ECONOMIC COMPARISON BETWEEN GROUND SOURCE HEAT PUMP AND AIR SOURE HEAT PUMP

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Abstract： This paper does the study on thermomechanical analysis of ground source heat pump (GSHP) and air source heat pump (ASHP). The result that the energy utilization rate of GSHP is above ASHP is obtained. The marketing researches of GSHP and ASHP units have been studied. EER and COP of ASHP in the same company have the little change with the changing cooling or heating capacity and they vary only with the ambient temperature. But the statistic of GSHP shows that EER and COP are increased with the rising cooling or heating capacity when the cooling and heating capacity is less than 1000 kW and they will not change when the cooling and heating capacity is greater than 1000 kW. The economic comparison between GSHP system and ASHP system is analyzed in Tianjin in China. The conclusions that when the cooling capacity is less than 46 kW, the ASHP system is economical, while the GSHP system is economical when the cooling capacity is greater than 46 kW are reached.

Key Words: Ground source heat pump, Air source heat pump, Energy efficiency ratio, Operating cost, initial cost.

1 INTRODUCTION

Energy and environment have become two major problems in the 21st century. As population and per capita energy consumption are increasing sharply, energy problem becomes more and more acute.
Building energy consumptions account for about 30% of total energy consumption in China and the most of the energy consumption is heating and air conditioning. Air conditioning energy consumption is always high and it is one of the greatest energy consumption appliances with illumination and refrigerator. According to report, air conditioning power consumption load takes up about 40% of the total power consumption load in summer, in large or middle cities in china. In addition, Climate change is a real threat to our future, and a major cause is the use of fossil fuels to power homes and business. Therefore, saving energy and reducing pollutant emissions becomes more important.

Water source heat pumps (WSHP) have been receiving increasing attention in recent years. WSHP, which uses broad shallow geothermal resources, including ground water, soil, surface water, and so on, is an efficient air conditioning and the energy can transfer from the low grade energy to the high grade energy through inputting a little high grade energy, such as electric energy. In areas where the technology has been properly applied, they are the systems of choice because of their reliability, high level of comfort, low demand, and low operating costs. However, there are certain requirements to source of water, water volume, water temperature, water quality, and so on, in WSHP directly using ground water or surface water. There can cause surface subsidence, ground cracking, ground collapse and other geology problems without reliable measure to recharge the water into ground in WSHP system with ground water which also can affect ground water quality, temperature, pressure etc. and may influence the locality ecology problems. *Water Law of the People's Republic of China* has been drawn up in order to protect the limited water resource and each city has formulated itself the municipal water regulations or laws. The emphasis of these policies is the approval and charge of water. Some cities charge twice for extracting and discharge leading to increase the operating cost. A few cities have prohibited using ground water on WSHP. So this paper focuses on ground source heat pump (GSHP) whose heat source is ground soil with ground closed loops.

2 THEORETICAL ANALYSES ON GSHP AND ASHP

Heat pumps have the ability to move heat energy from one environment to another, and in either direction. This allows the heat pump to both bring heat into an occupied space, and take it out. In the cooling mode a heat pump works the same as an ordinary air conditioner. A heat pump uses a refrigerant which absorbs heat as it vaporizes and releases the heat when it condenses. It uses an evaporator to absorb heat from inside an occupied space and rejects this heat to the outside through the condenser and the condenser and compressor are located. There is a reversing valve to change the flow direction in heating mode while the indoor heat exchanger becomes condenser and the outside becomes evaporator.

Ground source heat pump system based on the soil as outside heat source is the system supplying heating in winter and cooling in summer on account of temperature of ground soil remaining relatively steady. Water in ground closed loop exchange heat with the soil, then flow into ground source heat pump unit and exchange with refrigerant. In heating mode the water in ground closed loop absorbs heat from the ground soil and moves it into GSHP unit. Once the GSHP unit picks up heat it is compressed and then sends to the condenser (indoor soil). The condenser then rejects the heat into the house. In cooling mode the indoor coil now is evaporator and the outside becomes condenser (figure 1). ASHP and GSHP work on the same principle but ASHP system takes outdoor air as heat source. The shortcoming of ASHP is that cooling capacity, heating capacity, energy efficiency ratio and coefficient of performance will be reduced greatly at high temperature in summer or cold winter.

