BUILDING ENERGY CONSUMPTION SIMULATION AND ITS APPLICATION IN UNDERGROUND-WATER SOURCE THERMAL ENERGY MANAGEMENT SYSTEM

by

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In order to analyze the rationality of the compound well structure and the degree of heat penetration of groundwater in a groundwater ground source heat pump project in a certain district of a city, the author proposed a method for building energy consumption simulation and groundwater flow numerical model. The variation trend of groundwater temperature under different heat transfer temperature difference is simulated and predicted. The experimental results show that the fitting points where the error between the simulated predicted temperature and the actual measured temperature does not exceed 0.5 °C account for 51.7%, the fitting points where the error is 0.5~1 °C account for 28.7%, the fitting points where the error is 1~2 °C account for 18.1%, and the fitting points where the error is greater than 2 °C account for 1.5%. The dynamic change trend of the simulated predicted temperature curve is basically consistent with that of the actual measured temperature curve. It is proved that the building energy consumption simulation and the numerical model of groundwater flow can effectively analyze the rationality of the compound well structure of the groundwater ground source heat pump project and the degree of groundwater heat penetration.

Key words: *building energy consumption simulation, groundwater source, thermal energy management, heat pump engineering*

Introduction

With the continuous development of people's awareness of environmental protection and energy conservation, the issue of home energy consumption has attracted a lot of attention. All segments of society are beginning to pay more attention energy-saving construction, promoting the use of green building technologies, and making the construction industry move toward sustainable development. According to statistics, in the past the energy consumption of the building was equal to that of the existing buildings in the country, and the energy consumption of the house was equal to the total all the utilities of the economy in the country [1]. Electricity consumption alone is about twice that of developed countries with similar climates, but the level of indoor comfort is very different. It refers to the reduction of domestic energy consumption through various scientific and practical methods, and encourages the release of energy from surface water, groundwater, soil and other environmental sources of heat pumps and other technologies [2]. At the initial stage of the design, scientific

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research and accuracy of heating and cooling loads and the quantitative measurement of the specific effects of various energy saving measures are obtained in different regions and buildings have good results for improving the art design [3]. Ground source heating is a green building technology. It is a heat pump with rock and soil, water in the ground or water on the surface of the water as the temperature is less heat. According to the national standard, it is divided into buried underground-water pipes from heat pumps or underground heat sources, underground-water pumps and underground-water sources. The geothermal field is a field that heats the ground with the ground-water as a low heat and cold source. This type of heat pump is very advanced, which can improve the energy efficiency of the primary energy and reduce the pollution from other connections. Compared with the air source heat pump, the system can save energy twice, reduce the maximum power consumption, and its efficiency and output are not affected by at the temperature outside. Compared with other underground pumps, it has stable operation, low system cost, large capacity, high efficiency, low maintenance and easy to control people [4].

Literature review

Geological and hydrogeological conditions determine the type and occurrence conditions of groundwater. Different landforms, such as alluvial proluvial fan, alluvial plain and loess plateau, have different groundwater conditions. Groundwater can be divided into aeration zone water, phreatic water and confined water according to storage conditions. For the heat energy in the groundwater, the phreatic aquifer rock formation is the most ideal target layer for mining because of its shallow burial depth and relatively low cost, however, the change of the groundwater level is greatly affected by the climate conditions, and the thickness of the aquifer is limited, at the same time, it is easy to be polluted, so it is generally exploited in combination with confined aquifer [5]. Confined water, like phreatic water to a large extent, is recharged by precipitation infiltration and surface water infiltration, because there is an impermeable layer above the confined aquifer, it is less affected by hydrometeorological factors and suitable for exploitation. After the system draws groundwater to complete energy transmission, the water shall be reinjected into the corresponding aquifer to avoid waste of water resources.

At present, a simple method to estimate building heating load or air-conditioning cooling load is widely used in the HVAC field, but it is not the annual energy consumption of buildings, it cannot be used as an indicator to estimate the annual energy consumption. For example, in some cases, increasing the window wall ratio of the south exterior wall will increase the maximum heat consumption of the heating load by 40%, but the cumulative value of the total heating energy consumption in winter will decrease by 30%, the advantages of building energy consumption simulation are shown in fig. 1 [6].

