ANALYSIS ON DISTRIBUTED DEEP WELL WATER HEAT PUMP WITH CENTRAL HEAT EXCHANGERS

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Abstract The technical and economic performance of distributed deep well water irrigation heat pump system with central heat exchangers and terminal fan coil units were analyzed. Comparing two cooling modes of terminal fan coil, it is proved that this heat pump system is suitable for residential districts combining heating and air conditioning in China.

Keywords central heat exchangers, distributed water source heat pump, COP, economic performance.

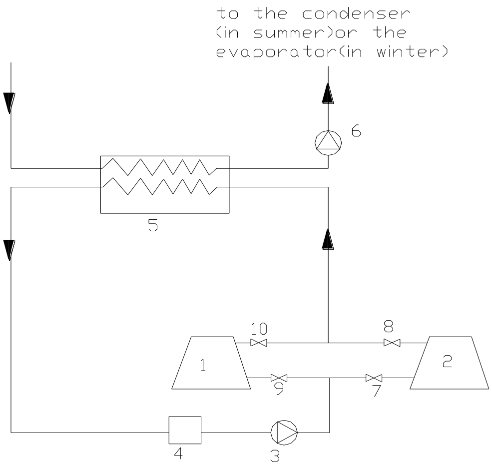
Introduction

With the further adjustment of energy structure in China, it has become a popular subject of study how to rationally use low efficiency energy and organize heating and cooling modes. The distributed water source heat pump operates reliably, and can cooperate with the buildings easily. It is easy to regulate and measure separately in the household. In especial, distributed water source heat pump using deep well water as cooling and heating source has great potentialities because of its super effect on the energy-saving and environmental protection. The temperature of deep well water has only a small fluctuation with season, so that it has great advantage for heat pump to operate. The temperature of deep well is about 1℃-2℃, higher than average temperature of whole year. For example, water temperature is about 4℃ in the north area of Northeast China, about 12℃ in the middle area of Northeast China, about from 12℃ to 14℃ in the south area of Northeast China, about from 15℃ to 19℃ in North China, about from 19℃ to 20℃ in East China, and about from 16℃ to 18℃ in Northwest China. The normal circular water temperature is from 15℃ to 33℃,therefore deep well water irrigation is very suitable for the area of the middle and lower reaches of the Changjiang River[1].

In this paper, a heat pump system for the areas with 15℃-20℃ deep well water temperature were analyzed. The distributed water source heat pump with deep well water irrigation central heat exchanger, and two cooling modes of FCU (fan coil unit) were economically and technically analyzed. Energy saving design and operation scheme in water source heat pump system were researched. It can provide basis on selecting and designing for rational and economic air conditioning system and operation scheme.

Distributed Water Source Heat Pump System with Deep Well Water Irrigation

The principle of deep well water irrigation system with a central heat exchanger is shown in Fig.1.Central heat exchanger is settled nearby the water source. In summer, turns on valve 7 and 10, at the same time turns off valve 8 and 9, and switches on the well water pump 1 (cool water well). Deep well water enters central heat exchanger 5, and exchanges heat with circular water, then returns to deep well 2 (heat water well). In the winter, the operation process is just reverse. The circular water that have exchanged heat with deep well water in the central heat exchanger enters the condenser (in summer) or evaporator (in winter) of every terminal heat pump unit, and exchanges heat with refrigerant and then returns to the central heat exchanger.



1-cool deep well and the pump 2-heat deep well and the pump 3-irrigating pump
4-fliter pool 5-central plate heat exchanger 6-circular pump 7~10 gate valve

Fig.1 Scheme of deep well water irrigation and central heat exchange system

From Fig.1, we can see that deep well water is used as a indirect medium. In fact, the heat (in winter) or cold (in summer) of deep ground sand was used to supply heat in cold seasons and cooling in hot seasons. The deep well water gives heat and stores cold in winter, and gives cold and stores heat in summer. If the heat for users in winter is equal to the heat off users in summer, the gain and loss of heat in underground keeps balance. Because only the heat of deep well water is used in the whole circulation and keeps balance in volume, the ground surface doesn't sink even if a great deal of underground water is used.

