

STUDY ON OPTIMAL OPERATION OF SOLAR ENERGY SYSTEM AND GROUND SOURCE HEAT PUMP SYSTEM

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Abstract: With China's energy shortage and the promulgation and implementation of the "Renewable Energy Law", solar energy, shallow geothermal energy as renewable energy, have been paid more and more attention in buildings, but either of them has its own defect with separate application. Due to the lack of research on the optimization of the Operation Mode of hybrid system of solar and ground source heat pump system, taking a project as an example, in this article research on how to optimize the hybrid system has been studied, the technical feasibility of the optimization of hybrid system has been analyzed and reasonable proposals on how to make full use of solar energy resources to achieve cascade utilization has been put forward.

Keywords: renewable energy solar energy geothermal heat pump operation mode optimization

1 INTRODUCTION

China's energy consumption structure is irrational. Coal-dominated energy supply has caused serious air pollution and greenhouse gas emissions. Therefore, the task of energy saving and developing clean and renewable energy is very urgent. Renewable energy usage in buildings is the requirement by the development and promotion of building industry technology. With the formal promulgation and implementation of "Renewable Energy Law" in January 2006, more and more importance has been attached to solar energy and shallow geothermal energy applications in the construction industry.

Ground source heat pump technology, that is, shallow geothermal energy resources is used in heating and air conditioning, is one of the main directions of the application of renewable energy and has its own advantage in energy saving and environmental protection. Therefore in recent years it has been used increasingly all over the world. With the implementation of "Technical code for ground-source heat pump systems", the market of ground-source heat pump systems is more and more normalized to play its role in energy saving and environmental protection better. But a problem is always haunting on us: the rehabilitation of soil temperature. With the continuous running of ground source heat pump system, excessive heat will be taken from or injected to the ground, causing the fluctuations of ground temperature, which will reduce the COP of the unit and in turn will result in the increase of energy consumption.

Figure 1 shows the temperature of soil and importing and exporting water temperature of ground heat exchanger in 10 years in a project in Beijing which is supplied by ground source heat pump systems alone.

