbin, Lanzhou and Lhasa) were selected to compare with. Design space heating index: Shanghai, 35W/m^2; Harbin, 70W/m^2; others, 50W/m^2. Rv of all these places is 2.

It is surprising (see Fig. 7) that there is no big difference of annual collector efficiency, although Lhasa is a little higher than the others. However, the solar fraction is different very much, Shanghai is the highest and Harbin the lowest.

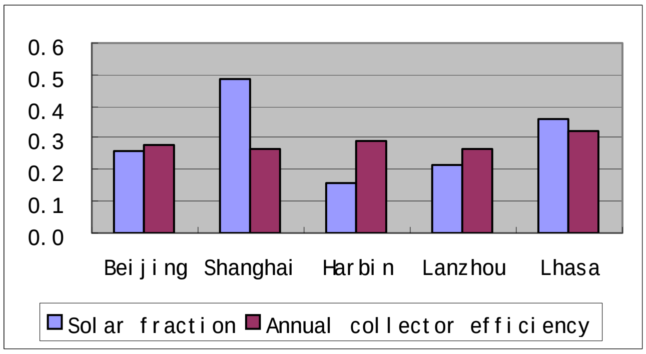

Fig.7 solar fraction and annual collector efficiency for five places

Obtained solar heat of Lhasa is highest due to its best solar radiation and temperate ambient climate. Shanghai's solar fraction is highest because of its lowest space heating load, That means the collector area per kw design load is lager than the other four. Although the ambient temperature is much lower than the other four, both the solar heat and collector efficiency is not lower (Fig. 7). This is due to its longer heating season, that is, the collector works less efficient but work longer.

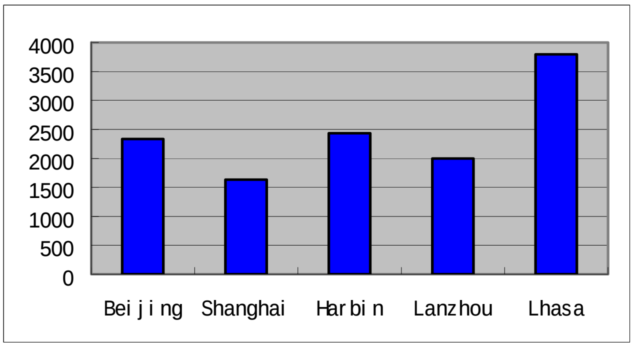

Fig.8 Obtained solar heat for five places (GJ)

The obtained solar heat is mainly dependent on the solar irradiance, length of heating periods and ambient temperature.

6. CONCLUSIONS

From the simulation and analysis, this paper concludes that:

(1) For many places of China, the solar systems with seasonal storage can save conventional energy greatly and can be competitive with gas-fired boiler heating;

(2) When the ratio of volume of seasonal storage tank to collector areas is 3~5, the system performance is optimal for many places of China.

(3) The obtained solar heat is mainly dependent on the solar irradiance, length of heating season and ambient temperature. Solar heating with seasonal storage in chilly places may also get good performance.

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