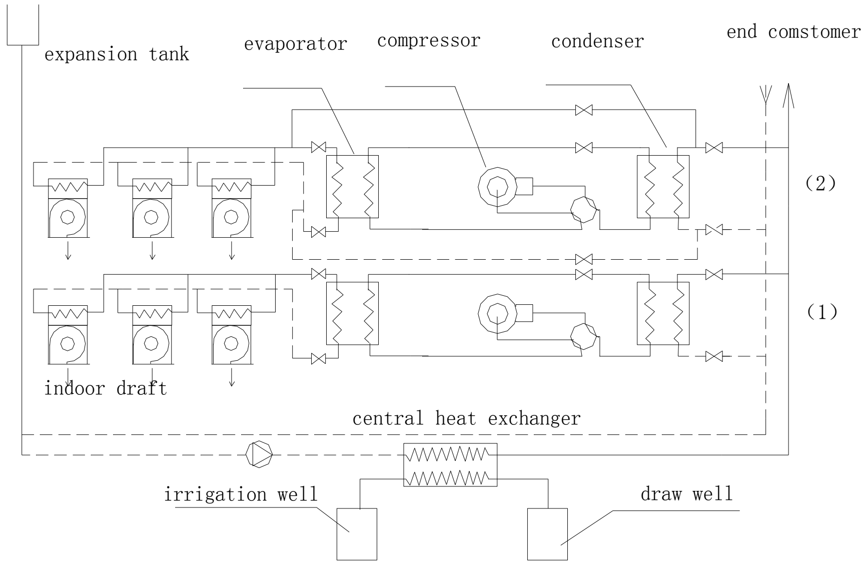


Fig.2 Schematic diagram of distributed water source heat pump system

As far as the initial investment is concerned, the cost of deep well and pump room is about 1000 yuan/m .If the depth of both deep wells are 150-200m, the cost is 300-400 thousand yuan. The cost is nearly equal to that of a medium-scale building that is supplied heat by central pipeline network (400 thousand yuan). On the other hand, because the deep well water temperature keeps between 15℃ and 20℃ all the year round, it needs less initial investment compared with air cooling or other water cooling chiller. The cost of the auxiliary heat source and cooling tower reduces.

Building developers can also make use of the system in building. The houses are installed with terminal units only after the houses are rented or sold. Users can also choose to install terminal units, thus the developers reduce their investments greatly.
According to the difference of heating and cooling style, there are two modes as shown in Fig.2. The first style: the chilled water or heating water made by heat pump supplies cold or heat to the indoor by the FCU. This belongs to conventional style shown in Fig.2 (1).

The second style: the circular water that exchanged heat with central heat exchanger is used directly to supply cold to each room by FCU in summer. When this mode can't meet requirements, switches on the heat pump. The operation is the same as the first style in other season. See Fig.2 (2).

Performance of Distributed Water Source Heat Pump System

Work coefficient of water source heat pump includes cooling coefficient and heating coefficient. They depend on the difference of high temperature and low temperature source, the performance of compressor, and working medium. The cooling coefficient and heating coefficient of piston compressor can be defined as[2]:

$$\varepsilon_c=774.13(t_K-t_Z)^{-1.527} \tag{1}$$
$$\varepsilon_h=55.33(t_K-t_Z)^{-0.7633} \tag{2}$$

where t_k is condensation temperature and t_z is evaporation temperature .

In the area of the middle and lower reaches of the Yellow River, the temperature of deep well normally fluctuates from 15℃ to 20℃(such as Beijing). The temperature in different areas is different. In this system, it should reduce circular currents of deep well and increase the temperature difference in supply water and return water in order to decrease the initial investment of deep well. In general, the temperature difference is from 5℃to 7℃. It should reduce the heat transfer temperature difference in central plate heat exchanger to fully utilize underground cool and heat. The heat transfer temperature difference is chosen as 2℃ and uses adverse-current style[3]. Normally the water flow in two sides of the plate heat exchanger is about equal, so the water temperature raise and fall from inlet to outlet in both sides of heat exchanger is equal. It is from 5℃ to 7℃. The cooling or heating mode of fan coil unit is shown in Fig.2 (1). The temperature of heat circular supply water and return water are 50℃and 42℃ in winter. The temperature of the chilled circular supply water and return water are 7℃and 12℃ in summer. The temperature difference of heat transfer is 4℃in the condenser and evaporator.