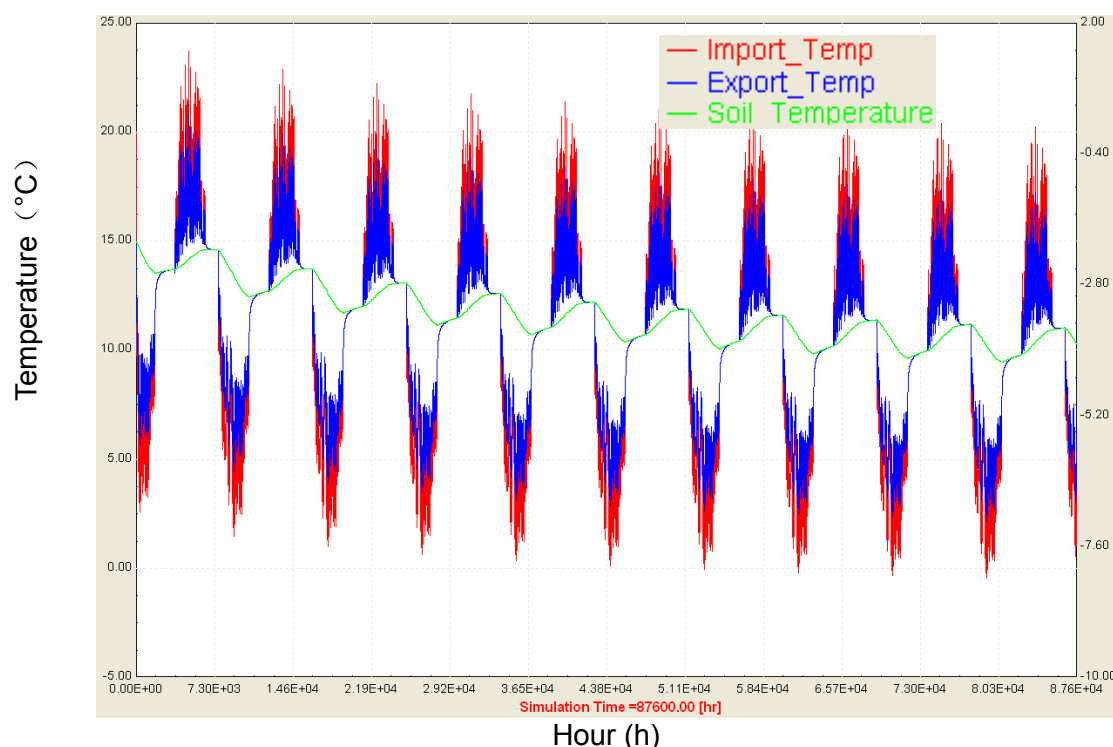


Figure 1: the variations of import and export water temperature of ground heat exchange and soil temperature in 10years

In figure 1 , it is shown that in 10 years the initial soil temperature drops from 15°C to 10.2 °C, down by 4.8 °C. In winter, minimum exporting water temperature of heat pump unit declines from the initial 3 °C to -0.5 °C, which is caused by the huge imbalance between heat absorption and heat rejection.

Solar energy technology is also one of the main directions of the applications of renewable energy. Solar energy is inexhaustible and clean energy. It is rich in natural resources and environmental protection. But there are also some disadvantages:

- (1) The density of solar energy is low, and varies with the time and location.
- (2) Solar energy is intermittent and unreliable. For weather conditions and other factors, solar irradiance can not be maintained constant. In case of continuous rain, the supply will be interrupted.

In addition, solar energy is a kind of radiant energy, with immediacy. Therefore its not easy to store and should be immediately converted into other forms of energy for use and storage.

Both of ground source heat pump technology and solar technology have their own limitations. The two can be combined to make up each other's deficiencies and improve resource utilization.

2 THE PRINCIPLE OF JOINT OPERATION OF SOLAR SYSTEMS AND GROUND SOURCE HEAT PUMP SYSTEM

The joint operation of the solar system and the ground source heat pump system, should comply with the following principles:

- (1) The building where the renewable energy is used should be energy efficient to reduce the system's initial investment. The density of solar energy is low while the price of solar collector system is still high. Compared with conventional systems, the initial investment of the ground source heat pump system is still high. To minimize the system's initial investment, the building envelope should meet with the requirements of corresponding standards which will thus

reduce load requirements of heating and air conditioning.

(2) The water temperature requirements of the end should be low enough to match the system. Currently, the cop of ground source heat pump unit with high temperature is low. For the conventional ground source heat pump unit, the exiting water temperature is lower when heating. Likewise, the efficiency of solar collector system is directly related with the exiting water temperature of the system. When the exiting temperature is higher, the heat loss is greater and the efficiency is lower. Therefore, priority should be given to the system whose requirement for supplying water temperature is low, such as radiant floor heating form.

(3) As solar energy resource is free for use and in the process of use only a small part of energy and cost is consumed, the solar energy resource should be maximized to be used once it is feasible in economy.

3 THE JOINT OPERATION OF SOLAR ENERGY AND GROUND SOURCE HEAT PUMP

Located in Beijing, the main function of the project is the office buildings and laboratories with an area of 2835m². Fan coil plus fresh air system is used in office area for summer cooling (chilled water supply and return water temperature 7 / 12 °C) while in winter floor heating system is used for heating (Through the radiator, the water supply and return water temperature is 45/40 °C). For test area, air conditioning is no need in summer, while in winter radiant heating system is used with supplying and returning water temperature is 50/45 °C respectively to ensure duty heating temperature. Ground source and solar source are used as the cold and heat source of the system. The end of the radiator system and radiant floor heating system run in series to increase the difference of system's supply and return water temperature.

The good performance of building envelope meet with the standards on energy efficient building, which results in the building's cooling and heating load is low. As hourly load calculation shows, the maximum heat load in winter is 110kW, and maximum summer cooling load is 60kW. The sum of heat load in heating season is 119746 kWh by the total while the gross hourly cooling load is 25072kWh. The huge difference between heat load and cold load will lead to the extreme heat imbalance problem once ground source heat pump system is used alone. Thus, long-term operating will result in increasingly low soil temperature, and also the decrease of the efficiency of heat pump system, and ultimately lead to the collapse of the ground source heat pump in winter. To address the imbalance problems in heat absorption and heat rejection and improve ground-source heat pump system efficiency, solar energy systems can be used with ground source heat pump system for joint operating.

