

Study on Solar and Heat Pump Combined Domestic Water Heating Systems with Diurnal Storage

Guoqing Yu¹, Jianyong Liu¹ and Hui Yang²

¹Department of building environment and services engineering, University of Shanghai for Science and Technology, Shanghai, China, guoqing.yu@163.com

²Branch in Shanghai, Guangdong Jirong engineering Co. Ltd, Shanghai, China, mrhuiyang@163.com

ABSTRACT: In the paper, a simple domestic water heating system is assumed and a solar and heat pump combined heating system with diurnal storage is designed for it. Hourly simulations during a whole year were conducted under various conditions, such as different solar collector area, storage volume and heating capacities of heat pump, different hot water consumption profiles and so on. Based on the results of various simulations, some conclusions were drawn, such as the total energy-saving fraction, the water temperature variation, the suitable match of collector area, heat pump capacity and storage volume.

Keywords: Solar heating, Heat pump, Domestic water heating

1. INTRODUCTION

In the whole world, the energy consumption for Domestic Water Heating (DWH) accounted for a large proportion of energy consumption in the world. How to improve the efficiency of heating system and to save energy is of great importance for the sustainable development of the world.

Solar heating is one important way to reduce energy used for domestic water heating. Today lots of solar DWH systems are assisted with electrical resistance heating in China. Because solar fraction rarely is higher than 70% due to cloudy or rainy days and economical consideration, these solar DWH systems will consume a lot of electricity and impose heavy burden on public grids. For the present, air source heat pump for heating is used more and more

widely. It will reduce the electrical load and electricity consumption. Solar DWH systems assisted by air source heat pump are very promising in cold (but not very cold) and temperate climates, such as middle and south China. Diurnal storage is also very important for store solar heat and using off-peak electricity. This paper studies the performance of solar and heat pump combined DWH with diurnal storage and find ways to make such systems work more efficiently and reduce electricity consumption and electrical peak load.

2. DESCRIPTION OF THE SOLAR AND HEAT PUMP COMBINED WATER HEATING SYSTEMS

2.1 The Schematic of the Solar and Heat Pump Combined Heating System

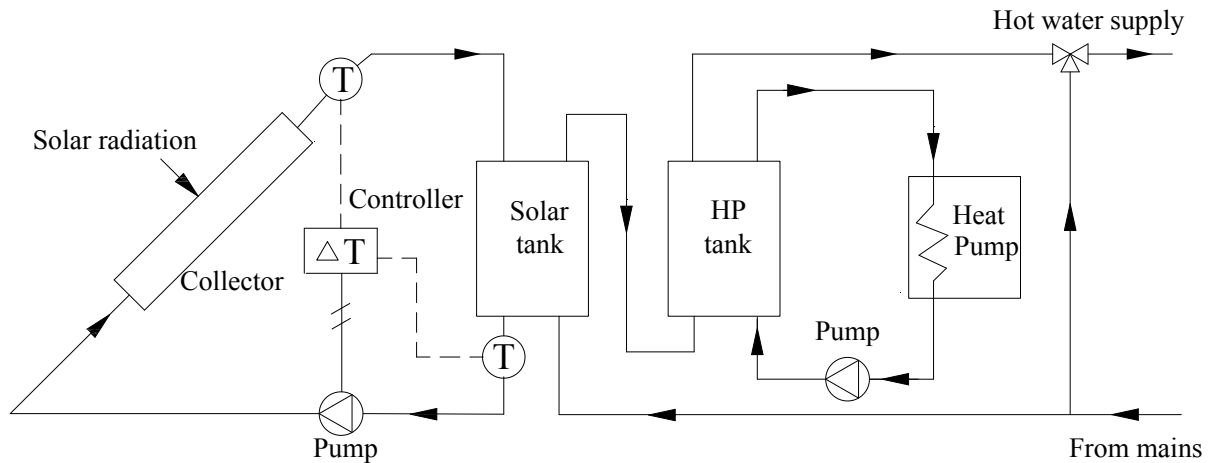


Figure 1: Schematic of solar and heat pump combined water heating system

A solar and heat pump water heating system is designed for domestic water heating. The schematic of the combined heating system is shown in Fig. 1. It includes solar collectors, heat pump, two pumps, a solar tank and a HP tank. Solar collectors are used to heat solar tank, and heat pump is used to heat the HP tank. There is a one-direction pipe connecting the two tanks, the water from mains first enters into the solar tank and then goes into the HP tank out of the HP tank.