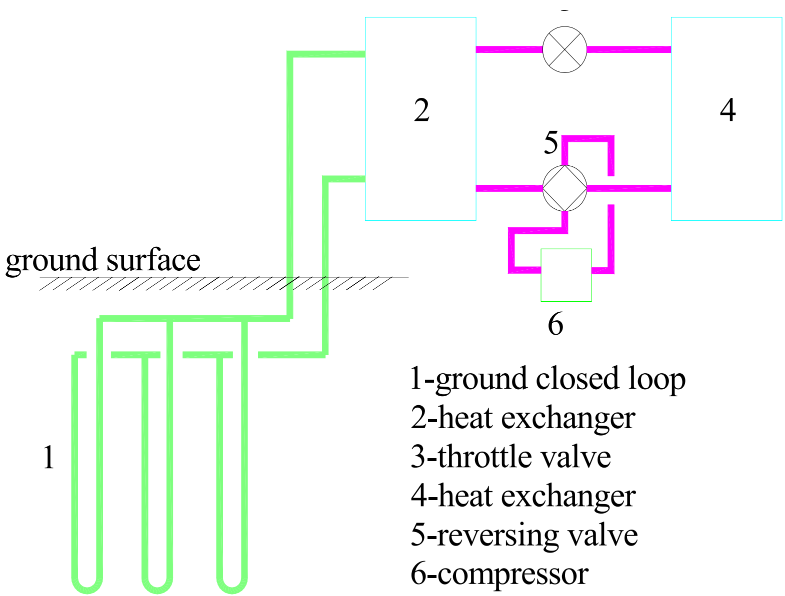

Figure 1: Working Principle of GSHP

The two types of heat pumps adopt the same refrigerant in order to compare them, while doing theoretical analyses. The gradual phase-out of R22 is practical according to the specified, but within one or two decades R22 will be still used as refrigerant in air conditionings and heat pumps. So R22 is adopted in theoretical analysis. Heat pump can be sorted into four categories: water-to-water heat pump, air-to-water heat pump, water-to-air heat pump and air-to-air heat pump. Ground source heat pump is belonged to water-to-water heat pump, while air source heat pump is air-to-water heat pump in this study. GSHP units produce hot water or chilled water in heat exchanger 4 (evaporator in summer and condenser in winter) using water or glycol solution in ground closed loop as the transfer medium and the ground as the heat sink or heat source. ASHP units deliver hot water or chilled water into the space using the air outdoor as the heat source and exchanging heat with refrigerant directly in heat exchanger 2 (condenser in summer and evaporator in winter).

Figure 2 shows the vapor compression refrigeration on the pressure-enthalpy chart of R22. In figure 1-2’-3-4 is an ideal vapor compression cycle, while 1-2-3-4 shows the cycle with actual compression process. The various process of the cycle 1-2’-3-4 (1-2-3-4) are as give below:

1) Process 1-2’: Isentropic compression of the vapor from state 1 to 2’.
2) Process 1-2: Actual compression process.
3) Process 2-3: Heat rejection in condenser at constant pressure.
4) Process 3-4: An irreversible adiabatic expansion of vapor through the expansion value. The pressure and temperature of the liquid are reduced. The process is shown by dotted line.
5) Process 4-1: Heat absorption in evaporator at constant pressure.