4 operation mode are possible for joint operation of solar systems and ground source heat pump system: (1) direct use of solar heating; (2) running in series of solar collector and condenser of heat pump unit; (3) heating ground heat exchanger with solar collector; (4) direct entry of solar energy into the evaporator.

The schematic picture of joint operation of solar system and the ground source heat pump system is shown in Figure 2.

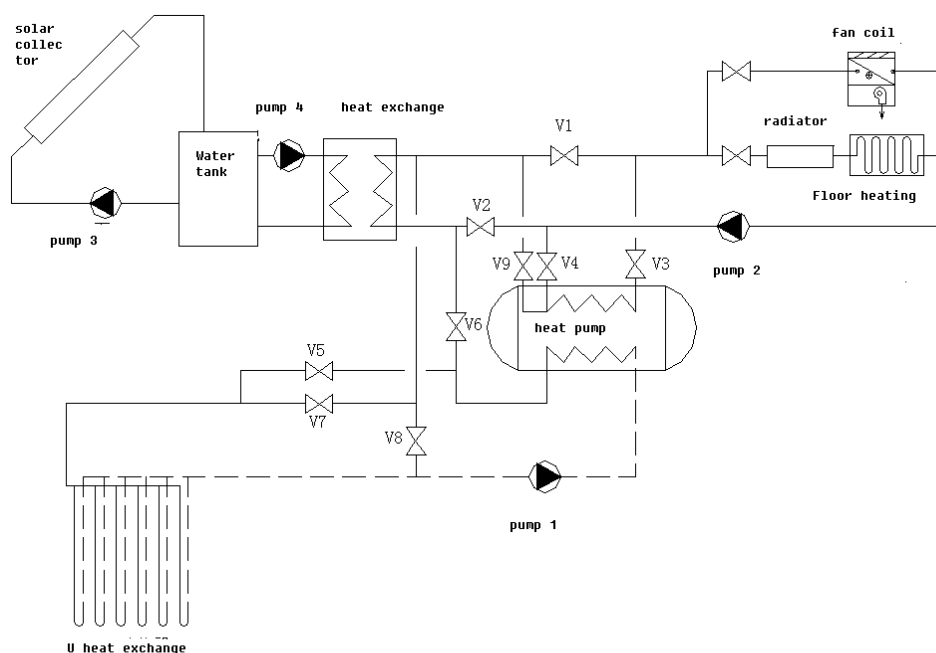


Figure 2: the combined operation mode of solar systems and ground source heat pump system

System control strategy: (1) Once the supplying water temperature through solar heating T_g is higher than $50\text{ }^{\circ}\text{C}$, in order to fulfill direct use of solar heating, the valve V_1 , V_2 and pump 2, 3, 4 are open, while valve V_3 , 4, 5, 6, 7, 8, 9, heat pump unit and pump 1 are closed (2) When the T_g temperature is below $50\text{ }^{\circ}\text{C}$, and higher than $40\text{ }^{\circ}\text{C}$, solar energy can not be directly used, but run in series with the heat pump condenser, at this time the valve V_2 , 3, 5, 9, pump 1 2, 3, 4 and heat pump unit are open while valve V_1 , 4, 6, 7, 8 are closed. (3) When the T_g temperature is below $40\text{ }^{\circ}\text{C}$, and higher than $25\text{ }^{\circ}\text{C}$, the solar energy is used for heating ground heat exchanger in the soil, at this time the valve V_3 , 4, 6, 7, pumps 1, 2, 3, 4 and heat pump unit are open while valve V_1 , 2, 5, 8, 9 are closed. (4) When the T_g temperature is below $25\text{ }^{\circ}\text{C}$, and higher than $15\text{ }^{\circ}\text{C}$, the solar energy directly enter into the evaporator of heat pump as low heat, at this time the valve V_3 , 4, 6, 8, pumps 1, 2, 3, 4 and heat pump unit are open while valve V_1 , 2, 5, 7, 9 are closed. (5) When the T_g temperature is below $15\text{ }^{\circ}\text{C}$, heat pump system is used for heating only. At this point, the valve V_3 , 4, 5, pumps 1, 2 and heat pump unit are open while valve V_1 , 2, 6, 7, 8, 9 are closed.