The operation of solar loop is controlled by a differential temperature controller. When the temperature difference between the collector outlet and the bottom of solar tank is greater than 8°C, the pump begins to run, when it is less than 2°C, the pump stops. The heat pump is controlled by the temperature sensor on the top of the HP tank, when it is lower than the preset supply temperature (60°C) by 2°C, the heat pump is put into operation, when it is greater than the preset temperature, it stops.

2.2 The Daily Water Use Profile

The daily water use is shown as Fig.2, it is typical for Chinese residential buildings. There are three peaks which respectively occur at 8:00, 12:00, 19:00. The daily total water consumption is 1500L.

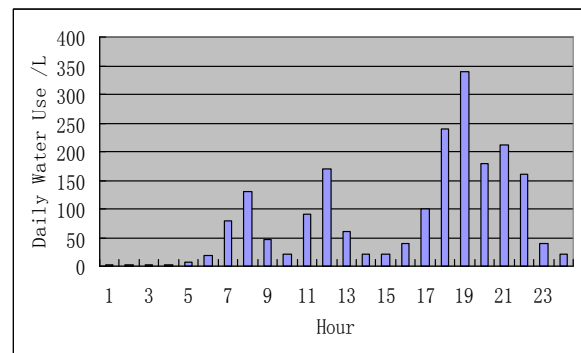


Figure 2: Profile of daily water use

2.3 Solar Collectors

Flat collectors are employed in this system. The total aperture area is 25 m². The collectors are positioned east-west and oriented to due south. The slope of collectors is 40°, 10° higher than the local latitude.

The efficiency of collectors is formulated as $\eta = \frac{Q_U}{A_c I_T} = a - b \frac{(T_i - T_a)}{I_T}$. For this case, a is 0.7 and the b is 4.167W/(m².°C). The modifiers of incidence angles in this simulation are considered.

2.4 Storage Tanks:

Two water tanks are used in this system. The solar tank is used to storage solar heat gains, its volume is 1.5m³, about 60L per collector area. The HP tank is used to store

hot water to meet the peak water load, its volume is 0.75m^3 .

2.5 Heat Pump

When the solar power is not enough, the heat pump is required to heat the supply hot water to required temperature. The heating capacity of the heat pump is 10kW in this case. The COP of the heat pump varies with the different ambient air temperature and condenser water temperature and it is tested in a standard laboratory, the results are shown in Fig. 3.

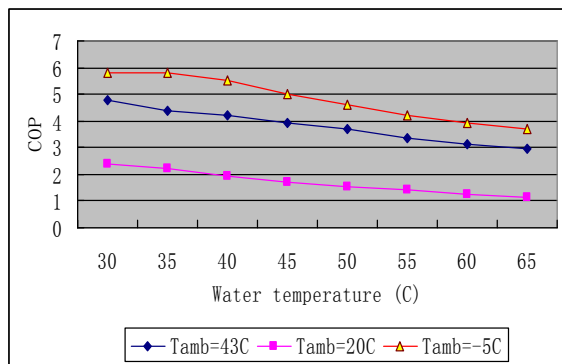


Figure 3: COP of heat pump

3. PERFORMANCE OF THE COMBINED HEATING SYSTEM

3.1 Overview

In order to study the characteristics and performance of combined water heating systems, hourly simulations are conducted on the basic case described in the above section. The hourly data during winter of typical meteorological year (TMY) comes from [1]. It is located in Shanghai. The results are shown in Table 1.

Table 1: Energy balance of a whole year

Items	Energy (GJ)	Fraction
Collector	53.11	52.0%
Heat pump	52.75	51.6%
Heat loss of tank 1	1.18	1.1%

Heat loss of tank 2	2.55	2.5%
Heat load	102.13	100%

Table 1 indicates that the contribution of solar and heat pump is nearly equal in the whole year, but their contribution in each month is much different, the monthly distribution is shown in Fig.4.

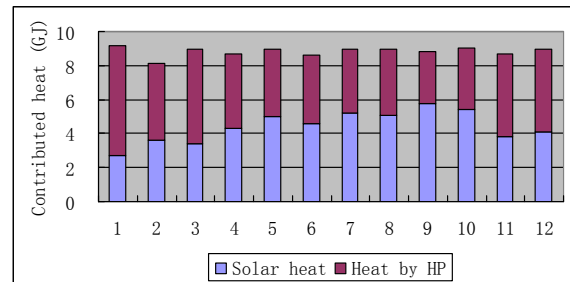


Figure 4: Monthly contribution of solar and heat pump

3.2 Efficiency of Solar Collectors

The collector efficiency is very important for energy saving and economical consideration. The annual average collector efficiency is 45.9%. The monthly efficiency is shown in Fig.5. It is rather good due to good solar radiation and temperate ambient air temperature in winter.