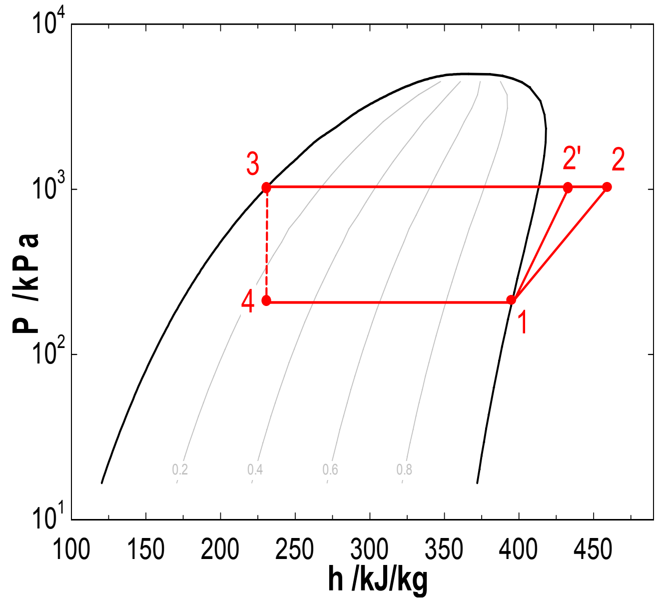

Figure 2: P-h Chart of Refrigeration cycle

The compressor efficiency and temperature difference of heat transfer are considered during the theoretical calculation. Overall efficiency of compressor is general 0.65-0.72 and 0.7 is adopted. The temperature difference between refrigerant and water is about 3-5℃ and there is 3 ℃, while that of refrigerant and air is 10-15℃ and there is 10℃。The temperature of chilled water is 12/7°C in the cooling temperature and the average is 10 ℃, while the temperature of hot water is 40/45 ℃ and the average temperature is 43 ℃ in the heating mode. EES is used to simulate the cooling or heating cycle and figure 3 and figure 4 are obtained.

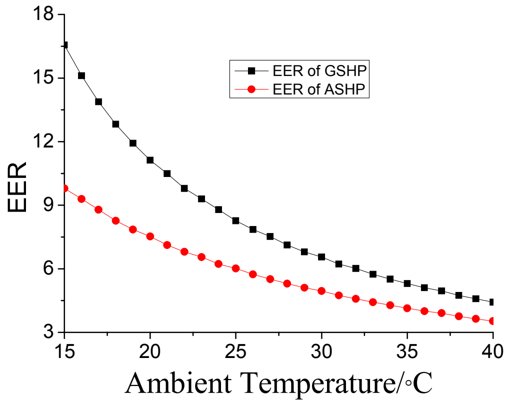

Figure 3: The Change of EER with Ambient Temperature

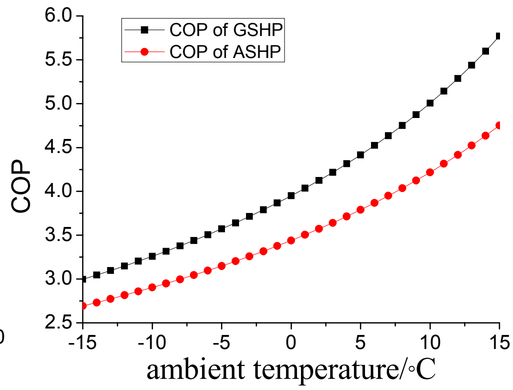

Figure 4: The Change of COP with Ambient Temperature

Figure 3 shows the relationship between EER and heat source temperature in the cooling mode. Both GSHP and ASHP EER are increased with decreasing ambient temperature. GSHP EER is higher than ASHP in the same ambient temperature and the difference is reducing with the rising temperature. The relationship between COP and the heat source temperature is showed in the heating mode (see figure 4) and the two heat pumps COP are rising with the increasing ambient temperature. The GSHP COP is also higher than ASHP and the difference will amplify with the increasing temperature. Furthermore, the heat source in GSHP is the ground soil whose temperature will not change with the air temperature in depth of 10m and is higher than air temperature in winter and lower than air temperature in summer. Therefore, EER and COP of GSHP will be higher. This means that the operating energy consumption of GSHP will be less than that of ASHP.

