Experimental Research on Solar Assisted Heat Pump Heating System with

Latent Heat Storage

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Abstract：Based on the status quo that conventional energy sources are more and more reduced and environmental pollution is increasingly serious, this paper presents a new model system of conserving energy and environmental protection, namely, a Solar Assisted Heat Pump Heating System with Latent Heat Storage. In this system, solar energy is the major heat source for a heat pump, and the supplementary heat source is soil. The disagreement in time between the space heat load and heat collected by solar heat collector is solved by latent heat storage. In order to obtain such system running conditions and effects in different heating periods, an experiment has been carried out during the whole heating period in Harbin, China. The experimental results show that this system is much better for heating in initial and late periods than that in middle periods. The average heating coefficient is 6.13 for heating in initial and late periods and 2.94 for heating in middle periods. At the same time, this paper also predicts system running properties in other regions.

Key words: solar energy, heat pump, latent heat storage, operation condition

1. INTRODUCTION

Energy & environmental problems are the vital social issues many countries encountered at present. In the processing of development, air pollution and environment social effects are becoming many countries' concern matters[1]. Development and utilizing new energy & sustainable energy are the most effective way to solve the following problems. People are thinking much of solar energy because of its gigantic quantity, wide distribution and cleanness.

With the development of social and people's living standard, the proportion of energy consuming of heating and air conditioning are more and more, so energy conservation of heating and air conditioning are more and more important. Notable economic and social benefit can be achieved so as to have technology and essential fund. It has far-reaching meaning of solving energy and environment problems if new type energy conservation and environment protection heating system – solar assisted ground-source heat pump (SAGHP) heating system with a latent heat storage tank will be practical and commercial [2~4].

The operation effects of the same system are different since different locations and climate conditions. Energy conservation effect of SAGHP heating system in cold climate is less than other areas because of long heating period, low outside & soil temperature and weak solar radiance. But it still has sufficient enhancement compared with other heating mode, such as air-source heating pump, sole ground-source heat pump etc.

2. CONSTITUTION OF THE SYSTEM

The experimental system was established at the laboratory of construction energy conservation in Harbin Institute of Technology (HIT) in 2004. It added a latent heat storage tank in original SAGHP system. The schematic diagram of the system is shown in Figure 1.

The experimental system consists of solar collection system, latent heat storage system, heat pump unit, U type pipe soil heat exchanger, terminal

device and pipes.
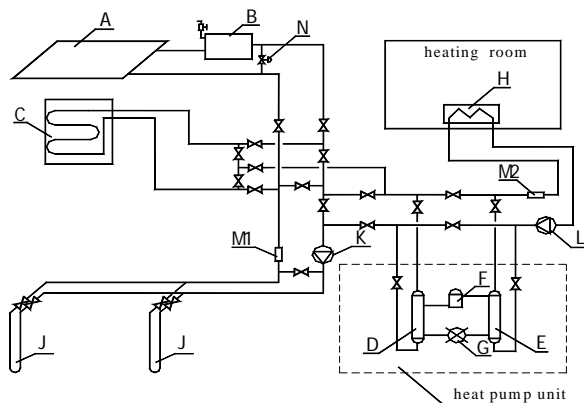
A-solar collector   B-expansion valve   C-storage tank
D-evaporator   E-condenser   F-compressor
G-expansion   valve   H-terminal   unit(fan   coil)
J-soil   heat   exchanger   K-circulation   pump1
L-circulation   pump2   M1、M2-flow   meter
N-magnetic valve

Fig.1 Schematic diagram of SAGHP system

2.1 Solar collection system

Solar collection system is made up of solar collector panel, collecting bucket, magnetic valve, circulation pump, pipes and valves. There are six solar collector panels with parallel connection; its total collection area is 11.9m^2, which are installed on the roof of the laboratory. Circulation pump is one-phase pipe pump produced by Shanghai JiaFu pump Ltd., which main parameters are flow: 2m^3/h, head: 15m, power: 120W.

