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Modeling study of ground source heat pump system based on the dynamic load of underground engineering

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Abstract. The load properties of underground engineering have an important influence on operating characteristics of ground source heat pump system. It has important reference value for design and operation management that Simulation analyzing operating conditions of ground source heat pump system under dynamic load conditions. It took an underground engineering as an example for dynamic load calculation in the paper, and simulated operating characteristics of ground source heat pump system under three operating conditions. The calculation results show that the engineering maintenance and management period is conducive to the recovery of soil temperature, and it improves the COP value of the unit. Some measures should be taken to restore soil temperature for long-term continuous operation of underground engineering. The use of heat recovery to make domestic hot water can relieve the problem of soil thermal imbalance to some extent. It is beneficial to improve heat pump unit performance.

1 Introduction

A large amount of waste heat is generated when equipment operation in underground engineering. The internal temperature of the engineering will rise, and it will lead to deterioration of the working environment, equipment operation failure, even system paralysis if not properly handled. At present central air-conditioning system were used in most of underground engineering in China. Because the engineering load in the spatial distribution is not uniform, it will cause huge energy waste. The use of ground heat exchanger can not only release the residual heat into the soil, but also overcome the problems of central air-conditioning system can't partition temperature control and energy consumption, it is very flexible and convenient. Vertical buried pipe heat exchange is less affected by outdoor temperature, has higher efficiency, and its application range is the most extensive. But the cost is higher, so it is important to establish accurate heat exchange model for the economic and sustainable operation of the ground source heat pump system [1,2]. The load characteristic has important influence to the operating characteristics of the ground source heat pump system [3,4,5]. The operating characteristics will also change when the load changes in underground engineering. Compared with the surface building, the underground engineering is affected by the surrounding geothermal heat, the internal temperature change is small. Because of the influence of day and night changes, and the method of use and other factors, the underground engineering load will change greatly. For example, when the engineering is running at full load, internal personnel and equipment will emit a lot of residual heat, and when the engineering is under maintenance, the rest of the heat is less, or even a thermal load. Therefore, it is of great practical significance to analyze the operation of the ground source heat pump system under dynamic load conditions [6,7].

2 Dynamic load analysis of underground engineering

Take an underground engineering hall as an example, the length l is 12.3m, the width b is 4.8m, the arch height h_1 is 2.4m, the arch height f is 1.1m, the rock material parameter is: λ= 2.04 W/ (m· K), a =0.0031 m^2/h, inner surface heat exchange factor h=7 W/(m^2·K). The natural temperature of the rock is 17.6℃, and the room is warmed up by 600h to reach the air temperature design requirement of 26℃.
The internal air system of the hall is analyzed, and its dynamic thermal balance equation can be expressed as:

$$V_a(\rho c)_a \frac{\partial T_a(\tau)}{\partial \tau} = Q_W(\tau) + Q_R(\tau) + Q_S(\tau) + Q_X(\tau) - Q_{JZ}(\tau) \quad (1)$$

$T_a(\tau)$: indoor air temperature, ℃;

$Q_W(\tau)$: heat transfer quantities through enclosure, W;

$Q_R(\tau)$: personnel heat release, W;

$Q_S(\tau)$: equipment heat release, W;

$Q_X(\tau)$: the heat of introduced or permeation fresh air, W;

$Q_{jz}(\tau)$: the heat carried away by ground source heat pump unit, W。

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Next, the heat is analyzed for each part.

2.1 Heat storage in the enclosure

For the limited length arch section project, the calculation can be approximated to the equivalent sphere, and the heat transfer of its internal enclosure structure can be calculated by press [8].

$$Q_w = F \cdot h(t_n - t_\infty)\left[1 - f_2(Fo, Bi)\right]m \tag{2}$$

$f_2(Fo,Bi) = \frac{Bi}{1+Bi}(1 - e^{Fo(1+Bi)^2} erfc[(Bi+1)\sqrt{Fo}]$, $F_0 = a(\tau + \tau_0)/R_0^2$, $Bi = \alpha R_o / \lambda$, In the equation, τ_0 is the project warm-up period time, here take 600h; F is the inner surface area of the enclosure, m^2。

2.2 The heat release by personnel

The amount of heat dissipated by personnel can be calculated in a press:

$$Q_r = 0.96 \cdot n \cdot q \tag{3}$$

In the equation, q *is the* total heat dissipation, W; n is the number of personnel, depending on the mode of the engineering, the number of personnel and the length of stay as shown in Table 1.

