Simulation Experiment on Energy Tower Coupled with Buried Pipe System of Ground-source Heat Pump for Cross-season Heat Storage

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Abstract. It is proposed to use energy tower instead of solar collector system to store heat for buried pipe system of ground-source heat pump in summer, so as to solve the problem that soil temperature is too low due to unbalanced cold and heat load of GSHP in cold and severe cold area. The simulation results show that the thermal storage power of energy tower is affected by soil temperature and environmental temperature. The lower the soil temperature, the better the thermal storage effect of energy tower system for soil. The thermal storage power and environmental temperature change in a positive relationship. It is proved that the application of cross-season heat storage is feasible for energy tower coupled with buried pipe system of ground-source heat pump in cold and severe cold area.

1. Introduction

The traditional ground source heat pump system uses underground rock and soil as a container for storing heat. The heat pump system stores the heat inside the building underground in summer, to reduce the temperature inside the building, and extracts the heat stored underground in winter to heat the building[1-2]. However, in specific practical engineering applications, it is difficult to balance the cooling load of the building in summer and the heat load in winter. Especially in cold and severe cold regions, the cooling load of the building in summer is much smaller than the heat load in winter, many years of operation will cause the heat pump to take more heat from the soil in winter than the system runs to the soil in summer. The heat balance of the soil will be destroyed, the soil temperature will gradually decrease, and the heat pump performance coefficient also will gradually decrease[3-4]. In areas where the ground source heat pump is used alone for heating in winter without cooling in summer, this problem will be more serious.

In order to overcome the problem of soil heat balance being damaged, many previous studies have proposed a combination of solar and ground source heat pumps to address this problem[5-7]. Solar energy is used as the auxiliary heat source of the soil-source heat pump, and the heat of the solar energy is to be stored into the soil seasonally, to make up the heat required for the imbalance of cold and heat. It will effectively increase the temperature of the soil around the buried pipe, thereby increasing the heating performance coefficient of the ground source heat pump during the heating period, makes the system more reliable. However, in practical applications, the use of solar energy is restricted by many factors, such as meteorological conditions, geographic location, collector price and collector installation conditions. For buildings with few solar resources or no space for collector
installation, solar energy systems cannot be used.

In recent years, Zhang Shu and others have studied the ground coupled heat pump system with seasonal air source heat storage suitable for cross-season applications [8-9]. The system uses summer high-temperature air instead of solar energy as an auxiliary heat source, the outdoor air heat exchanger is used to store the heat in the air into the soil in summer, and then the heat pump is used to take heat from the soil into the room in winter. Compared with solar heat storage, air source heat storage equipment is simple, investment and maintenance costs are lower. When there is no central heating pipe network, and there is not enough roof or other space to install solar collectors, the air source heat storage system can also achieve cross-season utilization of natural energy, provides a new way for the application of ground source heat pump heating technology in severe cold areas. However, the outdoor air heat exchanger only relies on the outdoor fan coil for simple heat exchange with air, although it can store heat when the air temperature is high, the heat storage effect is lower than that of solar heat storage.

For this reason, we propose to use energy towers instead of solar heat collection system to store heat for ground-source heat pump underground pipe systems for cross-season heat storage in summer, to solve the problem that the soil temperature is too low due to the imbalance of the cold and heat load of the ground source heat pump in cold and severe cold regions.

2. Energy tower coupled with buried pipe system of ground-source heat pump

In recent years, in the hot summer and cold winter regions such as Central China and East China, a new type of heat pump form—energy tower heat pump system has been gradually developed. It uses an energy tower as a heat exchange device with the air, assists the heat pump system to dissipate heat in summer, and extracts low-temperature heat energy contained in the air in winter. Energy towers are also called heat source towers, derived from the theory of reverse heat absorption of cooling towers, it is a tower-shaped new device that uses air as a source of cold and heat. Through the heat exchange between the tower and the air, the energy tower realizes multiple functions such as cooling, heating, and domestic hot water [10-12].