2.2   Latent heat storage system

Latent heat storage tank is made up of polythene plastic, which size is 1160mm×980mm×700mm. The insulation material is polystyrene, which thickness is 100mm.Serpentine heat exchanger (OD 32mm, ID 25.5mm, 9roles,) is in it, which total length is 46.25m. $CaCl_2 \cdot 6H_2O$ is as phase change material (PCM), which fusion point is 29.9℃ and latent heat is 187.49kJ/kg. PCM was encapsulated in cubic plastic keg, which size is 140mm×120mm×70mm and thickness is 1mm. There are 150 plastic kegs; each of them can contain 2kg's weightiness PCM.

2.3 Heat Pump Unit

Heat pump unit used in the experimental system is designed and made by us. Heating capacity of each unit Q_h is 2kW; single-phase kilowatt-hour meter (type DD862-4) measures the consumption of electricity of heat pump.

2.4 Soil heat exchanger

Soil heat exchanger used in the experimental system is U type heat exchanger, which is embedded in the 51 meter-long well. Heat exchanger is made of PVC (ID 25mm) that has the virtue of high intensity, non-corrosion and cheap price. Connection of exchanger is parallel.

2.5 Terminal unit

Terminal unit in experimental unit are 2 fan coils that installed in the two offices and is produced by Zhuhai Geli group Ltd. Its power is 20W and air rate can be adjusted according to need. Circulation pump of fan coil is produced by Songliao electric machinery that power is 30W and flow rate is 1.2m^3/h.

2.6 Others

Copper-constantan-thermocouple   is   used   to measure temperature. Calibrated dry water meter is adopted to scale flow rate at fixed-time. DFY5 type effective radiometer is used to measure solar radiation.

3. MAIN OPERATION MODE OF THE SYSTEM

In order to enhance solar energy furthest, show the energy conservation superiority of SAGHP heating system with a latent heat storage tank adequately and improve the performance coefficient of the system in the whole heating period, there are 6 operation mode when outside meteorological conditions change.

The first one is Heating by solar directly and meanwhile storage heat in the tank. This mode is suitable to fine days in transient period, high outside temperature, little inside heating load; strong solar radiation in daytime, big collection quantity of collector and high temperature of heat carrier medium of the system which is higher than the temperature heating directly. Solar supplies heat

directly and meanwhile stores heat in the tank so as to supply heat at night by storage tank. Collection efficient can be improved and collection hours of collector can be prolonged because latent heat storage of PCM limits the temperature of heat carrier medium at collector inlet.

The second mode is stopping heating and storage heat in the tank by solar collector. Indoor temperature can be maintained by thermal inertia of the building when there is no heating at the condition of indoor heat load is zero or very little in fine days during heating transient period. The total heat of collector stores in the storage tank.

The third mode is heating directly by the storage tank. Storage tank supplies heat directly if the temperature of the tank satisfies the request of heating at night or raining days during heating transient period.

The forth mode is solar collector and storage tank together as low-grade heat source of the heat pump. Collection heat of collector is not enough to meet the request of indoor heating so the temperature of heat carrier medium of the system cannot get to the demand of heating directly when indoor temperature is relative low and indoor heat load is rather big in the middle of heating period. Starting heat pump is necessary at this time.

The fifth mode is the tank as low-grade heat source to heating. The temperature of the tank is quite high but it doesn't get to the temperature that can supply heat directly when it is at night or cloudy day during heating period.

The last mode is ground source heat pump to supply heat. Ground-source heat pump is used when the temperature of the tank is very low and then the tank is shut off at night or cloudy days during heating period.

4. PERFORMANCE ANALYSIS OF SYSTEM OPERATION

Heating experiment has been done for 4 months from Nov. 15th, 2004 to Mar., 31st, 2005 in order to find the effect of SAGHP heating system with a latent storage heat tank. Heating objects are two offices in the laboratory that total floorage is 37.4m^2

Operation mode and effect of system are different with the variation of outside meteorological condition during transient and middle period. Two typical days are chosen in transient period (Mar. 20,2005) and middle period (Dec. 7, 2004) separately to analyze the operation effect.