3 MARKET SURVEY ON GSHP AND ASHP

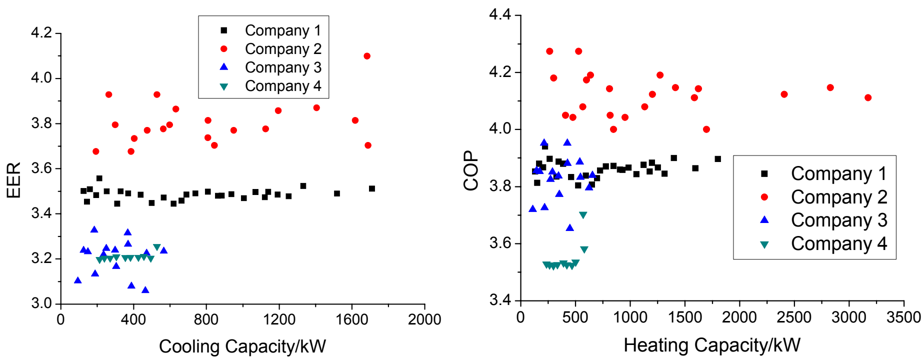

Figure 5: The Statistic of ASHP

Figure 5: The ambient temperature is 35°C in summer while it is 7°C in winter.

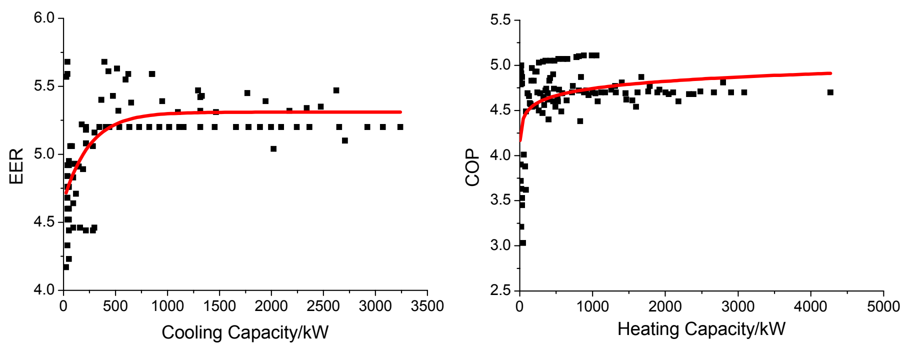

Figure 6: The Statistic of GSHP

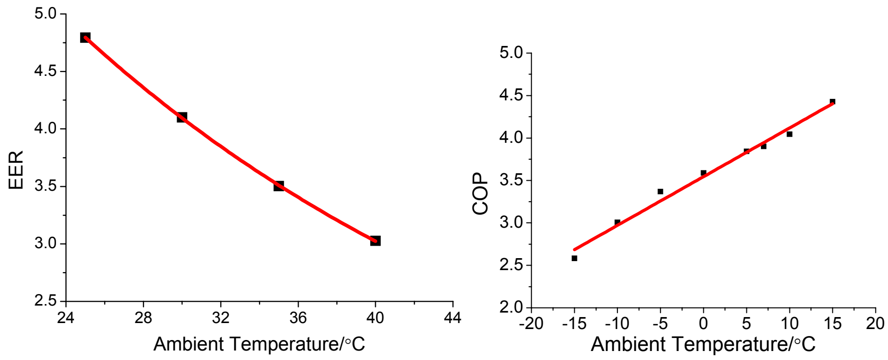

Figure 7: The Change of EER and COP with Ambient temperature

Figure 5-6 are the statistic of ASHP and GSHP. EER and COP of ASHP in the same company have the little change with the changing cooling or heating capacity and the different company has the different EER and COP owing to the different production level. EER and COP change only with the ambient temperature (see figure 7). But the statistic of GSHP shows that EER and COP are increased with the increasing cooling or heating capacity when the cooling and heating capacity is less than 1000 kW. When the cooling and heating capacity is greater than 1000 kW, EER and COP will not change.