Table 1. Number of Hall personnel in different engineering modes.

the mode of the engineering	Full-load operation		Maintenance management period	
the length of stay	Day (12h)	Night (12h)	Day (12h)	Night (12h)
the number of personnel	30	15	5	0

According to the literature [9,10] , the amount of thermal emission of personnel in underground engineering is 52W at 26℃ and the amount of latent heat emission is 73W.

2.3 Equipment and lighting heat dissipation

The heat dissipation in the hall mainly comes from the operation of various equipment, the thermal load is 150 to 400 W/m^2. For easy analysis, the total load of equipment and lighting is 15kW, and the maintenance management period is 10% of the total load.

2.4 fresh air load

Assuming that the amount of new air in the hall varies with the number of people in the room, the new air is usually calculated by introducing the interior air supplement of the project, which can be calculated according to the following formula:

$$Q_X = nL_p c_p \rho'_{out}(T'_{out} - T_n)/3600 \tag{4}$$

When fresh air is introduced from outside, due to the influence of the surrounding structure, the new wind outside the project will generally be reduced by about 3 to 5℃, in this article $\triangle t$=2℃, The new wind introduction is 25m^3/h, and the maintenance management period does not take into account the new air load.

$$T'_{out} = T_{out} - \Delta t \tag{5}$$

Among the equation, T_{out} is outdoor time-by-time dry ball temperature in summer, $T_{out'}$ is the inner temperature of the engineering.

3 The establishment of the model of the ground source heat pump system

The ground source heat pump system is modeled using TRNSYS software. Its greatest feature is the open and modular structure design, the user has direct access to the source code and part model of the software, and can be self-edited and added to the actual needs of the part model [11,12]. The model of the ground source heat pump system built in this paper mainly includes the buried pipe heat exchanger, heat pump unit, building load coupling model, temperature control model, load input and output model, as shown in Fig. 1.

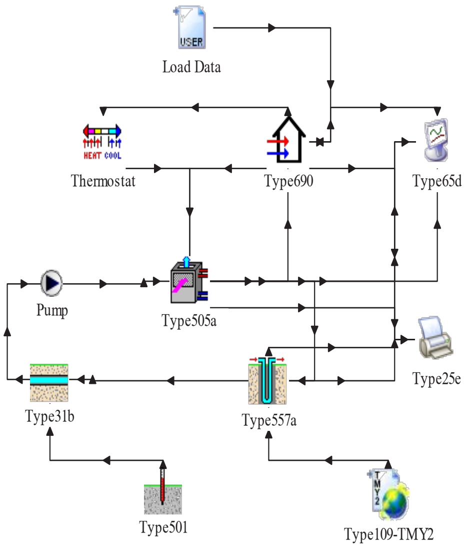

Fig. 1. TRNSYS simulation interface.

Type9: Data can be read from an external file and then joined to other parts of the simulation software. Because TRNSYS can't calculate the hot and humid load of underground buildings well, this paper uses MATLAB to calculate the hot and humid load of large residual heat room, imports the data into Type9, and carries on the subsequent simulation calculation.

Type108: Room temperature control signal. The room temperature is controlled by this module at 24℃. Thus indirectly control the operation of the heat pump unit;Type690: Buildings; Type557: Vertical buried pipe;

Type31: This module is used for horizontal tube temperature changes; Type3: Pump; Type505: Water-air water source heat pump; Type501: This module allows the original soil temperature to be pre-set; Type109: Weather parameters.

The relevant parameters such as the buried pipe used for the calculation are shown in Table 2.