4 THE OPTIMAL OPERATION CONDITIONS OF SOLAR SYSTEMS AND GROUND SOURCE HEAT PUMP SYSTEM

For Solar systems and ground source heat pump system, the way of the joint operation mainly depends on the area of the solar collector and the required supply and return water temperature of the end. For example: the larger the area of collector, the higher the supply water temperature of the system can be, which makes the direct solar heating possible. On the contrary, once the collector area is smaller, the hot water temperature will be low, which can not be used for direct heating. Similarly, if the required supply and return water temperature for the end is higher, for example, more than $60\text{ }^{\circ}\text{C}$, it is difficult to use solar heating directly. If the required supply and return water temperature of the end is low, below $40\text{ }^{\circ}\text{C}$, solar heating can be directly used. The following describes the joint running of ground source and solar system corresponding to different collector area.

In Beijing, the heating period is from 15 January to 11 March 15 of the following year, that is 2880 hours in total. In typical meteorological year, there are 1179h for solar radiation time,

which is 40.63% of the total heating time. In order to facilitate the analysis, this paper assumes that the required supply and return water temperature at the end is 50/40 °C. Figure 3 shows under different solar collector area, how much the number of hours are when the solar system water temperatures are more than 41 °C, 42 °C, 43 °C, 44 °C, 45 °C, 46 °C, 47 °C, 48 °C, 49 °C, 50 °C.

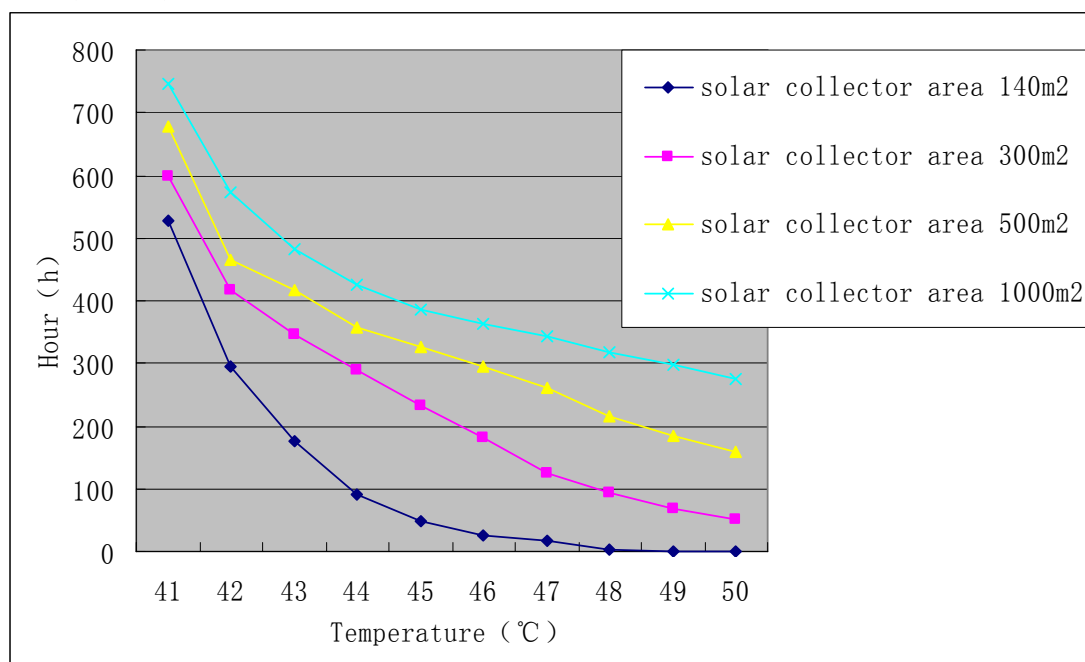


Figure 3: the number of hours when r hot water temperature exceeds 41 °C to 50 °C under different solar collector area