4 CALCULATIONS OF GSHP AND ASHP IN TIANJIN

This paper puts the emphasis on the economical comparison between GSHP and ASHP in Tianjin in China. In accordance with the weather condition of Tianjin, the outdoor design dry-bulb temperature for summer air conditioning is 33.4°C, the outdoor design wet-bulb temperature for summer is 26.9°C and the outdoor design temperature for winter air conditioning is -11°C. EER and COP of ASHP are obtained from figure 8. EER is 3.67 while COP is 2.99. The average temperature of the ground between 10~120m is 15.9°C in Tianjin. EER and COP of GSHP using the fitting curve in figure 7. Using these data, the operating energy consumption of heat pump unit can be calculated. The main operating energy consumption also includes the energy consumption of water pump besides the heat pump unit. On the basis of estimates, the underground water pump can consume energy about 0.0202 kWh/kW and the water pup indoor is about 0.0193 kWh/kW. ASHP systems include only inside water pumps and no underground water pumps. Figure 8 shows the heating and cooling power consumption per unit heat or cooling capacity. Power consumption using ASHP is constant but using GSHP is reduced with the rising heat or cooling capacity which is less than 1000 kW and it will not change when the heating or cooling capacity is more than 100 kW.

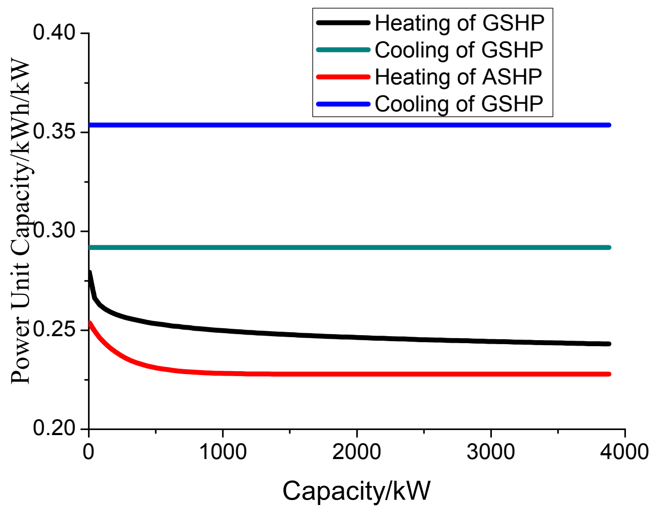

Figure 8: Power Consumption per Unit Capacity

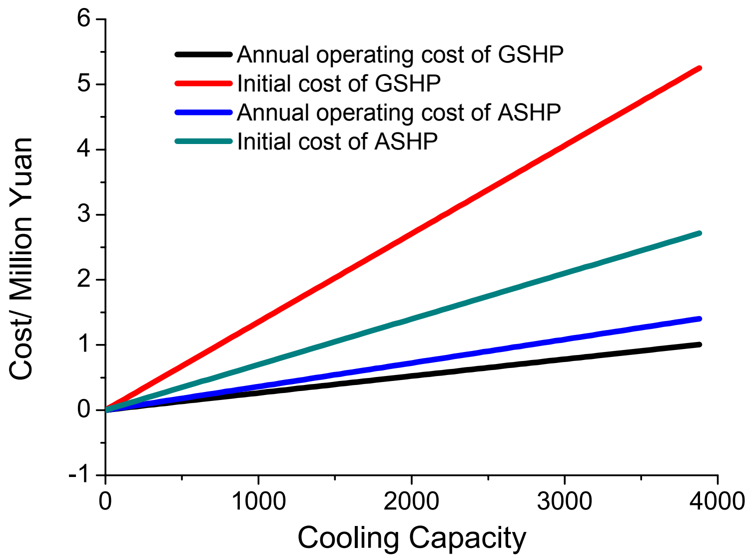

Figure 9: Operating Cost and Initial Cost

The heat pump should work 120 day and 12 hour per day in summer, while it should work 140 day and 16 hour per day in winter in Tianjin. The power charge is 0.5 Yuan per kWh. The operating cost can be calculated using these data and the data of figure 8 (see figure 9). The estimation that the GSHP unit expends about 425 Yuan per kW and the ground investment is about 929 Yuan per kW, while The ASHP unit is about 700 Yuan per kW is applied in this paper to compute the initial cost according to the ordinary project. The other cost is ignored because the other investment between GSHP and ASHP is same. From figure 9, the initial cost of GSHP is higher than ASHP but the annual operating cost of GSHP is lower than ASHP.

5 ECONOMIC ANALYSES

Though the operating cost of GSHP is lower than that of ASHP, GSHP is not always more economical than ASHP. So, the initial cost and the operating cost every year are adopted present value approach to compare the all cost of the two heat pumps.