Table 2. Simulation related parameters.

parameters	value	unit
Drilling diameter (d_b)	0.12	m
Branch Outer Diameter (d_{po})	0.032	m
Branch Inner Diameter (d_{pi})	0.027	m
Branch Spacing (x_c)	0.06	m
Heat conductivity of backfill materials (λ_g)	2.4	W/(m·K)
Tube wall thermal conductivity (λ_p)	0.6	W/(m·K)
Drilling depth (H)	100	m
Geothermal conductivity (λ_s)	2.4	W/(m·K)
Volume thermal capacity ($\rho_s c_s$)	2.0	MJ/(m³·k）
Circulating water flow (V)	1100	kg/h

4 Simulation results and analysis

4.1 Maintenance management period operation

The dynamic load of the underground engineering is analyzed Using the model in the oversection, and the in-and-out temperature and energy efficiency ratio of the unit are shown in Fig. 2 when the system operates for 20 years. It can be seen that the soil temperature can be better restored due to the maintenance period. The maximum incoming and the outgoing water temperatures of the units are 24.5℃ and 29.3℃ for the 10th opera Ting cycle. The unit COP is minimum 3.91, maximum 4.72, average 4.15.

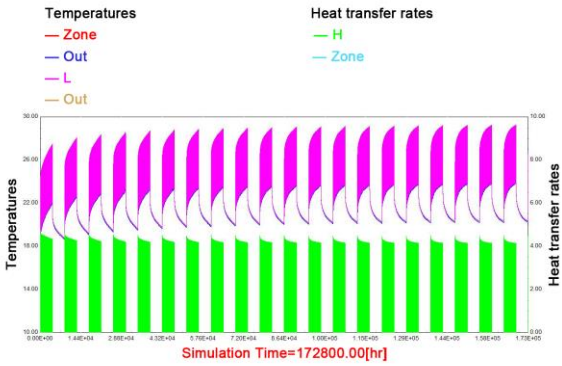

Fig. 2. Simulates the temperature and energy efficiency ratio of the incoming and outgoing units for 20 years of maintenance.

4.2 Continuous full load operation

In order to compare the impact of maintenance management period on the operation of the ground source heat pump system, it is assumed that the engineering has been running at full load, and simulates the water temperature and unit energy efficiency ratio of the ground source heat pump system for 10 years of continuous operation. The results are shown in Fig. 3. The maximum water inlet temperature in the 10th year rises to 27℃, and the maximum water temperature rises to 31.8℃. COP fell from 4.68 to 3.68, with an average COP of 3.89. It can be seen that the unit will release more heat to the soil for 20 years of intermittent operation, but due to intermittent operation of the soil temperature to a certain extent to restore, compared with continuous operation, the running effect of unit intermittent operation is better.

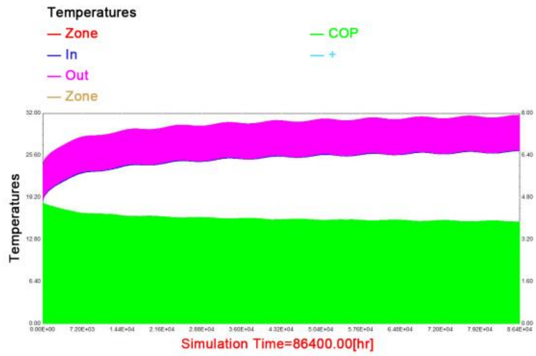

Fig. 3. Simulates the in-and-out water temperature and COP of the unit for 10 years of continuous operation at full load.

4.3 Condensation heat recovery method

Using the condensation heat generated by the heat pump unit to collect domestic hot water is an economical and effective way to solve the problem of soil heat imbalance. It is convenient and energy-saving to make domestic hot water by means of condensation heat recovery. Assuming that the number of personnel in the project is 30, the domestic hot water is based on 50L/d standard. Hot water needs to be heated from 20℃ to 55℃, and the daily water supply time is 6:00-22:00. Because the room is constant temperature control, the heat pump unit operation is intermittent. When the heat pump unit stops working, the domestic hot water is heated by the auxiliary electric heater. The ground-source heat pump system using heat recovery to make domestic hot water is shown in Fig. 4.