Since the energy tower has the function of absorbing the low-temperature heat energy stored in the natural air, we consider using the Energy tower coupled with buried pipe system of ground-source heat pump. In summer, the energy tower is used to absorb the heat of natural air and transfer it to the soil through the buried pipe heat exchanger to realize the heat storage of the soil; in winter, the heat stored in the soil is taken out by the ground source heat pump through the buried pipe heat exchanger to heat the building, which solves the problem of low soil temperature caused by the imbalance of cold and heat load in cold and severe cold areas. The schematic diagram of the cross-season heat storage energy tower coupled with buried pipe system of ground-source heat pump is shown in Figure 1.
Figure 1. Schematic diagram of cross-season heat storage system for energy tower coupling buried pipe system

In the non-heating seasons when the temperature is high, the system closes the switching valve 12 and opens the switching valve 11. At this time, the energy tower and the buried pipe system form a soil cross-season heat storage system, the energy tower absorbs the heat of natural air and the latent heat of condensation of water vapor in the air through the working medium, and transfers the heat to the soil to achieve heat storage.

During the heating period in winter, the switching valve 11 is closed and the switching valve 12 is opened. Under the action of the heat pump, the system takes out heat from the underground soil through the buried pipe heat exchange system, and after the heat pump host heats up, the user terminal supplies heating to the building. The system uses the soil as a huge heat accumulator, storing heat in summer and taking heat in winter, realizing the cross-season utilization of energy, and also solving the problem of unbalanced cold and heat load of the ground source heat pump system in winter and summer.

3. Experiment system

In order to simulate and verify the heat storage effect of the energy tower coupled with buried pipe system of ground-source heat pump, we have built an experimental system. As shown in Figure 2, the experimental system consists of an energy tower, a plate heat exchanger, an integrated water source heat pump unit, a control system and a data acquisition system. We use a set of integral water source heat pump unit to replace the buried pipe system, the integral water source heat pump unit extracts the
heat from the natural air absorbed by the energy tower through the plate heat exchanger, and then uses the fan coil to dissipate the heat to simulate an underground pipe system to store the heat in the underground soil. The control system can adjust the power of the heat pump unit through the frequency converter to control the outlet water temperature of the heat pump unit, simulate the different outlet water temperature of the buried pipe system under different soil temperature conditions, can better simulate the heat storage effect under different soil temperature conditions. In the experimental system, the energy tower is transformed by a cooling tower with a circulating water flow of 3t/h, the circulating pump power is 200W, and the energy tower fan power is 35W. In the system, temperature sensors and flow sensors with measurement accuracy of 0.2 are installed on the inlet and outlet pipes of the heat pump unit, and a data acquisition system is established. It can display and record inlet and outlet temperature and flow in real time, and calculate and record the heat storage power of the system in real time based on temperature and flow data.

4. Experimental data and analysis
After the installation and commissioning of the experimental system was completed, in the summer of 2018, we began to conduct experiments on simulating energy towers for soil heat storage. The test experiments were carried out under the conditions of 9℃, 10℃, 12℃, 14℃, 16℃ and 18℃ at the outlet water temperature of the heat pump unit. The lower the outlet water temperature of the heat pump unit, the lower the soil temperature, to simulate the heat storage effect of the soil under different temperature conditions. Figure 3-Figure 8 are curves of ambient temperature and heat storage power.
under different outlet water temperature conditions of the heat pump unit, Table 1 is a summary table of the data analysis of the energy tower heat storage experiment.