Based on th above parameters, we can draw condensation temperature (t_K) and evaporation temperature (t_Z) of heat pump, then calculate cooling coefficient (ε_C) and heating coefficient

(ε_h). The results are shown in table 1 and 2.

Table 1 Results in winter condition

Draw temperature from deep well(℃)	Irrigation Temperature from Deep well (℃)	Supply temperature of circulation(℃)	Return temperature of circulation (℃)	Temperature of Vaporization(℃)	Temperature of Condensation(℃)	ε_h
15	10	13	8	4	50	2.97
15	9	13	7	3	50	2.93
15	8	13	6	2	50	2.90
16	9	14	7	3	50	2.93
17	10	15	8	4	50	2.98
18	11	16	9	5	50	3.02
19	12	17	10	6	50	3.08
20	13	18	11	7	50	3.13

Table 2 Results in summer condition

Draw temperature from deep well(℃)	Irrigation Temperature from Deep well (℃)	Supply temperature of circulation(℃)	Return temperature of circulation (℃)	Temperature of Vaporization(℃)	Temperature of Condensation(℃)	ε_c
15	20	17	22	3	23.5	7.68
15	21	17	23	3	24.0	7.41
15	22	17	24	3	24.5	7.15
16	23	18	25	3	25.5	6.67
17	24	19	26	3	26.5	6.24
18	25	20	27	3	27.5	5.86
19	26	21	28	3	28.5	5.51
20	27	22	29	3	29.5	5.20

From tables 1 and 2, we can see that:

(1) Both cooling coefficient and heating coefficient will decrease with the increasing temperature difference between supply water and return water of deep well. The increase of power consumption of compressor that caused by the decrease of performance coefficient of the water heat pump must be considered when increasing the temperature difference between supply water and return water in order to reduce energy consumption by well water pump. So that the flow or the temperature difference between supply water and return water of deep well must be selected reasonably.

(2) In the areas where the temperature of underground water is different, the heating coefficient increases and the cooling coefficient drops with the increasing of the water temperature of deep

well.

(3) In general, the performance coefficient of the water source heat pump is about 3 in winter and 5-7 in summer. The system is more effective in saving energy compared with other types of heat pump systems.

The operation cost of water source heat pump system with deep well irrigation includes: power consumption of deep well circular pump and daily management cost; power consumption of circular pump and management cost, power consumption of the compressor and the terminal fan.

To take Beijing for example to discuss the daily operation cost in unit area. Operation power of ground circular heat pump L is 1.3W/m^2, circulation water current Q is 4kg/m^2.h, and electricity cost is 0.40 yuan/kWh. Heating time is from November to next March, and 4 months in total in the winter. Cooling time is from June to September, and 3months in total in summer. The total operation time is about 5000 hours. Operation cost is shown in Table 3.

Table 3 Total operation cost

Subentry	Heat pump performance coefficient	Indoor designed load (kcal/$m^{2)}$	Operationtime (hour)	Electric consumption (kwh/m^2a)	Amount to cost (yuan/ m^2a)
Winter	3.0	25	2900	20.0(heat pump)	8.00
Summer	4.5	25	2100	12.3(heat pump)	4.92
Fan			5000	7.50	3.00
Pump			5000	12.5	5.00
Total			5000		20.92

At present, the cost of supply heat is about 20yuan/m^2a in Beijing. it will be more than 21 yuan/m^2a if including the cost of air conditioning in summer. The cost of electricity is less than 0.2 yuan/m^2a, so the operation style of deep well water irrigation has a very large advantage in economy.

To take Beijing for example, considering the accumulated time frequency and saved cost when cooling by circular water instead of the chilled water[4]. The distributing diagram of air conditioning load time frequency in Beijing summer is shown in table 4.

Table 4 Air-conditioning load time frequency in Beijing summer[4] %

Load rate	5	10	20	30	40	50	60	70	80	90	100
Time frequency	12.2	6.5	23.6	16.5	14.9	10.1	7.3	4.7	2.9	1.0	0.3
Accumulated time frequency	12.2	18.7	42.3	58.8	73.7	83.8	91.1	95.8	98.7	99.7	100