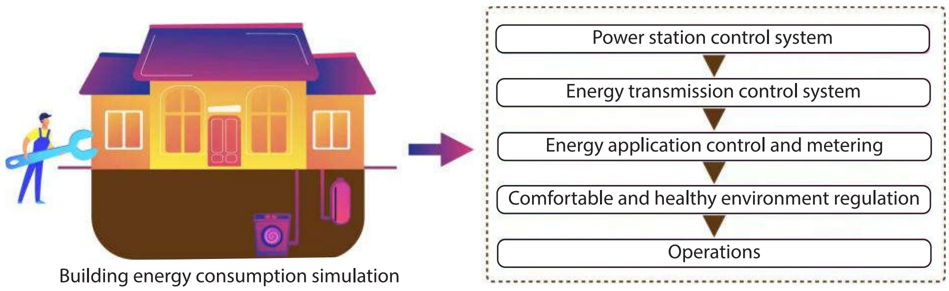

Figure 1. Advantages of building energy consumption simulation

Main application scope of building energy consumption simulation technology:

- Therefore, it is necessary to use experiments over the years to evaluate and evaluate how the building's environment and energy consumption will be guided by the architectural design standards. If the thermal insulation performance or wall thickness increases, the temperature loss in winter will be reduced in some areas, but the cold air load in summer will also increase. With the increase of thermal insulation thickness, the increase in income will be less than the line out of investment, that is, the best thermal insulation thickness. Because there are some restrictions and they are related to the local and indoor climate, the impact of some measures on the annual energy consumption of buildings is only found by careful testing [7].
- It is used to predict the efficiency of different air conditioners. In the actual work process, in most cases, the air conditioner works in the cloud design. A possible half of the loading problems are related to the local climate and the internal heating regulations of the specific buildings. In the actual work process, there may be many situations and problems, such as difficulty in meeting environmental regulations, or improper cooling and heating, which leads to increased energy consumption. By testing every hour every hour, we will understand the various activities that will occur in the real operation of the system, in order to be able to measure effectively against the standards and controls honor. Through careful testing, the annual energy consumption of air conditioning caused by different usage patterns can be estimated, in order to optimize the system and equipment set up. With the deepening of home energy conservation and the widespread use of ground-water source heat pump technology, more accurate and detailed energy consumption data electrical simulation should be used by using numerical tests. The main purpose of these projects is to provide evidence for engineering applications, follow the guidelines for the development of building energy analysis, and conduct effective research on practical use of the system by connecting the energy used to simulate the results of the buildings in the ground with water heat change law in the aquifer of the system [8].

Building energy consumption simulation in thermal energy management of underground-water source

Project overview

Water source heat pump project is proposed to be adopted for Building A in a city, with a heating and cooling area of 7582 m^2. According to the calculation, the water consumption of the building in winter heating period is greater than that in summer cooling, and the temperature of reinjection water in heating period is limited, so from the perspective of safety, the heating period is selected as the simulation period. The water source heat pump project of Building A is designed with one pumping well and three return wells. Since there are one user on the east and one user on the south, B and C also use the water source heat pump for heating and cooling. User B is 160.5 m away from Building A, and user C is 56 m away from Building A. Therefore, how to arrange the pumping wells of the water source heat pump project in Building A can ensure that there will be no impact on the heat penetration and water recovery of existing users B and C, which has become the key to whether the project can pass the approval of the water administrative department [9].

Hydrogeological conditions

The study area is located in the first step area of Hunhe River, its surface is flat, with a ground elevation of about 45.0 m, the surface lithology is Upper Pleistocene silty clay:

– Aquifer characteristics

The aquifer is divided into upper and lower layers, the upper layer is the upper Pleistocene alluvial proluvial sand gravel aquifer, and the surface layer is silty clay with a thickness of 8.0~9.0 m, below it is medium coarse sand with a small amount of gravel, and this layer contains a small amount of cohesive soil, with a thickness of about 13.0 m. The lower layer is the lower renewal proluvial sand gravel mixed clay aquifer, which is a semi cemented sand gravel mixed clay layer, the sand gravel is slightly weathered, with a thickness of about 29.0 m [10].