It can be seen from Figure 3:

- (1) Under the condition that the solar collector area is 140m², the maximum water temperature is 48 °C, so the direct use of solar heating can not be achieved.
- (2) Under the condition that the solar collector area is 300m², the number of hours when solar system water temperature exceeds 50 °C is 52h (1.81% of total heating time). Although the direct supply can be achieved, the time is short which makes direct use meaningless considering the increase of the complexity of control system and the initial investment.
- (3) Under the condition that the solar collector area is 500m², the number of hours when solar system water temperature exceeds 50 °C is 158h (5.5% of total heating time). The direct use of solar heating can be achieved.
- (4) Once solar collector area is increased from 140 m² to 1000 m², the number of hours when the water temperature of the solar system exceeds 41 °C does not vary largely, from 527 hours (18.3% of the total heating time) to 746 (25.9% of the total heating time) hours, but for more than 50 °C the number varies strikingly, from 0 hours (0% of the total heating time) to 275 hours (9.55% of total heating time).

5 THE SIMULATION OF OPTIMIZATION OF SOLAR SYSTEMS AND GROUND SOURCE HEAT PUMP SYSTEM

For the practical project in this paper, the TRNSYS software is used for simulation. As the solar collector area in the project is relatively small (140m²), so the joint operation mode that hot water after the heat exchange with solar energy enters into the ground heat exchanger or directly into the evaporator of heat pump unit are applied. Figure 4 and Figure 5 show,

respectively, the variations of import and export water and soil temperature under the condition that the joint operation of the system runs in 1 year and 10 years. It can be seen from the figure, once the solar system is only running in winter, in 10 years the initial soil temperature descends from 15 °C, down to 12.5 °C, down by 2.5 °C. Heat absorption and heat rejection is still an imbalance, which makes that solar energy is required to store energy in soil in the transition quarter. The specific simulations are shown in Figure 6.