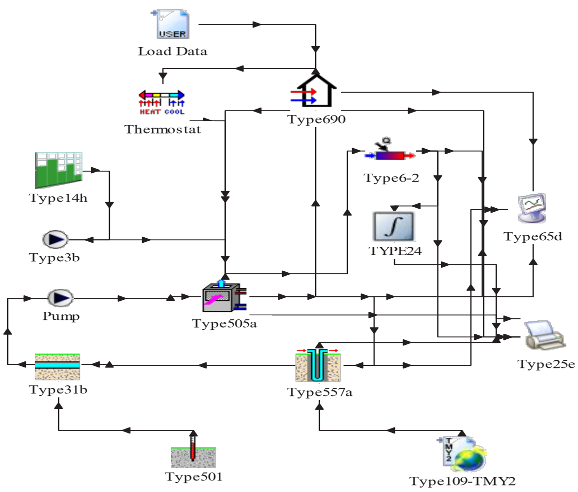

Fig. 4. Heat recovery method for making live hot water TRNSYS simulation.

The room temperature, the temperature of the buried pipe in and out of water, the average temperature of the rock and earth，the temperature of the hot water supply are analyzed when the heat pump system operate for 48h. As can be seen from Fig. 5, the temperature in the large residual heat room can be controlled near 24℃, the temperature of the heat pump unit in and out of water after the production of domestic hot water is significantly reduced, which is conducive to solving the problem of soil heat imbalance, but also improve the COP of the unit.

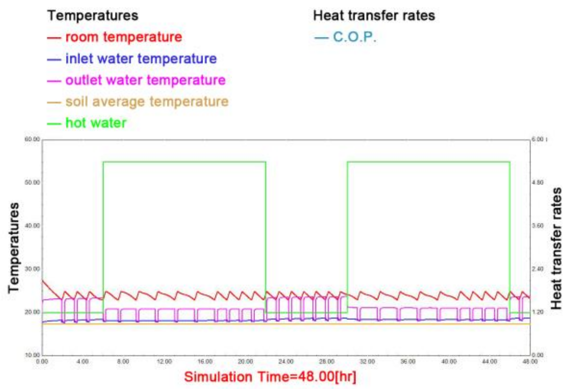

Fig. 5. The results of hot recovery mode running for 48h

The water temperature of the buried pipe was simulated for 10 years of continuous operation. As can be seen from Fig.6, before and after the heat recovery was used, the water temperature of the buried pipe was reduced from 26.95℃ to 23.78℃. Ten-year auxiliary heating power consumption is 22,700 million J, and if all the domestic hot water is heated by electric heating, the required electricity consumption is:

$$Q = cm \Delta t = 7.92 \times 10^{11} J \quad (6)$$

Therefore, the use of heat recovery method to make domestic hot water can not only save electricity but also to a certain extent to solve the problem of the thermal and hot load imbalance of the buried pipe, thereby improving the operating performance of the ground source heat pump system.

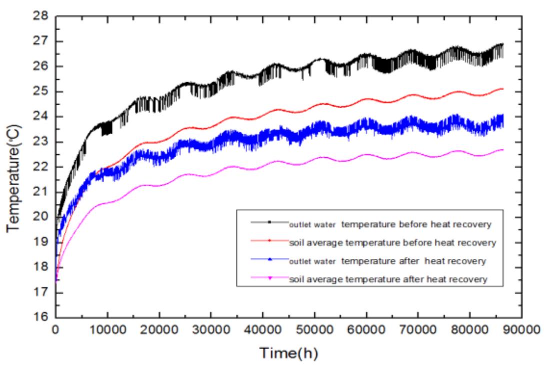

Fig.6. Comparison of the water temperature of the buried pipe before and after heat recovery

4 Conclusions

When the underground engineering adopts the ground source heat pump air conditioning system, different operating conditions will have an impact on the operating characteristics of the system, and the operation mode with engineering maintenance management period is conducive to the recovery of soil temperature, and also has a catalytic effect on improving the COP of the unit. If the unit needs a long period of continuous operation, it should to take certain measures to restore soil temperature. The use of condensation heat generated to make domestic hot water, can alleviate the problem of soil heat imbalance to a certain extent, is conducive to improving the performance of the heat pump unit.

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