– Groundwater characteristics

The buried depth of groundwater level is 10. 0~11.0 m, the groundwater temperature is 11 °C, the groundwater flow direction in the site is from northeast to southwest, and the hydraulic gradient is 1~2‰.

Hydrogeological conceptual model

- *Determination of aquifer type*. The aquifer is regarded as a phreatic aquifer, and the roof of pre Sinian granite gneiss is regarded as the bottom of the aquifer, according to the type, lithology, thickness, and water diversion characteristics of the aquifer, the model is generalized as a heterogeneous and isotropic aquifer, and the local part can be regarded as homogeneous.
- *Generalization of groundwater flow*. The groundwater level changes to a certain extent due to the influence of dry and wet seasons, and the water flow is in an unstable state, however, the regional groundwater generally flows in a laminar manner, which conforms to Darcy's law and can be regarded as an unstable 2-D plane flow [11].
- *Division of boundary types*. The four lateral boundaries of the study area are generalized as the known water head boundary, the groundwater level at the northern boundary is 34.0 m, and that at the southern boundary is 33.5 m. The four lateral boundaries are generalized as constant water temperature boundaries, and the groundwater temperature is 11 °C. The surface infiltration conditions in the study area are poor, and the atmospheric precipitation infiltration recharge is ignored. The granite gneiss at the bottom is regarded as the boundary of the water resisting layer [12].
- *Processing of source and sink items*. The groundwater exploitation in winter heating period mainly includes one pumping well of the proposed water source heat pump project in Building A, with the exploitation volume of 900 m^3 per day, there are three recharging wells for recharging, with a single well recharging volume of 300 m^3 per day, and two pumping wells for the water source heat pump project of user B, the pumping capacity of a single well is 1265 m^3 per day, and there are six reinjection wells with a single well reinjection capacity of 425 m^3 per day. The water source heat pump project of user C has one pumping well with water intake of 265 m^3 per day, 1 reinjection well with reinjection volume of 265 m^3 per day, the well spacing of each user's water source heat pump project is 40.0~50.0 m [13].

Basic mathematical model of building thermal process

The thermal inertia of the enclosure structure, especially the exterior wall material, is relatively large, and the response to the temperature is relatively slow, which has a great impact on the indoor temperature. When there is a temperature difference between the enclosure structure and the surrounding temperature, it will absorb or release heat [14]. It is very important to simulate and predict the building thermal process whether the process of heat storage and heat release can be accurately described. Generally, the wall body, including the exterior wall, interior wall, floor slab, doors and windows, has a uniform surface structure, and the thickness is far less than the surface size, therefore, the wall composed of multilayer materials can ignore the heat conduction in the direction parallel to the surface, and the heat conduction equation along the thickness direction:

$$c_p\rho\frac{\partial t}{\partial \tau}=\frac{\partial t}{\partial x}\left(k\frac{\partial t}{\partial x}\right) \tag{1}$$

On the indoor side, the boundary condition of eq. (1):

$$-k\frac{\partial t}{\partial x}\Big|_{x=l}=h_{\text{in}}\left(t_a-t\right)+q_r+\sum_j hr_j\left(t_j-t\right)+q_{r,\text{in}} \tag{2}$$

When the wall is an internal partition or floor, its boundary condition is the same as that in eq. (2), but it becomes $x = 0$, and there is no negative sign in front of k [15].