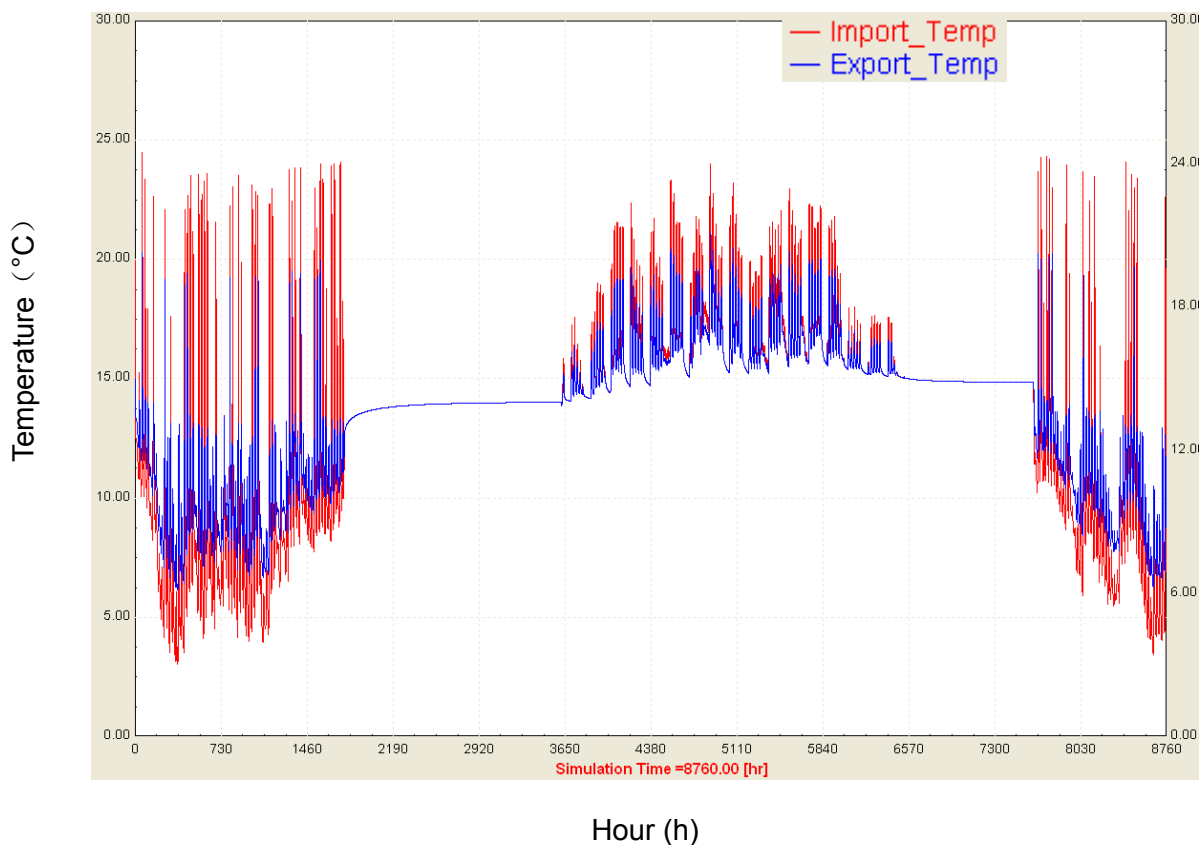


Figure 4: the variations of import and export water of ground heat exchange and soil temperature in 1years

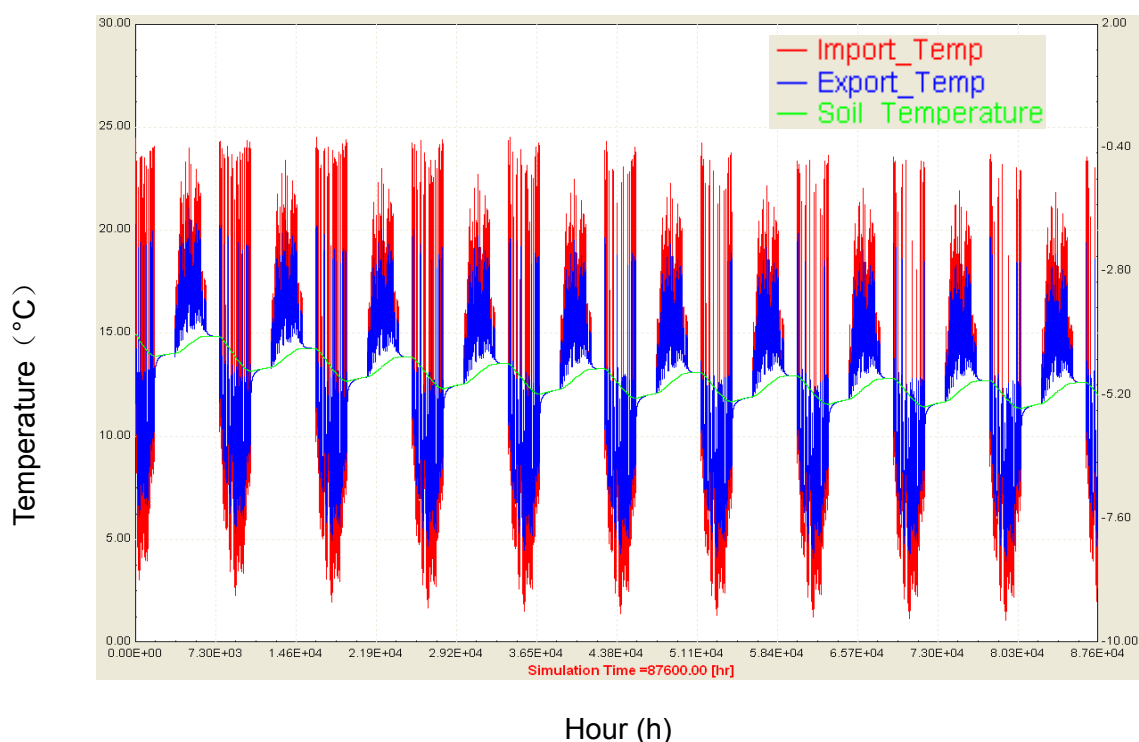


Figure 5: the variations of import and export water of ground heat exchange and soil temperature in 10 years

It can be seen from Figure 6, when the solar energy also store energy in the transition quarter, the average temperature in the 10 years is almost the same. The heat absorption and heat rejection is basically in a balance.