The equation of the present value of cost is following:

$$PC = \sum_{t=0}^{n} CO_t (P/A, i_0, t) \quad (1)$$

Where PC is present value of cost, CO_t is cash outflow of the *t* year, *t* is calculated fixed number of years, *t*=0,1,2⋯⋯*n*, *n* is the life of the system, i_0 is benchmark interest rate, $(P/A, i_0, t)$ is the compound interest factor.

There assume that the life expectancy of GSHP and ASHP system is 15 years and the benchmark interest rate is 10%. So the compound interest factor will be 7.606 from the table of compound interest in the reference (figure 10).

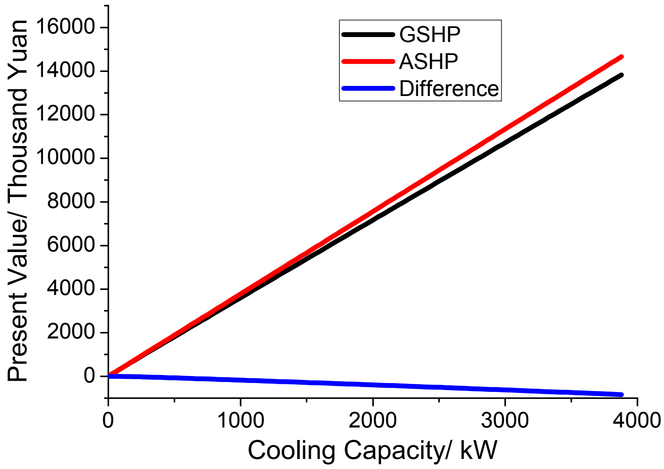

Figure 10: Present Value of all Cost

The conclusion obtained from figure 10 is that the present value of all cost of GSHP system is higher than that of ASHP when the cooling capacity is less than 46 kW but when the cooling capacity is greater than 46KW the present value of GSHP will be lower than that of ASHP. That is to say that when the cooling capacity is less than 46kW, the ASHP system is economical, while the GSHP system is economical when the cooling capacity is greater than 46kW.

6 CONCLUSIONS

This paper, based on thermodynamic analysis, simulates GSHP and ASHP by EES programming. EER in summer and COP in winter of GSHP are higher than ASHP, this is because ground soil temperature is more stable than air temperature and the soil temperature is lower than air temperature in summer while the soil temperature is higher than air in winter.

The marketing researches of GSHP and ASHP units have been studied. EER and COP of ASHP in the same company have the little change with the changing cooling or heating capacity and they change only with the ambient temperature. But the statistic of GSHP shows that EER and COP are increased with the increasing cooling or heating capacity when the cooling and heating capacity is less than 1000 kW and EER and COP will not change when the cooling and heating capacity is greater than 1000 kW.

The economic comparison between GSHP system and ASHP system is analyzed in Tianjin in China. The results that when the cooling capacity is less than 46 kW, the ASHP system is economical, while the GSHP system is economical when the cooling capacity is greater than 46 kW are reached.

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8 SUPPORTS

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