When the other side of the wall is outdoor:

$$k\frac{\partial t}{\partial x}\Big|_{x=0}=h_{\text{out}}\left(t_0-t\right)+q_{r,0}+hr_{\text{env}}\left(t_{\text{env}}-t\right) \tag{3}$$

The dynamic heat transfer equation of eqs. (1)-(3) can be listed for all walls (floor, wall, doors and windows) in the building. These enclosure structures enclose many building spaces in the building, the air temperature change in each building space can be listed:

$$c_{p,a}\rho_a V_a\frac{\mathrm{d}t_a}{\mathrm{d}\tau}=\sum_{j=1}^{n}F_j h_{\text{in}}\left[t_j\left(\tau\right)-t_a\left(\tau\right)\right]+q_{\text{cov}}+q_f+q_{\text{vent}}+q_{\text{hvac}} \tag{4}$$

where $c_{p,a}\rho_a V_a$ [kJ°C^{-1}] is the heat capacity of air in the building space, F_j [m^2] – the area of the internal surface j of the wall of the building space, t_j [°C] – the temperature of the interior surface j of the building space, n – the number of interior surfaces of building space, q_{cov} [W] – the heat transferred to the air by convection from indoor heat sources (personnel, lights, equipment), q_f [W] – the heat released by indoor furniture, q_{vent} [W] – the heat brought into the room due to indoor and outdoor air exchange or air exchange with adjacent rooms, and q_{hvac} [W] – the refers to the cold and heat delivered to the building space by the heating and air-conditioning system, [16].

At present, the main difference of various simulation software is whether to consider the heat transfer problem of the adjacent room, which is also the main difficulty of the dynamic simulation of the building thermal environment. Because the heat storage and release effect of the wall cannot be ignored, the PDE of eq. (1) must be solved for the simulation of building thermal process. In eq. (2)

$$\sum_j hr_j\left(t_j-t\right)$$

represents the long wave radiation heat transfer between the internal surfaces of each wall, and eq. (4) gives the thermal coupling relationship between the indoor air temperature and each surface, therefore, to solve the building thermal process, all parts of the room must be considered at the same time, not only the external envelope (exterior wall, roof) can be analyzed. When the other side of the wall is also indoor, the thermal coupling relationship between the external surface of the wall and the air temperature of the adjacent room and the exchange of air with the adjacent room included in q_{vent} in eq. (4) require that all rooms in the building must be considered simultaneously in the analysis and solution of the building thermal process. The DeST has fully considered the aforementioned problems in solving the building thermal process [17]. In addition, the dynamic simulation of building thermal environment will also involve the shading, sunlight transmission, heat conduction of windows, calculation of solar radiation absorbed by indoor surfaces through windows, and treatment of indoor furniture.

Numerical model of groundwater flow

According to the hydrogeological conceptual model, the mathematical model of groundwater flow in the study area is established, and its specific expression:

$$n\rho_0\beta_p\frac{\partial p}{\partial \tau}+n\rho_0\beta_r\frac{\partial t}{\partial \tau}+\rho_{ab}\frac{\partial p}{\partial \tau}=\nabla\rho\frac{K_p}{\mu}\left(\nabla_p+\rho_g\right) \tag{5}$$

$$p\left(x,y,z,\tau\right)\big|\tau=0=p_0\left(x,y,z\right),\ \left(x,y,z\right)\in D \tag{6}$$

$$p\left(x,y,z,\tau\right)\big|r_1=p\left(x,y,z\right),\ \left(x,y,z\right)\in\Gamma_1 \tag{7}$$

where n is the porosity, ρ_0 [kgm^{-3}] – the density of reinjection water, β_p [Pa^{-1}] – the compressibility coefficient of water, p [Pa] – the groundwater pressure, T [s] – the time, and β_r [°C^{-1}] – the thermal expansion coefficient of water, [18].

Equation (5) is the water flow equation in heterogeneous anisotropic porous media, eq. (6) is the groundwater pressure equation of each point in the study area at the initial time, and eq. (7) is the boundary condition equation of groundwater pressure in the study area.