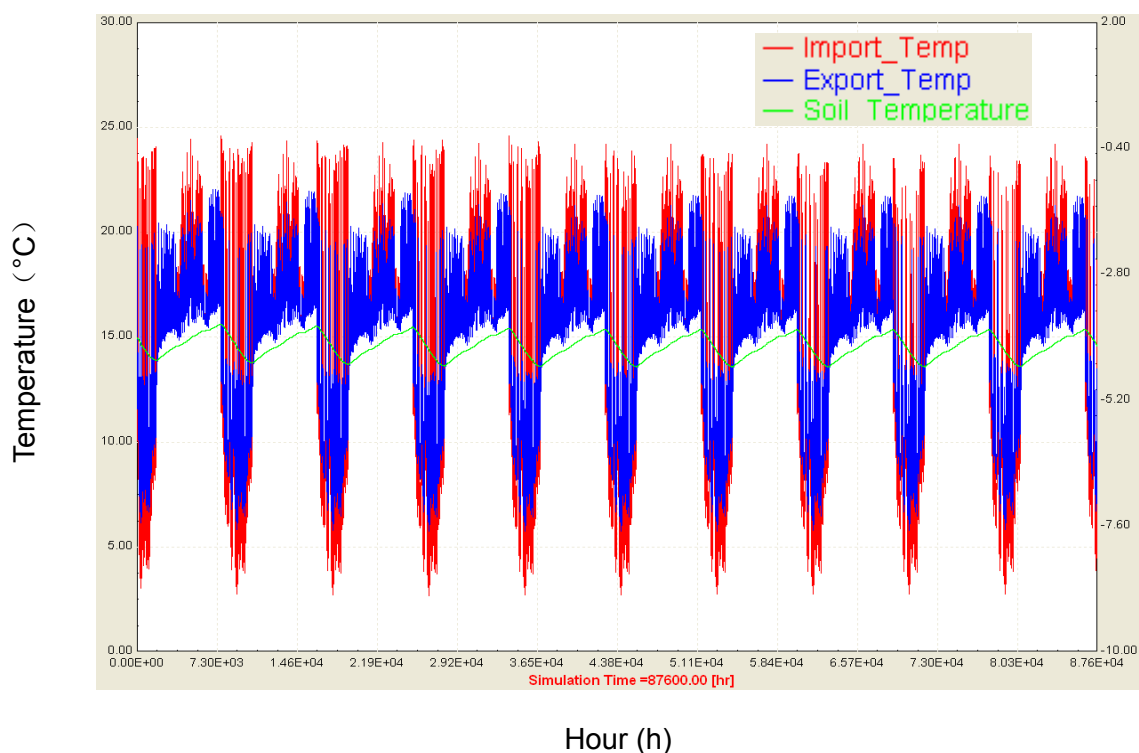


Figure 6: the variations of import and export water of ground heat exchange and soil temperature in 10 years

However, attention should be paid to a fact that the solar heat storage in the transition season will increase pump energy consumption and operating costs. Therefore, in practical engineering, heat storage in transitional season, should be considered seriously.

6 CONCLUSION

Solar energy, shallow geothermal energy as renewable energy, are playing increasingly important roles in energy use in the construction sector, whose application are important measures to solve China's energy and environmental issues. This paper describes the optimal operation and the suitable condition of joint operation of solar system and ground source heat pump system in details to put forward proposals for the rational use of renewable energy.

(1) Priority should be given to solar energy for joint operation of solar system and ground source heat pump system.

(2) In the use of solar energy resources, cascade utilization should be considered. To maximize solar energy effect, the order should be : direct supply, in series with the condenser of heat pump unit, solar heating ground heat exchanger, or solar power directly entry into the evaporator,

(3) The building should be energy conservation in the use of solar energy and shallow geothermal energy to minimize heating and cooling load, so as to take advantages of renewable energy.

(4) The solar collector area should be maximized, increasing the possibility of direct use of solar energy.

7 REFERENCES

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