Table 4 shows that the air conditioning system operations under the 80% designed load and in 98% of the time of a year and under the 50%-55% of designed load in 80% of the time in Beijing summer. For example, for a room with area is $100m^2$, the designed load is 25kcal /m^2, the indoor designed temperature t_n is 22℃to 28℃, the supply wind temperature is t_s is 17℃ to 22℃, supply water temperature t_g is 7℃, return water temperature t_h is12℃, circular supply water temperature t_1' is 18℃, return water temperature t_1". If the circular water replaces the chilled water, the accumulated time frequency depends on heat exchanged between the water and the air in the fan coil unit. It can be concluded from the heat of exchange, the heat balance formula, mean temperature difference equation (MTD) ,and efficiency energy-number of heat transfer unit (ε -NTU)

The heat of exchange

$$Q_c=KF\Delta t_m \tag{4}$$

Where K is heat transfer coefficient, W/m^2.℃, F is heat transfer area, m^2, Q_c is designed cooling load, W, Δt_m is logarithm average temperature difference, ℃.The equation of heat balance in exchanger

$$Q_c=(MC)_w(t_h- t_g)=(MC)_{air}(t_n-t_s) \tag{5}$$

Where M is mass flow of fluid, kg/s; C is specific heat of fluid, J/Kg. ℃. Logarithm average temperature difference of exchanger

$$\Delta t_m=\frac{(t_n-t_g)-(t_s-t_h)}{\ln\frac{(t_n-t_g)}{(t_s-t_h)}} \tag{6}$$

Efficient energy of exchanger

$$\varepsilon=\frac{Q_X}{Q_{\max}}=\frac{t_2'-t_2''}{t_2'-t_1'}=\frac{t_n-t_s}{t_n-t_1'} \tag{7}$$

Number of heat transfer unit of exchanger

$$NTU=\frac{KF}{(MC)_{air}} \tag{8}$$

Puts the known parameter into equations (4)~(8), and combines the ε - NTU diagram, then draws the ratio of real cooling load to designed cooling load .

The power consumption of the heat pump compressor is 12.31 kcal/m^2a[3]. It operates about 2100 hours in summer. The electricity cost is 0.4 yuan/kwh, the saved cost of the whole summer can be drawn by Table 4. The results are shown in Table 5.

From Table 5, the conclusion is as follows: In the area where the deep well water is 15℃, circular water can be used to supply cooling after it exchanges the heat with the deep well water in 83% of the summer time. The compressor needn't be used, about 407 yuan can be saved in the whole summer for a user with a $100m^2$ room. In the area where the deep well water is 20℃, circular water can be used to supply cold and not to use the compressor in 46% of the summer time. So that in the area where the deep well water is about 15℃-20℃, such as Beijing, if some measures to dehumidify in the end of the system are taken, the circular water can be used in the most of summer time. It is a very economic and saved way of cooling.

Table 5 The accumulated time frequency and saved cost when using circular water instead of the frozen water

Supply water temperature of deep well (℃)	15	16	17	18	19	20
Supply water temperature of FCU (℃)	17	18	19	20	21	22
Real cooling load (W)	1438.8	1279	1119.3	959.25	799.56	639.65
Ratio of real and designed load (%)	49.49	44	38.49	32.99	27.50	22
The accumulated time frequency (%)	82.8	78.2	71.5	63.3	54.7	45.6
Electricity consumption of compressor saved in summer (yuan)	407	385	352	312	269	224

Conclusions

In the distributed water source heat pump systems with deep well water irrigation and central heat exchanger and terminal fan coil units, the heat depolarized in summer can be utilized in winter and the cold in winter can be utilized in summer. The system is highly efficient and economic. Because it combines cooling and heating and uses lower efficiency energy but doesn't contaminate underground water and cause the ground surface sinking.

The heating coefficient increases and cooling coefficient decreases with increasing temperature of deep well water. When the temperature difference between supply water and return water of deep well increases, the operating energy consumption reduces, but performance coefficient decreases and electric consumption of compressor increases. The flow or the temperature difference between supply water and return water of deep well must be selected reasonably.

In the area where the temperature of deep well water keeps between 15-20℃ all over the year round. The performance coefficient of water source heat pump is about 3 in winter and 5~7 in summer. The system is more effective to save energy, compared with other types of heat pump system.

Compared with conventional FCU system such as Fig.2 (1) the distributed water heat pump system with deep well irrigation and central heat exchange and terminal FCU not only has advantage of household adjustment and measure but also supplies cold with circular water in the 46-83% of the summer time. The system achieves optimum energy saving and economic effects.

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