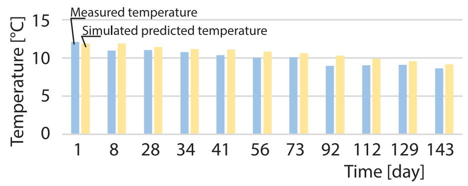

Figure 2. Comparison of measured temperature and simulated predicted temperature of composite well *F*$_1$ (recharge well)

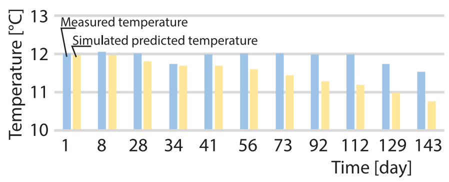

Figure 3. Comparison of measured temperature and simulated predicted temperature of composite well *F*$_1$ (pumping well)

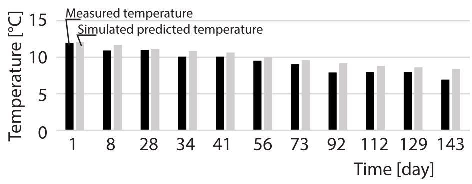

Figure 4. Comparison of measured temperature and simulated predicted temperature of composite well *F*$_2$ (recharge well)

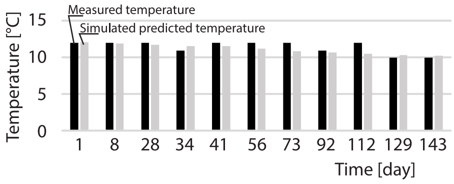

Figure 5. Comparison of measured temperature and simulated predicted temperature of composite well *F*$_2$ (pumping well)

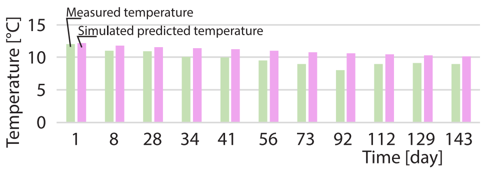

Figure 6. Comparison of measured temperature and simulated predicted temperature of composite well *F*$_7$ (recharge well)

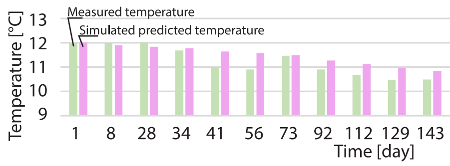

Figure 7. Comparison of measured temperature and simulated predicted temperature of composite well *F*$_7$ (pumping well)

Results and analysis

The water source heat pump project of the project has been running for a heating period (November 2019 to March 2020), the water temperature of some wells has been tracked and monitored, the measured temperature of compound wells (F_1, F_2, and F_7) is selected for comparison with the simulated predicted temperature, as shown in figs. 2-7.

It can be seen from figs. 2-7 that the fitting points with the error between the simulated predicted temperature and the actual measured temperature not exceeding 0.5 °C account for 51.7%, the fitting points with the error of 0.5~1 °C account for 28.7%, the fitting points with the error of 1~2 °C account for 18.1%, and the fitting points with the error of more than 2 °C account for 1.5%. The dynamic change trend of the simulated predicted temperature curve is basically consistent with that of the actual measured temperature curve, considering the accuracy of existing basic data, the accuracy of observation data, human error and other factors, it can be considered that the fitting effect is relatively ideal, the established simulation model can accurately predict the change of groundwater temperature, and can provide a more accurate basis for the design of water source heat pump projects [19-21].

Conclusion

Through the numerical simulation of groundwater and water temperature after the operation of the heat pump, the changes of groundwater and temperature can be estimated was good. Based on the analysis and comparison, choose the appropriate method can identify the interaction between users, and solve the shortcomings of the network quality process of the water heat pump milk based on experience, The changes and effects of various types of ground-water and hot water after the operation of the water heating pump work have seen a lot of live in the form of the output image, which not only provides the basis for the design of the water heat pump, but also provides operational support for the approval of it supervisors. The dignity of the well-constructed structure and the scale of the groundwater entering the ground of the underground-water heating system in one area of the city were analyzed, and the connection structure of ground-water and temperature are established, The difference between the ground-water temperature in the difference of the heat transfer difference is simulated and estimated. The test results showed that the well-mixed structure can meet the requirements of the water heater, and the heat transfer temperature of 5 °C is reasonable and is safer than 7 °C. The accuracy of the test results was verified by the work in the heating time and the actual analysis of the water in the ground.

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