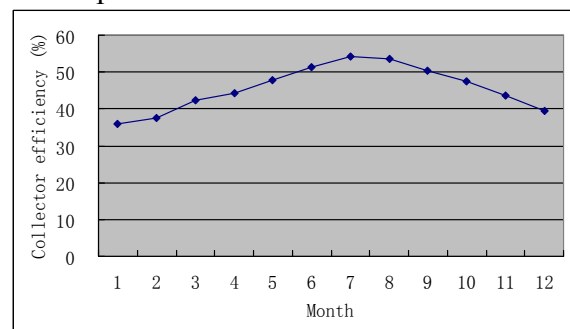


Figure 5: Monthly efficiency of collectors

3.3 COP of Heat Pump

The COP is another important factor of the combined system because it directly affects the consumption of electricity and hence the operating cost of the system. The monthly average COP of heat pump is indicated in Fig.6. The annual average COP of heat pump is 2.75. It means about 63.6% of electricity will be saved compared to solar system assisted by electrical resistance.

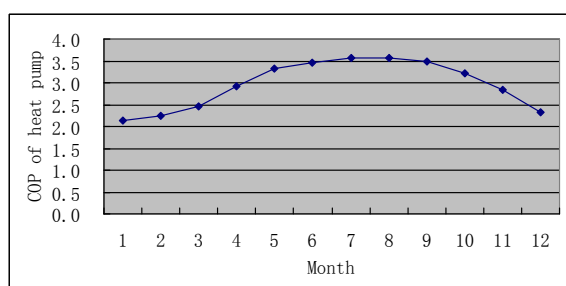


Figure 6: Monthly COP of heat pump

3.4 Water Temperature Variation

The water temperature at the top and bottom of the two tanks during a week in winter and summer is respectively shown in Fig.7 and Fig.8. Model of temperature stratified tank is used in the simulations, the temperature of the two tanks, temperature at the top and bottom of the same tank is much different.

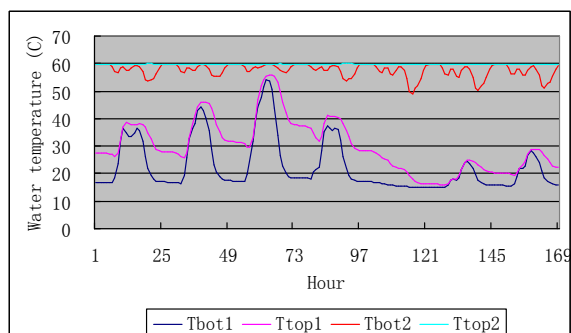


Fig.7 Temperature profile in Winter

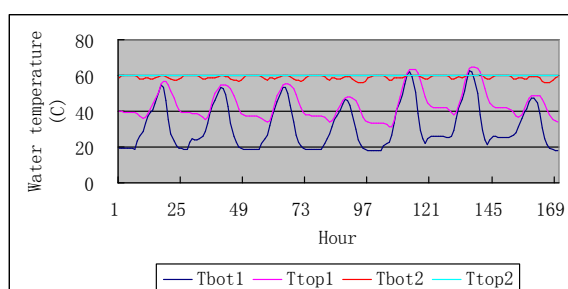


Fig.8 Temperature profile in summer

Bot: stands for bottom of tanks
Top: stands for top of tanks
1: stands for solar tank
2: stands for HP tank.

4. SENSITIVITY ANALYSIS

In order to study the characteristics of the combined heating systems, additional

simulations were conducted to find factors affecting the system performance.

4.1 Water Use Profiles

Three daily water use profile are studied, profile 1 is indicated in Fig.2, the water use in profile 2 is concentrated in evening from 18:00 to 21:00; the water use in profile 3 is evenly distributed during the daytime from 8:00-18:00. The total daily water consumption for the three modes is equal. The results are indicated in Fig.9.

Fig.9 indicates that the effects of water use profile do not affect the performance of the system significantly.