Solar radiance has great difference, so collection heat of collector is quite different accordingly in transient and middle period shown in Figure 2.
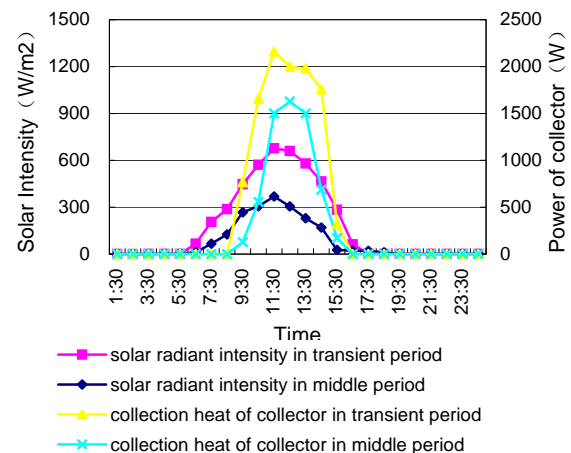

Fig. 2 Solar radiation intensity and heat gain of the collector in each operation period

Sunrise time is twenty to seven, sunset time is twenty past five in the evening, mean sunlight time is about 10.7 hours, and horizontal mean solar radiant intensity per area is 391.5W in transient period. The temperature of storage tank is high, so the inlet temperature of collector is high. Meanwhile considering the effect of thermal inertia, collector is opened at half past nine in the morning. With the enhancement of temperature of the tank and the decrease of solar radiance, the collector is closed when collection heat is little at half past three in the afternoon. The collection hour is 6 hours, and the capacity of collection per day is 32.84MJ.

Sunrise time is half past seven, sunset time is about half past four in the afternoon, mean sunlight time is about 9 hours, and horizontal mean solar radiant intensity per area is 198.7W in the middle of the heating period. Collector is opened at half past nine and closed at half past three in the afternoon since the outside temperature is low and the solar radiance is weak. The collection hour is 6 hours, and the capacity of collection per day is 16.58MJ.
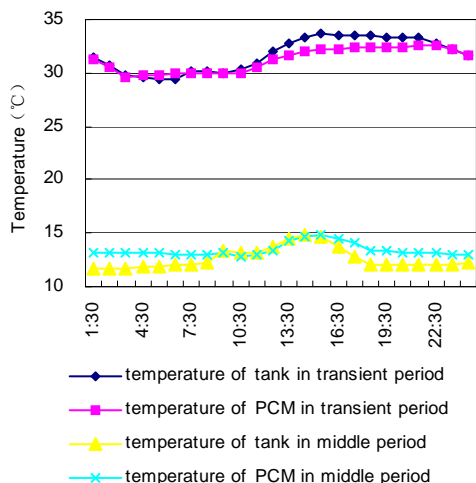
Fig.3 The curve of temperature parameter of the tank in each operation period

The operation situations of latent storage tank in the two heating periods are shown in Figure 3 and 4. Operating temperatures are different in two situations, which are shown in Figure 3. Collection heat of the collector is big, the outside temperature is relative high and the heating load is little, so the balance temperatures of the tank and the PCM in the tank are more than 30℃ in the transient period. The inlet temperature of the collector maintains at a little higher than 30℃ because of the latent storage of PCM, which improves the collection efficiency and prolongs the collection hours of the collector. The operation modes are the first, the second and the third modes that mentioned before in this period. Heat is stored in the storage tank in daytime, and the tank supplies heat directly at night. Figure 4 presents the curves of heat storage of the tank in two operation periods.