Figure 3. Curve of environmental temperature and thermal storage power at outlet temperature of 9°C

Figure 4. Curve of environmental temperature and thermal storage power at outlet temperature of 10°C

Figure 5. Curve of environmental temperature and thermal storage power at outlet temperature of 12°C
Figure 6. Curve of environmental temperature and thermal storage power at outlet temperature of 14°C

Figure 7. Curve of environmental temperature and thermal storage power at outlet temperature of 16°C

Figure 8. Curve of environmental temperature and thermal storage power at outlet temperature of 18°C
Table 1. Summary table of energy tower heat storage experiment

| The outlet water temperature of the water source heat pump unit (°C) | Maximum ambient temperature (°C) | Thermal storage power (kW) | Minimum ambient temperature (°C) | Thermal storage power (kW) | Ambient temperature average (°C) | Thermal storage power (kW) |
|---------------------------------------------------------------|---------------------------------|---------------------------|---------------------------------|---------------------------|-------------------------------|---------------------------|
| 9                                                             | 35.7                            | 9.34                      | 28.0                            | 8.45                      | 30.8                          | 8.94                      |
| 10                                                            | 32.9                            | 8.74                      | 27.8                            | 7.76                      | 29.8                          | 8.33                      |
| 12                                                            | 41.8                            | 7.31                      | 30.4                            | 6.43                      | 35.0                          | 6.77                      |
| 14                                                            | 37.3                            | 6.92                      | 29.9                            | 6.12                      | 33.2                          | 6.31                      |
| 16                                                            | 37.7                            | 5.55                      | 29.3                            | 5.15                      | 33.2                          | 5.40                      |
| 18                                                            | 37.7                            | 4.49                      | 28.8                            | 3.93                      | 32.3                          | 4.16                      |

From Figure 3 to Figure 8 and Table 1, it can be seen that in the experiment of simulating the energy tower for soil heat storage, the power of the energy tower for soil heat storage is seriously affected by the underground soil temperature. The outlet water temperature of the water source heat pump unit represents the corresponding soil temperature, when the outlet water temperature of the water source heat pump unit is 9°C, 10°C, 12°C, 14°C, 16°C, 18°C, the average heat storage power is 8.94kW, 8.33kW, 6.77kW, 6.31kW, 5.40kW, 4.16kW. The heat storage power decreases with the increase of the water temperature at the outlet of the water source heat pump unit. When the water temperature at the outlet of the water source heat pump unit is 9°C, the heat storage power of the energy tower is more than twice the heat storage power when the outlet water temperature of the water source heat pump unit is 18°C. It shows that the lower the temperature of the soil, the higher the heat storage power of the energy tower, and the better the effect of the energy tower for storing heat in the soil. This is because when the soil temperature is low, the temperature difference with the ambient temperature is large, so the heat storage is large, the heat storage power of the energy tower is also increased.

In addition, the heat storage power of the energy tower is also affected by the ambient temperature, the change of the heat storage power and the change of the ambient temperature are positive changes. When the ambient temperature increases, the heat storage power increases; conversely, when the ambient temperature decreases, the heat storage power also decreases. This is because the higher the ambient temperature, the more heat stored in the natural air is absorbed by the energy tower, and the higher the heat storage power. And when the ambient temperature is low, the heat storage power decreases.

5. Conclusion
1) Proposed the cross-season heat storage of the buried pipe system of the energy tower coupled with the ground source heat pump. In summer, the energy tower is used to absorb the heat in the natural air and the latent heat of condensation of the water vapor in the atmosphere to achieve soil heat storage, which can avoid the restrictions of meteorological conditions, geographical location, installation conditions and investment conditions that are encountered by the use of solar thermal storage systems, and it also has the advantages of continuous operation 24 hours a day and convenient application. It can be used as another cross-season soil heat storage method in addition to solar-soil heat storage to solve the problem of low soil temperature caused by imbalanced heat and cold loads of ground-source heat pumps in cold and severe cold regions.

2) The power of the energy tower to store heat for the soil is severely affected by the temperature of the underground soil. The lower the temperature of the soil, the higher the heat storage power of the energy tower, and the better the effect of the energy tower system for storing heat in the soil.

3) The heat storage power of the energy tower is affected by the ambient temperature, and the
change of the heat storage power and the change of the ambient temperature become a positive change, when the ambient temperature increases, the heat storage power increases; conversely, when the ambient temperature decreases, the heat storage power also decreases.

4) The experimental results prove that the cross-season heat storage of the energy tower coupled with buried pipe system of ground-source heat pump is feasible in cold and severe cold regions.

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