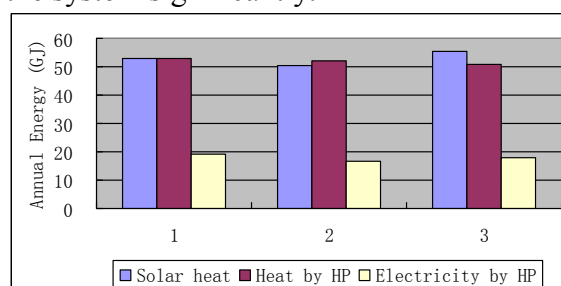


Figure 9: Effects of water use profile

4.2 Volume of Storage Tanks

The volume of the solar tank is mainly determined by the solar collector area, and it has no significant effect on the performance of the solar systems if the volume is greater than 37.5L per m² collector area^[2]. Only the effect of HP tank volume is studied in this paper, the results are shown in Fig.10. It shows that the volume of HP tank has little effect on the performance of the system and heat pump.

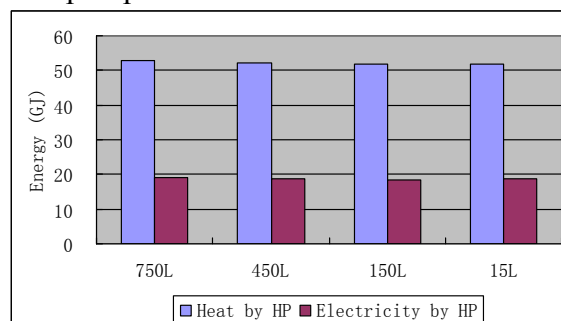


Figure 10: Effects of volume of HP tank

4.3 Heat Pump Capacities

The capacity of heat pump has little effect on the system if it is greater than 10kW in this case, however if it is small, e.g. 5kW, the supply water temperature maybe can not reach the required temperature in cold and cloudy days. Fig. 11 gives the supply water temperature variation during a week in winter.

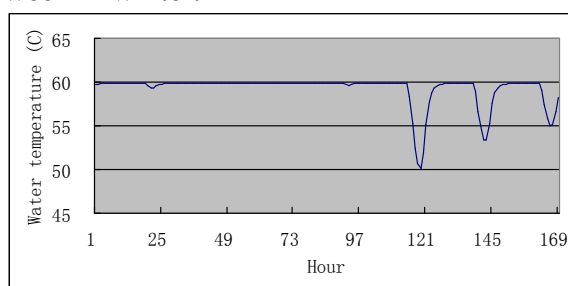


Figure 11: Water temperature

4.4 Collector Area

Different solar collector areas are simulated to study the effect of collector area. The results are shown in Fig.12. When the collector area From 5 to 25m², the solar heat gain increases by 3.8GJ, however the solar heat gain increases only 2.4GJ when collector area increases from 25 to 45m². It shows that 25m² is an optimum point. With the increase of collector area, the improvement of solar heat gain reduces.

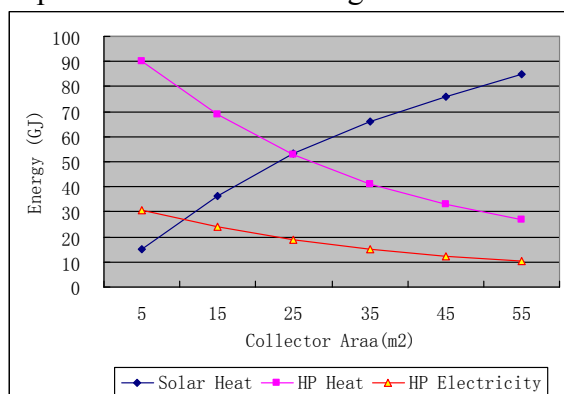


Figure 12: effect of collector area

5. CONCLUSIONS

In this paper, a solar and heat pump combined water heating system with diurnal storage is simulated hour by hour during a whole year under various conditions, some conclusions are drawn.

(1) The annual average COP of heat pump is 2.75. It means about 63.6% of electricity will be saved compared to solar system assisted by electrical resistance.

(2) The effects of water use profile and volume of HP tank do not affect the performance of the system significantly.

(3) With the increase of collector area, the increment of solar heat by increasing collector area reduces. It is suggested that the contribution of solar and heat pump should be nearly equal in the whole year for such systems.

ACKNOWLEDGEMENT

The research is supported by Leading Academic Discipline Project of Shanghai Municipal Education Commission, Project Number: J50502.

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