The collection heat of the collector is small, the outside temperature is low and indoor heat load is high so the balance temperature is about 12℃. The temperature of the tank doesn't get to the fusion temperature of PCM, The water in the tank transfers heat with PCM by sensible form. The system need to start heat pump and the operation mode is mainly the forth, the fifth and the sixth modes. Heat is stored in the tank in daytime, and meanwhile it is as the low-grade heat source of the heat pump, so the temperature in the tank varies little. The time that the tank is as the low-grade heat source solely is short, and the ground source heat pump supplies heat in the

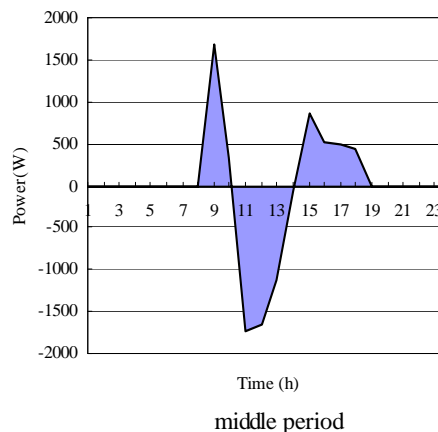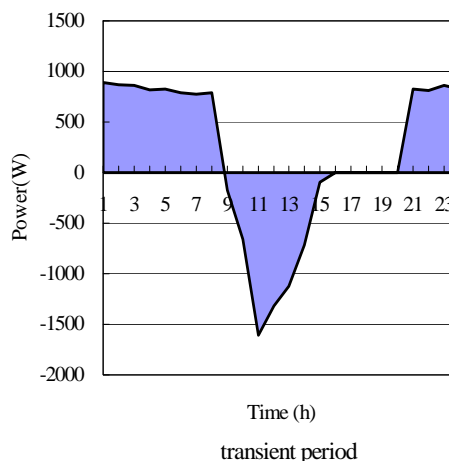other times. Figure 4 presents the curves of heat storage of the tank in two operation periods.

transient period

middle period

Fig. 4 The curve of thermal energy storage of the tank in each operation period

The curve of temperature and heat supplied in two operation periods was shown in Fig. 5. The outside temperature is lower in the middle of the heating period than that in the transient period. The heat supplied in the system is more and heating becomes continuous from intermittent in the middle period, the indoor temperature in middle period decreases relative to transient period. The mean outside temperature is 4.85℃, the mean heating power per day is 518.7W, the mean indoor temperature is 21.2℃ in the transient period; while the mean outside temperature is –12.9℃, the mean heating power per day is 2056.6W, the mean indoor temperature is 19.3℃ in the middle period.
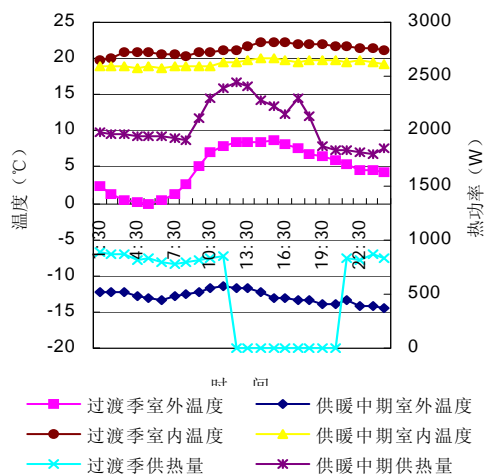
Fig.5 Curve of temperature and supplied heat in each operation period

Table 1 reflects the whole operation performance of transient and middle period of heating. The energy conservation performance can be revealed sufficiently in the transient period that can be seen from the table. The heat collected by the solar collector can satisfy the request of the system, there is no need to use heat pump and other auxiliary heat source. The consumption of electricity of heating of the system is little. The operational mean coefficient of performance (COP) can get to 6.13 and it is far higher than other heating mode. The temperature of the tank is rather high because heat storage is at the same time when it is heating; the temperature difference of heat elimination of the fan coil is big and the corresponding heating power is great, so the value of the COP of the first mode is the highest and is about 7.66.With the continuous heating, the temperature of the tank descends gradually, the temperature difference of heat elimination of the fan coil reduces and the heating power declines, the COP is about 7.3 and is smaller than that of the first mode. The operation temperature of the tank is very high, so the inlet temperature of the collector is high and the mean collection efficiency is quite low and is about 35.7%.

The heating load increases, meanwhile the heat solar collector collected decreases that can't meet the need of heating and heat pump or some auxiliary heat source must be used in the middle period of heating. The operational COP of the system is rather small and is about 2.94 since heat pump runs and the total

consumption of electricity added. The tank that is as low-grade heat source of the heat pump emits heat, and at the same time the tank absorbs the heat collected by the collector. So the average temperature of the tank is relatively high, the inlet temperature of the evaporator of the heat pump enhances, heating capacity of the heat pump increases and the COP of the system is relatively high that gets to 3.26 correspondingly in the forth mode. With the decline of the solar radiant intension and the closing of collector, the tank is as the low-grade heat source of the heat pump solely and then the system operates in the fifth mode. With the heat released of the tank, the temperature of the tank declined gradually, then the inlet temperature of the evaporate of the heat pump reduces and leading to the heating capacity decreases, The COP of the whole system cut down relative to the forth mode that is 3.14. The tank is closed and the sixth mode operates when the temperature of the tank reduces to a certain value. The total COP is lower than that in the forth and the fifth mode that is about 2.8 because the mean soil temperature is rather low at this time. The ground –source heat pump has the minimum value of COP in all over the mode in the heating condition so ground-source heat pump is as auxiliary heat source. It is used to heating only when the solar collector and the tank are all closed.

In the middle of heating period, there must exist the equation of $Q_s=Q_c+Q_t+Q_g+P$ theoretically . The situation of $Q_s>Q_c+Q_t+Q_g+P$ appears in mode ④⑤ ⑥. There are three reasons: 1) the heat pump must run in mode ④⑤⑥, the temperature of the water in the tank, the temperature of PCM and the temperature of heat carrier medium on the side of the evaporator are all very low, heat in the environment can be absorbed in the operation process, 2) using the method of the product of arithmetic mean value of heat power in per time and total hours, peak value of the curve of heat power can be weakened, and certain error may be made and 3) there has been a certain extent system error in measure meters of temperature and flow.

It lies on the outside temperature and solar radiant intensity when choosing system operation modes and determining the value of COP of the

Tab. 1. Operating results of the system experiment.

Transient period	mode	mode	mode	Total or mean
Initial & ending time(h)	9:30～11:30	11:30～15:30	0:00～9:30 21:30～0:00	0:00~11:30 21:30~0:00
Collection heat of collector Q_c(MJ)	16.0	28.67	0	44.67
Mean efficiency of collector η	0.327	0.370	0	0.357
Heat exchange of tank Q_t(MJ) Storage is minus, emission is plus	-9.86	-27.92	38.49	0.71
Total heat supply Q_s(MJ)	6.59	0	37.82	44.41
Total consumption of electricity P (MJ)	0.86	1.21	5.18	7.25
Mean COP	7.66	——	7.3	6.13
Middle period	mode④	mode⑤	mode⑥	Total or mean
Initial & ending time(h)	9:30～15:30	15:30～18:30	0:00～9:30 18:30～0:00	0:00~ next day0:00
Collection heat of collector Q_c(MJ)	26.05	0	0	26.05
Mean efficiency of collectorη	0.439	0	0	0.439
Heat exchange of tank Q_t(MJ)	5.20	18.26	0	23.46
Heat extraction of soil Q_g(MJ)	0	0	58.7	58.7
Total heat supply Q_s (MJ)	49.97	31.61	95.68	177.26
Total consumption of electricity P (MJ)	15.34	10.08	34.78	60.2
Mean COP	3.26	3.14	2.80	2.94

system. It is more ideal and will have good practical effect that the system runs in the district of high outside temperature and abundant solar energy.

5. CONCLUSION

1) SAGHP system with a latent storage tank is an energy conservation and environmental protection heating method. Solar energy and soil heat are together as complex heat source that enhance the reliability and flexibility of the operation of the system.

2) The storage tank adjusts the balance of supply and requirement between the heat of the collector and space heat load. Heat storage capacity improves because of using PCM, meanwhile collection efficiency of collector in the transient period and reliability of the system enhance too.

3) Mean COP is about 6.13 and 2.94 separately in transient and middle period of this system in Harbin from the analysis of typical experimental data. It is concluded that it will have notable energy conservation effect in other heating area.

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